ECOPHYSIOLOGY OF DRYLAND CORN AND GRAIN SORGHUM AS AFFECTED BY ALTERNATIVE PLANTING GEOMETRIES AND SEEDING RATES

by

LUCAS A. HAAG

B.S., Kansas State University, 2005
M.S., Kansas State University, 2008

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2013

Abstract

Previous work in the High Plains with alternative planting geometries of corn and grain sorghum has shown potential benefits in dryland production. Studies conducted in 2009-2011 at Tribune, KS evaluated five planting geometries in corn and grain sorghum: conventional, clump, cluster, plant-one skip-one (P1S1), and plant-two skip-two (P2S2). Geometries were evaluated at three plant densities in corn: 3.0, 4.0, and 5.1 plants m^{-2}. Every measured corn production characteristic was affected by planting geometry, seeding rate, or an interaction in at least one of the years. Corn planted in a P2S2 configuration produced the least above-ground biomass, kernels $plant^{-1}$, kernels ear row^{-1}, and the highest kernel weight. Conventionally planted corn minimized harvest index and maximized stover production. Alternative geometries produced similar harvest indices. Grain yield response to seeding rate varied by geometry and year. Responsiveness and contribution of yield components were affected by geometry. Yield and yield components, other than ears $plant^{-1}$, were the least responsive to seeding rate in a cluster geometry. Clump planting consistently maximized kernels $plant^{-1}$. Prolificacy was observed in the cluster treatment and barrenness in the skip-row treatments. Light interception at silking was highest for clump and conventional geometries and lowest for the skip-row treatments. Corn in a P2S2 configuration did not fully extract available soil water. Conventionally planted corn had the lowest levels of soil water at tassel-silk indicating early-season use which potentially affected kernel set. In the lowest yielding year, grain water use efficiency was highest for clump and P2S2. Across-years, grain yields were lower for corn planted in a P2S2 geometry. Across-years corn yields were maximized when planted in clump at low or intermediate plant density, conventional and P1S1 at low plant density, P1S1 at high density, or cluster at any density.

Planting grain sorghum in a P1S1 or P2S2 configuration reduced total biomass, grain yield, water use efficiency for grain production (WUEg), and water use efficiency for biomass production (WUEb) compared to conventional, clump, or cluster geometries at the yield levels observed in this study. Total water use was unaffected by planting geometry although cumulative water use at flower / grain fill was higher for conventional, clump, and cluster than for skip-row configurations. Sorghum planted in a conventional geometry was always in the highest grouping of grain yields. Grain yields from sorghum in either a cluster or clump geometry were each in the

top yield grouping two of three years. When evaluated across-years, sorghum planted in a clump, cluster, or conventional geometry resulted in similar levels of above-ground biomass, grain yield, WUEg, and WUEb. Clump or cluster planting appear to have substantially less downside in a high yielding year than skip-row configurations.

A comparison of corn and sorghum reinforced the findings of others that the relative profitability of the crops is largely dependent on the environment for any given crop year. Relative differences in grain yield, WUEg, WUEb, and net returns varied by year. Net returns over the three year study were maximized by conventional, cluster, and clump planted sorghum as well as clump planted corn.

ECOPHYSIOLOGY OF DRYLAND CORN AND GRAIN SORGHUM AS AFFECTED BY ALTERNATIVE PLANTING GEOMETRIES AND SEEDING RATES

by

LUCAS A. HAAG

B.S., Kansas State University, 2005
M.S., Kansas State University 2008

A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2013

Approved by:	Approved by:

Major Professor
Scott A. Staggenborg

Major Professor
Alan J. Schlegel

Abstract

Previous work in the High Plains with alternative planting geometries of corn and grain sorghum has shown potential benefits in dryland production. Studies conducted in 2009-2011 at Tribune, KS evaluated five planting geometries in corn and grain sorghum: conventional, clump, cluster, plant-one skip-one (P1S1), and plant-two skip-two (P2S2). Geometries were evaluated at three plant densities in corn: 3.0, 4.0, and 5.1 plants m^{-2}. Every measured corn production characteristic was affected by planting geometry, seeding rate, or an interaction in at least one of the years. Corn planted in a P2S2 configuration produced the least above-ground biomass, kernels $plant^{-1}$, kernels ear row^{-1}, and the highest kernel weight. Conventionally planted corn minimized harvest index and maximized stover production. Alternative geometries produced similar harvest indices. Grain yield response to seeding rate varied by geometry and year. Responsiveness and contribution of yield components were affected by geometry. Yield and yield components, other than ears $plant^{-1}$, were the least responsive to seeding rate in a cluster geometry. Clump planting consistently maximized kernels $plant^{-1}$. Prolificacy was observed in the cluster treatment and barrenness in the skip-row treatments. Light interception at silking was highest for clump and conventional geometries and lowest for the skip-row treatments. Corn in a P2S2 configuration did not fully extract available soil water. Conventionally planted corn had the lowest levels of soil water at tassel-silk indicating early-season use which potentially affected kernel set. In the lowest yielding year, grain water use efficiency was highest for clump and P2S2. Across-years, grain yields were lower for corn planted in a P2S2 geometry. Across-years corn yields were maximized when planted in clump at low or intermediate plant density, conventional and P1S1 at low plant density, P1S1 at high density, or cluster at any density.

Planting grain sorghum in a P1S1 or P2S2 configuration reduced total biomass, grain yield, water use efficiency for grain production (WUEg), and water use efficiency for biomass production (WUEb) compared to conventional, clump, or cluster geometries at the yield levels observed in this study. Total water use was unaffected by planting geometry although cumulative water use at flower / grain fill was higher for conventional, clump, and cluster than for skip-row configurations. Sorghum planted in a conventional geometry was always in the highest grouping

of grain yields. Grain yields from sorghum in either a cluster or clump geometry were each in the top yield grouping two of three years. When evaluated across-years, sorghum planted in a clump, cluster, or conventional geometry resulted in similar levels of above-ground biomass, grain yield, WUEg, and WUEb. Clump or cluster planting appear to have substantially less downside in a high yielding year than skip-row configurations.

A comparison of corn and sorghum reinforced the findings of others that the relative profitability of the crops is largely dependent on the environment for any given crop year. Relative differences in grain yield, WUEg, WUEb, and net returns varied by year. Net returns over the three year study were maximized by conventional, cluster, and clump planted sorghum as well as clump planted corn.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I thank Dr. Alan Schlegel and Dr. Scott Staggenborg for the guidance, knowledge, and expertise they have generously shared with me. I appreciate the freedom and flexibility they provided me in the pursuit of this and other endeavors. They have provided me fine examples to learn from in conducting quality and relevant research. These men have not only provided me a wealth of technical guidance, but have also been friends and mentors on a personal level and I treasure that relationship.

Dr. Kevin Dhuyvetter and Dr. John Holman have generously given of their time and expertise to serve as members of my committee. Both of these gentlemen have provided me a wealth of guidance on a wide variety of issues over the years and I am fortunate to have their support and guidance on this particular project. I am very grateful for the generosity of Dr. Ari Jumpponen who agreed to serve as outside chair of the committee.

Dr. Gerard Kluitenberg was a key resource in this project, particularly in guiding my use of Matlab for the processing and interpolation of the soil water data presented in this dissertation. Additionally he has been someone I can rely on as a sounding board for thoughts and as a source of guidance both professionally and personally. Mr. Jason Waite, fellow graduate student, and I have been through a lot together over the past several years, through which he has never been anything less than a most dedicated friend. He has continually pushed me to do better and to believe that the work we carried out had value despite the doubts of others.

Very little research would be accomplished without the skilled dedication of assistant scientists, technicians, and student technicians. I owe special thanks to my friends and former co-workers at the Tribune Experiment Station: Dewayne Bond, Jeff Slattery, and Dale Nolan. Student technicians who contributed greatly to this project include Rosalio (Ross) Trejo and Nathan Schmidt at Tribune and Keith Gustin, Blake Bergkamp, Blake Nieheus, Christopher Maddy, and Mary Kreikemeier at Manhattan.

The inspiration and encouragement to continue in graduate studies was thanks to my undergraduate advisor and continued mentor, Dr. Randy Taylor, P.E. Guidance and support specific to this research project was provided by Robert Klein, University of Nebraska - West Central Research-Extension Center, and Dr. Bob Stewart, West Texas A&M University. These gentlemen have generously shared with me the type of wisdom that can only come from many years of experience. If over my career I provide a fraction of the service to the agricultural industry that these gentlemen have I shall consider it a success.

All of the aforementioned individuals have helped make graduate school the experience of a lifetime. Thank you.

This research was made possible by the support of the Ogallala Aquifer Program, a cooperative project between Kansas State University, Texas A&M University, West Texas A&M University, Texas Tech University, and USDA-ARS Lubbock and Bushland, Texas.

Dedication

This work is dedicated to my family, especially my wife Jennifer, who joined me part way through this endeavor and has sacrificed much during our first year of marriage. Her unwavering love, support, and faith in me has been essential to the completion of this work.

My parents Gayle and Elaine, and my siblings, Buck and wife Kaitlin, Shelby, and Denton have provided me with nothing but love and support through my many ventures in life for which I am forever thankful. I hope to repay them with the same love and support.

A dedication would not be complete without recognizing and giving thanks to my heavenly father for providing me the talents and strength necessary throughout this time.

Chapter 1 - Evaluation of alternative planting geometries and plant densities on dryland corn production

Introduction

High Plains dryland corn production

Crop production throughout the Great Plains, and especially the High Plains is limited by growing season water supply. Evapotranspiration demand during periods of cropping exceeds precipitation making soil water storage a necessity for successful crop production. Vast advancements in crop productivity throughout the High Plains have resulted from improvements in precipitation storage efficiency (PSE) and precipitation use efficiency (PUE) as tillage has been reduced, often through no-till systems, and levels of surface residue have increased (McGee et al., 1997; Nielsen et al., 2005), weed control improved (Smika, 1990; Wicks and Smika, 1973), and cropping systems intensified (Farahani et al., 1998). A significant change in PUE has resulted from replacing a portion of the fallow period in a wheat-fallow (W-F) rotation with a summer annual crop (Nielsen et al., 2005; Peterson et al., 1996; Schlegel et al., 2002). In addition to improving PUE of dryland cropping systems, this intensification provides greater economic returns (Dhuyvetter et al., 1996; Schlegel et al., 2002) and opportunities to better manage weed populations (Lyon and Baltensperger, 1995; Holtzer et al., 1996). Commonly utilized summer annual crops include corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], proso millet (*Panicum miliaceum* L.), and sunflower (*Helianthus annuus* L.). The production of corn has the largest support system available to producers with regard to genetics, herbicide and marketing options, and end-user demand, making it a popular crop choice.

Dryland corn production throughout the High Plains region has steadily increased over the past 20+ years (Figure 1.1) (NASS, 2013). Advancements in no-till farming practices, herbicides, corn hybrids, and crop insurance programs, coupled with increasing demand for corn have fueled this growth. Harvested acres have steadily increased throughout crop reporting districts located in the High Plains region of western Kansas, western Nebraska, eastern Colorado and the Oklahoma and Texas Panhandles with even limited acreage in the Texas Southern High Plains (Figure 1.1) with total harvested acreage in 2011 totaling over 800,000 hectares (nearly 2 million acres).

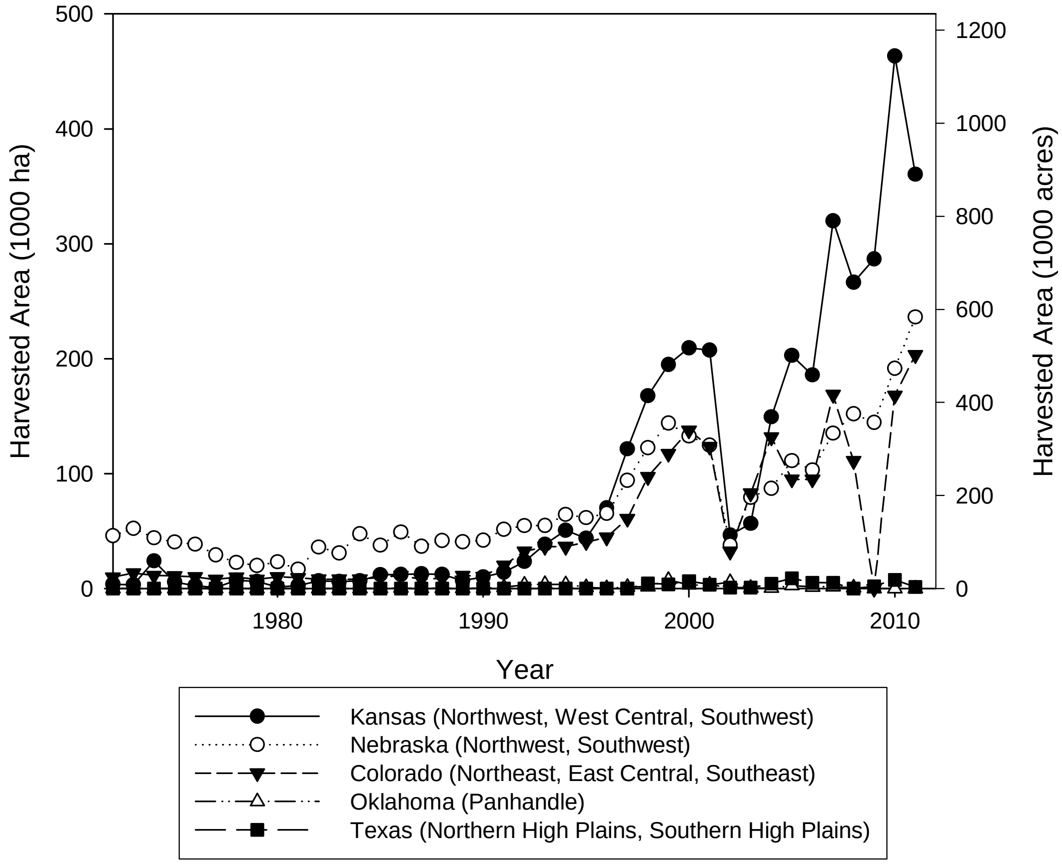

Figure 1.1 - Non-irrigated harvested corn acres summed by state from central and southern High Plains crop reporting districts.

Adoption of dryland corn and growth of harvested acres occurred earliest in Nebraska. By the early 1990's adoption in Kansas and Colorado had approached that of Nebraska with Kansas exceeding Nebraska's harvested acreage in most years since 1996. Dryland corn production in the Oklahoma and Texas Panhandles and Texas southern plains has been fairly limited in land area and highly variable in both area planted and harvested. Alternative crop choices such as sorghum and cotton (*Gossypium hirstum L.*), higher evaporative demand, less surface residues, and higher levels of tillage in the cropping system are all factors which make dryland corn production more difficult in that region.

Although advancements have been made, corn grain productivity is still limited by growing season water supply. Improvements in fallow efficiency prior to seeding the corn crop can result in higher levels of available soil water at planting which in general results in increased grain yields (Nielsen et al., 2009). However, more critical is the timing and amounts of in-season precipitation, which has been shown to explain as much as 67% of the variability in grain yields (Nielsen et al., 2010), incorporating available soil water at planting improved the relationship to explain 93% of the variability. It is well known that water stress at critical growth stages can have significant effects on grain yield. Water stress at and immediately following silking has been shown to cause the greatest effect on grain yield (Claassen and Shaw 1970; Robins and Domingo 1953; Denmead and Shaw, 1960; Eck, 1986), primarily through reductions in kernels plant^{-1} (Grant et al., 1989).

Previous research efforts

Seeding rate

As interest in and adoption of dryland corn production in the region has increased, the correct plant population necessary to maximize yields in a productive year, while resisting crop failure during drought, has been a reoccurring question. Multiple research studies spanning several decades in the region have attempted to determine optimal seeding rates. Early work from a two year study at Colby, Kansas reported yields declined as seeding rates increased from 4.0 to 6.9 plants m^{-2} (16,200 to 27,900 plants ac^{-1}) with a subsequent study indicating an optimal seeding rate near 3.4 plants m^{-2} (13,800 plants ac^{-1}) (Anonymous, 1975). Work by Havlin and Lamm (1988) also at Colby, found no difference in yield when corn was seeded at 2.1, 2.5, and 3.7 plants m^{-2} (8.5- 10- and 15,000 plants ac^{-1}).

A variety of studies at Tribune, Kansas would estimate the optimal corn seeding rate to be near 3.7 plants m^{-2} (15,000 plants ac^{-1}) when evaluated across multi-year studies (Schlegel, 2007; A. Schlegel, personal communication). In southwest Kansas, Norwood and Currie (1996) evaluated three seeding rates, 3.0, 4.4, and 5.9 plants m^{-2} (12-, 18-, and 24,000 plants ac^{-1}) over four site-years. Yields declined with increasing seeding rate in one year of the study, in two years yields increased, with the fourth year resulting in a quadratic response with an optimum near the intermediate seeding rate. In a subsequent study during a period of above normal rainfall, Norwood (2001) reported non-linear positive responses in grain yield as population increased from 3.0 to 5.9 plants m^{-2} (12- to 24,000 plants ac^{-1}). Fjell (2005) showed large differences in optimal seeding rate due to environmental conditions at any given site-year in western Kansas.

Densities that optimized yields ranged from 4.0 to 4.9 plants m^{-2} (16- to 20,000 plants ac^{-1}) in four of the seven years of the study. During the three driest years of the study grain yields declined with increasing population, resulting in the lowest seeding rate in the study being optimal. In western Nebraska, Blumenthal et al. (2003) reported increasing grain yields as seeding rate increased from 1.73 to 2.73 plants m^{-2} (7- to 11,000 plants ac^{-1}), at higher plant densities yields became unstable. This work was later used to calibrate a crop simulation model which resulted in production probability distributions of economic return across a range of plant populations and soil water availabilities (Lyon et al., 2003). In general, model predictions suggested a base seeding rate of 3 plants m^{-2} (12,100 plants ac^{-1}) in western Nebraska dryland conditions and that probability of profit declined with decreasing levels of available soil water at planting.

Row-spacing

While seeding rates in the region have been evaluated by several researchers, row-spacing until recently was essentially an untouched topic in the High Plains region. This is likely driven by the almost exclusive adoption of a 76 cm (30 inch) row spacing for the production of irrigated corn in the region in addition to its use in neighboring eastern regions with established histories of dryland or rainfed corn production.

In general when resources are non-limiting, uniform, or equidistant cropping will maximize light interception, photosynthesis, and thus overall efficiency. However, when resources are limiting, non-uniform treatment of the land may provide advantages (Loomis, 1983). Research in more productive corn production areas with fewer water resource limitations has evaluated changing geometry through use of rows narrower than 76 cm (30 inches) resulting in a configuration more closely resembling equidistant. These studies have often been conducted in combination with plant density treatments, occasionally resulting in significant interactions along with potential interactions of row spacing with hybrid (Farnham, 2001). The results of these studies have been mixed in nature finding positive (Nielsen, 1988; Widdicombe and Thelen, 2002; Sharratt and McWilliams, 2005) and negative (Farnham, 2001; Johnson et al., 1998) responses often with mixed responses from individual site-years (Farnham, 2001; Nielsen, 1988; Staggenborg et al., 2001). Some Studies have reported no effects from reductions in row spacing (Westgate et al., 1997; Van Roekel and Coulter, 2012; Porter et al., 1997; Shapiro and

Wortmann, 2006). Thelen (2006) provided examples of how site-year variability and even within field variability could result in highly variable responses to narrow rows.

Wide rows were shown to redistribute solar radiation from upper to lower leaves although the redistribution is not typically enough to offset interception reductions in the upper canopy, resulting in a net reduction in solar radiation interception (Ottman and Welch, 1989). Increased solar radiation interception by narrower row was shown (Yao and Shaw, 1964a; Aubertin and Peters, 1961; Sharratt and McWilliams, 2005), especially at lower plant populations (Maddonni et al., 2001; Maddonni and Otegui, 1996) and supports the generalization that positive responses to reducing row spacing in corn are more prevalent in light limited environments, perhaps those above 43° N latitude (Lee, 2006). Andrade et al. (2002) summarized that response to narrow rows was close to zero when the standard row spacing was able to capture >90% of light at the critical times relating to kernel set. However, increased light interception, especially earlier in the season, results in higher water use which can be a detriment in water-limited environments (Sharratt and McWilliams, 2005; Staggenborg et al., 2001; Andrade et al., 2002). In eastern Canada, Fulton (1970) evaluated 50 and 100 cm (20 and 40 inch) rows at a range of plant densities and water levels and found that narrow rows only increased grain yields in the presence of high plant densities and high soil moisture levels. Barbieri et al. (2012) reported 8.4% higher ET from planting until 55 days after planting (DAP) for corn grown in 35 cm (13.8 inch) rows compared with 70 cm (27.6 inch) rows.

In the row spacing studies most closely related to High Plains dryland corn production Staggenborg et al. (2001) showed in eastern Kansas that the response to narrower row spacing of 38 and 51 cm compared to 76 cm (15 and 20 inches compared to 30 inches) was highly dependent upon environmental conditions and yield potential for a given site-year. In general narrow row spacing resulted in decreased grain yields when conventional rows yielded less than 7.5 Mg ha^{-1} (120 bu. ac^{-1}). Under a limited irrigation scenario in the Texas Panhandle Bean and Gerik (2005) reported higher yields for corn planted in 1.02 m (40 inch) rows than that planted in 51 or 76 cm (20 or 30 inch) rows.

Skip-row

Use of the skip-row concept in semi-arid areas, while relatively new to corn production, has been the subject of study and producer adoption in both grain sorghum and cotton. Evaluations of skip-row sorghum were performed under dryland (Blum and Naveh, 1976;

Routley et al., 2003; Olson et al., 2010; Abunyewa et al., 2010; Abunyewa et al., 2011) and limited irrigation (Musick and Dusek, 1972) conditions. Skip-row planting of cotton in various configurations is a common dryland practice on the southern High Plains primarily due to crop insurance implications, despite no clear advantage over conventional row spacing and in some cases decreased water use efficiency (WUE) (Hons and McMichael, 1986). Skip-row planting of corn under limited irrigation scenarios were evaluated in the Texas Panhandle (Musick and Dusek, 1972; Baumhardt, 2010) and resulted in reduced grain yields on a land area basis.

In the last decade, research conducted in the High Plains region has evaluated wider and non-uniform row spacing in an attempt to stabilize and improve dryland corn yields. In the early and mid 2000's work in Nebraska, and later in Kansas and Colorado, evaluated corn planted in a variety of skip-row configurations. Vigil et al. (2008) reported that skip-row configurations in corn and grain sorghum offered a 376 kg ha^{-1} (6 bu. ac^{-1}) advantage in grain yield over conventional row spacing when evaluated across 11 site-years at Akron, Colorado and Scott County, Kansas. The response to skip-row geometries in this study was most positive at conventional yield levels of less than 3500 kg ha^{-1} (56 bu. ac^{-1}). Pavlista et al. (2010) evaluated conventional and plant-two rows skip-two rows (P2S2) configurations at three seeding rates, 2.5, 3.7, and 5.0 plants m^{-1} (10-, 15-, and 20,000 plants ac^{-1}). No significant geometry x seeding rate interaction was observed. Across four site-years yields in the P2S2 configuration were higher than yields in conventional geometry in one instance, lower than conventional in one instance, and equivalent to conventional in two site-years. The largest advantage to the P2S2 configuration was at the site-year when conventional planting yielded the least, 4670 kg ha^{-1} (74.4 bu. ac^{-1}), the P2S2 produced 5460 kg ha^{-1} (87 bu. ac^{-1}) of grain.

Lyon et al. (2009) summarized 23 site-years of data evaluating conventional, P2S2, plant-one row skip-one row (P1S1), and plant-two rows skip-one row (P2S1) that were collected from 10 locations across the central High Plains and 4 higher yielding locations in central and eastern Nebraska. Planting geometry affected grain yield at 13 of the 23 site-years. The P2S2 treatment (and potentially other skip-row treatments in the study) produced higher grain yields five times and lower yields eight times. Regression analysis was used to determine threshold conventional yields below which a skip-row configuration would yield a positive response compared with a conventional configuration and were estimated as 4600, 6300, and 4500 kg ha^{-1} (74, 101, and 72 bu. ac^{-1}) for P2S2, P1S1, and P2S1, respectively.

Although the anticipated response of alternative geometries has been characterized relative to conventional grain yield, there is potential that some interactions may occur in ear development which complicates this issue. Two site-years of the study conducted by Pavlista et al. (2010) produced essentially the same conventional corn grain yield of 7220 kg ha^{-1} (115 bu. ac^{-1}), but produced accompanying P2S2 yields of 7510 and 5780 kg ha^{-1} (119.7 and 92.1 bu. ac^{-1}). When P2S2 performed worse it was largely accompanied with more prolificacy in both geometries, indicating an environmental situation and hybrid selection which promoted prolificacy, and a shorter primary ear in the P2S2 treatment. When P2S2 performed better than conventional there was less prolificacy in both treatments and a longer primary ear in the P2S2 treatment compared to conventional.

Other researchers have failed to observe a consistent positive response to planting corn in a skip-row configuration. In the northern Great Plains a P2S1 (plant two rows, skip one row) configuration showed no effects on grain yield, harvest index, or PUE, but did increase total above-ground biomass production and biomass PUE (Allen, 2012). At seven site-years in western Kansas, Olson et al. (2010) reported no yield difference between a P2S2 system over conventional planting, including site-years at yield levels below 5 Mg ha^{-1} (80 bu. ac^{-1}). In that study, the P2S2 system had numerically lower grain yields of 63 to 502 kg ha^{-1} (1 to 8 bu. ac^{-1}) compared to conventional. A three year study at Tribune, Kansas (Schlegel, 2007; also included in the analysis of Lyon et al., 2009) evaluated four geometries, P1S1, P2S2, P2S1, and conventional at three seeding rates, 2.5, 3.7, and 4.9 plants m^{-2} (10-, 15-, and 20,000 plants ac^{-1}). Planting geometry only affected grain yields in one of three years with conventional producing higher grain yields than either P2S1 or P2S2. Seeding rate resulted in a different response each year, in the lowest yielding year increasing seeding rate decreased grain yield, in the highest yielding year increasing seeding rate increased grain yield, and in the moderate year a curvilinear response was observed with the 3.5 plants m^{-2} (15,000 plants ac^{-1}) seeding rate being optimal. Work has also been conducted on row configuration in dryland areas of Australia. In a one year study, Simons et al. (2008) reported higher corn grain yields for a P1S1 system than either a conventional or P2S2 system with conventional row spacing of 92 cm (36 inches). In this study the P1S1 configuration resulted in a higher harvest index (HI) than conventional planting.

Clump

Clump planting of sorghum has been shown to improve grain yields, reduce tillering, change plant architecture, change dry matter partitioning and increase harvest index in the central and southern High Plains (Bandaru et al., 2006; Haag and Schlegel, 2009; Pidaran et al., 2011; Kapanigowda et al., 2010a; Krishnareddy et al., 2010). Clump planting of sorghum has also shown to be an effective technique for reducing tillering at low plant populations. Tillering in dryland corn production is occasionally an issue, driven both by genotype and its propensity to tillering and accentuated by low plant populations (Tetio-Kagho and Gardner, 1988a). It was hypothesized that clump planting of corn may reduce tillering among other potential effects that could positively affect grain yields.

Mohammed et al. (2012) evaluated dryland corn geometries in the Texas Panhandle at densities of 2.96 and 3.96 plants m^{-2} (12- and 16,000 plants ac^{-1}). They reported that planting corn in three or four plant clumps reduced leaf-are index (LAI) at the V11 growth stage by 5-14% and resulted in a 5-10% higher harvest index than corn planted in conventional rows while total aboveground biomass was not different among treatments. Clump planted corn also had higher numbers of harvestable ears and higher kernel weights although no effect on grain yield was observed.

Kapanigowda et al. (2010b) evaluated corn planted in three plant clumps and corn planted conventionally in 76 cm (30 inch) rows in the Texas Panhandle. Corn was seeded at 3.9 plants m^{-2} (15,800 plants ac^{-1}) and grown under three water treatments, dryland, 75 (2.95), and 125 mm (4.92 inches) of applied irrigation water. Each level of irrigation water was applied with two methods, low-energy precision application (LEPA) and low-elevation spray applicators (LESA). They reported reduced tiller production, increased grain yields of 13 to 55%, and increased harvest indices of 10 to 33% for corn grown in clump geometry. Clump planting also resulted in a lower intercept for the water production function, indicating it took less water to produce the first kernel of grain on plants in a clump configuration than plants planted conventionally.

Work resembling current attempts at clump planted corn has been conducted in the edge of tropical rainforest in Nigeria (Babalola and Oputa, 1981). They reported lower grain yields for corn planted in three seeds per hill in 90 cm (35 inch) rows compared with plants spaced equidistantly in that row spacing. They also measured higher stomatal resistances on the ear leaves of clump planted plants. This study however was conducted in a humid climate where the driest growing season precipitation was 749 mm (29.5 inches), nearly double that of some areas of the High Plains, thus likely an environment where reduced light interception could have negatively affected yields.

Current recommendations

Currently seeding rates recommendations vary across the region. Dryland corn production is not yet mainstream in the Texas Panhandle but recommendations (Bean, 2007) include only planting with moisture present in 76 to 91 cm (2.5 to 3 feet) of the soil profile and to not exceed seeding rates of 3.7 plants m^{-2} (15,000 plants ac^{-1}).

Colorado dryland corn seeding recommendations specify that seeding rates of 3 to 4 plants m^{-2} (12- to 16,000 plants ac^{-1}) will maximize yields for average and below average rainfall years, but that soil moisture conditions at seeding time should be used to fine-tune decisions (Bauder and Waskom, 2003). Recommendations for western Kansas are generalized between 3.5 to 4.9 plants m^{-2} (14- to 20,000 plants ac^{-1}) with mention of skip-row systems for areas with inherently low yield potential (Roozeboom et al., 2007).

Recommendations for western Nebraska dryland corn are more specific and dependent upon location, surface residue level, profile soil water, and hybrid maturity (Klein and Lyon, 2011). Suggested seeding rates range from “do not plant corn” and seeding rates of 2.0 to 4.0 plants m^{-2} (8- to 16,000 plants ac^{-1}). Western Nebraska recommendations also prescribe skip-row planting in the P2S2 pattern at anticipated yield levels of less than 4706 kg ha^{-1} (75 bu. ac^{-1}) and the P1S1 pattern at yield levels less than 6274 kg ha^{-1} (100 bu. ac^{-1}).

Objective

In general the response to skip-row plantings in the High Plains have been somewhat inconsistent, however occasional occurrences of success have continued to peak the interests of producers and researchers alike. Additional site-years of observation may help further clarify the yield potentials at which various planting geometries are optimal. Clump planting of sorghum and early experimentation on clump planting of corn has shown the potential of planting geometry to alter plant responses to the environment. Perhaps a better understanding of the dynamics involved would inform better management decisions regarding alternative planting geometries. Also unknown is the effect of alternative planting geometries on optimal seeding rate. The purpose of this study was to agronomically evaluate geometries including conventional, clump, and skip row treatments, across a range of plant densities, on the ecophysiology of dryland corn in the central High Plains.

Materials and Methods

Production management

Plots were established in 2009, 2010, and 2011 at the K-State Southwest Research-Extension Center near Tribune, Kansas. This site is located in the central High Plains with a long-term annual precipitation of 429 mm (16.9 inches). A significant portion of the precipitation (48 %) falls during the months of May, June, and July. Throughout the study duration, temperature and solar radiation were recorded by an automated weather station located no further than 853 meters (2,800 feet) from the study location. Growing degree days were calculated with an upper temperature threshold, described as method 2 in McMaster and Wilhelm (1997), using a base temperature of 10° C (50° F) and a maximum temperature of 30° C (86° F).

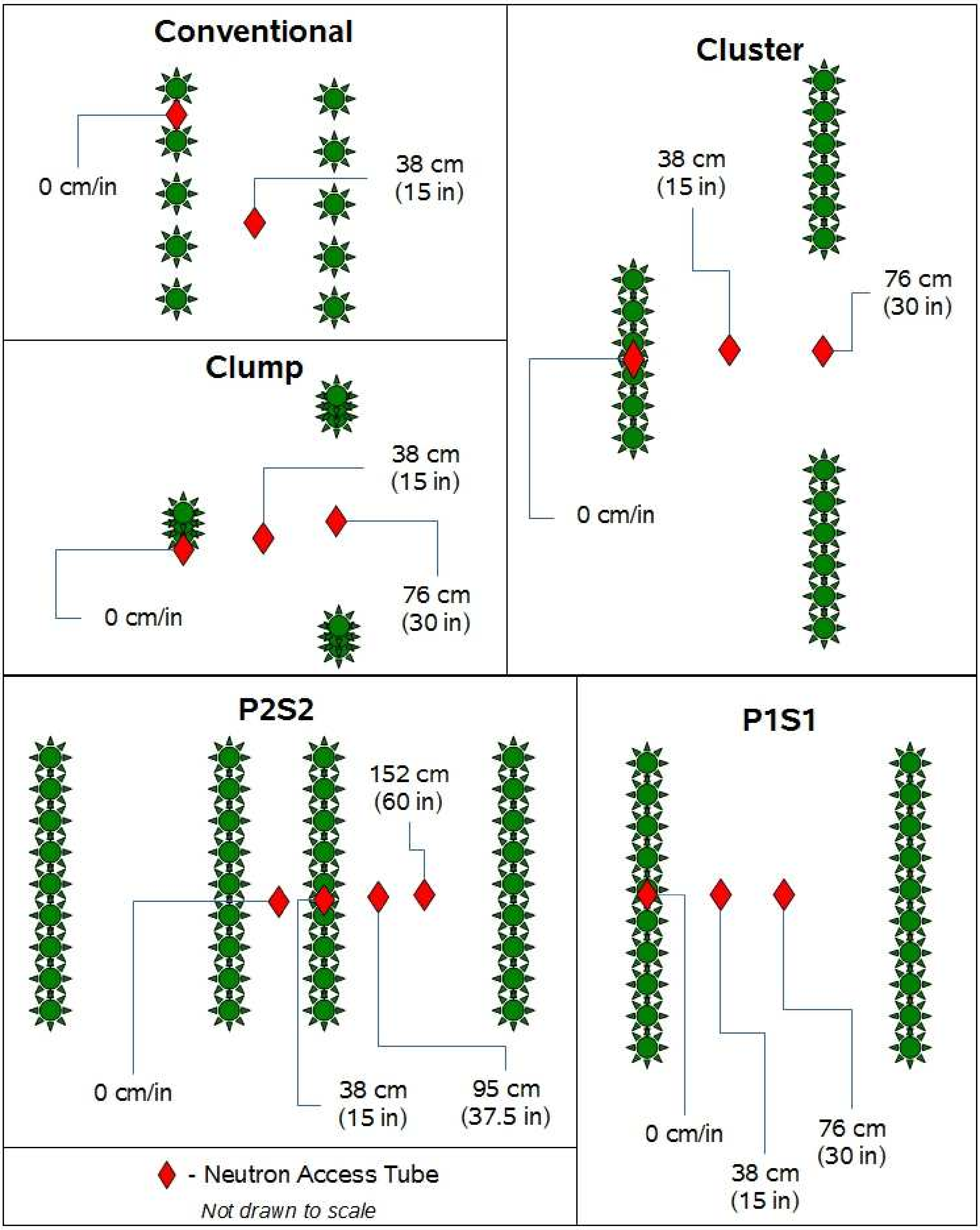

Figure 1.2 - Spatial arrangement of plants and neutron access tubes in corn planting geometries under evaluation.

The study was a factorial design of five planting geometries (Figure 1.2). All geometries were planted in 76 cm (30 inch) row spacing. Geometries evaluated included conventional rows in which plants were equidistantly spaced within rows, clumps of three plants each, clusters where six plants were planted sequentially alternating between two rows, plant-one skip-one skip row (P1S1), and plant-two skip-two skip rows (P2S2). Each of the geometries were seeded at three rates termed low, intermediate, and high with seeding rates of approximately 3.0, 4.0, and 5.1 plants m^{-2} (12,300, 16,200, and 20,600 plants ac^{-1}), respectively.

Plots measuring 8 rows in width by 12 m (40 feet) in length were no-till planted into wheat stubble from the previous year using a Case-IH 1200 vacuum planter (CNH North America, Racine, WI). Blank plates were machined in-house to the author's design for metering the desired plant geometries. Corn was typically planted to a depth of 7 cm (2.75 inches). Additional details regarding cultural practices are presented in Table 1.1.

Table 1.1. - Production practices for corn geometry x seeding rate study, Tribune, Kansas, 2009-2011

Year	2009	2010	2011
Location	Dixon Dryland Annex, SWREC-Tribune Irrigation Field	SWREC-Tribune Dryland Station	Dixon Dryland Annex, SWREC-Tribune Irrigation Field
Soil Type	Ulysses Silt Loam	Richfield Silt Loam	Ulysses Silt Loam
Soil Description	Fine-silty, mixed, superactive, mesic Aridic Haplustolls	Fine, smectitic, mesic Aridic Argiustolls	Fine-silty, mixed, superactive, mesic Aridic Haplustolls
Planting Date	5/7/2009 (DOY 127)	5/4/2010 (DOY 124)	5/21/2011 (DOY 141)
Fertility	90 kg ha^{-1} (80 lb ac^{-1}) N applied 5/12/09 (DOY 132)	90 kg ha^{-1} (80 lb ac^{-1}) N applied 3/23/2010 (DOY 82) 56 l ha-1 (6 gal ac^{-1}) 10-34-0 at planting	90 kg ha^{-1} (80 lb ac^{-1}) N applied 4/6/2011 (DOY 96)
Hybrid	Pioneer 33B54	Pioneer 33B54	Pioneer 33B54
Light Interception	N/A	7/1/2010 (DOY 182)	8/3/2011 (DOY 215)
Harvest Date	10/28/2009 (DOY 301) 10/11/09 Hard Freeze - 6° C (22° F)	9/8/2010 (DOY 251)	9/30/2011 (DOY 273)

Soil water

Volumetric soil water contents were determined for each geometry in the intermediate seeding rate by neutron attenuation. Access tubes were placed in an effort to represent a repeatable cross-section perpendicular to a given geometry for interpolation that would be representative of the true soil water status (Figure 1.2). Neutron attenuation readings were recorded at 15 cm (6 inch) intervals to a depth of 183 cm (6 feet) at various times throughout the season. At a minimum, measurements were taken as near to planting as possible typically representing a postemergence early vegetative growth stage, at R1 (tassel/silk), and at harvest after reaching physiological maturity. In some years additional measurements were recorded during the growing season. Existing calibrations and unavailable soil water values from other experiments at the experiment station were used to calculate volumetric plant-available water from the ratio of raw neutron counts to the average seasonal standard count.

Values of profile available soil water were calculated for each tube at each measurement time from the neutron data. Analysis of variance was used to test for differences with respect to tube position. This analysis utilized geometry by tube position combinations in a one-way analysis to test if differences in profile soil water across the entire study area were affected by tube location. Values of available water content were also evaluated within geometry and depth with respect to tube position to test if spatial differences in available soil water existed within a given geometry.

Calculated volumetric soil water measurements from neutron attenuation measurements were used as the input for a spatial interpolation procedure to obtain a more complete cross-sectional representation of soil water status (Kandelous et al., 2011). Interpolation was conducted using the griddata procedure with the v4 method in Matlab (MathWorks, 2012). This procedure uses biharmonic spline interpolation to estimate values at desired interpolation points (Sandwell, 1987). Interpolation was conducted on a domain measuring in width equal to the repeatable pattern of each geometry and depth to the deepest point of soil water measurement, 183 cm (72 inches) for all geometries. Cells in the interpolated domain were 2.54 cm x 2.54 cm (1 inch x 1 inch) in dimension.

Volumetric water content for each combination of plot by time of measurement was calculated by computing the mean volumetric water content of the cells in the interpolated domain. Total profile water was calculated by multiplying the volumetric water content for each plot by time of measurement combination by the profile depth. Total water use for each combination of plot by time of measurement was calculated by subtracting profile water at postemergence or other beginning period of interest from the profile total and the ending measurement then adding precipitation. This method is inclusive of both evaporation (E) and transpiration (T) components while assuming zero water loss due to runoff and deep percolation. Change in soil water with respect to spatial location was calculated by subtracting grid cell values of the two interpolated cross-sections of interest. For ease of visual interpretation and display, each interpolated cross-section was mirrored as necessary to generate a cross section measuring 305 cm (120 inches) across, the smallest common factor among the various individual cross sections.

Light interception

Photosynthetic photon flux density (PPFD) was measured using a LAI-2000 (LI-COR, Inc., Lincoln, NE) which recorded simultaneous measurements from a 1 m line quantum sensor attachment (Model LI-191SB, LI-COR, Inc., Lincoln, NE) and a quantum sensor placed outside the crop canopy (Model LI-190, LI-COR, Inc., Lincoln, NE). Measurements of photosynthetically active radiation (PAR) transmitted through the plant canopy (I_{tr}) were measured at the soil surface. Due to the non-uniform nature of the plant geometries special consideration was made to select locations for sensor measurement. Measurements were made with the line quantum sensor placed parallel to planted rows at approximately 5 cm (2 inch) increments between planted rows. In the clump and cluster treatments two sets of measurements were taken to fully represent the entire spatial arrangement of plants (Figure 1.3). When necessary, the sensor was masked to only intercept light from the length necessary to obtain measurements from spatially repeatable areas as shown in (Figure 1.3). When a portion of the sensor was masked, measurements were scaled to the equivalent value for a 1 m operating length. Measurement of incident PAR (I_o) was obtained simultaneously from the sensor placed outside the plant canopy.

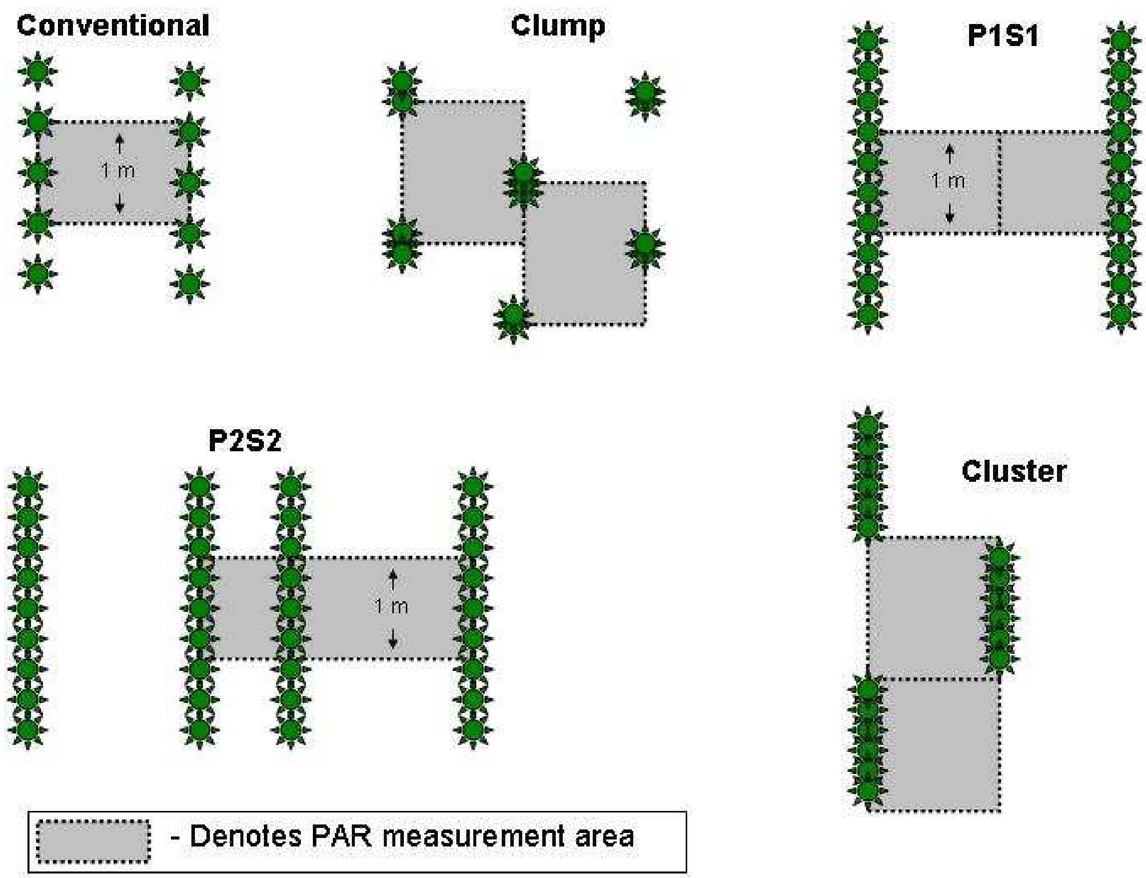

Figure 1.3 - Sampling areas for photosynthetically active radiation (PAR) within planting geometries.

Intercepted photosynthetically active radiation (IPAR) was calculated as $I_o – I_{tr}$ and thus includes potential PAR reflected from the canopy and soil. Gallow and Daughtry (1986) found that prior to the R5 stage in corn the potential errors due to this inclusion of reflected PAR were less than 3.5%. The fraction of PAR intercepted was calculated as $\theta = (I_o – I_{tr})/I_o$. The simple average of the fractional interception values (average of θ's) for a spatially repeatable portion of the planting geometry were used to calculate the overall fraction of PAR intercepted (θ) for a given treatment. Field measurements were scheduled to center around solar noon on any given day to reduce the influence of sun angle. Measurements were taken in either open sky or uniformly overcast conditions. Occurrences of obviously erroneous data were replaced with the mean θ value from the same spatial location in other plots of the same treatment. In 2010 0.07% of the values were identified and replaced and 1.2% of the values in 2011. Sensors were intercalibrated by collecting measurements side-by-side with a full sky view at solar noon.

Plot harvest and data collection

At physiological maturity, 20 plants from the conventional, P1S2, and P2S2 treatments, 18 plants (3 clusters) from the cluster treatment, and 21 plants (7 clumps) from the clump treatment were hand harvested at ground level. The conventional, P1S1, and P2S2 treatments were associated with a harvest area of 6.6, 5.0, and 3.9 m^2 (71, 54, and 42 ft^2) for the low, intermediate, and high seeding rates, respectively. The cluster treatment had harvest areas of 5.9, 4.5, and 3.5 m^2 (64, 48, 38 ft^2) and the clump had harvest areas of 6.9, 5.2, and 4.1 m^2 (75, 56, and 44 ft^2) for the low, intermediate, and high seeding rates, respectively. Plants were harvested from areas having uniform stand as per the treatment intentions, implying complete emergence. Ears were removed and counted as harvestable or incomplete. Kernel rows (KR) and kernels ear-row^{-1} (KER) were counted on each ear. Ears were mechanically shelled; wet grain weight and oven-dry cob weights were recorded. Grain samples were analyzed for moisture and test weight (GAC2100, Dickey John Auburn, IL, USA). A subsample of grain was dried at 60° C for a minimum of 72 hours. Kernel weight (KW) was determined by counting 300 seeds from the subsample, drying, and reweighing. Grain from the subsample was ground using a sample mill for use in determining N and P concentration in the grain. Grain concentrations for N and P were obtained by the sulfuric acid – hydrogen peroxide digestion method (Thomas et al., 1967) and were performed by the K-State Soil Testing Lab, Manhattan, Kansas. Above ground biomass, less the ears, was dried at 60° C for a minimum of 1 week and weighed to obtain stover weight. Grain yields were corrected to 155 g kg^{-1} (15.5%) moisture content for analysis, total above ground biomass is the sum of the stover, grain, and cob on a dry matter basis. Harvest index was calculated by dividing grain yield by total above ground biomass, both components on a dry matter basis. Plant rectangularity, a method to quantify spatial uniformity of a planting arrangement, was calculated for each treatment averaging the calculated rectangularity for each plant (Wiley and Heath, 1970, Maddonni et al, 2001) in a repeatable pattern.

Statistical analysis

Statistical analysis was completed using the PROC MIXED procedure is SAS 9.2. Denominator degrees of freedom were obtained using the containment method. Variance component estimation was performed with the restricted maximum likelihood technique

(REML). In instances where variance components were estimated as near zero or negative the NOBOUND option was invoked to attempt completion of a G matrix that was positive definite.

Invoking NOBOUND in these situations provides better control of the Type I error rate and better power in estimates of whole-plot error variances (Littell et al., 2006). Individual ear data with measurements of KR and KER were analyzed as a RCBD with subsampling, each ear as a subsample. Statistical analysis of soil water data was performed on profile totals or within a given depth. Data were analyzed as individual years with replication taken as a random effect term. Data were also analyzed across years with year and replication within year taken as random effects terms. Means separation was performed using LSD on the LSMEANS output utilizing the PDMIX800 macro (Saxton, 1998).

All reported means are least square means (LSMEANS) resulting from a mixed-model analysis. Each analysis fits the optimal mixed-model for that specific dataset and its variance-covariance structure. As a result, means presented in the across-years analysis will differ slightly than the arithmetic means of the individual years. In addition to each analysis being fit with a unique model, the across-years analysis uses a model with a different structure of random effects. Each unique model results in unique estimates for the LSMEANS. The across-years analysis also results in an unbalanced design due to five replications in 2010 and four replications in 2009 and 2011. The use of LSMEANS from the PROC MIXED procedure is the most appropriate way to handle unbalanced data (Milliken and Johnson, 2009). Reports of other agronomic research have shown LSMEANS to differ from arithmetic means when conducting across-years analysis with unbalanced data (Teasdale et al., 2007).

Results

2009 Tribune

Corn grain yields as a whole were exceptional in 2009 with a mean yield of 6970 kg ha^{-1} (111 bu ac^{-1}). In-season precipitation was above normal for the majority of the growing season (Figure 1.4), recovering from a deficit that persisted from planting up until DOY 147.

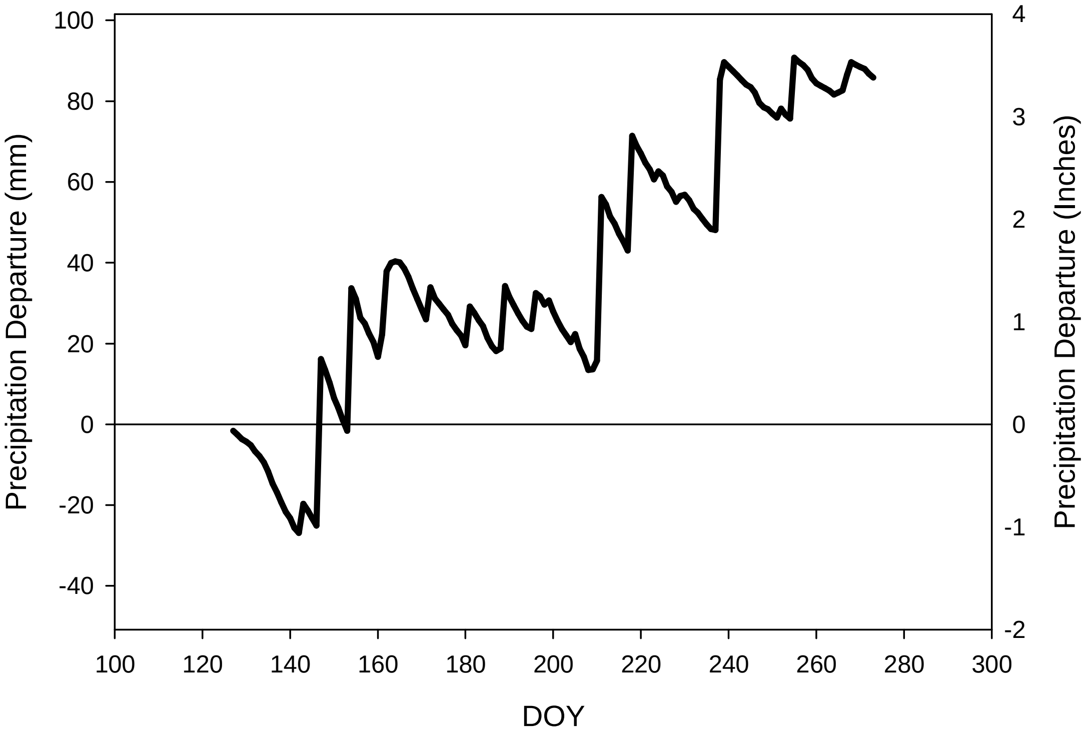

Figure 1.4 - Corn growing season precipitation departure from normal, Tribune, Kansas 2009.

Additional precipitation increased the cumulative total further above average in the time period after silking and during grain fill (Figure 1.5) ending with 366 mm (14.41 inches) of in-season precipitation. Heat unit accumulation was normal throughout the growing season (Figure 1.6).

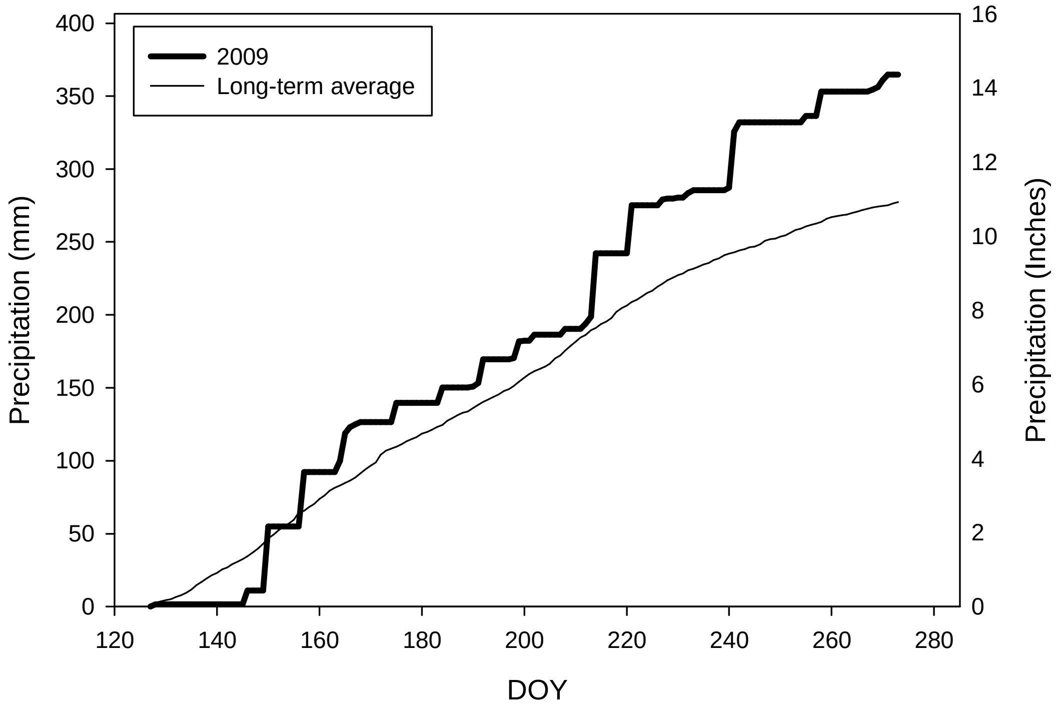

Figure 1.5 - Corn season cumulative precipitation, Tribune, Kansas 2009.

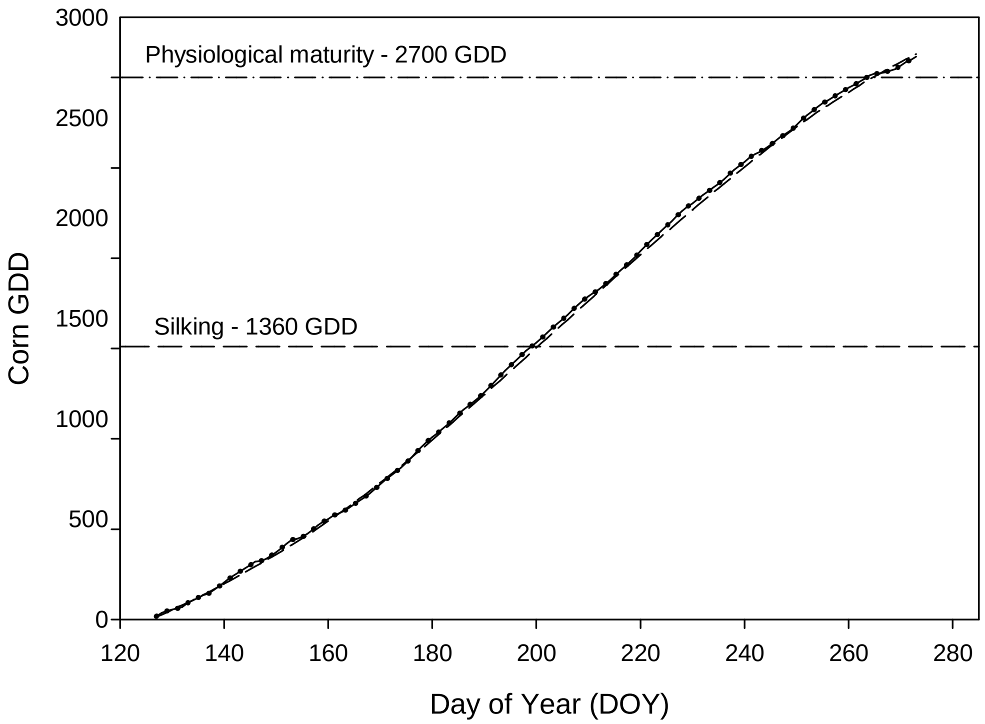

Figure 1.6 - Cumulative corn heat units, Tribune, Kansas 2009.

Table 1.2 – Corn biomass, yield, and yield components as affected by planting geometry and seeding rate, Tribune, Kansas, 2009.

Geometry	Seeding rate	Above-ground biomass	Stover	Grain yield	Harvest index	Kernels $plant^{-1}$	Kernel rows	Kernels ear row^{-1}	Ears $plant^{-1}$	Kernel weight	Yield $plant^{-1}$
	plants m^2 (1000 plants ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (bu ac^{-1})						mg	g
Clump		10.6 (9,440) ab†	4.71 (4200) bc	6.95 (111) ab‡	0.55 ab	640 a	17.3	41.5 a	1.02 b	246 bc	159 a‡
Cluster		10.6 (9,450) ab	4.88 (4350) ab	6.76 (108) b	0.54 b	621 a	17.5	39.9 b	1.08 a	240 c	150 ab
Conventional		11.1 (9,940) a	5.15 (4600) a	7.09 (113) ab	0.54 b	643 a	17.6	42.5 a	1.00 b	241 c	156 a
P1S1		11.2 (9,990) a	4.85 (4320) ab	7.52 (120) a	0.57 a	627 a	17.1	41.5 ab	0.99 b	257 a	162 a
P2S2		9.9 (8,840) b	4.40 (3930) c	6.52 (104) b	0.55 ab	554 b	17.0	36.6 c	0.98 b	254 ab	142 b
	3.0 (12.3)	10.5 (9,350)	4.54 (4050) b	7.02 (112)	0.57 a	748 a	17.5 a‡	44.4 a	1.03	261 a	195 a
	4.0 (16.2)	10.6 (9,460)	4.71 (4200) b	6.97 (111)	0.55 a	610 b	17.4 ab	40.2 b	1.01	247 b	151 b
	5.1 (20.6)	11.0 (9,800)	5.14 (4590) a	6.91 (110)	0.53 b	493 c	17.0 b	36.5 c	1.00	234 c	116 c
Clump	3.0 (12.3)	10.2 (9,140)	4.38 (3910)	6.94 (111)	0.57	772	17.5	45.3	1.03	260 abc‡	201
	4.0 (16.2)	11.2 (10,000)	4.82 (4300)	7.56 (120)	0.57	682	17.4	42.8	1.00	252 bc	172
	5.1 (20.6)	10.3 (9,180)	4.92 (4390)	6.36 (101)	0.52	465	16.9	36.4	1.04	225 e	105
Cluster	3.0 (12.3)	10.9 (9,680)	4.75 (4240)	7.22 (115)	0.56	726	17.3	43.5	1.08	264 ab	191
	4.0 (16.2)	10.2 (9,070)	4.71 (4200)	6.46 (103)	0.54	613	18.2	39.3	1.09	234 de	143
	5.1 (20.6)	10.8 (9,600)	5.17 (4620)	6.61 (105)	0.52	523	17.1	36.8	1.08	224 e	117
Conventional	3.0 (12.3)	11.2 (9,950)	4.99 (4450)	7.29 (116)	0.55	805	17.8	47.6	1.03	254 bc	203
	4.0 (16.2)	11.6 (10,400)	5.27 (4700)	7.52 (120)	0.54	640	17.4	42.3	1.00	247 cd	158
	5.1 (20.6)	10.6 (9,490)	5.20 (4630)	6.44 (103)	0.51	485	17.5	37.6	0.99	222 e	107
P1S1	3.0 (12.3)	10.4 (9,280)	4.43 (3950)	7.07 (113)	0.57	730	17.4	44.7	1.00	270 a	197
	4.0 (16.2)	10.7 (9,530)	4.68 (4170)	7.10 (113)	0.56	608	17.1	41.6	0.99	245 cd	150
	5.1 (20.6)	12.5 (11,200)	5.43 (4850)	8.37 (133)	0.57	545	16.8	38.1	0.98	255 abc	139
P2S2	3.0 (12.3)	9.7 (8,670)	4.15 (3710)	6.59 (105)	0.57	706	17.4	41.1	1.01	260 abc	184
	4.0 (16.2)	9.3 (8,310)	4.07 (3630)	6.21 (99)	0.56	510	16.7	35.0	0.99	257 abc	131
	5.1 (20.6)	10.7 (9,540)	4.99 (4450)	6.76 (108)	0.53	447	16.9	33.7	0.94	246 cd	110
LSD = 0.05											
Geometry		0.9 (800)	0.33 (290)	0.74 (12)	0.02	58	0.5	1.6	0.04	11	16
Population		0.7 (620)	0.25 (230)	0.57 (9)	0.01	45	0.4	1.2	0.03	8	12
Geometry x Seeding Rate		1.6 (1,400)	0.57 (510)	1.28 (20)	0.03	100	0.9	2.8	0.08	19	27
				ANOVA P>F							
Effect											
Geometry		0.0040	0.0010	0.0985	0.0135	0.0218	0.1294	<0.0001	0.0002	0.0069	0.0902
Seeding Rate		0.6736	<0.0001	0.9234	<0.0001	<0.0001	0.0992	<0.0001	0.3175	<0.0001	<0.0001
Geometry x Seeding Rate		0.1129	0.2260	0.1002	0.4335	0.2482	0.5009	0.1966	0.8701	0.0679	0.1460

† Letters within a column and an effect represent differences at LSD (0.05) unless noted otherwise
‡ Letters within a column and an effect represent differences at LSD (0.10)

Biomass, stover, grain yield, and harvest index

Total above-ground biomass was affected by planting geometry (P=0.0040). Corn planted in a P2S2 configuration produced 9.91 Mg ha^{-1} (8840 lb ac^{-1}) of total above-ground biomass, less than corn grown in a conventional or P1S1 configuration (Table 1.2). The conventional and P1S1 geometries produced biomass averaging 11,2 Mg ha^{-1} (9970 lb ac^{-1}). Biomass production for the clump and cluster treatments was comparable to all other geometries (Table 1.2).

Both planting geometry (P=0.0010) and seeding rate (P<0.0001) affected stover (biomass less grain) production (Table 1.2). Conventional, cluster, and P1S1 occupied the top LSD group with an average stover production of 4.96 Mg ha^{-1} (4420 lb ac^{-1}) with the conventional geometry producing the greatest amount of stover, 5.15 Mg ha^{-1} (4600 lb ac^{-1}). Corn planted in a P2S2 configuration resulted in less stover production, 4.40 Mg ha^{-1} (3930 lb ac^{-1}), than all geometries except clump. Stover production from the clump configuration was comparable to the skip-row treatments. Stover production increased as seeding rate increased (Table 1.2) with the two lowest seeding rates producing lower levels of stover, an average of 4.63 Mg ha^{-1} (4130 lb ac^{-1}) compared to the high seeding rate with a stover production of 5.14 Mg ha^{-1} (4590 lb ac^{-1}).

Corn grain yield was affected (P=0.0985) by planting geometry (Table 1.2). The P1S1 geometry produced grain yields higher than the cluster or P2S2 configurations. Corn grown in clump or conventional configurations produced similar yields to the other treatments. Differences among grain yields due to planting geometry were driven primarily by changes in KP through the KER yield component. Although only the P2S2 geometry resulted in lower KP (LSD=0.05), the trend in KER was very similar, with little contribution coming from the KR yield component. Differences in KW accentuated the differences in KER in contributing to final grain yield in the case of the P1S1 geometry although similarly high KW for the P2S2 geometry was inadequate to overcome the lower KER in being the source of reduced grain yield.

Grain yield in 2009 was not affected by seeding rate (Table 1.2), all yield components flexed downward as plant density increased to maintain equivalent grain yields. The combined effects of yield component compensation resulted in no differences in grain yield as plant density increased.

Harvest index (HI) was affected by both planting geometry and seeding rate (Table 1.2). Harvest index for the P1S1 geometry was the highest at 0.57 and comparable to HI in the clump and P2S2 treatments, both with a HI of 0.55. The cluster and conventional geometries resulted in the lowest value for HI, 0.54. The combined effect of yield component compensation resulted in declining harvest index as total above-ground biomass increased with increasing plant density while grain yields remained constant. Geometry effects on harvest index in 2009 were driven by both total above-ground biomass and grain yields.

Yield components

Both treatment main effects affected kernels plant^{-1} (KP) (Table 1.2). The P2S2 geometry resulted in a lower KP, 554, than any other geometry, which averaged 633 (Table 1.2). KP declined 34% as seeding rate increased from the low to the high rate. Both of the contributing yield components to KP were affected by seeding rate alone or by both seeding rate and geometry treatments (Table 1.2). Kernel rows (KR) were affected by seeding rate (P=0.0992) and declined from 17.5 to 17.0 as seeding rate increased, indicating an increasing proportion of ears with 16 KR. Kernels per ear row^{-1} (KER) was affected by both planting geometry and plant population (Table 1.2). Corn planted in clump or conventional geometry resulted in more KER than the cluster or P2S2 configuration. The cluster geometry resulted in KER less than clump and conventional, but more than P2S2, which produced the least KER. Ears plant^{-1} was affected by planting geometry (Table 1.2). Corn planted in the cluster geometry had more ears plant^{-1} than any other geometry, 1.08 compared to an average of 1.00.

Kernel weight was affected by a geometry x seeding rate interaction (P=0.0679) (Table 1.2). In general, kernel weight declined with increasing seeding rate in each geometry (Figure 1.7). The magnitude of the decline was affected by planting geometry with clump, cluster, and conventional planting having relatively larger declines in kernel weight with respect to increasing plant population than either of the skip-row treatments. The two skip-row treatments were the most resilient to changes in kernel weight with respect to plant density. Over the range of seeding rates, the clump, cluster, and conventional geometries decreased 35, 40, and 32 mg respectively, while the P1S1 and P2S2 treatments declined 15 and 14 mg respectively, not a significant change (Figure 1.7).

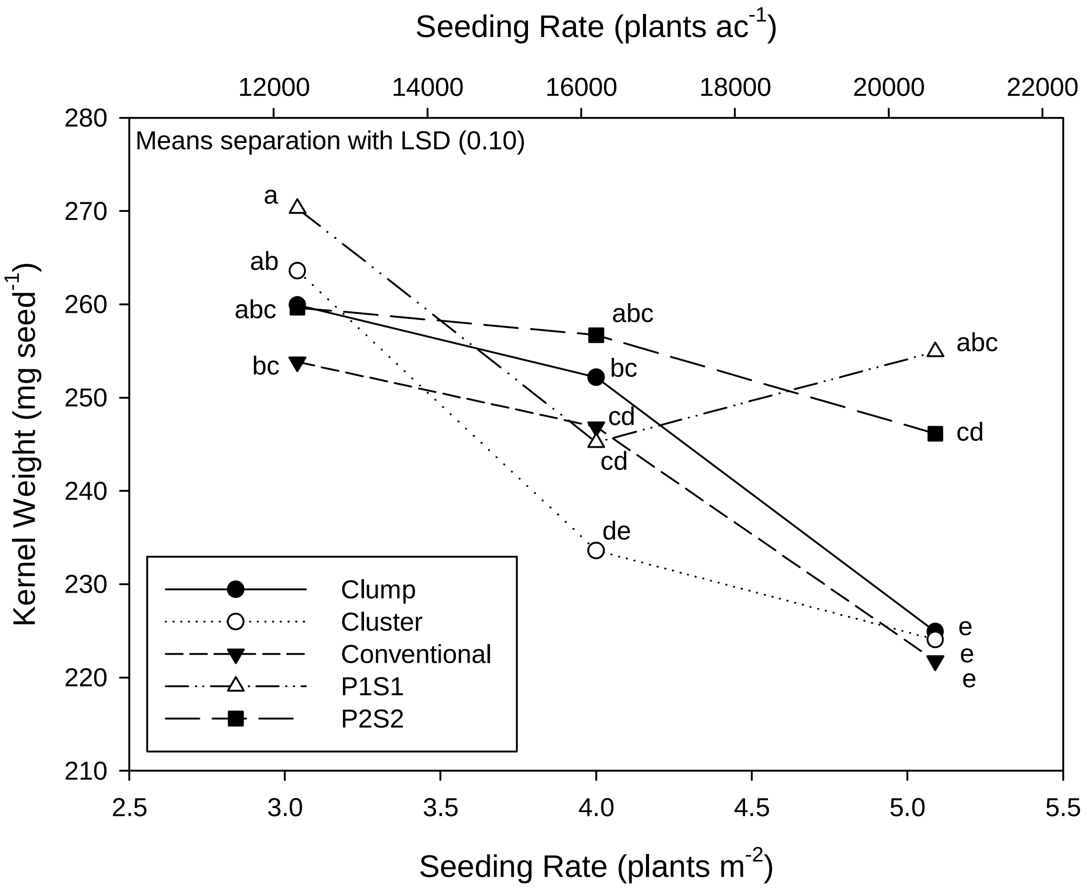

Figure 1.7 - Effect of planting geometry and seeding rate on corn kernel weight, Tribune, Kansas 2009.

Grain yield plant^{-1} was affected by planting geometry (0.0902) and seeding rate (<0.0001). Corn planted in a P2S2 configuration resulted in a lower yield plant^{-1}, 142 g, than the clump, conventional and P1S1 geometries, which averaged 159 g. Yield plant^{-1} for the cluster geometry was not different than any other configuration. As seeding rate increased, yield plant^{-1} decreased 68.7%.

Soil water, water use, and water use efficiency

Profile water totals across measurement positions

Profile water totals were different among measurement positions for three of the seven measurement times in 2009 (Table 1.3). At the second in-season measurement on 13 July, the lowest levels of profile soil water were found in the in-between and in-row positions of the conventional and P2S2 geometries. All other treatments had higher and similar levels of soil water, with the highest levels found in the middle of the skip in the P2S2 geometry and the 76 cm (30 inch) position in the cluster geometry. At the fourth in-season measurement on 28 July the highest level of soil water was found in the middle of the skip of the P2S2 geometry and was similar to measurements in the 38 and 76 cm (15 and 30 inch) clump positions, 76 cm (30 inch) cluster position, and 38 and 76 cm (15 and 30 inch) P1S1 positions. The lowest level was located in-row in the conventional geometry, and was similar to the in-row clump position, 0 and 38 cm (0 and 15 inch) cluster positions, 38 cm (15 inch) conventional position, and the 0, 38, and 95 cm (0, 15, and 37.5 inch) positions in the P2S2 geometry. Observed differences at the fifth in-season measurement on 5 August were similar to the previous measurement

Soil water content by depth within geometries

Differences in soil water content by position in the clump geometry typically occurred at depths of less than 61 cm (24 inches) in 2009 (Table 1.4). In general, water contents at the 76 cm (30 inch) position were higher than water contents at the 30, 46, and 61 cm (12, 18, and 24 inch) depths. The maximum number of differences, at five depths, was observed on 28 July, which coincided with tassel-silk. From this point forward the number of observed differences declined sharply to 1 and 2 on the remaining measurements. Differences among positions were observed for the majority of depths on 21 and 28 July. At these times and at depths of 30 to 61 cm (12 to 24 inches) water contents were highest for the 76 cm (30 inch) position and lowest for the in-clump position. Water contents at the 38 cm (15 inch) position were intermediate in comparison.

Table 1.3 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in corn planting geometries. Tribune, Kansas 2009.

Geometry	Tube position	06/19/09		07/02/09		07/13/09			07/21/09		07/28/09		08/05/09			10/05/09	
	cm (inches)	Available soil water, mm (inches)															
Clump	0	195	(7.67)	158	(6.21)	131	(5.15)	abc	111	(4.37)	98	(3.84)	100	(3.95)	bcde	91	(3.57)
	38 (15)	191	(7.52)	161	(6.35)	137	(5.40)	ab	115	(4.52)	100	(3.94)	107	(4.21)	bc	94	(3.70)
	76 (30)	192	(7.57)	161	(6.35)	139	(5.46)	ab	119	(4.70)	103	(4.07)	110	(4.34)	ab	96	(3.79)
Cluster	0	176	(6.94)	163	(6.40)	131	(5.14)	abc	109	(4.29)	92	(3.63)	93	(3.65)	bcde	76	(2.99)
	38 (15)	175	(6.88)	161	(6.34)	131	(5.15)	abc	109	(4.27)	91	(3.60)	90	(3.56)	bcde	71	(2.81)
	76 (30)	178	(7.01)	171	(6.75)	144	(5.68)	a	121	(4.78)	105	(4.14)	105	(4.14)	bcd	82	(3.23)
Conventional	0	154	(6.07)	131	(5.16)	105	(4.15)	cde	89	(3.52)	72	(2.85)	71	(2.78)	e	57	(2.23)
	38 (15)	166	(6.52)	142	(5.59)	116	(4.56)	bcde	96	(3.78)	81	(3.20)	83	(3.25)	bcde	66	(2.60)
P1S1	0	178	(7.02)	154	(6.06)	128	(5.04)	abcd	109	(4.31)	97	(3.80)	98	(3.85)	bcde	83	(3.25)
	38 (15)	180	(7.08)	159	(6.25)	135	(5.31)	abc	114	(4.50)	99	(3.91)	98	(3.87)	bcde	83	(3.27)
	76 (30)	176	(6.92)	165	(6.48)	143	(5.64)	abc	123	(4.85)	107	(4.22)	104	(4.11)	bcd	83	(3.25)
P2S2	0	153	(6.02)	124	(4.90)	100	(3.95)	de	86	(3.39)	75	(2.96)	77	(3.05)	cde	56	(2.21)
	38 (15)	149	(5.88)	122	(4.81)	99	(3.90)	e	84	(3.31)	75	(2.94)	75	(2.97)	de	55	(2.15)
	95 (37.5)	162	(6.37)	146	(5.76)	129	(5.08)	abc	110	(4.35)	97	(3.81)	106	(4.16)	bcd	73	(2.89)
	152 (60)	158	(6.21)	151	(5.95)	145	(5.72)	a	133	(5.23)	123	(4.86)	139	(5.48)	a	99	(3.91)
LSD = 0.10																	
	Tube Position	33	(1.28)	29	(1.15)	28	(1.10)		27	(1.08)	26	(1.01)	31	(1.22)		35	(1.38)
		ANOVA P>F															
Effect																	
	Tube Position	0.3446		0.1466		0.0870			0.1519		0.1026		0.0873			0.4892	

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Table 1.4 - Soil water by depth in corn planted in clump planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
06/19/2009	15 (6)	0.5721	0.259		0.265		0.262	
	30 (12)	0.9720	0.275		0.277		0.276	
	46 (18)	0.0592	0.259	b†	0.268	ab	0.274	a
	61 (24)	0.5627	0.249		0.247		0.257	
	76 (30)	0.5210	0.241		0.235		0.238	
	91 (36)	0.0692	0.232	a	0.222	b	0.226	ab
	107 (42)	0.1370	0.220		0.214		0.215	
	122 (48)	0.5357	0.214		0.212		0.209	
	137 (54)	0.5681	0.214		0.210		0.207	
	152 (60)	0.4949	0.219		0.213		0.213	
	168 (66)	0.8323	0.216		0.214		0.213	
	183 (72)	0.5411	0.213		0.211		0.208	
07/02/2009	15 (6)	0.3101	0.222		0.228		0.233	
	30 (12)	0.0047	0.237	b	0.249	a	0.254	a
	46 (18)	0.0568	0.228	b	0.242	a	0.245	a
	61 (24)	0.4983	0.224		0.226		0.233	
	76 (30)	0.5533	0.220		0.214		0.217	
	91 (36)	0.1395	0.217		0.211		0.208	
	107 (42)	0.1163	0.211		0.208		0.203	
	122 (48)	0.2582	0.201		0.205		0.198	
	137 (54)	0.3816	0.197		0.202		0.196	
	152 (60)	0.5028	0.202		0.206		0.203	
	168 (66)	0.6300	0.204		0.203		0.201	
	183 (72)	0.6623	0.205		0.200		0.203	
07/13/2009	15 (6)	0.7583	0.209		0.213		0.214	
	30 (12)	0.0045	0.207	b	0.219	a	0.225	a
	46 (18)	0.0203	0.187	b	0.203	a	0.212	a
	61 (24)	0.1194	0.185		0.194		0.203	
	76 (30)	0.6795	0.193		0.194		0.198	
	91 (36)	0.4769	0.202		0.200		0.197	
	107 (42)	0.2946	0.203		0.203		0.198	
	122 (48)	0.0663	0.198	ab	0.202	a	0.193	b
	137 (54)	0.6839	0.198		0.201		0.197	
	152 (60)	0.7862	0.201		0.203		0.203	
	168 (66)	0.2970	0.204		0.202		0.200	
	183 (72)	0.5231	0.206		0.200		0.203	
07/21/2009	15 (6)	0.8762	0.203		0.204		0.206	
	30 (12)	0.0705	0.197	b	0.201	b	0.211	a
	46 (18)	0.0760	0.175	b	0.187	a	0.192	a
	61 (24)	0.0575	0.166	b	0.176	ab	0.185	a
	76 (30)	0.2268	0.168		0.172		0.177	
	91 (36)	0.9990	0.180		0.180		0.180	
	107 (42)	0.9141	0.187		0.188		0.187	
	122 (48)	0.2732	0.190		0.193		0.187	
	137 (54)	0.9231	0.193		0.194		0.194	
	152 (60)	0.9698	0.198		0.199		0.199	
	168 (66)	0.1652	0.202		0.197		0.197	
	183 (72)	0.1869	0.205		0.195		0.202	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.4 (continued) – Soil water by depth in corn planted in clump planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
07/28/2009	15 (6)	0.0600	0.201	a†	0.190	b	0.197	a
	30 (12)	0.1044	0.192		0.196		0.203	
	46 (18)	0.0309	0.168	b	0.176	b	0.189	a
	61 (24)	0.1024	0.158		0.161		0.177	
	76 (30)	0.3124	0.155		0.157		0.162	
	91 (36)	0.8131	0.161		0.164		0.164	
	107 (42)	0.2206	0.170		0.177		0.169	
	122 (48)	0.3496	0.180		0.187		0.179	
	137 (54)	0.4709	0.186		0.193		0.187	
	152 (60)	0.0408	0.198	a	0.198	a	0.192	b
	168 (66)	0.4008	0.201		0.198		0.196	
	183 (72)	0.1491	0.206		0.195		0.199	
08/05/2009	15 (6)	0.9823	0.219		0.220		0.218	
	30 (12)	0.0760	0.206	b	0.210	ab	0.217	a
	46 (18)	0.1088	0.178		0.188		0.197	
	61 (24)	0.2172	0.160		0.170		0.180	
	76 (30)	0.3666	0.156		0.162		0.167	
	91 (36)	0.4542	0.159		0.160		0.166	
	107 (42)	0.2860	0.165		0.170		0.170	
	122 (48)	0.1285	0.170		0.181		0.174	
	137 (54)	0.7580	0.183		0.187		0.184	
	152 (60)	0.4630	0.195		0.196		0.193	
	168 (66)	0.1405	0.199		0.195		0.193	
	183 (72)	0.4699	0.205		0.198		0.198	
10/05/2009	15 (6)	0.9678	0.215		0.213		0.215	
	30 (12)	0.1001	0.211		0.212		0.221	
	46 (18)	0.1048	0.181		0.194		0.194	
	61 (24)	0.2018	0.170		0.170		0.179	
	76 (30)	0.9306	0.164		0.164		0.165	
	91 (36)	0.8007	0.162		0.160		0.159	
	107 (42)	0.9532	0.160		0.161		0.160	
	122 (48)	0.2143	0.158		0.165		0.162	
	137 (54)	0.4771	0.164		0.169		0.168	
	152 (60)	0.5042	0.174		0.177		0.177	
	168 (66)	0.9915	0.180		0.180		0.180	
	183 (72)	0.6426	0.189		0.185		0.185	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Differences in soil water content by position were only observed at the 15 and 168 cm (6 and 66 inch) depths on the first sampling date in the cluster geometry (Table 1.5). As the season progressed, differences became more apparent amongst positions and became more commonplace at multiple and deeper depths. In general, the highest water content values were observed at the 76 cm (30 inch) position and declined closer to the planted row until the lowest values were observed, which were in the planted row. By the end of the season most differences had disappeared except at the 76, 168, and 183 cm (30, 66, and 72 inch) depths.

In the conventional geometry, differences were present at most depths on 2 July and 13 July, with differences observed at seven depths distributed across the profile (Table 1.6). As the season progressed and by the time tassel-silk was reached, the number of depths with observable differences declined indicating a rather complete and spatially uniform extraction of soil water. At the end of the growing season, differences were observed at the bottom of the profile with more soil water being present in the inter-row area than under the rows.

In the P1S1 configuration, based on observed differences in soil water, the front of soil water extraction progressed with sampling date and reached a depth of 107 cm (42 inches) on 28 July which coincided with tassel-silk (Table 1.7). In general, soil water content increased as measurement position moved away from the planted row. The relative differences observed at the bottom of the profile were considered pre-existing trends not related to the study.

Corn planted in a P2S2 geometry resulted in differences in soil water with respect to sampling position at the very first sampling time and differences grew in magnitude, frequency, and depth of occurrence as the growing season progressed (Table 1.8). The highest levels of soil water were observed in the 152 cm (60 inch) position, the center of the skip, and declined to the lowest levels of soil water which were observed between the pair of planted rows. Differences in soil water were observed at all depths except 61 cm (24 inches) at the final two measurement times.

Table 1.5 - Soil water by depth in corn planted in cluster planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
06/19/2009	15 (6)	0.0755	0.252	b	0.263	a	0.260	a
	30 (12)	0.3540	0.276		0.272		0.273	
	46 (18)	0.8828	0.266		0.266		0.268	
	61 (24)	0.2368	0.246		0.252		0.252	
	76 (30)	0.3803	0.235		0.241		0.235	
	91 (36)	0.7859	0.223		0.223		0.225	
	107 (42)	0.8473	0.215		0.213		0.214	
	122 (48)	0.4673	0.208		0.200		0.209	
	137 (54)	0.4516	0.197		0.195		0.203	
	152 (60)	0.8662	0.192		0.191		0.194	
	168 (66)	0.0818	0.190	a	0.182	b	0.185	ab
	183 (72)	0.4053	0.191		0.183		0.184	
07/02/2009	15 (6)	0.0002	0.205	c†	0.221	b	0.238	a
	30 (12)	0.1249	0.229		0.241		0.247	
	46 (18)	0.5658	0.238		0.241		0.244	
	61 (24)	0.0114	0.228	c	0.233	b	0.238	a
	76 (30)	0.1297	0.220		0.224		0.232	
	91 (36)	0.7048	0.217		0.219		0.221	
	107 (42)	0.7051	0.217		0.213		0.216	
	122 (48)	0.2955	0.214		0.205		0.211	
	137 (54)	0.1749	0.212		0.202		0.205	
	152 (60)	0.3030	0.210		0.202		0.204	
	168 (66)	0.0665	0.209	a	0.197	b	0.201	b
	183 (72)	0.0279	0.202	a	0.195	b	0.201	a
07/13/2009	15 (6)	0.0163	0.196	b	0.198	b	0.210	a
	30 (12)	0.0300	0.201	b	0.208	b	0.223	a
	46 (18)	0.0488	0.194	b	0.204	ab	0.216	a
	61 (24)	0.0049	0.181	c	0.196	b	0.211	a
	76 (30)	0.0007	0.187	c	0.198	b	0.206	a
	91 (36)	0.6180	0.198		0.201		0.204	
	107 (42)	0.8221	0.205		0.203		0.203	
	122 (48)	0.2603	0.206		0.197		0.201	
	137 (54)	0.2102	0.206		0.197		0.204	
	152 (60)	0.3851	0.207		0.201		0.201	
	168 (66)	0.0524	0.206	a	0.195	b	0.201	ab
	183 (72)	0.0045	0.204	a	0.196	b	0.203	a
07/21/2009	15 (6)	0.5405	0.192		0.191		0.194	
	30 (12)	0.1027	0.194		0.198		0.204	
	46 (18)	0.1813	0.181		0.189		0.193	
	61 (24)	0.0194	0.163	b	0.173	b	0.185	a
	76 (30)	0.0007	0.160	c	0.172	b	0.184	a
	91 (36)	0.0243	0.170	b	0.178	b	0.188	a
	107 (42)	0.4405	0.185		0.187		0.191	
	122 (48)	0.5597	0.195		0.190		0.196	
	137 (54)	0.1054	0.199		0.190		0.199	
	152 (60)	0.2796	0.203		0.195		0.198	
	168 (66)	0.0203	0.204	a	0.191	b	0.199	a
	183 (72)	0.0006	0.204	a	0.193	c	0.200	b

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.5 (continued) – Soil water by depth in corn planted in cluster planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
07/28/2009	15 (6)	0.0543	0.187	a†	0.182	b	0.182	b
	30 (12)	0.4242	0.189		0.190		0.194	
	46 (18)	0.2867	0.176		0.178		0.183	
	61 (24)	0.0346	0.157	b	0.163	b	0.172	a
	76 (30)	0.0162	0.151	b	0.158	b	0.170	a
	91 (36)	0.0274	0.151	b	0.158	b	0.172	a
	107 (42)	0.0631	0.160	b	0.170	ab	0.178	a
	122 (48)	0.1268	0.177		0.176		0.188	
	137 (54)	0.4018	0.189		0.184		0.192	
	152 (60)	0.2992	0.199		0.190		0.195	
	168 (66)	0.0231	0.203	a	0.190	b	0.195	b
	183 (72)	0.0004	0.202	a	0.193	b	0.203	a
08/05/2009	15 (6)	0.4669	0.211		0.206		0.212	
	30 (12)	0.0319	0.205	a	0.195	b	0.205	a
	46 (18)	0.1872	0.183		0.179		0.184	
	61 (24)	0.0496	0.157	b	0.161	b	0.170	a
	76 (30)	0.0071	0.149	b	0.156	b	0.167	a
	91 (36)	0.0385	0.149	b	0.156	b	0.166	a
	107 (42)	0.0333	0.158	b	0.164	b	0.172	a
	122 (48)	0.1245	0.168		0.169		0.180	
	137 (54)	0.1595	0.178		0.175		0.185	
	152 (60)	0.5368	0.191		0.187		0.192	
	168 (66)	0.1111	0.194		0.186		0.193	
	183 (72)	0.0203	0.200	a	0.193	b	0.200	a
10/05/2009	15 (6)	0.1301	0.200		0.198		0.202	
	30 (12)	0.5016	0.207		0.205		0.209	
	46 (18)	0.6095	0.190		0.186		0.190	
	61 (24)	0.3517	0.164		0.165		0.168	
	76 (30)	0.0308	0.153	b	0.153	b	0.159	a
	91 (36)	0.2076	0.148		0.149		0.153	
	107 (42)	0.3992	0.150		0.150		0.153	
	122 (48)	0.2132	0.152		0.149		0.156	
	137 (54)	0.1077	0.156		0.153		0.162	
	152 (60)	0.5069	0.165		0.161		0.167	
	168 (66)	0.0552	0.172	a	0.164	b	0.172	a
	183 (72)	0.0023	0.176	b	0.170	c	0.181	a

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.6 - Soil water by depth in corn planted in conventional planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position 0		36 cm (15 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$			
06/19/2009	15 (6)	0.6651	0.258		0.256	
	30 (12)	0.0521	0.268	b†	0.274	a
	46 (18)	0.0147	0.255	b	0.267	a
	61 (24)	0.0503	0.240	b	0.249	a
	76 (30)	0.3458	0.231		0.237	
	91 (36)	0.1838	0.218		0.225	
	107 (42)	0.0095	0.200	b	0.208	a
	122 (48)	0.1301	0.177		0.184	
	137 (54)	0.3486	0.169		0.171	
	152 (60)	0.2646	0.173		0.178	
	168 (66)	0.0457	0.175	b	0.184	a
	183 (72)	0.1576	0.182		0.190	
07/02/2009	15 (6)	0.1989	0.211		0.203	
	30 (12)	0.0231	0.219	b	0.233	a
	46 (18)	0.2094	0.226		0.235	
	61 (24)	0.0405	0.220	b	0.224	a
	76 (30)	0.5190	0.218		0.223	
	91 (36)	0.1441	0.208		0.214	
	107 (42)	0.0206	0.198	b	0.205	a
	122 (48)	0.0518	0.190	b	0.192	a
	137 (54)	0.1285	0.179		0.182	
	152 (60)	0.0386	0.173	b	0.182	a
	168 (66)	0.0066	0.173	b	0.185	a
	183 (72)	0.0186	0.179	b	0.188	a
07/13/2009	15 (6)	0.4398	0.198		0.193	
	30 (12)	0.0248	0.198	b	0.206	a
	46 (18)	0.0169	0.181	b	0.197	a
	61 (24)	0.0845	0.177	b	0.185	a
	76 (30)	0.7884	0.186		0.187	
	91 (36)	0.6882	0.190		0.192	
	107 (42)	0.0995	0.189	b	0.196	a
	122 (48)	0.8877	0.189		0.189	
	137 (54)	0.1051	0.183		0.184	
	152 (60)	0.0837	0.178	b	0.186	a
	168 (66)	0.0178	0.175	b	0.188	a
	183 (72)	0.0135	0.181	b	0.190	a
07/21/2009	15 (6)	0.3577	0.196		0.188	
	30 (12)	0.3830	0.193		0.196	
	46 (18)	0.0208	0.170	b	0.181	a
	61 (24)	0.0676	0.156	b	0.166	a
	76 (30)	0.4084	0.159		0.163	
	91 (36)	0.5957	0.165		0.169	
	107 (42)	0.4083	0.173		0.178	
	122 (48)	0.5775	0.182		0.180	
	137 (54)	0.9682	0.182		0.182	
	152 (60)	0.4322	0.181		0.185	
	168 (66)	0.0845	0.179	b	0.187	a
	183 (72)	0.1529	0.184		0.190	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.6 (continued) - Soil water by depth in corn planted in conventional planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position: 0		Tube position: 36 cm (15 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$			
07/28/2009	15 (6)	0.1702	0.186		0.181	
	30 (12)	0.1524	0.185		0.190	
	46 (18)	0.0577	0.164	b†	0.175	a
	61 (24)	0.2542	0.154		0.156	
	76 (30)	0.8399	0.150		0.150	
	91 (36)	0.2068	0.147		0.153	
	107 (42)	0.3106	0.153		0.159	
	122 (48)	0.3386	0.164		0.168	
	137 (54)	0.3467	0.171		0.174	
	152 (60)	0.1010	0.175		0.184	
	168 (66)	0.0713	0.178	b	0.187	a
	183 (72)	0.1119	0.182		0.190	
08/05/2009	15 (6)	0.8598	0.205		0.204	
	30 (12)	0.3104	0.186		0.197	
	46 (18)	0.1406	0.165		0.176	
	61 (24)	0.0277	0.151	b	0.156	a
	76 (30)	0.3448	0.147		0.151	
	91 (36)	0.2309	0.147		0.151	
	107 (42)	0.2333	0.149		0.156	
	122 (48)	0.3473	0.157		0.161	
	137 (54)	0.1041	0.165		0.168	
	152 (60)	0.0589	0.170	b	0.181	a
	168 (66)	0.0301	0.173	b	0.185	a
	183 (72)	0.0636	0.181	b	0.189	a
10/05/2009	15 (6)	0.1862	0.203		0.197	
	30 (12)	0.3180	0.196		0.199	
	46 (18)	0.1594	0.173		0.180	
	61 (24)	0.2834	0.151		0.158	
	76 (30)	0.2176	0.145		0.147	
	91 (36)	0.1324	0.141		0.144	
	107 (42)	0.2665	0.140		0.143	
	122 (48)	0.4589	0.144		0.145	
	137 (54)	0.0441	0.143	b	0.149	a
	152 (60)	0.0245	0.148	b	0.159	a
	168 (66)	0.0144	0.155	b	0.169	a
	183 (72)	0.0235	0.166	b	0.179	a

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.7 - Soil water by depth in corn in plant-1 skip-1 (P1S1) planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position: 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
06/19/2009	15 (6)	0.0077	0.249	b†	0.266	a	0.270	a
	30 (12)	0.7790	0.274		0.272		0.274	
	46 (18)	0.5384	0.262		0.267		0.267	
	61 (24)	0.8920	0.250		0.252		0.249	
	76 (30)	0.5543	0.237		0.238		0.233	
	91 (36)	0.6426	0.222		0.222		0.218	
	107 (42)	0.8765	0.207		0.209		0.205	
	122 (48)	0.6229	0.197		0.196		0.191	
	137 (54)	0.1766	0.198		0.195		0.193	
	152 (60)	0.0245	0.203	a	0.197	b	0.195	b
	168 (66)	0.0705	0.201	a	0.201	a	0.194	b
	183 (72)	0.1917	0.204		0.200		0.199	
07/02/2009	15 (6)	0.0053	0.213	c	0.229	b	0.255	a
	30 (12)	0.0468	0.232	c	0.241	b	0.258	a
	46 (18)	0.1504	0.233		0.237		0.252	
	61 (24)	0.5357	0.226		0.232		0.233	
	76 (30)	0.8135	0.222		0.225		0.221	
	91 (36)	0.8725	0.213		0.214		0.212	
	107 (42)	0.8107	0.207		0.207		0.204	
	122 (48)	0.8995	0.198		0.198		0.196	
	137 (54)	0.1997	0.198		0.194		0.191	
	152 (60)	0.0508	0.200	a	0.196	ab	0.194	b
	168 (66)	0.3760	0.200		0.201		0.197	
	183 (72)	0.9122	0.202		0.202		0.201	
07/13/2009	15 (6)	0.0662	0.204	b	0.215	ab	0.222	a
	30 (12)	0.0012	0.207	c	0.217	b	0.231	a
	46 (18)	0.0051	0.195	b	0.204	b	0.226	a
	61 (24)	0.0142	0.188	b	0.199	b	0.213	a
	76 (30)	0.2141	0.191		0.198		0.206	
	91 (36)	0.5819	0.198		0.199		0.203	
	107 (42)	0.9133	0.197		0.198		0.196	
	122 (48)	0.7290	0.196		0.199		0.195	
	137 (54)	0.2720	0.198		0.195		0.193	
	152 (60)	0.1190	0.199		0.196		0.192	
	168 (66)	0.7159	0.198		0.199		0.197	
	183 (72)	0.0210	0.203	a	0.200	b	0.201	b
07/21/2009	15 (6)	0.2491	0.197		0.205		0.208	
	30 (12)	0.0021	0.199	c	0.203	b	0.209	a
	46 (18)	0.0212	0.186	b	0.192	b	0.202	a
	61 (24)	0.0188	0.171	b	0.180	b	0.190	a
	76 (30)	0.0303	0.167	b	0.174	b	0.187	a
	91 (36)	0.0402	0.174	b	0.178	b	0.190	a
	107 (42)	0.4355	0.182		0.183		0.189	
	122 (48)	0.6332	0.187		0.189		0.190	
	137 (54)	0.5576	0.194		0.191		0.191	
	152 (60)	0.2625	0.196		0.194		0.191	
	168 (66)	0.8907	0.196		0.196		0.195	
	183 (72)	0.1156	0.202		0.200		0.200	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.7 (continued) – Soil water by depth in corn planted in plant-1 skip-1 (P1S1) planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
07/28/2009	15 (6)	0.8905	0.196		0.196		0.194	
	30 (12)	0.0401	0.196	b†	0.197	b	0.200	a
	46 (18)	0.2763	0.182		0.183		0.188	
	61 (24)	0.2185	0.166		0.171		0.175	
	76 (30)	0.0439	0.157	b	0.163	ab	0.169	a
	91 (36)	0.0242	0.158	b	0.162	b	0.174	a
	107 (42)	0.0510	0.162	b	0.167	b	0.179	a
	122 (48)	0.1924	0.174		0.177		0.184	
	137 (54)	0.2653	0.186		0.185		0.189	
	152 (60)	0.5657	0.195		0.192		0.191	
	168 (66)	0.7060	0.195		0.195		0.193	
	183 (72)	0.0571	0.201	a	0.198	b	0.202	a
08/05/2009	15 (6)	0.9507	0.211		0.212		0.211	
	30 (12)	0.9131	0.206		0.204		0.204	
	46 (18)	0.7904	0.189		0.186		0.189	
	61 (24)	0.6719	0.169		0.169		0.172	
	76 (30)	0.0616	0.159	b	0.162	ab	0.167	a
	91 (36)	0.0922	0.156	b	0.160	ab	0.167	a
	107 (42)	0.0326	0.158	b	0.162	b	0.171	a
	122 (48)	0.1167	0.166		0.170		0.176	
	137 (54)	0.2099	0.179		0.177		0.184	
	152 (60)	0.9154	0.189		0.187		0.188	
	168 (66)	0.8600	0.194		0.193		0.192	
	183 (72)	0.0174	0.202	a	0.197	b	0.200	a
10/05/2009	15 (6)	0.7995	0.206		0.209		0.206	
	30 (12)	0.3566	0.207		0.206		0.202	
	46 (18)	0.8123	0.190		0.187		0.186	
	61 (24)	0.7144	0.170		0.172		0.169	
	76 (30)	0.7182	0.160		0.161		0.159	
	91 (36)	0.9983	0.155		0.155		0.155	
	107 (42)	0.4808	0.156		0.155		0.153	
	122 (48)	0.4583	0.154		0.157		0.157	
	137 (54)	0.4760	0.160		0.161		0.164	
	152 (60)	0.7261	0.167		0.167		0.169	
	168 (66)	0.7171	0.172		0.173		0.174	
	183 (72)	0.2916	0.180		0.178		0.182	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.8 - Soil water by depth in corn planted in a plant-2 skip-2 (P2S2) planting geometry. Tribune, Kansas 2009.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$							
06/19/2009	15 (6)	0.0516	0.249	b†	0.246	b	0.265	a	0.256	ab
	30 (12)	0.1864	0.266		0.263		0.275		0.269	
	46 (18)	0.6555	0.254		0.253		0.265		0.255	
	61 (24)	0.8808	0.235		0.227		0.241		0.235	
	76 (30)	0.8406	0.221		0.208		0.220		0.221	
	91 (36)	0.9130	0.209		0.199		0.205		0.207	
	107 (42)	0.9523	0.191		0.188		0.187		0.193	
	122 (48)	0.9303	0.180		0.181		0.182		0.186	
	137 (54)	0.4039	0.179		0.181		0.186		0.181	
	152 (60)	0.5249	0.182		0.187		0.189		0.185	
	168 (66)	0.3375	0.183		0.190		0.192		0.189	
	183 (72)	0.7354	0.189		0.192		0.190		0.193	
07/02/2009	15 (6)	0.0006	0.199	b	0.206	b	0.235	a	0.245	a
	30 (12)	0.0010	0.220	b	0.217	b	0.251	a	0.260	a
	46 (18)	0.0055	0.216	b	0.213	b	0.246	a	0.247	a
	61 (24)	0.3081	0.210		0.204		0.228		0.224	
	76 (30)	0.4707	0.205		0.198		0.211		0.216	
	91 (36)	0.5782	0.200		0.191		0.203		0.204	
	107 (42)	0.9412	0.191		0.185		0.190		0.191	
	122 (48)	0.9504	0.180		0.180		0.181		0.184	
	137 (54)	0.7559	0.178		0.178		0.181		0.184	
	152 (60)	0.3239	0.180		0.185		0.188		0.188	
	168 (66)	0.3110	0.180		0.189		0.189		0.189	
	183 (72)	0.9249	0.190		0.191		0.191		0.193	
07/13/2009	15 (6)	0.0006	0.193	c	0.195	c	0.217	b	0.232	a
	30 (12)	0.0002	0.203	c	0.200	c	0.226	b	0.253	a
	46 (18)	0.0008	0.185	c	0.185	c	0.213	b	0.241	a
	61 (24)	0.0133	0.172	bc	0.169	c	0.196	ab	0.220	a
	76 (30)	0.0093	0.172	b	0.166	b	0.191	a	0.210	a
	91 (36)	0.0085	0.177	b	0.175	b	0.193	a	0.201	a
	107 (42)	0.2773	0.181		0.178		0.193		0.191	
	122 (48)	0.5356	0.181		0.176		0.188		0.185	
	137 (54)	0.5187	0.177		0.176		0.186		0.183	
	152 (60)	0.2437	0.179		0.184		0.191		0.188	
	168 (66)	0.2178	0.180		0.186		0.193		0.190	
	183 (72)	0.8803	0.192		0.194		0.193		0.196	
07/21/2009	15 (6)	0.0007	0.187	c	0.190	c	0.204	b	0.218	a
	30 (12)	<.0001	0.196	c	0.192	c	0.213	b	0.238	a
	46 (18)	0.0018	0.177	c	0.176	c	0.197	b	0.224	a
	61 (24)	0.0170	0.161	b	0.157	b	0.178	b	0.208	a
	76 (30)	0.0039	0.157	bc	0.152	c	0.173	b	0.202	a
	91 (36)	0.0010	0.160	c	0.156	c	0.178	b	0.198	a
	107 (42)	0.0389	0.165	b	0.164	b	0.182	a	0.187	a
	122 (48)	0.2584	0.171		0.169		0.183		0.182	
	137 (54)	0.3331	0.174		0.173		0.183		0.182	
	152 (60)	0.1954	0.178		0.181		0.188		0.186	
	168 (66)	0.3297	0.180		0.185		0.190		0.188	
	183 (72)	0.9454	0.192		0.191		0.191		0.193	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.8 (continued) – Soil water by depth in corn planted in a plant-2 skip-2 (P2S2) planting geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$							
07/28/2009	15 (6)	0.1402	0.183		0.194		0.195		0.198	
	30 (12)	0.0002	0.193	bc†	0.190	c	0.201	b	0.225	a
	46 (18)	0.0057	0.174	b	0.171	b	0.187	b	0.215	a
	61 (24)	0.0217	0.156	b	0.154	b	0.167	b	0.199	a
	76 (30)	0.0019	0.149	b	0.145	b	0.161	b	0.196	a
	91 (36)	0.0010	0.149	c	0.147	c	0.164	b	0.192	a
	107 (42)	0.0030	0.151	c	0.151	c	0.171	b	0.186	a
	122 (48)	0.0094	0.159	b	0.157	b	0.175	a	0.182	a
	137 (54)	0.0419	0.166	b	0.166	b	0.180	a	0.181	a
	152 (60)	0.0800	0.177	b	0.176	b	0.188	a	0.186	a
	168 (66)	0.3080	0.179		0.183		0.188		0.190	
	183 (72)	0.7899	0.192		0.190		0.192		0.195	
08/05/2009	15 (6)	0.0281	0.209	b	0.201	b	0.212	b	0.224	a
	30 (12)	0.0009	0.203	b	0.194	b	0.204	b	0.238	a
	46 (18)	<.0001	0.179	bc	0.172	c	0.190	b	0.223	a
	61 (24)	0.0024	0.156	bc	0.153	c	0.173	b	0.206	a
	76 (30)	0.0006	0.149	c	0.147	c	0.168	b	0.203	a
	91 (36)	0.0005	0.148	c	0.149	c	0.173	b	0.199	a
	107 (42)	0.0041	0.150	b	0.152	b	0.178	a	0.195	a
	122 (48)	0.0072	0.154	b	0.154	b	0.181	a	0.193	a
	137 (54)	0.0115	0.158	b	0.161	b	0.182	a	0.191	a
	152 (60)	0.0139	0.171	b	0.174	b	0.187	a	0.191	a
	168 (66)	0.0481	0.174	b	0.181	ab	0.188	a	0.191	a
	183 (72)	0.8310	0.193		0.190		0.192		0.195	
10/05/2009	15 (6)	0.0427	0.187	b	0.196	ab	0.204	a	0.205	a
	30 (12)	0.0029	0.198	b	0.195	b	0.202	b	0.219	a
	46 (18)	0.0226	0.175	b	0.173	b	0.182	b	0.200	a
	61 (24)	0.1560	0.156		0.151		0.161		0.177	
	76 (30)	0.0295	0.148	b	0.142	b	0.151	b	0.170	a
	91 (36)	0.0045	0.145	b	0.143	b	0.150	b	0.168	a
	107 (42)	0.0021	0.143	bc	0.141	c	0.150	b	0.164	a
	122 (48)	0.0013	0.142	c	0.142	c	0.153	b	0.167	a
	137 (54)	0.0007	0.143	c	0.144	c	0.156	b	0.171	a
	152 (60)	0.0039	0.149	c	0.147	c	0.162	b	0.176	a
	168 (66)	0.0030	0.152	c	0.155	c	0.169	b	0.181	a
	183 (72)	0.0100	0.165	b	0.165	b	0.174	b	0.188	a

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Cross-section analysis of soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. Planting geometry did not affect profile available water, range of soil water content, or standard deviation (SD) of soil water content at the first measurement in 2009 (Table 1.9). On the 2 July measurement, during early vegetative growth, the widening range of soil water content affected by geometry became apparent as the cross-section under the P2S2 geometry had a larger range in soil water content than any other geometry ($P=0.0062$). Similar contrasts are present in the other geometries, however not statistically differentiable.

At the mid vegetative sampling on 13 July, profile water differences among geometry treatments were undetectable although treatment induced spatial patterns resulted in differences in the range ($P<0.0001$) and SD ($P=0.0007$) for soil water contents among geometries (Table 1.9). The trend for both range and SD were essentially the same, with the profile under a P2S2 geometry having the largest range in soil water contents and largest variability as quantified by SD. The P1S1 configuration followed and was not uniquely different than the profile underlying a cluster or clump configuration. The conventional geometry resulted in the smallest range and lowest SD indicating a more uniform spatial pattern of soil water. While no differences in cumulative water use were observed, in the interval from early vegetative measurement on 2 July until mid vegetative measurement on 13 July, corn in a cluster configuration had the highest water use followed by clump, conventional, and P1S1 having similar levels of water use ($P=0.0001$) (Table 1.9). Corn in a P2S2 configuration had the lowest water use.

Profile water, cumulative water use, and interval water use from the prior measurement were not different with regard to planting geometry when evaluated on 21 July during late vegetative growth (Table 1.9). Differences in spatial location of soil water content are reflected in differences in range and SD of water contents in the cross-sections underlying the various planting geometries. The P2S2 geometry exhibited a larger range and higher level of variability than any other geometry.

The sampling on 28 July coincided with tassel-silk. Again no differences were detectable in profile soil water content (Table 1.9), however the same numerical trend that had been persistent for several samplings remained with the conventional treatment having the lowest level of profile soil water and P2S2 the highest. Again the profile under the P2S2 configuration exhibited the largest range and highest level of variability followed by like values among the clump, cluster, and P1S1 treatments. The cross-section under the conventional geometry continued to have a small range and a level of variability lower than any other treatment. Cumulative water use was different among the treatments with clump, cluster, and conventional using similar amounts of soil water, P2S2 using the least, and P1S1 being intermediate. Interval water use was not statistically differentiable, however P2S2 used 1.9 cm (0.75 inches) of water compared to 2.4 cm (0.94 inches) for the other treatments on average.

Data collected at the last two samplings of the season, 5 August and 5 October, indicated that although treatment differences in profile water could not be identified, the average spatial variability of water contents, as evaluated by SD across geometries, continued to increase (Table 1.9). Cumulative water use remained numerically the lowest for the P2S2 configuration. Profile available water remained the lowest numerically for the conventional configuration. From the period of tassel-silk to grain fill soil water depletions were evident across the full depth of the profile. Soil water content at corn harvest remained spatially affected by planting geometry and was most noticeable following corn in a P2S2 configuration (Table 1.8). Water use from the interval of grain fill to corn harvest was numerically highest for corn in the P2S2 geometry (Table 1.9).

Water use / Water use efficiency

No differences among planting geometries were observed in 2009 for water use, grain water use efficiency, or biomass water use efficiency (Table 1.10).

Table 1.9 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated soil water values, and water use as affected by corn planting geometry. Tribune, Kansas, 2009.

Geometry	06/19/2009 Profile available water	06/19/2009 Range	06/19/2009 SD	07/02/2009 Profile available water	07/02/2009 Range	07/02/2009 SD	07/02/2009 Cumulative water use	07/13/2009 Profile available water	07/13/2009 Range	07/13/2009 SD	07/13/2009 Cumulative water use	07/13/2009 Interval water use
	mm (in)	v v^{-1}	v v^{-1}	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)
Clump	196 (7.72)	0.090	0.025	162 (6.38)	0.077 b	0.019	58 (2.28)	137 (5.40)	0.060 bc	0.013 b	102 (4.01)	44 (1.73) b
Cluster	181 (7.14)	0.108	0.032	165 (6.50)	0.081 b	0.017	40 (1.58)	133 (5.25)	0.061 bc	0.012 bc	91 (3.58)	51 (1.99) a
Conventional	166 (6.55)	0.111	0.037	140 (5.51)	0.080 b	0.020	50 (1.98)	112 (4.43)	0.050 c	0.010 c	97 (3.82)	47 (1.83) b
P1S1	184 (7.23)	0.097	0.030	161 (6.34)	0.080 b	0.020	46 (1.82)	136 (5.37)	0.066 b	0.013 b	90 (3.55)	44 (1.73) b
P2S2	161 (6.34)	0.113	0.034	139 (5.48)	0.111 a	0.025	46 (1.80)	120 (4.73)	0.110 a	0.021 a	84 (3.30)	38 (1.51) c
LSD = 0.10												
Geometry	35 (1.39)	0.024	0.0099	31 (1.21)	0.014	0.0065	14 (0.57)	30 (1.17)	0.014	0.003	15 (0.58)	3 (0.12)
							ANOVA P>F					
Effect												
Geometry	0.4445	0.4306	0.3806	0.4007	0.0062	0.3061	0.3176	0.5100	<0.0001	0.0007	0.2895	0.0001

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Geometry	07/21/2009 Profile available water	07/21/2009 Range	07/21/2009 SD	07/21/2009 Cumulative water use	07/21/2009 Interval water use	07/28/2009 Profile available water	07/28/2009 Range	07/28/2009 SD	07/28/2009 Cumulative water use	07/28/2009 Interval water use
	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)
Clump	116 (4.55)	0.064 b	0.015 b	141 (5.53)	39 (1.52)	100 (3.94)	0.068 b	0.019 ab	163 (6.44) a	23 (0.90)
Cluster	111 (4.36)	0.061 b	0.014 b	131 (5.14)	40 (1.56)	93 (3.66)	0.066 bc	0.016 bc	156 (6.13) a	25 (0.99)
Conventional	94 (3.70)	0.053 b	0.013 b	133 (5.22)	36 (1.40)	77 (3.04)	0.054 c	0.016 c	157 (6.16) a	24 (0.94)
P1S1	116 (4.55)	0.068 b	0.015 b	128 (5.04)	38 (1.49)	100 (3.93)	0.064 bc	0.017 bc	151 (5.94) ab	23 (0.91)
P2S2	103 (4.07)	0.100 a	0.020 a	118 (4.63)	34 (1.33)	92 (3.61)	0.097 a	0.020 a	137 (5.38) b	19 (0.75)
LSD = 0.10										
Geometry	30 (1.17)	0.017	0.003	15 (0.59)	5 (0.20)	28 (1.09)	0.014	0.003	15 (0.61)	4 (0.16)
						ANOVA P>F				
Effect										
Geometry	0.6607	0.0031	0.0366	0.1652	0.2825	0.5984	0.0023	0.0895	0.0816	0.1379

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Table 1.9 (continued) - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated soil water values, and water use as affected by corn planting geometry. Tribune, Kansas, 2009.

Geometry	08/05/2009								10/05/2009							
	Profile available water		Range	SD	Cumulative water use		Interval water use		Profile available water		Range	SD	Cumulative water use		Interval water use	
	mm	(in)	$v\ v^{-1}$	$v\ v^{-1}$	mm	(in)	mm	(in)	mm	(in)	$v\ v^{-1}$	$v\ v^{-1}$	mm	(in)	mm	(in)
Clump	108	(4.26)	0.084	0.022	204	(8.02)	40	(1.59)	96	(3.78)	0.075	0.021	340	(13.37)	136	(5.35)
Cluster	95	(3.74)	0.083	0.021	202	(7.96)	46	(1.83)	76	(2.99)	0.069	0.021	345	(13.58)	143	(5.62)
Conventional	78	(3.08)	0.077	0.021	204	(8.03)	48	(1.87)	63	(2.49)	0.075	0.023	343	(13.49)	139	(5.46)
P1S1	101	(3.96)	0.077	0.021	199	(7.83)	48	(1.88)	85	(3.35)	0.072	0.022	338	(13.30)	139	(5.48)
P2S2	100	(3.93)	0.114	0.024	177	(6.97)	40	(1.59)	72	(2.82)	0.095	0.023	329	(12.95)	152	(5.98)
LSD = 0.10																
Geometry	36	(1.40)	0.027	0.005	24	(0.94)	14	(0.55)	41	(1.60)	0.017	0.005	29	(1.15)	14	(0.55)
	ANOVA P>F															
Effect																
Geometry	0.6531		0.1450	0.7613	0.2709		0.7598		0.6611		0.1252	0.8850	0.8865		0.3300	

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Table 1.10 - Corn water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb) as affected by planting geometry. Tribune, Kansas, 2009.

Geometry	Water Use		WUEg		WUEb	
	mm (in)		kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})		kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})	
Clump	340	(13.4)	19.0	(431)	33.4	(756)
Cluster	345	(13.6)	15.9	(361)	29.6	(672)
Conventional	343	(13.5)	18.5	(420)	33.9	(769)
P1S1	338	(13.3)	17.7	(402)	31.6	(716)
P2S2	329	(13.0)	16.0	(363)	28.5	(645)
LSD = 0.05						
Geometry	31	(1.2)	3.8	(85)	5.8	(132)
			ANOVA P>F			
Effect						
Geometry	0.9113		0.4911		0.4305	

2010 Tribune

In-season precipitation was above normal from DOY 139 though the end of the growing season (Figure 1.8) with an ending in-season precipitation of 337 mm (13.28 inches) (Figure 1.9). Heat unit accumulation was below normal for 33 days after planting but then remained normal to above normal for the rest of the growing season (Figure 1.10) finishing 107 GDD above normal. Grain yields in 2010 were the lowest of any year in the study averaging 4.58 Mg ha^{-1} (73 bu ac^{-1}) across all treatments (Table 1.11).

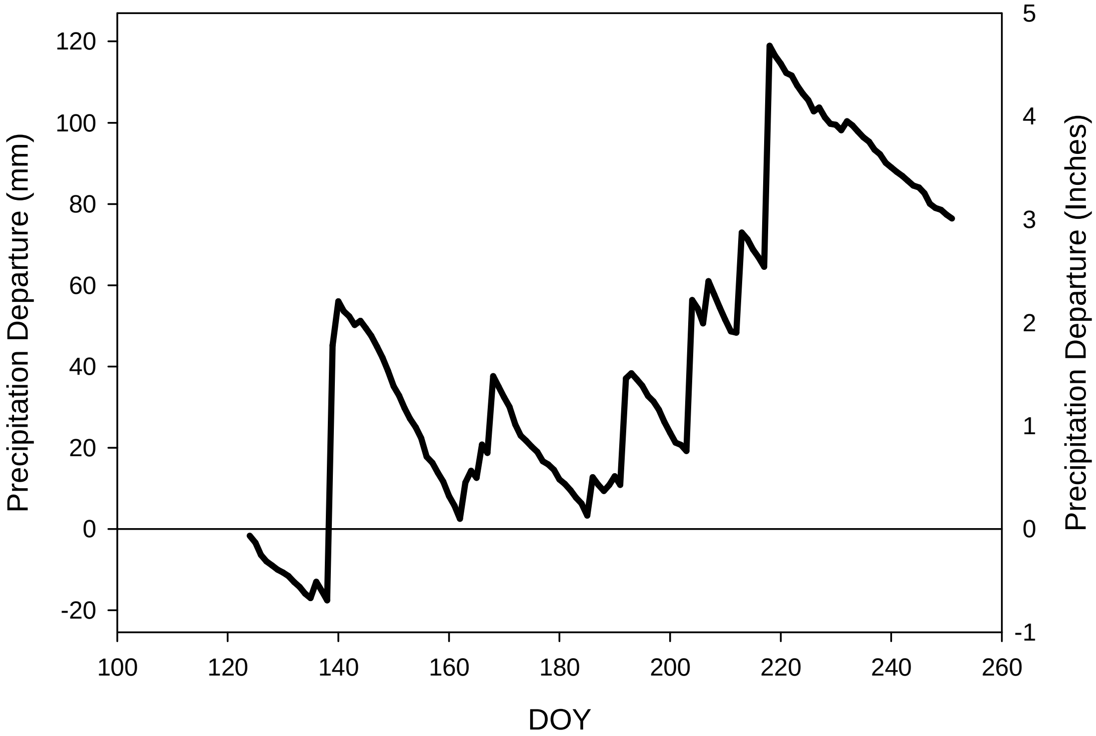

Figure 1.8 - Corn growing season precipitation departure from normal, Tribune, Kansas 2010.

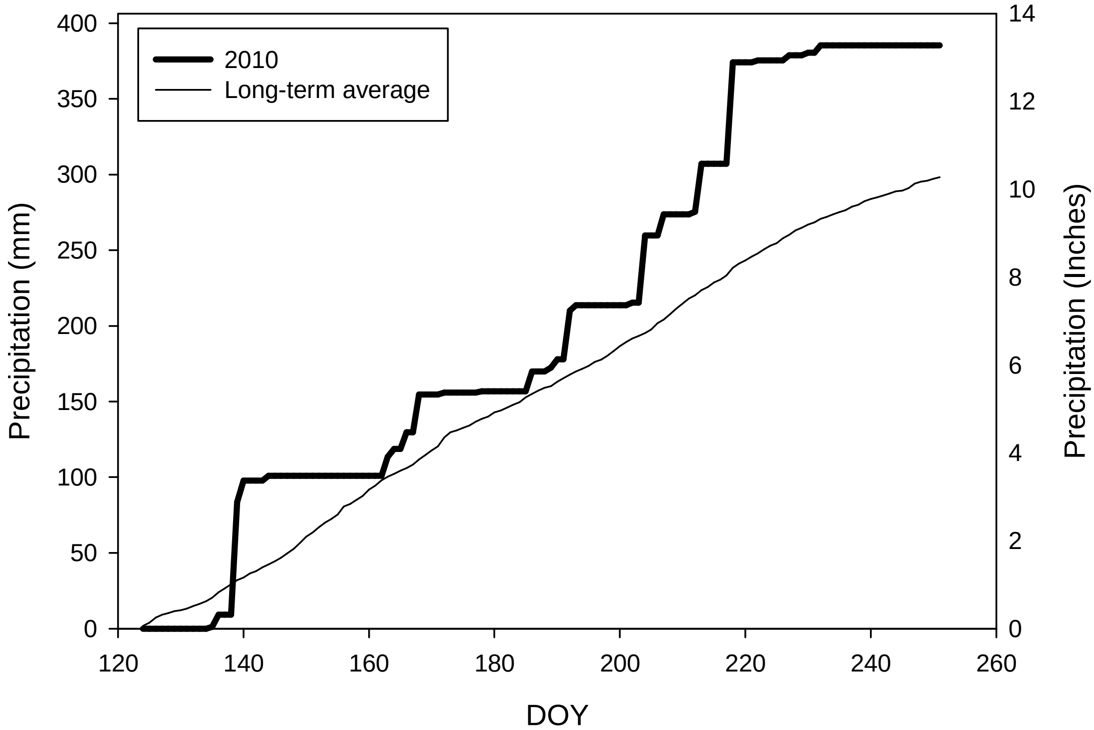

Figure 1.9 - Corn season cumulative precipitation, Tribune, Kansas 2010.

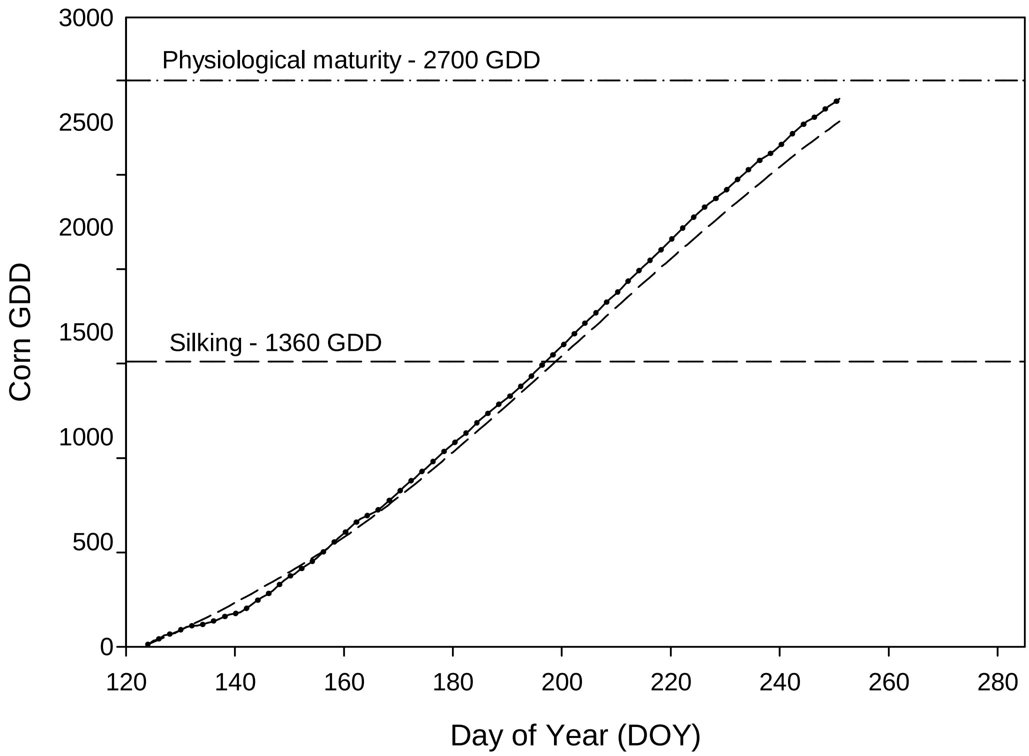

Figure 1.10 - Cumulative corn heat units, Tribune, Kansas, 2010.

High levels of plot to plot variability were observed in 2010 with no identifiable cause. As a result LSD values are relatively large and cloud the ability to statistically differentiate treatment effects even though numerical differences and trends are quite evident in some cases. The P1S1 geometry at the intermediate seeding rate resulted in unexplainable low grain yields and yield components. Individual plot data were inspected, no obvious errors were found, nor does the author recall any in-field observations that would explain the results. Attempts were made to implement a spatial error model using the procedures outlined by Stroup et al. (1994) and Littell et al. (2006); however no underlying spatial patterns could be detected for use in means adjustment.

Biomass, stover, grain yield, and harvest index

In 2010, planting geometry affected total above-ground biomass production ($P=0.0414$). Corn planted in clump, cluster, and conventional geometries produced higher levels of biomass than corn planted in a P2S2 configuration (Table 1.11). Corn planted in a P1S1 configuration resulted in numerically greater biomass than that in a P2S2 configuration and less than that in clump, cluster, or conventional geometries, but the differences were not significant.

Conventionally planted corn resulted in higher stover production than any other geometry (Table 1.11). Corn planted in the clump or cluster geometries produced less stover than the conventional treatment, but produced more than either of the skip-row treatments. Stover production was also affected by seeding rate ($P<0.0001$) and increased at each level of seeding rate increase with an overall increase of 1.07 Mg ha^{-1} (952 lb ac^{-1}) as seeding rates increased from the low to high seeding rate (Table 1.11).

Grain yields in 2010 were affected by a geometry x seeding rate interaction ($P=0.0901$). Corn yield response to increasing plant population varied by geometry (Figure 1.11). Corn planted in a clump configuration did not respond to increasing seeding rate until the highest rate which resulted in lower grain yields (Figure 1.11). Corn planted in a cluster configuration had a relatively flat response to seeding rate. As seeding rate increased, grain yield decreased linearly for corn planted in a conventional geometry. Corn planted in a P2S2 configuration produced a quadratic response over the observed range of plant populations. In the P1S1 configuration the highest and lowest seeding rates produced grain yields higher than that of the middle seeding rate (Figure 1.11). At the highest seeding rate, corn planted in a cluster configuration produced higher grain yield than either the conventional or P2S2 geometries.

Table 1.11 - Effect of planting geometry and seeding rate on corn biomass, grain yield, and yield components, Tribune, Kansas 2010.

Geometry	Seeding rate	Above-ground biomass	Stover	Grain yield	Harvest index	Kernels plant^{-1}	Kernel rows	Kernels ear row^{-1}	Ears plant^{-1}	Kernel weight	Yield plant^{-1}
	plants m^{2} (1000 plants ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (bu ac^{-1})						mg	g
Clump		8.88 (7920) a†	4.57 (4080) b	5.09 (81)	0.48 a	520 a	17.0	33.6 a	1.00	215	113
Cluster		8.66 (7730) a	4.59 (4100) b	4.82 (77)	0.46 a	469 ab	17.0	32.3 b	1.03	219	104
Conventional		8.72 (7780) a	5.14 (4590) a	4.23 (67)	0.39 b	426 b	16.8	31.1 b	0.99	217	95
P1S1		7.97 (7110) ab	4.16 (3710) c	4.52 (72)	0.46 a	448 ab	16.7	31.3 b	0.94	216	100
P2S2		7.66 (6830) b	4.08 (3640) c	4.23 (67)	0.45 a	412 b	16.8	29.3 c	1.00	221	93
	3.0 (12.3)	8.06 (7190)	3.99 (3560) c	4.81 (77)	0.50 a	579 a	17.3 a	36.1 a	1.04 a	229 a	134 a
	4.0 (16.2)	8.33 (7430)	4.47 (3990) b	4.57 (73)	0.45 b	439 b	16.9 b	30.7 b	0.99 ab	219 b	96 b
	5.1 (20.6)	8.74 (7800)	5.06 (4520) a	4.36 (69)	0.40 c	347 c	16.4 c	27.8 c	0.94 b	204 c	72 c
Clump	3.0 (12.3)	8.55 (7630)	3.95 (3530)	5.44 (87) a‡	0.54 a‡	661	17.5	38.7 a	1.01	230	152 a
	4.0 (16.2)	9.14 (8150)	4.52 (4030)	5.47 (87) a	0.50 abcd	537	17.0	33.4 bc	1.00	214	115 bcd
	5.1 (20.6)	8.94 (7970)	5.24 (4680)	4.37 (70) abcdef	0.40 ef	361	16.6	28.7 ef	0.99	200	72 fg
Cluster	3.0 (12.3)	7.78 (6940)	3.84 (3420)	4.67 (74) abcdef	0.50 abc	565	17.3	34.9 b	1.07	230	130 abc
	4.0 (16.2)	8.46 (7550)	4.56 (4070)	4.61 (73) abcdef	0.45 cde	434	17.0	31.2 cd	1.02	222	97 def
	5.1 (20.6)	9.74 (8690)	5.38 (4800)	5.17 (82) ab	0.44 def	407	16.6	30.8 de	1.00	206	86 defg
Conventional	3.0 (12.3)	8.88 (7930)	4.77 (4250)	4.87 (78) abcde	0.45 cdef	579	17.2	37.1 a	1.12	229	136 abc
	4.0 (16.2)	8.43 (7520)	4.95 (4420)	4.12 (66) bcdef	0.40 ef	408	17.0	30.5 def	0.98	213	87 defg
	5.1 (20.6)	8.84 (7880)	5.71 (5100)	3.70 (59) def	0.33 g	290	16.2	25.9 gh	0.86	208	61 g
P1S1	3.0 (12.3)	8.22 (7340)	3.86 (3450)	5.16 (82) abc	0.52 ab	595	17.2	37.1 a	1.01	238	144 ab
	4.0 (16.2)	6.99 (6240)	4.05 (3610)	3.48 (55) f	0.39 efg	360	16.6	28.1 fg	0.89	206	73 fg
	5.1 (20.6)	8.70 (7770)	4.55 (4060)	4.91 (78) abcd	0.46 bcde	389	16.4	28.6 ef	0.92	203	81 efg
P2S2	3.0 (12.3)	6.86 (6120)	3.55 (3170)	3.91 (62) cdef	0.48 abcd	493	17.3	32.5 cd	1.01	221	109 cde
	4.0 (16.2)	8.64 (7710)	4.29 (3830)	5.15 (82) abc	0.50 abcd	455	16.7	30.4 def	1.05	238	108 cde
	5.1 (20.6)	7.48 (6680)	4.41 (3940)	3.63 (58) ef	0.38 fg	288	16.3	24.9 h	0.93	204	60 g
LSD = 0.05											
Geometry		0.92 (820)	0.27 (240)	0.87 (14)	0.05	73	0.3	1.3	0.08	11	17
Population		0.71 (630)	0.21 (180)	0.67 (11)	0.04	57	0.2	1.0	0.06	9	13
Geometry x Seeding Rate		1.60 (1400)	0.46 (410)	1.50 (24)	0.08	126	0.5	2.3	0.14	19	30
				ANOVA P>F							
Effect											
Geometry		0.0414	<0.0001	0.2080	0.0053	0.0404	0.1933	<0.0001	0.3043	0.7821	0.1373
Seeding Rate		0.1632	<0.0001	0.4029	<0.0001	<0.0001	<0.0001	<0.0001	0.0084	<0.0001	<0.0001
Geometry x Seeding Rate		0.1172	0.1074	0.0901	0.0835	0.2107	0.9635	<0.0001	0.3028	0.1013	0.0496

† Letters within a column and an effect represent differences at LSD (0.05) unless noted otherwise

‡ Letters within a column and an effect represent differences at LSD (0.10)

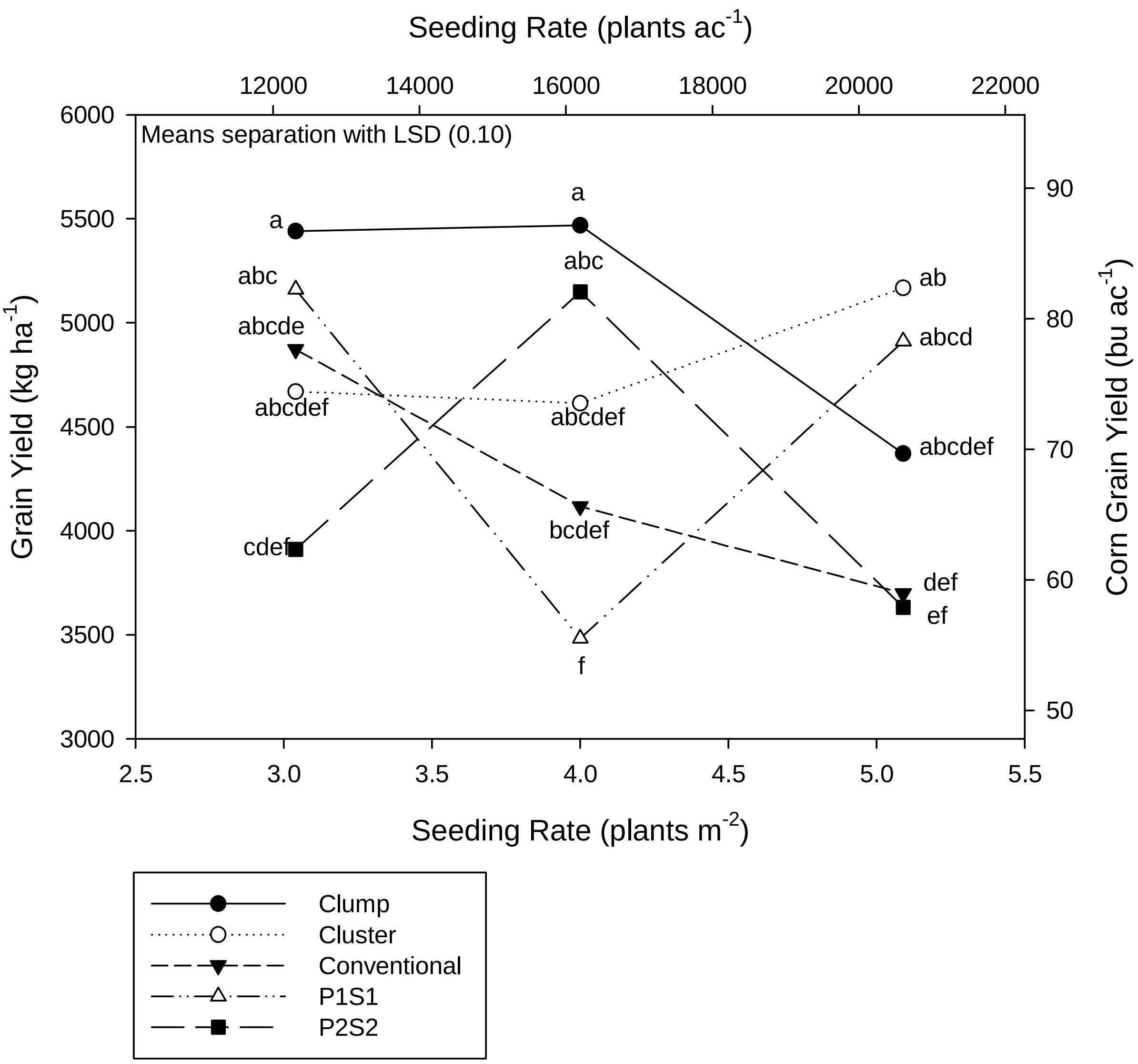

Figure 1.11 - Effect of planting geometry and seeding rate on corn grain yield, Tribune, Kansas 2010.

Harvest index was affected by a geometry x seeding rate interaction in 2010 (P=0.0835). The highest HI values were produced by clump, cluster, P1S1, and P2S2 geometries at the low seeding rate, and clump and P2S2 geometries at the mid seeding rate. The highest HI for conventionally planted corn occurred at the low seeding rate and was lower than the HI for clump or P1S1 at that same seeding rate. The lowest HI values across all treatment combinations were produced by the conventional and P2S2 geometries at the highest seeding rate (Figure 1.12). P1S1 at the mid seeding rate was also in the group, but likely as an artifact of aforementioned data quality. Corn planted in the cluster configuration had the smallest range in

HI values, 0.06, while the other geometries had ranges in HI of 0.12 to 0.14 (Table 1.11). Although the interaction effect was comparatively weaker, very strong main effects were detected for geometry (P=0.0053) and seeding rate (P<0.0001) (Table 1.11). When looking solely at the main effects, harvest index was lower for conventionally planted corn, 0.39, than any of the other geometries which averaged 0.46, an increase of 18%. Harvest index declined as seeding rate increased, decreasing 0.05 or 9 to 10% for each step in seeding rate.

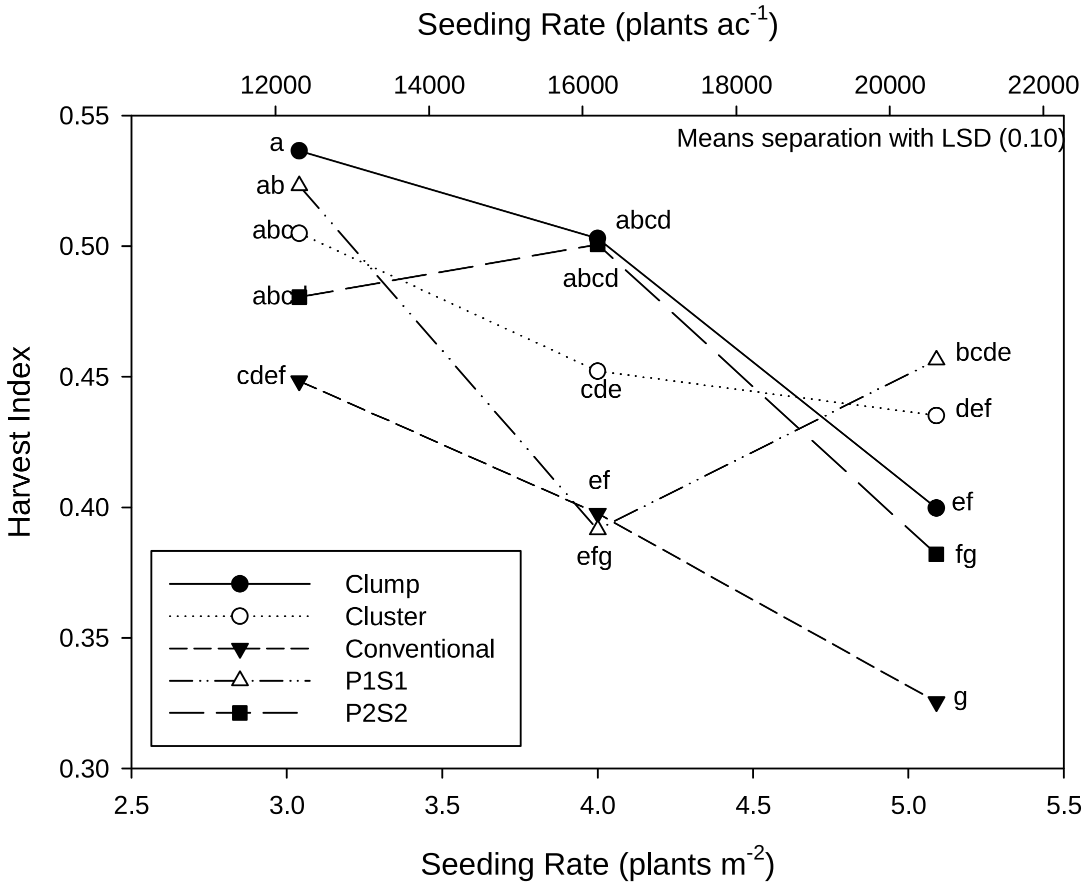

Figure 1.12 - Effect of planting geometry and seeding rate on harvest index of corn, Tribune, Kansas 2010.

Yield components

Kernels plant^{-1} was affected by both geometry (P=0.0404) and seeding rate (P<0.0001) main effects (Table 1.11). Kernels plant^{-1} were highest for clump planted corn with 520 kernels plant^{-1}, followed by cluster, P1S1, conventional, and P2S2 with 412 KP, a reduction of 21%. Kernels plant^{-1} for the clump configuration was higher than corn grown in conventional or P2S2 geometries. Kernels plant^{-1} for corn in the cluster and P1S1 treatments could not be statistically differentiated from the other treatments. Kernels plant^{-1} declined 24 and 21% as seeding rate increased from low to intermediate and intermediate to high rates, respectively.

Kernel rows declined as seeding rate increased ($P<0.0001$). At the lowest seeding rate, kernel rows averaged 17.3 (Table 1.11). As seeding rate was increased to the intermediate and high rates, KR declined to 16.9 and 16.4, respectively, indicating an increasing proportion of ears with 16 KR.

Kernels ear row^{-1} was affected by a geometry x seeding rate interaction ($P<0.0001$) (Table 1.11). The highest values for KER were produced by the clump, P1S1, and conventional geometries at the lowest seeding rate (Figure 1.13). In general KER declined as seeding rate increased, however the decline occurred at different rates depending upon planting geometry (Figure 1.13). Corn planted in clump and cluster geometries at the mid seeding rate produced similar KER as corn in P2S2 and cluster geometries at the low seed rate. Conventionally planted corn had the largest decline in KER as plant density increased, decreasing 11.2 kernels or 30% (Table 1.11). Clump, P2S2, and P1S1 had reductions in KER of 26, 23, 23%, respectively. Corn planted in a cluster configuration had the smallest change in KER as seeding rates increased, decreasing only 4.1 kernels or 12%. Most of that adjustment occurred between the low and mid seeding rates with a very modest change between the mid and high seeding rates (Figure 1.13). At the highest seeding rate corn grown in a cluster configuration produced the highest KER with corn grown in conventional and P2S2 configurations producing KER lower than the other treatments.

Ears plant^{-1} was affected by seeding rate ($P=0.0084$). Ears plant^{-1} declined as seeding rate increased (Table 1.11). Ears plant^{-1} at the lowest seeding rate was 1.04 indicating that some prolificacy occasionally occurred at that seeding rate. An ears plant^{-1} value of 0.94 at the highest seeding rate suggests that some plants were barren at that plant density.

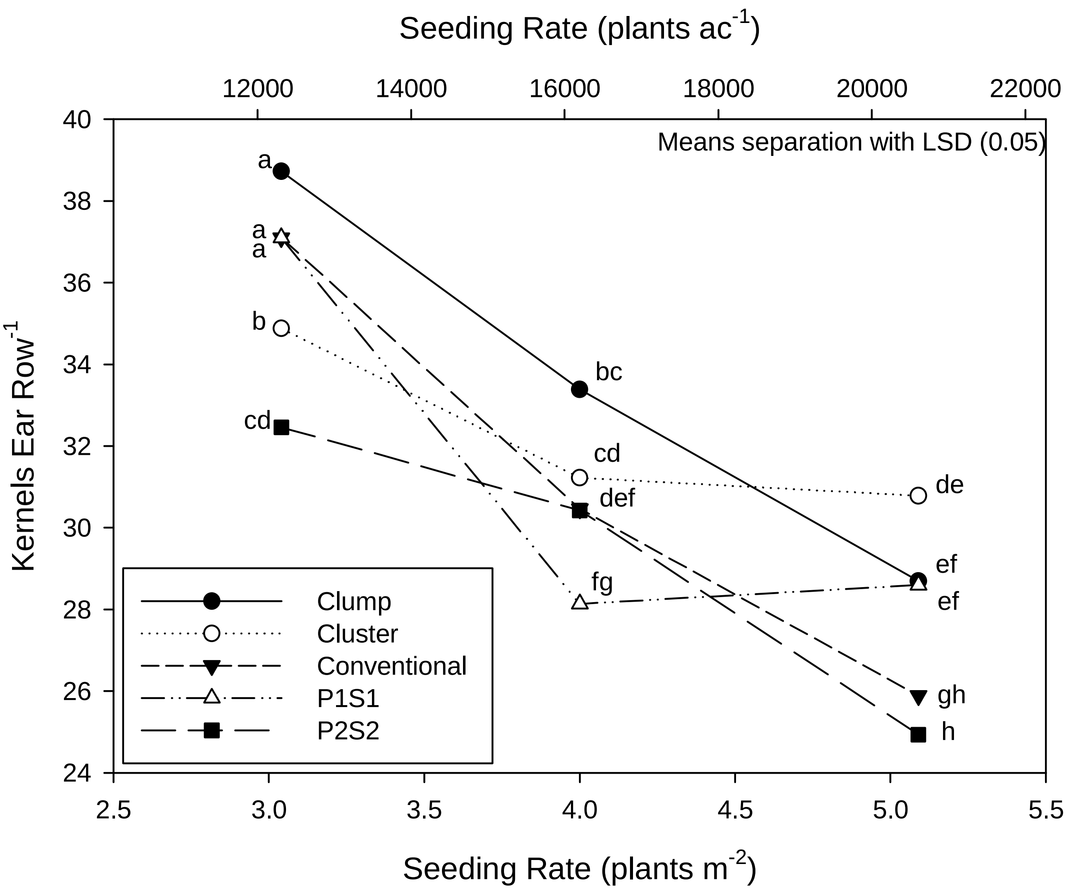

Figure 1.13 - Effect of planting geometry and seeding rate on corn kernels ear row^{-1} (KER), Tribune, Kansas 2010.

Kernel weight was different for each seeding rate (P<0.0001) and declined 11% as seeding rate increased (Table 1.11).

Grain yield plant^{-1} differed in response to a geometry x seeding rate interaction (P=0.0469) (Table 1.11). The highest per plant grain yields were obtained at the lowest seeding rate in the geometries other than P2S2 (Figure 1.14). At the lowest seeding rate, corn planted in the clump or P1S1 configurations produced higher yield plant^{-1} than P2S2. Corn in a conventional or cluster geometry were numerically higher than P2S2 and lower than clump or conventional but not statistically distinguishable from either. As seeding rate increased from the low to the high rate, grain yield plant^{-1} decreased for all geometries other than conventional. As seeding rate increased from the mid to high rate, yield plant^{-1} declined for all geometries except P1S1 which remained flat in response (Figure 1.14). At the highest seeding rate corn in a cluster geometry produced higher yield plant^{-1} than corn in either the conventional or P2S2 configuration (Figure 1.14).

Light interception and grain nutrient content

Light interception varied among planting geometries (P=0.0022) (Table 1.12). Corn planted in conventional, clump, or cluster configuration resulted in an average fraction of PAR intercepted of 0.558 while corn in the skip-row configurations averaged 0.404, a reduction of 28%.

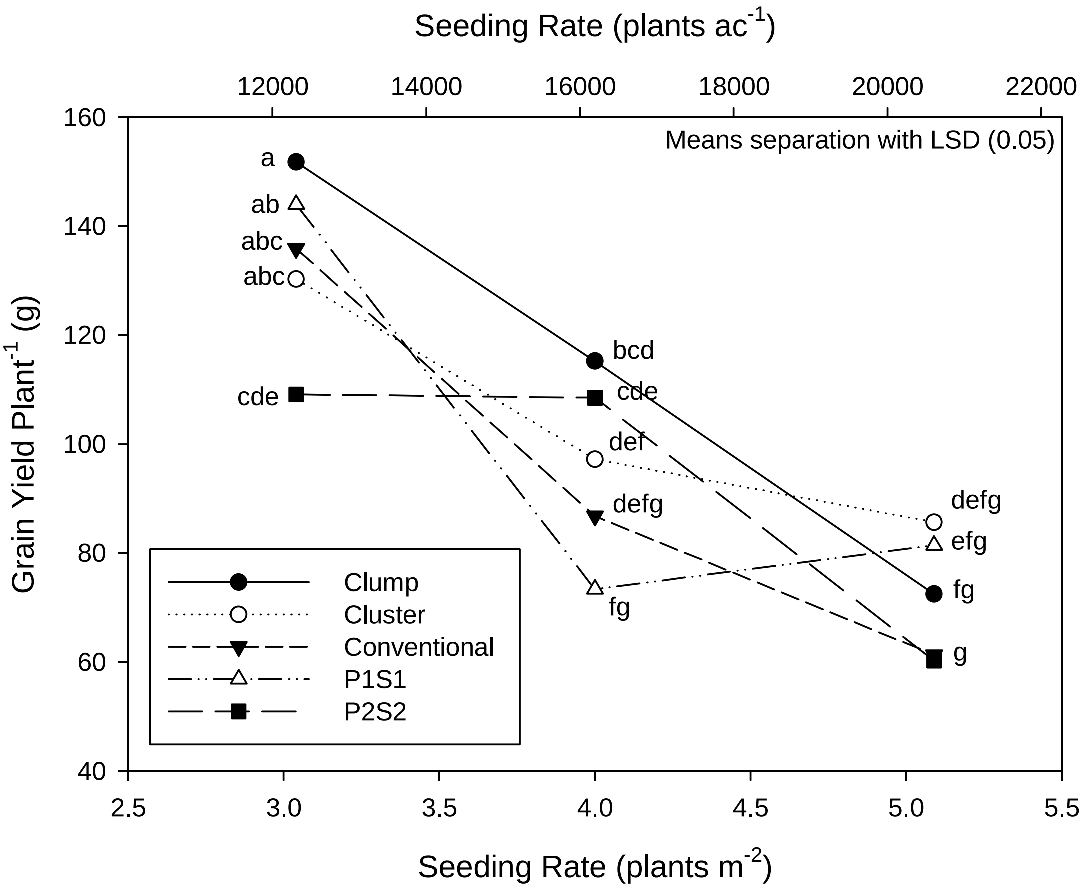

Figure 1.14 - Effect of planting geometry and seeding rate on corn grain yield plant^{-1}, Tribune, Kansas, 2010.

Table 1.12 - Effect of corn planting geometry on intercepted photosynthetically active radiation (IPAR), Tribune, Kansas 2010.

Geometry	Fraction of PAR intercepted (θ)	
Clump	0.530	a[†]
Cluster	0.557	a
Conventional	0.588	a
P1S1	0.410	b
P2S2	0.398	b
LSD = 0.05		
Geometry	0.077	
ANOVA P>F		
Effect		
Geometry	0.0022	

† Letters within a column represent differences at LSD (0.05)

Planting geometry affected grain N content in 2010 (P=0.0691) (Table 1.13). Corn planted in a conventional configuration resulted in higher grain N content than any of the other geometries. Grain N for the conventional geometry was 14.9 g kg^{-1} (1.49%)while the average of the four other geometries was 13.7 g kg^{-1} (1.37%) an 8% reduction in N content. This response when paired with differences in grain yield resulted in N removal values being affected by a geometry x seeding rate interaction (P=0.0604) (Table 1.13). These trends generally followed the previously discussed trends in grain yield except that the relatively higher N content for grain grown in a conventional geometry accentuated removal values.

Table 1.13 - Effect of planting geometry and seeding rate on corn grain N and P content and removal, Tribune, Kansas, 2010.

Geometry	Seeding rate	Grain N content		N removal			Grain P content		P removal	
	plants m^2 (1000 plants ac^{-1})	g kg^{-1}		kg ha^{-1}	(lb ac^{-1})		g kg^{-1}		kg ha^{-1}	(lb ac^{-1})
Clump		14.0	b‡	60	53	a‡	3.4	ab‡	15	13
Cluster		13.7	b	55	49	ab	3.3	bc	13	12
Conventional		14.9	a	52	46	b	3.3	bc	12	11
P1S1		13.5	b	50	45	b	3.3	c	12	11
P2S2		13.8	b	48	43	b	3.4	a	12	11
	3.0 (12.3)	13.8		56	50		3.3		13	12
	4.0 (16.2)	13.8		52	47		3.3		13	11
	5.1 (20.6)	14.3		51	46		3.4		12	11
Clump	3.0 (12.3)	14.2		65	58	a‡	3.4		16	14
	4.0 (16.2)	13.3		61	55	ab	3.4		16	14
	5.1 (20.6)	14.3		52	47	bcde	3.3		12	11
Cluster	3.0 (12.3)	13.4		53	47	bcd	3.2		13	11
	4.0 (16.2)	13.8		53	48	abcd	3.3		13	12
	5.1 (20.6)	13.8		59	53	ab	3.4		15	13
Conventional	3.0 (12.3)	15.0		61	54	ab	3.2		13	12
	4.0 (16.2)	14.4		50	44	bcde	3.4		12	11
	5.1 (20.6)	15.2		46	41	cde	3.3		10	9
P1S1	3.0 (12.3)	12.6		54	49	abcd	3.2		14	13
	4.0 (16.2)	14.3		41	36	e	3.3		10	9
	5.1 (20.6)	13.5		55	49	abcd	3.3		14	12
P2S2	3.0 (12.3)	13.6		45	40	de	3.4		11	10
	4.0 (16.2)	13.2		57	51	abc	3.3		14	13
	5.1 (20.6)	14.6		43	38	de	3.6		11	10
LSD = 0.05										
Geometry		1.0		8	8		0.1		2	2
Population		0.8		7	6		0.1		2	2
Geometry x Seeding Rate		1.8		15	13		0.2		4	4
		ANOVA P>F								
Effect										
Geometry		0.0691		0.0715			0.0586		0.2157	
Seeding Rate		0.3629		0.3826			0.2298		0.6120	
Geometry x Seeding Rate		0.5229		0.0604			0.3164		0.1010	

† Letters within a column and an effect represent differences at LSD (0.05) unless otherwise noted.
‡ Letters within the column and effect represent differences at LSD (0.10)

Soil water, water use, and water use efficiency

Profile water totals across measurement positions

Profile water totals were only different at one of the four measurement times, the second in-season measurement on 30 July, which would have been during the R1 growth stage (Table 1.14). Profile water in the middle of the skip in the P2S2 geometry was higher than any other tube position. The next highest level was observed in the 95 cm (37.5 inch) position of the P2S2 geometry and was similar to observations in the 76 cm (30 inch) clump position, 38 and 76 cm (15 and 30 inch) positions in the cluster, and the 76 cm (30 inch) position in P1S1. The lowest was observed in-row in the conventional geometry, and was similar to observations in many other positions.

Table 1.14 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in corn planting geometries. Tribune, Kansas, 2010.

Geometry	Tube position	06/18/10		07/02/10		07/30/10			09/14/10	
	cm (inches)	Available soil water, mm (inches)								
Clump	0	174	(6.87)	140	(5.51)	102	(4.03)	cd	82	(3.22)
	38 (15)	171	(6.73)	142	(5.58)	103	(4.04)	cd	81	(3.19)
	76 (30)	172	(6.78)	140	(5.52)	106	(4.18)	bcd	80	(3.15)
Cluster	0	178	(7.02)	143	(5.61)	103	(4.05)	cd	81	(3.19)
	38 (15)	177	(6.95)	149	(5.86)	115	(4.54)	bc	87	(3.44)
	76 (30)	177	(6.99)	152	(5.98)	115	(4.51)	bc	85	(3.33)
Conventional	0	163	(6.41)	124	(4.90)	89	(3.48)	d	70	(2.74)
	38 (15)	163	(6.42)	130	(5.13)	94	(3.68)	cd	75	(2.94)
P1S1	0	166	(6.53)	131	(5.15)	95	(3.74)	cd	74	(2.89)
	38 (15)	171	(6.72)	139	(5.45)	105	(4.14)	cd	71	(2.80)
	76 (30)	169	(6.65)	150	(5.91)	118	(4.63)	bc	75	(2.96)
P2S2	0	182	(7.16)	141	(5.53)	98	(3.88)	cd	77	(3.05)
	38 (15)	175	(6.91)	141	(5.56)	104	(4.08)	cd	83	(3.29)
	95 (37.5)	178	(7.01)	161	(6.35)	130	(5.12)	b	96	(3.77)
	152 (60)	196	(7.70)	185	(7.27)	183	(7.22)	a	108	(4.25)
LSD = 0.10										
	Tube Position	28	(1.09)	27	(1.06)	25	(0.97)		23	(0.92)
		ANOVA P>F								
Effect										
	Tube Position	0.9192		0.1158		<0.0001			0.4461	

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Soil water content by depth within geometries

Differences with respect to position were only observed at the near-surface measurement on 30 July for the clump treatment which coincided with tassel-silk. Water content at 38 and 76 cm (15 and 30 inches) away from the clump was higher than immediately adjacent to the clump (Table 1.15). Relatively few differences were observed in the cluster treatment as well (Table 1.16). The near-surface measurement on 2 July found more soil water 38 and 76 cm (15 and 30 inches) away from the cluster than immediately adjacent to it, while on 14 September the reverse was observed with the lowest level observed furthest away from the cluster. Few differences were observed in conventional geometry corn (Table 1.17). When differences were observed they were consistent in higher levels of soil water being found in the inter-row space.

Corn in a P1S1 planting geometry resulted in detectable differences in soil water at several depths and timings in 2010 (Table 1.18). The greatest number of differences were observed at the 2 July measurement. In the upper three depths, soil water content generally decreased as measurement location moved from the center of the skip towards the planted row.

Corn planted in a P2S2 configuration resulted in pronounced differences in soil water observed at three of the four measurement times in 2010 (Table 1.19). At the 2 July measurement, soil water contents were the lowest between the planted rows and adjacent to a planted row at the 15, 30, and 46 cm (6, 12, and 18 inch) depths. At these depths soil water contents 95 cm (37.5 inches) from the middle of the planted rows were higher than water contents between the rows or in-row, but were lower than soil water contents observed 152 cm (60) inches from the center of the planted rows, which had the highest soil water contents. At depths of 61 to 107 cm (24 to 42 inches), only groupings of soil water content were detected, with the two locations closest to the planted rows having lower levels of soil water than the two locations away from the planted rows. On 30 July, which coincided with tassel-silk, soil water contents were highest in the middle of the skip at all except the deepest two measurement depths. Measurements taken 95 cm (37.5 inches) from the middle of the planted rows had the next highest water contents at each depth except the bottom two depths. At the 152 cm (60 inch) depth, similar levels of soil water were observed for the 0, 38, and 95 cm (0, 15, and 37.5 inch) measurement positions. The same general relationships observed on 30 July were observed on 14 September, although the differences were less sharp with respect to position and detectable at fewer depths.

Table 1.15 - Soil water by depth in corn in clump planting geometry. Tribune, Kansas, 2010.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
06/18/2010	15 (6)	0.8668	0.261		0.261		0.263	
	30 (12)	0.7068	0.259		0.259		0.261	
	46 (18)	0.4175	0.255		0.257		0.258	
	61 (24)	0.8702	0.261		0.261		0.262	
	76 (30)	0.6963	0.258		0.255		0.257	
	91 (36)	0.8392	0.244		0.242		0.241	
	107 (42)	0.3969	0.236		0.231		0.228	
	122 (48)	0.4817	0.211		0.202		0.206	
	137 (54)	0.8654	0.186		0.182		0.186	
	152 (60)	0.8350	0.166		0.168		0.165	
	168 (66)	0.5332	0.168		0.165		0.165	
	183 (72)	0.6526	0.175		0.172		0.172	
07/02/2010	15 (6)	0.3011	0.185		0.200		0.200	
	30 (12)	0.5443	0.215		0.215		0.226	
	46 (18)	0.9222	0.223		0.220		0.220	
	61 (24)	0.6159	0.234		0.235		0.230	
	76 (30)	0.4789	0.238		0.240		0.234	
	91 (36)	0.9699	0.231		0.232		0.232	
	107 (42)	0.7990	0.227		0.228		0.224	
	122 (48)	0.8975	0.209		0.208		0.206	
	137 (54)	0.7387	0.190		0.185		0.181	
	152 (60)	0.8620	0.166		0.169		0.169	
	168 (66)	0.7228	0.166		0.165		0.162	
	183 (72)	0.4027	0.172		0.168		0.171	
07/30/2010	15 (6)	0.0657	0.174	b†	0.185	a	0.187	a
	30 (12)	0.3495	0.198		0.195		0.200	
	46 (18)	0.8164	0.197		0.195		0.197	
	61 (24)	0.3447	0.195		0.198		0.200	
	76 (30)	0.8164	0.194		0.192		0.195	
	91 (36)	0.1677	0.175		0.178		0.182	
	107 (42)	0.8419	0.177		0.178		0.179	
	122 (48)	0.9684	0.186		0.186		0.187	
	137 (54)	0.7429	0.187		0.184		0.188	
	152 (60)	0.9141	0.176		0.177		0.176	
	168 (66)	0.5317	0.174		0.170		0.168	
	183 (72)	0.3026	0.174		0.168		0.173	
09/14/2010	15 (6)	0.5987	0.149		0.148		0.143	
	30 (12)	0.2315	0.183		0.187		0.184	
	46 (18)	0.1764	0.189		0.190		0.187	
	61 (24)	0.9812	0.189		0.190		0.190	
	76 (30)	0.6657	0.183		0.185		0.185	
	91 (36)	0.7357	0.167		0.166		0.168	
	107 (42)	0.2402	0.160		0.164		0.162	
	122 (48)	0.7872	0.168		0.166		0.166	
	137 (54)	0.7088	0.171		0.168		0.170	
	152 (60)	0.4215	0.170		0.168		0.167	
	168 (66)	0.2389	0.169		0.165		0.167	
	183 (72)	0.1321	0.173		0.168		0.171	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.16 - Soil water by depth in corn in cluster planting geometry. Tribune, Kansas, 2010.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
06/18/2010	15 (6)	0.3569	0.256		0.262		0.270	
	30 (12)	0.2707	0.258		0.258		0.268	
	46 (18)	0.2412	0.261		0.254		0.264	
	61 (24)	0.2738	0.254		0.248		0.257	
	76 (30)	0.6764	0.244		0.240		0.242	
	91 (36)	0.1947	0.233		0.235		0.229	
	107 (42)	0.1705	0.220		0.224		0.216	
	122 (48)	0.1757	0.215		0.216		0.208	
	137 (54)	0.2505	0.209		0.206		0.198	
	152 (60)	0.3327	0.193		0.193		0.190	
	168 (66)	0.8655	0.185		0.184		0.183	
	183 (72)	0.4051	0.178		0.173		0.174	
07/02/2010	15 (6)	0.0309	0.182	b†	0.198	a	0.200	a
	30 (12)	0.1107	0.210		0.220		0.230	
	46 (18)	0.1179	0.219		0.223		0.242	
	61 (24)	0.2298	0.223		0.223		0.240	
	76 (30)	0.6341	0.223		0.223		0.230	
	91 (36)	0.2804	0.221		0.226		0.221	
	107 (42)	0.0547	0.216	ab	0.222	a	0.212	b
	122 (48)	0.2165	0.212		0.214		0.207	
	137 (54)	0.4949	0.208		0.210		0.204	
	152 (60)	0.2290	0.195		0.195		0.191	
	168 (66)	0.9482	0.186		0.185		0.186	
	183 (72)	0.3985	0.175		0.172		0.171	
07/30/2010	15 (6)	0.2243	0.178		0.196		0.192	
	30 (12)	0.5903	0.199		0.205		0.204	
	46 (18)	0.6056	0.202		0.203		0.207	
	61 (24)	0.2457	0.192		0.191		0.199	
	76 (30)	0.1267	0.176		0.180		0.186	
	91 (36)	0.0684	0.168	b	0.181	a	0.181	a
	107 (42)	0.1117	0.167		0.181		0.178	
	122 (48)	0.1201	0.172		0.185		0.181	
	137 (54)	0.5872	0.189		0.196		0.191	
	152 (60)	0.3417	0.195		0.201		0.197	
	168 (66)	0.4988	0.189		0.192		0.190	
	183 (72)	0.6412	0.183		0.180		0.179	
09/14/2010	15 (6)	0.0950	0.153	a	0.153	a	0.145	b
	30 (12)	0.8869	0.189		0.188		0.189	
	46 (18)	0.2986	0.195		0.191		0.196	
	61 (24)	0.2331	0.188		0.182		0.186	
	76 (30)	0.6438	0.172		0.175		0.174	
	91 (36)	0.1473	0.157		0.168		0.166	
	107 (42)	0.2280	0.153		0.162		0.158	
	122 (48)	0.3168	0.153		0.160		0.157	
	137 (54)	0.1675	0.165		0.175		0.171	
	152 (60)	0.3007	0.181		0.190		0.184	
	168 (66)	0.6080	0.182		0.185		0.185	
	183 (72)	0.9912	0.179		0.178		0.179	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.17 - Soil water by depth in corn in conventional planting geometry. Tribune, Kansas, 2010.

Date	Depth	ANOVA P>F	Tube position			
			0		36 cm (15 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}			
06/18/2010	15 (6)	0.9974	0.256		0.255	
	30 (12)	0.8649	0.255		0.257	
	46 (18)	0.4753	0.254		0.258	
	61 (24)	0.3878	0.249		0.256	
	76 (30)	0.2137	0.253		0.246	
	91 (36)	0.3592	0.241		0.233	
	107 (42)	0.6116	0.215		0.220	
	122 (48)	0.4031	0.184		0.192	
	137 (54)	0.6881	0.173		0.169	
	152 (60)	0.8305	0.170		0.168	
	168 (66)	0.7926	0.173		0.171	
	183 (72)	0.5491	0.181		0.178	
07/02/2010	15 (6)	0.0575	0.180	b†	0.196	a
	30 (12)	0.5531	0.209		0.216	
	46 (18)	0.5018	0.216		0.220	
	61 (24)	0.7549	0.222		0.220	
	76 (30)	0.4100	0.226		0.223	
	91 (36)	0.5169	0.223		0.221	
	107 (42)	0.7349	0.213		0.215	
	122 (48)	0.6432	0.190		0.195	
	137 (54)	0.9328	0.172		0.173	
	152 (60)	0.1774	0.161		0.166	
	168 (66)	0.1847	0.164		0.168	
	183 (72)	0.2953	0.174		0.175	
07/30/2010	15 (6)	0.1265	0.169		0.181	
	30 (12)	0.8203	0.192		0.194	
	46 (18)	0.6526	0.188		0.190	
	61 (24)	0.6624	0.180		0.180	
	76 (30)	0.8679	0.177		0.176	
	91 (36)	0.6285	0.173		0.171	
	107 (42)	0.1632	0.174		0.178	
	122 (48)	0.2701	0.178		0.185	
	137 (54)	0.6614	0.175		0.177	
	152 (60)	0.3187	0.166		0.170	
	168 (66)	0.1956	0.167		0.171	
	183 (72)	0.3434	0.175		0.177	
09/14/2010	15 (6)	0.0917	0.137	b	0.144	a
	30 (12)	0.5376	0.179		0.184	
	46 (18)	0.5501	0.182		0.183	
	61 (24)	0.1447	0.176		0.172	
	76 (30)	0.4152	0.170		0.166	
	91 (36)	0.7438	0.162		0.161	
	107 (42)	0.1551	0.158		0.162	
	122 (48)	0.1415	0.161		0.168	
	137 (54)	<.0001	0.163	b	0.170	a
	152 (60)	0.1916	0.162		0.168	
	168 (66)	0.2813	0.166		0.170	
	183 (72)	0.4390	0.174		0.176	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.18 - Soil water by depth in corn in plant-1 skip-1 (P1S1) planting geometry. Tribune, Kansas, 2010.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
06/18/2010	15 (6)	0.8781	0.255		0.258		0.257	
	30 (12)	0.2118	0.257		0.264		0.263	
	46 (18)	0.2074	0.258		0.264		0.262	
	61 (24)	0.4347	0.252		0.256		0.248	
	76 (30)	0.7726	0.241		0.245		0.242	
	91 (36)	0.6171	0.239		0.231		0.234	
	107 (42)	0.4854	0.230		0.220		0.225	
	122 (48)	0.6865	0.205		0.208		0.210	
	137 (54)	0.0857	0.183	b†	0.192	a	0.194	a
	152 (60)	0.4223	0.168		0.176		0.170	
	168 (66)	0.6878	0.167		0.168		0.165	
	183 (72)	0.5494	0.169		0.172		0.172	
07/02/2010	15 (6)	0.0449	0.182	b	0.190	b	0.210	a
	30 (12)	0.0063	0.213	c	0.225	b	0.241	a
	46 (18)	0.0029	0.223	c	0.234	b	0.242	a
	61 (24)	0.3065	0.221		0.228		0.235	
	76 (30)	0.3280	0.219		0.222		0.231	
	91 (36)	0.3257	0.222		0.216		0.227	
	107 (42)	0.3250	0.222		0.212		0.218	
	122 (48)	0.8122	0.208		0.205		0.210	
	137 (54)	0.1536	0.185		0.193		0.195	
	152 (60)	0.1077	0.167		0.179		0.175	
	168 (66)	0.5304	0.166		0.171		0.167	
	183 (72)	0.3837	0.166		0.168		0.170	
07/30/2010	15 (6)	0.4415	0.171		0.176		0.186	
	30 (12)	0.2507	0.198		0.208		0.213	
	46 (18)	0.1835	0.199		0.209		0.207	
	61 (24)	0.4031	0.190		0.196		0.193	
	76 (30)	0.1946	0.176		0.185		0.189	
	91 (36)	0.1931	0.171		0.174		0.186	
	107 (42)	0.2214	0.174		0.172		0.187	
	122 (48)	0.1163	0.178		0.181		0.195	
	137 (54)	0.1027	0.182		0.186		0.197	
	152 (60)	0.1261	0.174		0.184		0.188	
	168 (66)	0.2549	0.172		0.178		0.183	
	183 (72)	0.4368	0.171		0.176		0.181	
09/14/2010	15 (6)	0.0369	0.143	a	0.137	b	0.132	b
	30 (12)	0.7184	0.186		0.182		0.183	
	46 (18)	0.3780	0.190		0.193		0.189	
	61 (24)	0.3966	0.182		0.182		0.176	
	76 (30)	0.9125	0.168		0.169		0.170	
	91 (36)	0.5658	0.162		0.158		0.163	
	107 (42)	0.4976	0.159		0.151		0.158	
	122 (48)	0.8284	0.161		0.156		0.160	
	137 (54)	0.8342	0.166		0.164		0.168	
	152 (60)	0.3484	0.165		0.167		0.173	
	168 (66)	0.1289	0.167		0.169		0.176	
	183 (72)	0.1033	0.169		0.172		0.180	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.19 - Soil water by depth in corn in plant-2 skip-2 (P2S2) planting geometry. Tribune, Kansas, 2010.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$							
06/18/2010	15 (6)	0.0801	0.257	ab†	0.233	b	0.264	a	0.276	a
	30 (12)	0.0328	0.259	a	0.241	b	0.264	a	0.272	a
	46 (18)	0.0331	0.261	a	0.251	b	0.262	a	0.268	a
	61 (24)	0.3272	0.251		0.250		0.252		0.260	
	76 (30)	0.7620	0.244		0.247		0.242		0.248	
	91 (36)	0.4788	0.238		0.239		0.237		0.247	
	107 (42)	0.5624	0.234		0.234		0.231		0.243	
	122 (48)	0.5528	0.228		0.225		0.220		0.234	
	137 (54)	0.6028	0.217		0.218		0.202		0.215	
	152 (60)	0.4952	0.179		0.183		0.177		0.194	
	168 (66)	0.4830	0.178		0.182		0.174		0.183	
	183 (72)	0.0827	0.182		0.183		0.177		0.178	
07/02/2010	15 (6)	0.0001	0.176	c	0.173	c	0.219	b	0.258	a
	30 (12)	<.0001	0.205	c	0.204	c	0.236	b	0.259	a
	46 (18)	<.0001	0.218	c	0.215	c	0.247	b	0.256	a
	61 (24)	0.0030	0.218	b	0.222	b	0.241	a	0.252	a
	76 (30)	0.0240	0.217	b	0.219	b	0.232	a	0.238	a
	91 (36)	0.0435	0.219	b	0.223	b	0.229	ab	0.238	a
	107 (42)	0.0921	0.222	b	0.221	b	0.224	b	0.236	a
	122 (48)	0.2369	0.223		0.217		0.221		0.230	
	137 (54)	0.4751	0.218		0.216		0.210		0.222	
	152 (60)	0.6656	0.185		0.189		0.181		0.194	
	168 (66)	0.4877	0.176		0.182		0.173		0.188	
	183 (72)	0.1494	0.180		0.181		0.176		0.177	
07/30/2010	15 (6)	0.0030	0.154	c	0.171	bc	0.199	b	0.243	a
	30 (12)	<.0001	0.193	c	0.197	c	0.212	b	0.255	a
	46 (18)	<.0001	0.198	c	0.198	c	0.215	b	0.255	a
	61 (24)	<.0001	0.189	c	0.193	c	0.207	b	0.248	a
	76 (30)	<.0001	0.171	c	0.178	c	0.193	b	0.232	a
	91 (36)	<.0001	0.161	c	0.169	c	0.191	b	0.230	a
	107 (42)	<.0001	0.167	c	0.169	c	0.197	b	0.228	a
	122 (48)	0.0007	0.177	c	0.174	c	0.205	b	0.225	a
	137 (54)	0.0055	0.196	c	0.194	c	0.212	b	0.226	a
	152 (60)	0.1020	0.192		0.197		0.197		0.211	
	168 (66)	0.5829	0.185		0.190		0.184		0.195	
	183 (72)	0.4172	0.183		0.185		0.177		0.190	
09/14/2010	15 (6)	0.0817	0.143	b	0.151	ab	0.157	a	0.159	a
	30 (12)	0.0499	0.184	bc	0.182	c	0.195	ab	0.202	a
	46 (18)	0.0198	0.192	b	0.191	b	0.204	a	0.206	a
	61 (24)	0.0037	0.183	c	0.186	c	0.193	b	0.201	a
	76 (30)	0.0066	0.167	c	0.171	bc	0.175	b	0.182	a
	91 (36)	0.1057	0.155		0.162		0.167		0.174	
	107 (42)	0.1162	0.154		0.157		0.163		0.172	
	122 (48)	0.1033	0.156		0.155		0.165		0.176	
	137 (54)	0.2041	0.170		0.174		0.184		0.191	
	152 (60)	0.2804	0.177		0.183		0.189		0.194	
	168 (66)	0.3301	0.180		0.186		0.189		0.194	
	183 (72)	0.4405	0.181		0.184		0.183		0.192	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Cross-section analysis of soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. No differences were observed amongst planting geometries at the first measurement on 18 June (Table 1.20). Conventional corn had the lowest numerical profile available water, a trend which would continue through the growing season. Measurements were taken on 2 July during early vegetative growth. The effects of planting geometry on spatial distribution of soil water were made evident though differences in range (P=0.0114) (Table 1.20). P2S2 had the largest range indicating uneven distribution of soil water. Cross-sections under the clump, cluster, and P1S1 configurations had similar ranges but were narrower than P2S2. The smallest range, although not differentiable from clump or P1S1, was the conventional geometry, indicating a more uniform distribution of soil water contents. From postemergence until the early vegetative measurement, corn in a P2S2 configuration had less water use than any other geometry. Change in soil water over this time period would indicate root extraction potentially coming from as deep as 51 cm (20 inches) with the most intense extraction occurring at depths less than 25 cm (10 inches).

Measurements obtained on 30 July coincided with tassel-silk. At this point in time, profile water remained numerically the lowest for corn grown in a conventional configuration (Table 1.20). The largest range in soil water contents was found in the profile underlying the P2S2 configuration followed by P1S1 and cluster configurations which had similar ranges. The smallest ranges were found in profiles under the conventional and clump configurations. The profile under the P2S2 planting geometry also had SD larger than any other treatment. At the time of tassel-silk, cumulative water use was less for the P2S2 configuration than any other.

The final sampling of the season, at harvest, occurred on 14 September. Interval water use from tassel-silk to harvest was highest for the P2S2 geometry, although not distinguishable from the P2S1 and cluster geometries, and was followed by the clump geometry. Corn in a conventional geometry had the least water use from tassel-silk until harvest.

Table 1.20 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated soil water values, and water use as affected by corn planting geometry. Tribune, Kansas, 2010.

Geometry	06/18/2010 Profile available water	06/18/2010 Range	06/18/2010 SD	07/02/2010 Profile available water	07/02/2010 Range	07/02/2010 SD	07/02/2010 Cumulative water use
	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)
Clump	179 (7.05)	0.124	0.041	143 (5.62)	0.127 bc	0.036	38 (1.50) a
Cluster	185 (7.27)	0.115	0.032	150 (5.90)	0.141 ab	0.031	37 (1.44) a
Conventional	170 (6.69)	0.125	0.040	130 (5.12)	0.119 c	0.033	42 (1.65) a
P1S1	176 (6.94)	0.119	0.039	140 (5.53)	0.132 bc	0.033	38 (1.48) a
P2S2	187 (7.35)	0.133	0.034	158 (6.23)	0.155 a	0.033	30 (1.19) b
LSD = 0.10							
Geometry	28 (1.11)	0.045	0.014	29 (1.15)	0.015	0.006	6 (0.23)
			ANOVA P>F				
Effect							
Geometry	0.8324	0.9620	0.7744	0.5271	0.0114	0.7585	0.0435

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Geometry	07/30/2010 Profile available water	07/30/2010 Range	07/30/2010 SD	07/30/2010 Cumulative water use	07/30/2010 Interval water use	09/14/2010 Profile available water	09/14/2010 Range	09/14/2010 SD	09/14/2010 Cumulative water use	09/14/2010 Interval water use
	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	cm (in)	mm (in)
Clump	104 (4.10)	0.092 c	0.024 b	179 (7.06) a	141 (5.56)	78 (3.07)	0.125	0.027	303 (11.9)	124 (4.87) bc
Cluster	114 (4.48)	0.108 b	0.023 b	175 (6.90) a	139 (5.46)	83 (3.25)	0.128	0.027	304 (12.0)	129 (5.08) abc
Conventional	92 (3.62)	0.088 c	0.022 b	182 (7.17) a	140 (5.53)	71 (2.78)	0.125	0.025	301 (11.9)	119 (4.69) c
P1S1	105 (4.13)	0.107 b	0.023 b	175 (6.91) a	138 (5.43)	68 (2.68)	0.136	0.027	310 (12.2)	135 (5.31) ab
P2S2	127 (5.02)	0.143 a	0.030 a	163 (6.43) b	133 (5.25)	89 (3.50)	0.135	0.027	300 (11.8)	136 (5.37) a
LSD = 0.10										
Geometry	25 (0.98)	0.013	0.004	11 (0.45)	9 (0.37)	22 (0.89)	0.031	0.006	17 (0.7)	11 (0.45)
					ANOVA P>F					
Effect										
Geometry	0.1973	<0.0001	0.0466	0.0995	0.6099	0.4871	0.9338	0.9639	0.8413	0.0910

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Water use / Water use efficiency

No differences among planting geometries were observed in 2010 for water use (Table 1.21). Grain water use efficiency was affected by planting geometry with clump and P2S2 having the highest values and were similar to cluster and conventional. Corn in the P1S1 configuration resulted in the lowest grain water use efficiency. Biomass water use efficiency was also affected by planting geometry in 2010 with corn planted in a P1S1 configuration having a lower efficiency than all other geometries.

Table 1.21 - Corn water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb) as affected by planting geometry. Tribune, Kansas, 2010.

Geometry	Water Use		WUEg			WUEb		
	mm (in)		$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)			$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)		
Clump	303	(11.9)	15.7	(356)	a†	30.5	(691)	a
Cluster	304	(12.0)	13.4	(304)	ab	28.3	(641)	a
Conventional	301	(11.9)	13.3	(302)	ab	30.3	(687)	a
P1S1	310	(12.2)	10.1	(230)	b	23.2	(525)	b
P2S2	300	(11.8)	15.3	(346)	a	29.5	(669)	a
LSD = 0.05								
Geometry	17	(0.7)	2.8	(64)		3.1	(69)	
			ANOVA P>F					
Effect								
Geometry	0.8413		0.0310			0.0058		

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

2011 Tribune

Exceptional grain yields were produced in 2011 averaging 7.86 Mg ha^{-1} (125 bu ac^{-1}) in-spite of record high temperatures. Heat unit accumulation occurred much more rapidly than the long-term normal (Figure 1.15). In-season precipitation was below normal through much of the vegetative growth stages and even into early reproductive stages (Figure 1.16). Due to dry conditions, silking was delayed several days past the typical heat unit trigger of 1360 GDD. Substantial precipitation was received just as the corn was fully reaching the R1 (silking) growth stage (Figure 1.16). Cumulative in-season precipitation was 358 mm (14.08 inches) (Figure 1.17).

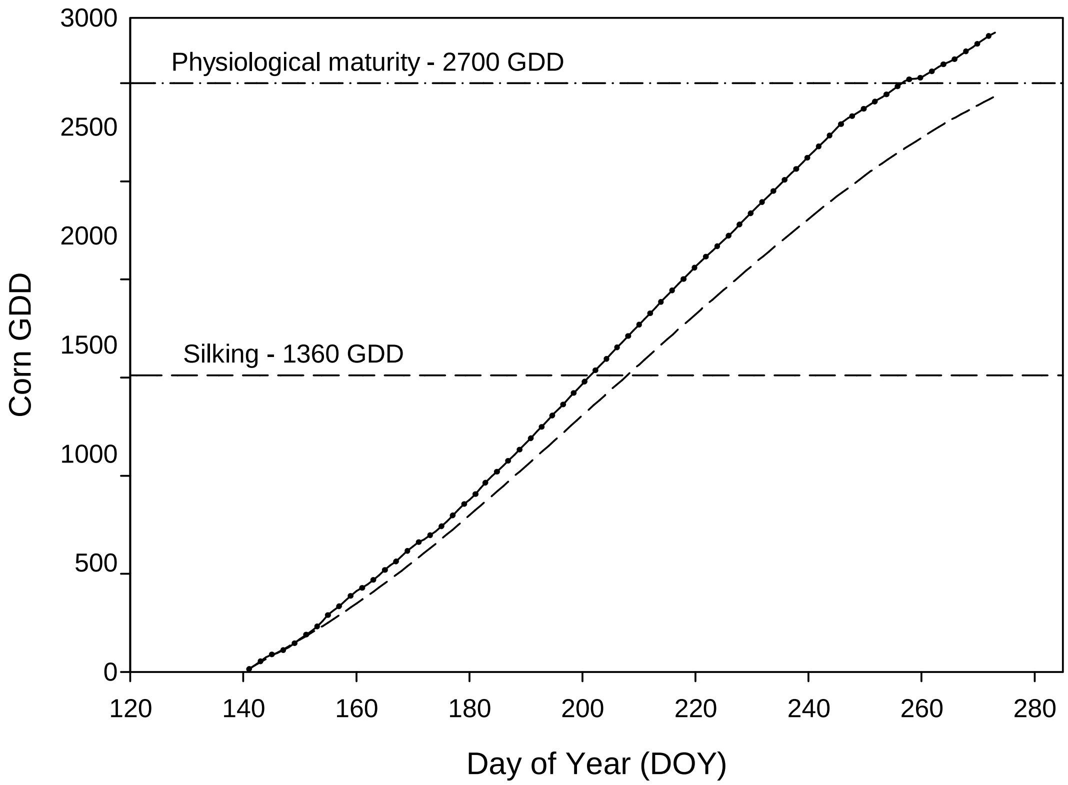

Figure 1.15 - Cumulative corn heat units, Tribune, Kansas, 2011.

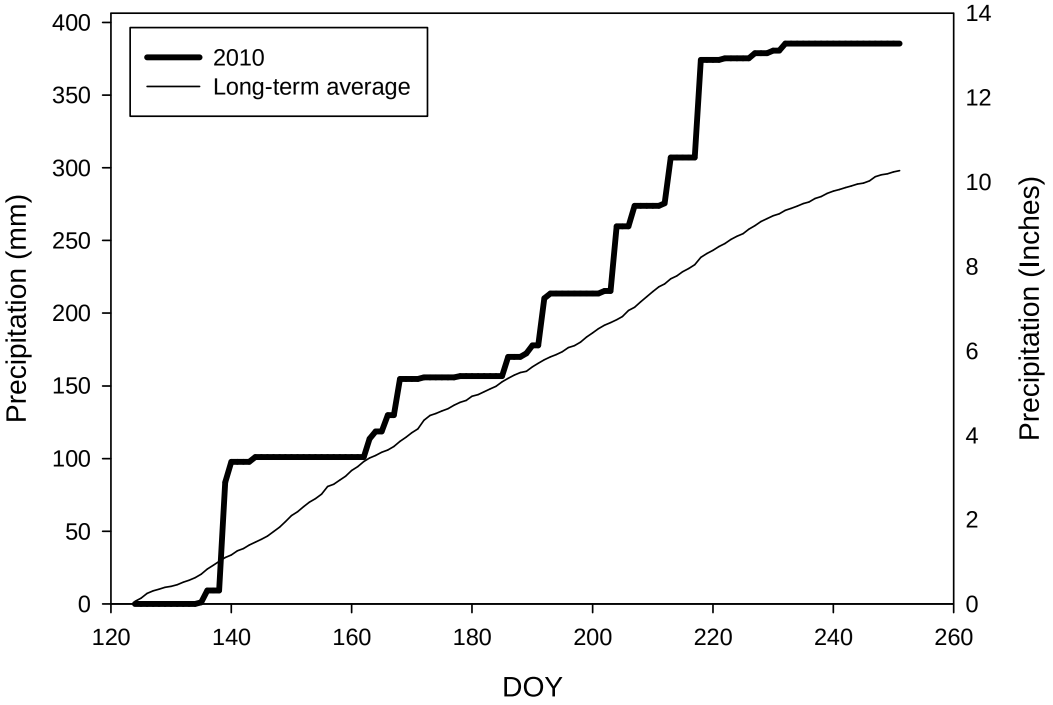

Figure 1.16 - Corn growing season precipitation departure from normal, Tribune, Kansas 2011.

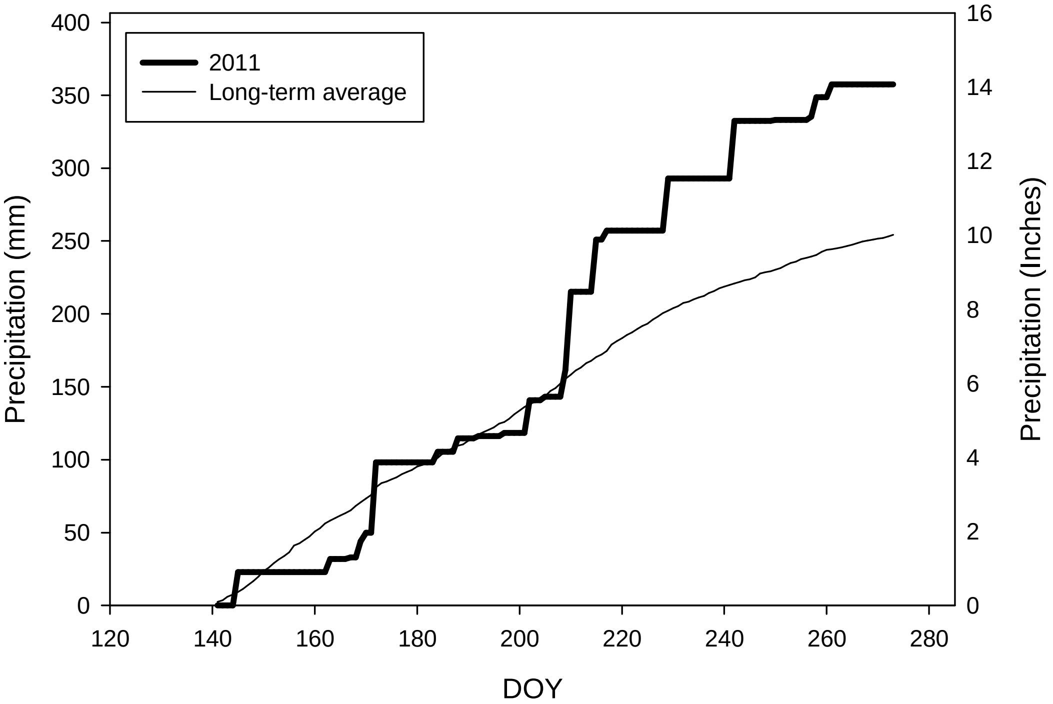

Figure 1.17 - Corn season cumulative precipitation, Tribune, Kansas 2011.

Biomass, stover, grain yield, and harvest index

Planting geometries produced differing levels of above-ground biomass (P=0.0040). Corn planted in a P2S2 configuration produced 10.4 Mg ha^{-1} (9310 lb ac^{-1}) of biomass, less biomass than any other geometry, which together averaged 11.45 Mg ha^{-1} (10,200 lb ac^{-1}) of total above-ground biomass (Table 1.22).

Stover production was affected by both planting geometry (P<0.0001) and seeding rate (P=0.0394) in 2011 (Table 1.22). Corn planted in clump, cluster, and conventional geometries produced an average of 4.86 Mg ha^{-1} (4340 lb ac^{-1}) of stover, 480 and 800 kg ha^{-1} (430 and 700 lb ac^{-1}) more than corn in a P1S1 or P2S2 configuration, respectively. Corn in a P1S1 configuration produced 320 kg ha^{-1} (280 lb ac^{-1}) more stover than corn in a P2S2 configuration, which produced the lowest level of stover. Stover production was highest for corn seeded at the high seeding rate and lowest for corn seeded at the intermediate rate. Corn seeded at the low rate, resulted in stover production that was not different than the other two seeding rates (Table 1.22).

Grain yields were not affected by treatments in 2011 even though many yield components varied by treatment. Grain yields ranged from 7.54 Mg ha^{-1} (120 bu ac^{-1}) for P2S2 to 8.07 Mg ha^{-1} (129 bu ac^{-1}) for corn planted in the cluster and P1S1 geometries (Table 1.22). Grain yields averaged 7.86 Mg ha^{-1} (125 bu ac^{-1}) across all three seeding rates with a range of only (2 bu ac^{-1}).

Planting geometry (P<0.0001) and seeding rate (P=0.0010) both affected harvest index (Table 1.22). Corn planted in either of the skip-row configurations resulted in a harvest index of 0.61, higher than the cluster, clump, or conventional geometries. Higher HI in the P1S1 treatment was driven by both increased grain yields and reduced biomass whereas the relatively higher HI for the P2S2 configuration was driven solely by lower above-ground biomass as grain yields were reduced compared to other treatments. Corn grown in the conventional geometry resulted in the lowest harvest index of 0.57 due to both above average biomass production and below average grain yield. Harvest index for corn planted at the low and intermediate densities was 0.01 to 0.02 higher, respectively, than that planted at the high density (Table 1.22).

Table 1.22 - Effect of planting geometry and seeding rate on corn biomass, grain yield, and yield components, Tribune, Kansas 2011.

Geometry	Seeding rate	Above-ground biomass	Stover	Grain yield	Harvest index	Kernels plant^{-1}	Kernel rows	Kernels ear row^{-1}	Ears plant^{-1}	Kernel weight	Yield plant^{-1}
	plants m^{2} (1000 plants ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (bu ac^{-1})						mg	g
Clump		11.5 (10,200) a†	4.83 (4310) a	7.87 (125)	0.58 bc	719 a	17.4 ab	43.6 a	1.01	238 c	173 a‡
Cluster		11.6 (10,400) a	4.81 (4290) a	8.07 (129)	0.59 b	694 ab	17.2 b	43.2 ab	1.01	251 b	176 a
Conventional		11.5 (10,300) a	4.95 (4410) a	7.74 (123)	0.57 c	709 a	17.6 a	43.2 ab	1.00	237 c	171 ab
P1S1		11.2 (9,990) a	4.38 (3910) b	8.07 (129)	0.61 a	679 b	16.9 c	42.2 b	1.01	256 ab	176 a
P2S2		10.4 (9,310) b	4.06 (3630) c	7.54 (120)	0.61 a	615 c	17.0 c	40.9 c	0.98	264 a	163 b
	3.0 (12.3)	11.2 (10,000)	4.58 (4090) ab	7.87 (125)	0.59 a	773 a	17.4 a	47.0 a	1.02 a	284 a	220 a
	4.0 (16.2)	11.1 (9,940)	4.47 (3990) b	7.89 (126)	0.60 a	695 b	17.2 ab	43.3 b	1.00 b	240 b	166 b
	5.1 (20.6)	11.4 (10,100)	4.76 (4250) a	7.81 (124)	0.58 b	581 c	17.0 b	37.5 c	0.99 b	224 c	129 c
Clump	3.0 (12.3)	11.9 (10,600)	5.02 (4480)	8.14 (130)	0.58	773	17.5	48.0 ab	1.01	294 a	227 a
	4.0 (16.2)	11.3 (10,100)	4.50 (4010)	8.03 (128)	0.60	756	17.5	44.3 d	1.00	224 de	169 cd
	5.1 (20.6)	11.2 (10,000)	4.97 (4430)	7.44 (118)	0.56	627	17.0	38.6 g	1.01	197 f	123 e
Cluster	3.0 (12.3)	11.3 (10,100)	4.60 (4110)	7.94 (126)	0.59	779	17.4	47.5 ab	1.06	284 a	221 a
	4.0 (16.2)	11.9 (10,600)	4.81 (4290)	8.37 (133)	0.59	710	17.2	44.9 cd	1.00	249 bc	176 c
	5.1 (20.6)	11.7 (10,400)	5.01 (4470)	7.91 (126)	0.57	593	17.1	37.3 g	0.99	221 de	131 e
Conventional	3.0 (12.3)	12.2 (10,900)	5.22 (4660)	8.24 (131)	0.57	817	17.8	48.2 a	1.01	281 a	230 a
	4.0 (16.2)	10.8 (9,670)	4.60 (4100)	7.39 (118)	0.58	709	17.6	42.2 ef	1.00	220 de	156 d
	5.1 (20.6)	11.4 (10,200)	5.02 (4480)	7.61 (121)	0.56	601	17.4	39.1 g	1.00	210 ef	126 e
P1S1	3.0 (12.3)	10.9 (9,680)	4.25 (3790)	7.82 (125)	0.61	774	17.4	45.3 cd	1.03	282 a	218 ab
	4.0 (16.2)	11.4 (10,200)	4.46 (3980)	8.27 (132)	0.61	694	16.7	43.6 de	1.00	251 bc	174 c
	5.1 (20.6)	11.3 (10,100)	4.43 (3950)	8.11 (129)	0.61	570	16.6	37.6 g	1.00	235 cd	134 e
P2S2	3.0 (12.3)	9.9 (8,860)	3.82 (3410)	7.24 (115)	0.62	723	17.0	46.2 bc	1.00	280 a	202 b
	4.0 (16.2)	10.2 (9,130)	4.00 (3570)	7.38 (118)	0.61	607	17.0	41.6 f	0.98	256 b	155 d
	5.1 (20.6)	11.1 (9,920)	4.37 (3900)	7.99 (127)	0.61	516	16.9	34.8 h	0.98	256 b	132 e
LSD = 0.05											
Geometry		0.6 (570)	0.28 (250)	0.49 (8)	0.01	27	0.3	1.1	0.03	11	9
Population		0.5 (450)	0.22 (200)	0.38 (6)	0.01	21	0.2	0.8	0.02	8	7
Geometry x Seeding Rate		1.1 (1000)	0.49 (440)	0.85 (14)	0.02	46	0.5	1.9	0.05	18	16
				ANOVA P>F							
Effect											
Geometry		0.0040	<0.0001	0.1603	<0.0001	<0.0001	<0.0001	<0.0001	0.2146	<0.0001	0.0519
Seeding Rate		0.6736	0.0394	0.9087	0.0010	<0.0001	0.0008	<0.0001	0.0228	<0.0001	<0.0001
Geometry x Seeding Rate		0.1129	0.1104	0.1274	0.2021	0.1471	0.3016	0.0042	0.7272	0.0001	0.0284

† Letters within a column and an effect represent differences at LSD (0.05) unless noted otherwise

‡ Letters within a column and an effect represent differences at LSD (0.10)

Yield components

Kernels plant^{-1} was numerically highest for corn planted in clump geometry (719 kernels plant^{-1}) and lowest for corn planted in a P2S2 configuration (615 KP) (Table 1.22). Corn planted in clump or conventional geometries (average of 714 KP) produced higher KP than corn planted in either of the skip-row geometries. Corn planted in the cluster geometry was not different than corn planted in either clump, conventional, or P1S1 configurations (Table 1.22). Corn in a P2S2 geometry produced less kernels plant^{-1} than any other geometry treatment. Kernels plant^{-1} responded negatively to increasing seeding rate, declining from a high of 773 KP at the low rate to 581 KP at the high rate.

In 2011, as seeding rate increased, kernel rows decreased. Corn seeded at the low rate resulted in mean kernel rows of 17.4 likely due to a higher proportion of ears with 18 kernel rows. This was higher than corn planted at the high rate which had a mean of 17 KR, likely resulting from an approximately equal proportion of 16 and 18 KR. Kernel rows were also affected by planting geometries ($P<0.0001$). Corn planted in a conventional geometry resulted in the highest number of KR (17.6) than any other geometry, although not statistically different than clump planted which produced 17.4 (Table 1.22). Clump planted corn produced equivalent KR as conventional and cluster, but higher than either of the skip-row treatments. The P1S1 and P2S2 geometries resulted in the lowest number of KR with a mean of 16.95.

Kernels ear row^{-1} was affected by a geometry x seeding rate interaction ($P=0.0042$, Table 1.22). At the lowest seeding rate, KER was highest for corn planted in a conventional, clump, or cluster geometry, followed by the P2S2 and P1S1 geometries (Figure 1.18). As seeding rate increased to the intermediate rate, the conventional geometry had the highest rate of decline (6 kernels) and went from the highest KER to one of the lowest along with the P2S2 geometry (Figure 1.18). The P1S1 treatment had the smallest change in KER between the low and intermediate seeding rate treatments declining only 1.7 kernels. The rate of decline in KER as seeding rate increased to the highest level was similar for all geometry treatments except conventional (Figure 1.18). There was little difference among planting geometries at the highest seeding rate, only corn grown in a P2S2 configuration differed with the lowest KER of 34.8 compared to the other geometries which averaged 38.2 (Table 1.22).

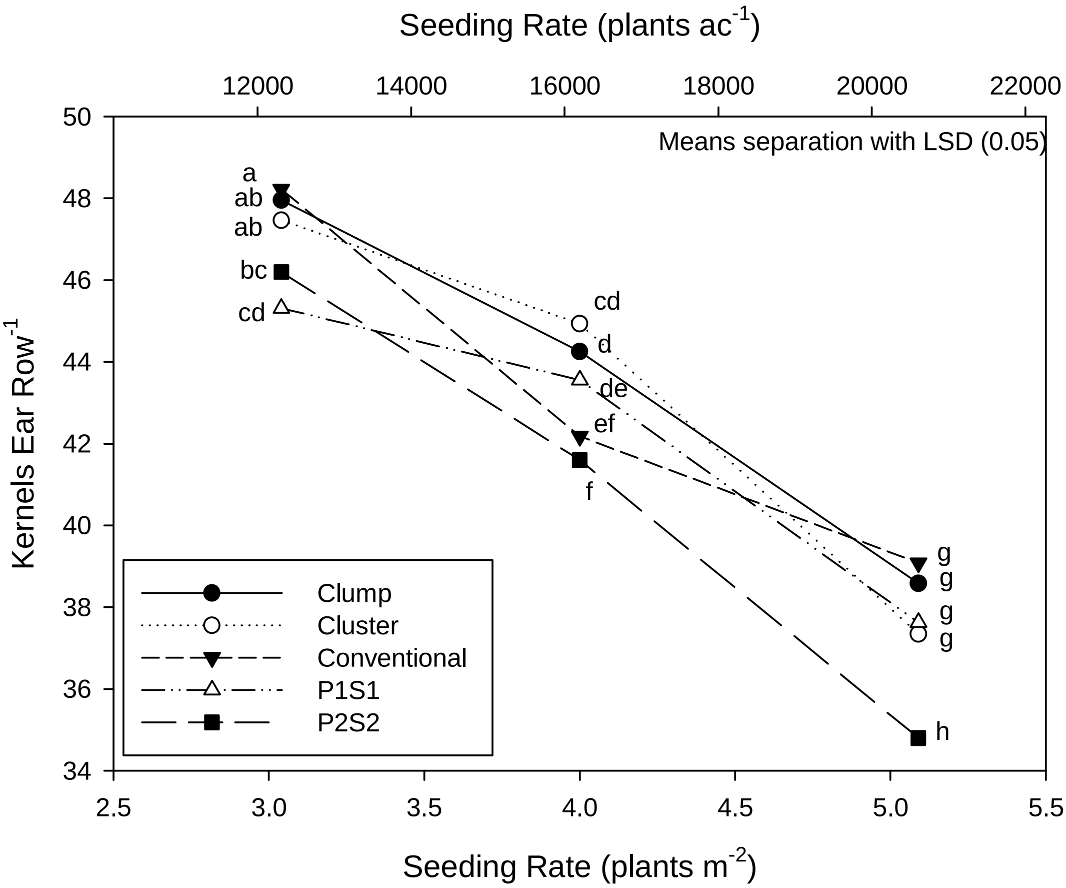

Figure 1.18 - Effect of planting geometry and seeding rate on corn kernels per ear row^{-1} (KER), Tribune, Kansas, 2011.

Ears plant^{-1} was affected by seeding rate (P=0.0228) (Table 1.22). As seeding rate increased, ears plant^{-1} declined from 1.02 for the lowest seeding rate to an average of 0.995 for the mid and high seeding rate, which did not differ from each other.

The planting geometry x seeding rate interaction affected KW in 2011 (P=0.0001) (Table 1.22). In all geometries KW declined as seeding rate increased, however planting geometry played a role in the responsiveness of KW to increasing plant density (Figure 1.19). At the lowest seeding rate, no differences were observed in KW due to planting geometry. As seeding rate increased to the intermediate level, KW declined rapidly, 61 and 70 mg kernel^{-1}, respectively, for conventional and clump geometries to an average level of 222 mg kernel^{-1} (Figure 1.19). Kernel weights in the other three geometries declined more moderately, an average of 31 mg kernel^{-1} to an average level of 252 mg kernel^{-1}. At the highest seeding rate, corn planted in a P2S2 configuration resulted in the highest KW, which was no different than the KW of P2S2, P1S1, or cluster treatments at the mid range seeding rate. P1S1 resulted in a KW that was higher than either conventional or clump planted corn at the highest seeding rate (Figure 1.19). Kernel weight of corn planted in a cluster geometry was numerically lower than P1S1 and higher than either conventional clump but could not be distinguished as being different from any of those treatments (Figure 1.19). Overall, corn planted in a conventional or clump configuration had the largest response in KW with respect to increasing plant population.

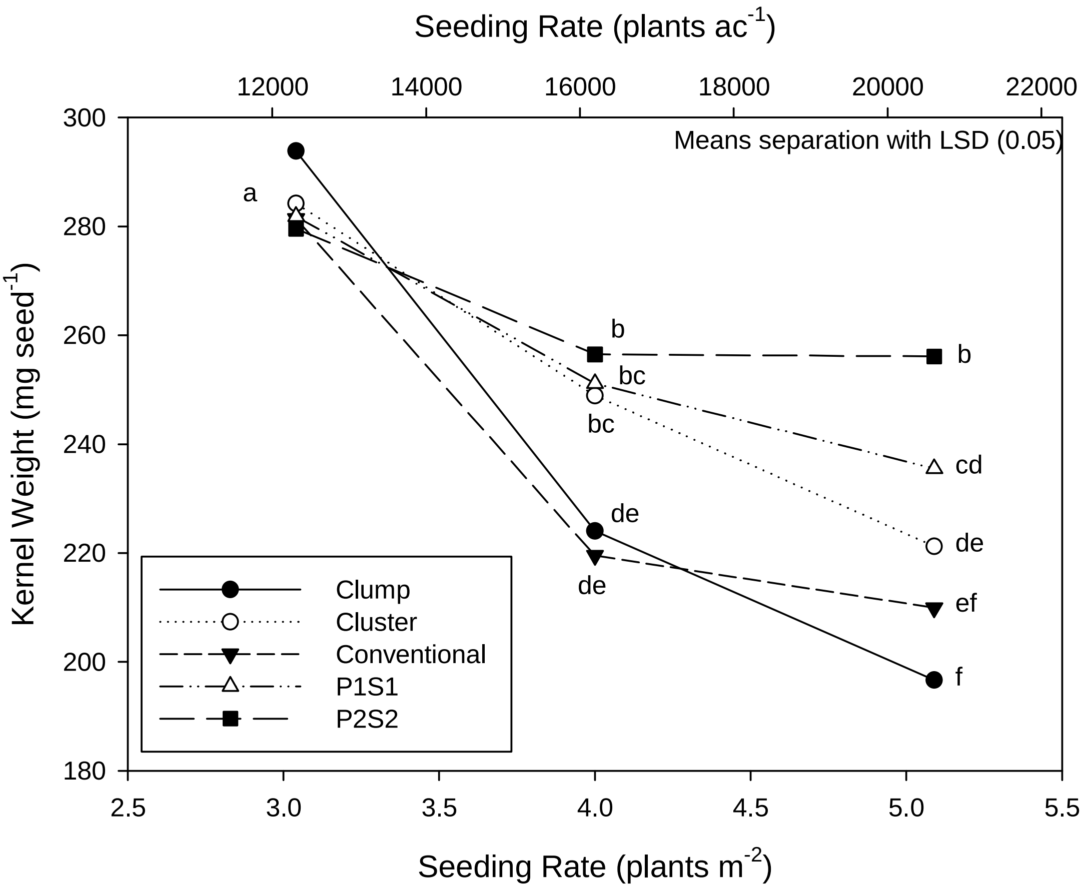

Figure 1.19 - Effect of planting geometry and seeding rate on corn kernel weight, Tribune, Kansas, 2011.

Yield plant^{-1} was affected by a planting geometry x seeding rate interaction (P=0.0284) (Table 1.22). At the lowest seeding rate corn planted in a P2S2 configuration resulted in less yield plant^{-1} than any of the other geometries. Yield plant^{-1} declined with increasing plant population for all seeding rates (Figure 1.20). The decrease in yield was most pronounced for corn planted in a conventional geometry. As seeding rates increased from the low to intermediate rates, grain yield per plant for the conventional geometry declined 58 g compared to 58, 47, 45, and 44 g for the clump, P2S2, cluster, and P1S1 configurations, respectively. Yield per plant for any geometry at either the mid or high seeding rate never exceeded yield plant^{-1} at the low population (Figure 1.20). At the mid seeding rate, corn in the cluster and P1S1 configurations resulted in higher yield plant^{-1} than the conventional or P2S2 configurations and was numerically higher than corn in a clump configuration. Contrary to the first increment in plant density, corn in a conventional geometry had the smallest reduction in grain yield plant^{-1} as seeding rates increased from the mid to the high rate. At the highest seeding rate, no difference in yield plant^{-1} due to planting geometry was observed.

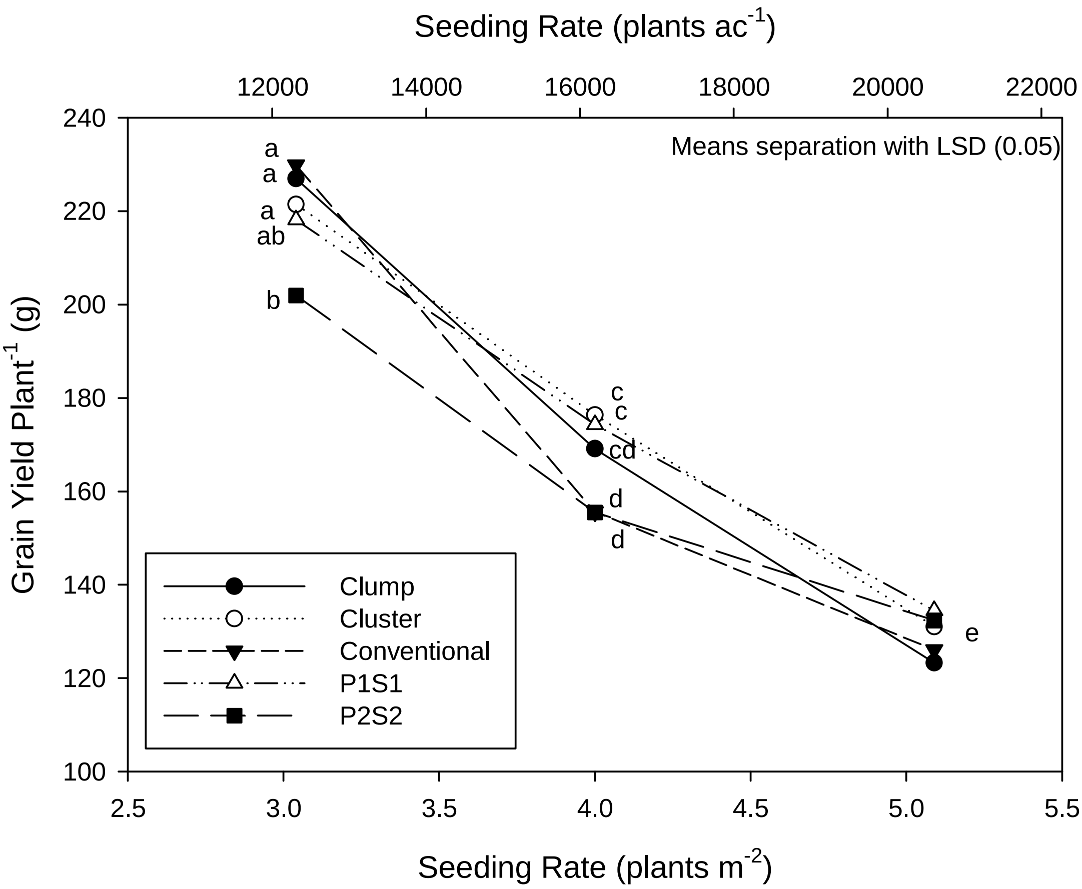

Figure 1.20 - Effect of planting geometry and seeding rate on corn grain yield plant^{-1}, Tribune, Kansas, 2011.

Light interception and grain nutrient content

Planting geometry affected light interception in 2011 (P=0.0007) (Table 1.23). The highest IPAR values were for corn planted in conventional or clump geometries and comparable to the cluster geometry. Corn in a P1S1 configuration intercepted less light than clump or conventional, and a similar amount as cluster. The P2S2 configuration resulted in less IPAR than any other geometry and was 32% less than the average IPAR values for conventional and clump planted corn.

Table 1.23 - Effect of corn planting geometry on intercepted photosynthetically active radiation (IPAR), Tribune, Kansas 2011.

Geometry	Fraction of PAR intercepted (θ)	
Clump	0.826	a
Cluster	0.754	ab
Conventional	0.842	a
P1S1	0.673	b
P2S2	0.564	c
LSD = 0.05		
Geometry	0.083	
ANOVA P>F		
Effect		
Geometry	0.0007	

† Letters within a column represent differences at LSD (0.05)

Grain N content and N removal was affected by planting geometry in 2011 (Table 1.24). Grain N content was higher for the clump, conventional, and P1S1 geometries and averaged 12.4 g kg^{-1} (1.24%) compared to the P2S2 and cluster configurations which averaged 11.6 g kg^{-1} (1.16%). Nitrogen removal via grain was higher for all geometry treatments when compared to the P2S2 configuration. This reduced level of N removal was clearly affected not only by lower grain N content but also lower grain yields (Table 1.22). Grain P content was affected by geometry (P=0.0620) and was higher for corn planted in cluster, conventional, or P1S1 geometries as compared to P2S2 (Table 1.24). These differences in grain P content along with differences in grain yield (Table 1.22) resulted in differences in P removal by the grain with corn planted in a P2S2 configuration having a lower level of P removal than any other geometry (Table 1.24).

Table 1.24 - Effect of planting geometry and seeding rate on corn grain N and P, 2011.

Geometry	Seeding rate	Grain N content		N removal			Grain P content		P removal		
	plants m2 (1000 plants ac-1)	g kg-1		kg ha-1 (lb ac-1)			g kg-1		kg ha-1 (lb ac-1)		
Clump		12.5	a	83	74	a	2.8	ab‡	19	17	a
Cluster		11.7	b	80	71	a	2.9	a	20	18	a
Conventional		12.3	a	81	72	a	2.9	a	19	17	a
P1S1		12.3	a	84	75	a	3.0	a	20	18	a
P2S2		11.5	b	73	65	b	2.7	b	17	15	b
	3.0 (12.3)	12.0		80	71		2.9		19	17	
	4.0 (16.2)	12.1		81	72		2.9		19	17	
	5.1 (20.6)	12.1		80	71		2.8		19	17	
Clump	3.0 (12.3)	12.0		83	74		2.8		19	17	
	4.0 (16.2)	12.5		85	76		2.8		19	17	
	5.1 (20.6)	13.1		82	73		2.9		18	16	
Cluster	3.0 (12.3)	11.5		77	69		2.9		19	17	
	4.0 (16.2)	11.9		84	75		2.9		20	18	
	5.1 (20.6)	11.6		78	70		3.0		20	18	
Conventional	3.0 (12.3)	12.6		88	78		3.1		21	19	
	4.0 (16.2)	12.6		79	70		3.0		19	17	
	5.1 (20.6)	11.7		75	67		2.8		18	16	
P1S1	3.0 (12.3)	12.4		82	73		3.0		20	18	
	4.0 (16.2)	12.0		84	75		3.0		21	19	
	5.1 (20.6)	12.5		85	76		2.9		19	17	
P2S2	3.0 (12.3)	11.4		69	62		2.6		16	14	
	4.0 (16.2)	11.5		72	64		2.7		17	15	
	5.1 (20.6)	11.6		78	69		2.7		18	16	
LSD = 0.05											
Geometry		0.6		6	5		0.2		2	2	
Population		0.5		4	4		0.2		1	1	
Geometry x Seeding Rate		1.0		10	9		0.4		3	3	
		ANOVA P>F									
Effect											
Geometry		0.0030		0.0028			0.0620		0.0030		
Seeding Rate		0.8339		0.8952			0.8526		0.6455		
Geometry x Seeding Rate		0.2956		0.1330			0.7767		0.2701		

† Letters within a column and an effect represent differences at LSD (0.05) unless otherwise note

‡ Letters within the column and effect represent differences at LSD (0.10)

Soil water, water use, and water use efficiency

Profile water totals across measurement positions

Differences in profile water totals were evident at every date of measurement in 2011 (Table 1.25). At the first measurement, the highest levels of profile water were observed in all three positions in the P1S1 geometry and the 95 and 152 cm (37.5 and 60 inch) positions in the P2S2 geometry. The lowest levels occurred in-row in the conventional and in-between rows in the P2S2 geometries. Similar values occurred in all clump treatments, in-row in the cluster and P2S2 treatments, and in-between rows in the conventional treatment. At the first in-season measurement on 26 July coinciding with R1 (tassel-silk), the highest level of profile soil water was observed in the middle of the skip in the P2S2 treatment. The next highest levels were found in the 95 cm (37.5 inch) P2S2 position and were similar to all tube position the P1S1 treatment. The lowest level of soil water was observed in the in-row conventional position and was similar to several other positions in the clump, cluster, and P2S2 geometries (Table 1.25). At the second in-season measurement on 18 August, the highest level of profile soil water was again observed at the 152 cm (60 inch) followed by the 95 cm (37.5 inch) positions in the P2S2 treatment. The lowest level was observed in-row of the conventional treatment, and was similar to all positions in the clump geometry, the in-row position in the cluster geometry, and the between-row positions in the conventional and P2S2 treatment. At harvest, the lowest values were in all positions of the clump, cluster, and conventional treatments along with the between-row position in the P2S2 treatments and the in-row position of the P1S1 and P2S2 geometries. Profile water in the middle of the P2S2 skip was higher than any other position at corn harvest (Table 1.25).

Table 1.25 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in corn planting geometries. Tribune, Kansas, 2011.

Geometry	Tube position	07/08/11			07/26/11			08/18/11			09/30/11		
	cm (inches)	Available soil water, mm (inches)											
Clump	0	127	(4.99)	efg	68	(2.69)	de	62	(2.44)	g	37	(1.45)	e
	38 (15)	124	(4.89)	efg	68	(2.66)	de	72	(2.83)	efg	41	(1.60)	e
	76 (30)	126	(4.96)	efg	67	(2.62)	de	70	(2.77)	efg	39	(1.55)	e
Cluster	0	129	(5.10)	defg	71	(2.80)	de	69	(2.70)	efg	38	(1.50)	e
	38 (15)	139	(5.49)	bcde	79	(3.11)	cd	82	(3.21)	de	41	(1.62)	e
	76 (30)	136	(5.34)	cdef	79	(3.11)	cd	78	(3.06)	def	39	(1.53)	e
Conventional	0	117	(4.61)	g	63	(2.50)	e	63	(2.46)	g	39	(1.52)	e
	38 (15)	124	(4.86)	efg	66	(2.59)	de	66	(2.62)	fg	39	(1.52)	e
P1S1	0	148	(5.84)	abc	94	(3.69)	bc	90	(3.54)	cd	45	(1.78)	cde
	38 (15)	154	(6.07)	ab	98	(3.87)	bc	99	(3.89)	c	51	(1.99)	bcd
	76 (30)	156	(6.15)	a	105	(4.14)	bc	104	(4.11)	bc	52	(2.03)	bc
P2S2	0	116	(4.58)	g	68	(2.70)	de	71	(2.79)	efg	42	(1.64)	de
	38 (15)	122	(4.82)	fg	74	(2.93)	de	79	(3.10)	def	45	(1.76)	cde
	95 (37.5)	146	(5.77)	abc	98	(3.87)	b	118	(4.63)	b	58	(2.28)	bc
	152 (60)	145	(5.72)	abcd	133	(5.23)	a	141	(5.57)	a	75	(2.93)	a
LSD = 0.10													
	Tube Position	17	(0.65)		16	(0.61)		15	(0.58)		9	(0.36)	
		ANOVA P>F											
Effect													
	Tube Position	0.0005			<0.0001			<0.0001			<0.0001		

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Soil water content by depth within geometries

Lower levels of soil water were observed 76 cm (30 inches) away from the clump than adjacent to the clump at several depths on 8 July and 26 July (Table 1.26). This trend became much more evident on 18 August at grain fill. At depths of 15, 40, and 46 cm (6, 12, and 18 inches) soil water contents immediately adjacent to the clump were lower than at distances of 38 and 76 cm (15 and 30 inches) away from the clump. This relationship was observed for only two depths, 30 and 183 cm (12 and 72 inches), on 30 September.

At the 8 July measurement of corn planted in a cluster configuration, soil water at depths of 91, 107 and 122 cm (36, 42, and 48 inches) tended to be highest at a distance of 38 cm (15 inches) from the cluster (Table 1.27). At the 26 July sampling, which coincided with tassel-silk, the trend was for the highest levels of soil water to be detected 76 cm (30) inches from the cluster. This trend was detected at depths of 15, 76, 91, and 137 cm (6, 30, 36, and 54 inches). At the 107 cm (42 inch) depth on 8 August and 9 September and the 91 cm (36 inch) depth on 30 September, the highest water contents were found 38 cm (15 inches) from the cluster.

Few differences among measurement position were observed for corn planted in a conventional geometry in 2011 (Table 1.28). Where differences were detected, the most being at three different depths during grain fill on 8 August, soil water contents were higher between rows than within the planted row.

Corn planted in a P1S1 configuration tended to result in lower levels of soil water to be present in the planted row and increased with distance from the planted row into the skip (Table 1.29). This trend was seen on 8 July and was most evident in relative differences and spatial continuity at the 26 July and 18 August samplings, which coincided with tassel-silk and grain fill.

Table 1.26 - Soil water by depth in corn in clump planting geometry. Tribune, Kansas, 2011.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
07/08/2011	15 (6)	0.0976	0.217	a†	0.209	b	0.208	b
	30 (12)	0.2939	0.223		0.225		0.229	
	46 (18)	0.3784	0.228		0.228		0.224	
	61 (24)	0.0649	0.225	a	0.221	ab	0.218	b
	76 (30)	0.5213	0.214		0.216		0.214	
	91 (36)	0.5431	0.208		0.198		0.208	
	107 (42)	0.4031	0.199		0.199		0.201	
	122 (48)	0.1878	0.188		0.184		0.190	
	137 (54)	0.7842	0.173		0.171		0.172	
	152 (60)	0.9619	0.166		0.165		0.166	
	168 (66)	0.4968	0.162		0.163		0.164	
	183 (72)	0.2105	0.165		0.170		0.167	
07/26/2011	15 (6)	0.4648	0.176		0.177		0.174	
	30 (12)	0.2647	0.168		0.172		0.171	
	46 (18)	0.3716	0.160		0.163		0.160	
	61 (24)	0.0378	0.157	a	0.155	a	0.151	b
	76 (30)	0.2965	0.155		0.153		0.152	
	91 (36)	0.4539	0.159		0.159		0.156	
	107 (42)	0.5996	0.167		0.164		0.164	
	122 (48)	0.1456	0.175		0.169		0.175	
	137 (54)	0.6992	0.172		0.170		0.171	
	152 (60)	0.2880	0.166		0.163		0.166	
	168 (66)	0.6072	0.163		0.164		0.163	
	183 (72)	0.2781	0.165		0.169		0.167	
08/18/2011	15 (6)	0.0008	0.198	b	0.232	a	0.228	a
	30 (12)	0.0761	0.171	b	0.187	a	0.186	a
	46 (18)	0.0530	0.162	b	0.168	a	0.168	a
	61 (24)	0.2132	0.153		0.157		0.156	
	76 (30)	0.4786	0.150		0.152		0.150	
	91 (36)	0.6205	0.151		0.149		0.149	
	107 (42)	0.4748	0.151		0.153		0.153	
	122 (48)	0.2792	0.157		0.156		0.161	
	137 (54)	0.6804	0.160		0.160		0.158	
	152 (60)	0.8648	0.162		0.161		0.161	
	168 (66)	0.6738	0.161		0.163		0.161	
	183 (72)	0.4571	0.165		0.168		0.167	
09/30/2011	15 (6)	0.3800	0.171		0.170		0.165	
	30 (12)	0.0253	0.162	b	0.169	a	0.169	a
	46 (18)	0.3106	0.153		0.157		0.156	
	61 (24)	0.7347	0.148		0.148		0.147	
	76 (30)	0.4372	0.143		0.144		0.143	
	91 (36)	0.5854	0.140		0.142		0.140	
	107 (42)	0.5375	0.140		0.139		0.141	
	122 (48)	0.3737	0.141		0.140		0.143	
	137 (54)	0.4412	0.141		0.143		0.142	
	152 (60)	0.8186	0.144		0.144		0.146	
	168 (66)	0.1518	0.144		0.149		0.147	
	183 (72)	0.1006	0.150		0.156		0.154	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.27 - Soil water by depth in corn in cluster planting geometry. Tribune, Kansas, 2011.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
07/08/2011	15 (6)	0.7206	0.219		0.229		0.227	
	30 (12)	0.1049	0.226		0.237		0.240	
	46 (18)	0.2104	0.222		0.228		0.233	
	61 (24)	0.6266	0.219		0.222		0.225	
	76 (30)	0.8254	0.217		0.219		0.218	
	91 (36)	0.0323	0.209	b†	0.216	a	0.209	b
	107 (42)	0.0749	0.202	ab	0.208	a	0.197	b
	122 (48)	0.0909	0.191	ab	0.196	a	0.188	b
	137 (54)	0.1812	0.174		0.183		0.176	
	152 (60)	0.2833	0.165		0.170		0.170	
	168 (66)	0.8153	0.167		0.170		0.168	
	183 (72)	0.9795	0.172		0.172		0.173	
07/26/2011	15 (6)	0.7573	0.180		0.182		0.179	
	30 (12)	0.3977	0.173		0.171		0.174	
	46 (18)	0.2459	0.157		0.159		0.163	
	61 (24)	0.1068	0.152		0.156		0.161	
	76 (30)	0.0373	0.153	b	0.161	a	0.163	a
	91 (36)	0.0546	0.157	b	0.167	a	0.167	a
	107 (42)	0.1251	0.169		0.177		0.174	
	122 (48)	0.1529	0.174		0.181		0.179	
	137 (54)	0.1454	0.173		0.180		0.177	
	152 (60)	0.4085	0.170		0.174		0.173	
	168 (66)	0.7001	0.168		0.172		0.171	
	183 (72)	0.9742	0.173		0.173		0.172	
08/18/2011	15 (6)	0.0944	0.213	b	0.233	a	0.231	a
	30 (12)	0.1864	0.181		0.189		0.188	
	46 (18)	0.5988	0.164		0.168		0.166	
	61 (24)	0.4048	0.153		0.159		0.156	
	76 (30)	0.0150	0.148	b	0.156	a	0.155	a
	91 (36)	0.0333	0.150	b	0.157	a	0.155	a
	107 (42)	0.0161	0.153	b	0.163	a	0.154	b
	122 (48)	0.2142	0.158		0.165		0.161	
	137 (54)	0.0496	0.159	b	0.167	a	0.165	a
	152 (60)	0.1817	0.164		0.169		0.170	
	168 (66)	0.4756	0.166		0.171		0.171	
	183 (72)	0.9702	0.175		0.174		0.174	
09/30/2011	15 (6)	0.5478	0.171		0.172		0.167	
	30 (12)	0.9681	0.166		0.167		0.166	
	46 (18)	0.4966	0.151		0.151		0.153	
	61 (24)	0.9188	0.146		0.145		0.144	
	76 (30)	0.5756	0.141		0.143		0.141	
	91 (36)	0.0989	0.139	ab	0.142	a	0.138	b
	107 (42)	0.0090	0.139	b	0.144	a	0.137	b
	122 (48)	0.1174	0.139		0.142		0.139	
	137 (54)	0.1496	0.139		0.143		0.141	
	152 (60)	0.5987	0.145		0.145		0.147	
	168 (66)	0.5214	0.149		0.152		0.153	
	183 (72)	0.8541	0.161		0.159		0.162	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.28 - Soil water by depth in corn in conventional planting geometry. Tribune, Kansas, 2011.

Date	Depth	ANOVA P>F	Tube position			
			0		36 cm (15 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}			
07/08/2011	15 (6)	0.0307	0.201	b†	0.216	a
	30 (12)	0.1292	0.223		0.229	
	46 (18)	0.8051	0.224		0.225	
	61 (24)	0.7575	0.221		0.222	
	76 (30)	0.6940	0.217		0.216	
	91 (36)	0.2514	0.194		0.209	
	107 (42)	0.3424	0.193		0.198	
	122 (48)	0.3980	0.177		0.183	
	137 (54)	0.1659	0.162		0.164	
	152 (60)	0.5801	0.160		0.159	
	168 (66)	0.3741	0.163		0.160	
	183 (72)	0.3583	0.169		0.165	
07/26/2011	15 (6)	0.9842	0.177		0.177	
	30 (12)	0.7339	0.170		0.169	
	46 (18)	0.6268	0.158		0.157	
	61 (24)	0.6679	0.153		0.152	
	76 (30)	0.2458	0.152		0.155	
	91 (36)	0.0029	0.154	b	0.161	a
	107 (42)	0.0179	0.161	b	0.170	a
	122 (48)	0.1085	0.168		0.173	
	137 (54)	0.5813	0.165		0.167	
	152 (60)	0.8245	0.161		0.162	
	168 (66)	0.5825	0.163		0.160	
	183 (72)	0.3177	0.170		0.164	
08/18/2011	15 (6)	0.3169	0.205		0.214	
	30 (12)	0.7146	0.177		0.176	
	46 (18)	0.6040	0.165		0.163	
	61 (24)	0.9635	0.155		0.155	
	76 (30)	0.0815	0.149	b	0.152	a
	91 (36)	0.0334	0.147	b	0.151	a
	107 (42)	0.1340	0.149		0.155	
	122 (48)	0.0648	0.152	b	0.159	a
	137 (54)	0.1824	0.153		0.158	
	152 (60)	0.9444	0.158		0.158	
	168 (66)	0.5273	0.164		0.161	
	183 (72)	0.3797	0.171		0.166	
09/30/2011	15 (6)	0.9397	0.169		0.169	
	30 (12)	0.5293	0.164		0.166	
	46 (18)	0.8757	0.153		0.153	
	61 (24)	0.2854	0.147		0.148	
	76 (30)	0.2726	0.143		0.145	
	91 (36)	0.1374	0.139		0.141	
	107 (42)	0.7567	0.139		0.140	
	122 (48)	0.3012	0.137		0.140	
	137 (54)	0.8755	0.141		0.141	
	152 (60)	0.4509	0.144		0.144	
	168 (66)	0.1262	0.151		0.147	
	183 (72)	0.2853	0.161		0.156	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.29 - Soil water by depth in corn in plant-1 skip-1 (P1S1) geometry. Tribune, Kansas, 2011.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
07/08/2011	15 (6)	0.0071	0.220	b†	0.225	b	0.235	a
	30 (12)	0.2748	0.234		0.238		0.244	
	46 (18)	0.5927	0.237		0.241		0.236	
	61 (24)	0.0628	0.231	b	0.241	a	0.234	b
	76 (30)	0.4918	0.229		0.229		0.232	
	91 (36)	0.2963	0.221		0.220		0.224	
	107 (42)	0.6119	0.212		0.215		0.216	
	122 (48)	0.0479	0.201	b	0.206	a	0.206	a
	137 (54)	0.1777	0.189		0.193		0.194	
	152 (60)	0.6684	0.181		0.183		0.184	
	168 (66)	0.8621	0.177		0.175		0.177	
	183 (72)	0.8247	0.178		0.179		0.177	
07/26/2011	15 (6)	0.7001	0.189		0.185		0.185	
	30 (12)	0.6342	0.182		0.180		0.182	
	46 (18)	0.4475	0.172		0.175		0.176	
	61 (24)	0.1217	0.167		0.174		0.178	
	76 (30)	0.1078	0.167		0.174		0.184	
	91 (36)	0.0727	0.175	b	0.176	b	0.191	a
	107 (42)	0.0886	0.183	b	0.189	ab	0.196	a
	122 (48)	0.0655	0.187	b	0.191	ab	0.194	a
	137 (54)	0.0479	0.183	b	0.189	a	0.191	a
	152 (60)	0.7180	0.185		0.186		0.187	
	168 (66)	0.7201	0.180		0.182		0.180	
	183 (72)	0.9824	0.179		0.180		0.180	
08/18/2011	15 (6)	0.4326	0.220		0.227		0.233	
	30 (12)	0.4522	0.193		0.196		0.201	
	46 (18)	0.2183	0.177		0.184		0.185	
	61 (24)	0.1936	0.169		0.178		0.176	
	76 (30)	0.1025	0.165		0.170		0.175	
	91 (36)	0.0853	0.161	b	0.165	ab	0.173	a
	107 (42)	0.1120	0.165		0.171		0.175	
	122 (48)	0.0889	0.166	b	0.173	ab	0.178	a
	137 (54)	0.0326	0.169	b	0.178	a	0.181	a
	152 (60)	0.5130	0.178		0.180		0.180	
	168 (66)	0.8251	0.179		0.180		0.180	
	183 (72)	0.9121	0.182		0.182		0.183	
09/30/2011	15 (6)	0.5358	0.173		0.174		0.170	
	30 (12)	0.9680	0.172		0.173		0.173	
	46 (18)	0.3214	0.161		0.164		0.163	
	61 (24)	0.0912	0.153	b	0.161	a	0.157	ab
	76 (30)	0.1867	0.149		0.152		0.153	
	91 (36)	0.1268	0.145		0.146		0.148	
	107 (42)	0.0425	0.142	b	0.146	a	0.146	a
	122 (48)	0.1462	0.140		0.144		0.146	
	137 (54)	0.2456	0.141		0.145		0.147	
	152 (60)	0.2620	0.146		0.148		0.151	
	168 (66)	0.2792	0.150		0.153		0.157	
	183 (72)	0.7488	0.159		0.161		0.162	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 1.30 - Soil water by depth in corn in plant-2 skip-2 (P2S2) geometry. Tribune, Kansas, 2011.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$							
07/08/2011	15 (6)	<.0001	0.201	b†	0.205	b	0.260	a	0.248	a
	30 (12)	0.0001	0.204	b	0.212	b	0.251	a	0.243	a
	46 (18)	0.0030	0.207	b	0.213	b	0.243	a	0.237	a
	61 (24)	0.0361	0.209	b	0.214	b	0.227	a	0.229	a
	76 (30)	0.0023	0.208	b	0.210	b	0.219	a	0.223	a
	91 (36)	0.0010	0.197	c	0.204	b	0.211	a	0.211	a
	107 (42)	0.0520	0.191	c	0.194	bc	0.202	ab	0.204	a
	122 (48)	0.4727	0.183		0.184		0.187		0.191	
	137 (54)	0.4286	0.176		0.175		0.173		0.179	
	152 (60)	0.8192	0.171		0.172		0.170		0.173	
	168 (66)	0.9594	0.174		0.175		0.174		0.173	
	183 (72)	0.8666	0.177		0.179		0.179		0.178	
07/26/2011	15 (6)	<.0001	0.176	c	0.177	c	0.206	b	0.239	a
	30 (12)	<.0001	0.164	c	0.170	c	0.192	b	0.230	a
	46 (18)	<.0001	0.156	c	0.159	c	0.178	b	0.217	a
	61 (24)	<.0001	0.152	c	0.155	c	0.175	b	0.208	a
	76 (30)	<.0001	0.151	c	0.157	c	0.175	b	0.203	a
	91 (36)	<.0001	0.154	d	0.161	c	0.183	b	0.202	a
	107 (42)	<.0001	0.163	c	0.166	c	0.186	b	0.196	a
	122 (48)	0.0028	0.171	c	0.174	c	0.183	b	0.193	a
	137 (54)	0.0906	0.173	b	0.173	b	0.176	b	0.184	a
	152 (60)	0.5459	0.174		0.174		0.172		0.179	
	168 (66)	0.9158	0.174		0.176		0.174		0.175	
	183 (72)	0.8425	0.177		0.179		0.180		0.178	
08/18/2011	15 (6)	0.0001	0.216	b	0.218	b	0.257	a	0.262	a
	30 (12)	<.0001	0.176	c	0.186	c	0.231	b	0.243	a
	46 (18)	<.0001	0.163	c	0.166	c	0.206	b	0.226	a
	61 (24)	<.0001	0.154	c	0.158	c	0.190	b	0.213	a
	76 (30)	<.0001	0.151	c	0.156	c	0.183	b	0.204	a
	91 (36)	<.0001	0.148	d	0.155	c	0.177	b	0.198	a
	107 (42)	<.0001	0.153	c	0.157	c	0.177	b	0.196	a
	122 (48)	0.0004	0.159	c	0.162	c	0.176	b	0.191	a
	137 (54)	0.0037	0.163	c	0.168	bc	0.174	b	0.187	a
	152 (60)	0.0774	0.168	b	0.169	b	0.175	ab	0.181	b
	168 (66)	0.5341	0.173		0.176		0.178		0.179	
	183 (72)	0.1051	0.176		0.180		0.183		0.184	
09/30/2011	15 (6)	<.0001	0.173	b	0.171	b	0.190	a	0.191	a
	30 (12)	0.0073	0.163	b	0.167	b	0.178	a	0.181	a
	46 (18)	0.0660	0.153	b	0.153	b	0.162	ab	0.168	a
	61 (24)	0.1211	0.148		0.148		0.152		0.160	
	76 (30)	0.0341	0.144	b	0.146	b	0.148	b	0.157	a
	91 (36)	0.0213	0.141	b	0.144	b	0.145	b	0.156	a
	107 (42)	0.0101	0.140	b	0.143	b	0.146	b	0.160	a
	122 (48)	0.0155	0.144	b	0.144	b	0.150	b	0.162	a
	137 (54)	0.0073	0.146	b	0.147	b	0.151	b	0.167	a
	152 (60)	0.0055	0.148	b	0.150	b	0.155	b	0.170	a
	168 (66)	0.0090	0.151	c	0.155	bc	0.163	ab	0.173	a
	183 (72)	0.0014	0.157	b	0.161	b	0.173	a	0.178	a

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Differences in soil water content were apparent at every sampling time for corn in a P2S2 configuration (Table 1.30). In general, soil water contents were lowest in-between and under the planted rows (position 0), increased with distance away from the planted rows, and were highest in the middle of the skip. This relationship was observed through the 107 cm (42 inch) depth on 8 July was observed at deeper depths with each sequential measurement. At the 8 July measurement, two distinct LSD groups were present, the two locations closest to the planted rows and the two locations located in the skip. As the season progressed three distinct groups were present on 26 July and 18 August, coinciding with tassel-silk and grain fill, with soil water contents closest to the planted rows being less than those at the 95 cm (37.5 inch) position, which were less than those at the mid-skip 152 cm (60 inch) position. At the final measurement two groups generally existed with water contents higher mid-skip than the other positions.

Cross-section analysis of soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. The first measurement in 2011 occurred later than in previous years of the study with the corn in early vegetative growth. Profile water content differed among planting geometries (P=0.0365) (Table 1.31) and was highest for the profile underlying the P1S1 configuration, although not different than cluster or P2S2. Profile water content was lowest for the cross-section underlying the conventional geometry, although not different than clump or cluster.

The measurements obtained on 26 July coincided with tassel-silk. Geometries affected profile water (P=0.0087), with profiles underlying the P1S1 and P2S2 geometries having a higher level of soil water than any of the other geometries (Table 1.31). The profile underlying the P2S2 geometry had the largest range and standard deviation indicating spatial variability in soil water contents. The smallest range, standard deviation, and visual appearance of uniformity were exhibited by the conventional treatment. Cumulative water use differed among planting geometries (P=0.0014) and was lower for the P2S2 geometry than any other.

Measurements coinciding with grain fill were obtained on 18 August. Planting geometry affected profile water (P=0.0021) with the highest levels found in the skip-row treatments, the lowest level in the conventional, and intermediate levels in the clump and cluster treatments (Table 1.31). The largest range and standard deviation of soil water content was again attributed to the P2S2 treatment. Cumulative water use was less in the profile underlying the P2S2 configuration than any other. Water use by the clump treatment was intermediate and similar to cluster and P1S1 geometries. P2S2 had the lowest water use during this time period (Table 1.31).

Differences in profile water will still evident at the time of grain harvest (P=0.0125) (Table 1.31). Soil profiles underlying the skip-row treatments had higher levels of soil water than the other treatments. The largest range and standard deviation were again observed for the P2S2 geometry. Cumulative water use was highest for P1S1 and cluster geometries, and similar among clump, conventional, and P2S2 geometries. Water use for the interval of grain fill to harvest also differed among treatment with the highest values attributed to the skip-row treatments, the lowest to conventional, and clump and cluster being intermediate.

Table 1.31 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated soil water values, and water use as affected by corn planting geometry. Tribune, Kansas 2011.

Geometry	07/08/2011 Profile available water	07/08/2011 Range	07/08/2011 SD	07/26/2011 Profile available water	07/26/2011 Range	07/26/2011 SD	07/26/2011 Cumulative water use
	mm (in)	v v^{-1}	v v^{-1}	mm (in)	v v^{-1}	v v^{-1}	mm (in)
Clump	128 (5.04) b	0.074	0.024	69 (2.70) b	0.044 bc	0.011 b	88 (3.47) a
Cluster	141 (5.54) ab	0.080	0.024	79 (3.10) b	0.041 bc	0.010 b	91 (3.58) a
Conventional	125 (4.91) b	0.075	0.026	66 (2.60) b	0.037 c	0.010 b	87 (3.44) a
P1S1	157 (6.19) a	0.078	0.023	100 (3.93) a	0.046 b	0.011 b	86 (3.38) a
P2S2	140 (5.53) ab	0.105	0.027	95 (3.74) a	0.099 a	0.019 a	74 (2.92) b
LSD = 0.10							
Geometry	17 (0.66)	0.023	0.005	16 (0.64)	0.009	0.002	6 (0.22)
				ANOVA P>F			
Effect							
Geometry	0.0365	0.1578	0.6516	0.0087	<0.0001	<0.0001	0.0014

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Geometry	08/18/2011 Profile available water	08/18/2011 Range	08/18/2011 SD	08/18/2011 Cumulative water use	08/18/2011 Interval water use	09/30/2011 Profile available water	09/30/2011 Range	09/30/2011 SD	09/30/2011 Cumulative water use	09/30/2011 Interval water use
	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)
Clump	76 (2.98) bc	0.123 ab	0.028 b	231 (9.09) a	143 (5.61) b	41 (1.61) b	0.046 b	0.012 b	330 (13.0) bc	99 (3.91) cd
Cluster	84 (3.31) b	0.128 a	0.027 b	235 (9.25) a	144 (5.68) ab	41 (1.61) b	0.043 b	0.012 b	343 (13.5) ab	108 (4.25) bc
Conventional	68 (2.67) c	0.102 c	0.022 c	235 (9.26) a	148 (5.82) a	40 (1.56) b	0.039 b	0.011 b	328 (12.9) c	93 (3.66) d
P1S1	103 (4.06) a	0.108 bc	0.023 c	232 (9.15) a	146 (5.77) ab	51 (1.99) a	0.045 b	0.013 ab	350 (13.8) a	117 (4.61) ab
P2S2	110 (4.33) a	0.137 a	0.031 a	209 (8.22) b	135 (5.31) c	56 (2.20) a	0.064 a	0.015 a	327 (12.9) c	119 (4.67) a
LSD = 0.10										
Geometry	16 (0.63)	0.017	0.003	8 (0.31)	4 (0.15)	8 (0.32)	0.010	0.002	13 (0.5)	9 (0.36)
					ANOVA P>F					
Effect										
Geometry	0.0021	0.0170	0.0014	0.0003	0.0005	0.0125	0.0071	0.0702	0.0419	0.0012

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Water use / Water use efficiency

Planting geometry affected water use in 2011. Corn planted in a P1S1 configuration resulted in the highest water use and was similar to corn in cluster configuration, while corn planted in a conventional or P2S2 configuration resulted in the lowest water use and was similar to corn in a clump configuration (Table 1.32). Grain and biomass water use efficiencies were not affected by planting geometry in 2011.

Table 1.32 - Corn water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb) as affected by planting geometry. Tribune, Kansas, 2011.

Geometry	Water Use			WUEg		WUEb	
	mm (in)			$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)		$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)	
Clump	330	(13.0)	bc†	20.6	(466)	34.2	(775)
Cluster	343	(13.5)	ab	20.6	(468)	34.6	(785)
Conventional	328	(12.9)	c	19.0	(431)	33.0	(749)
P1S1	350	(13.8)	a	20.0	(453)	32.8	(743)
P2S2	327	(12.9)	c	19.0	(432)	31.3	(709)
LSD = 0.05							
Geometry	13	(0.5)		1.7	(38)	2.5	(57)
				ANOVA P>F			
Effect							
Geometry	0.0419			0.2997		0.2080	

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

2009-2011 Tribune across-years analysis

Cumulative growing season precipitation was generally consistent across years (Figure 1.21), although timing of precipitation events with respect to critical growth stages, heat stress, and available soil water at planting influenced yield. Rate of heat unit accumulation likely influenced grain filling rates and duration also affecting grain yields. Over the course of the study, grain yields averaged 6461 kg ha^{-1} (102.9 bu ac^{-1}), which are above average for dryland corn production at Tribune.

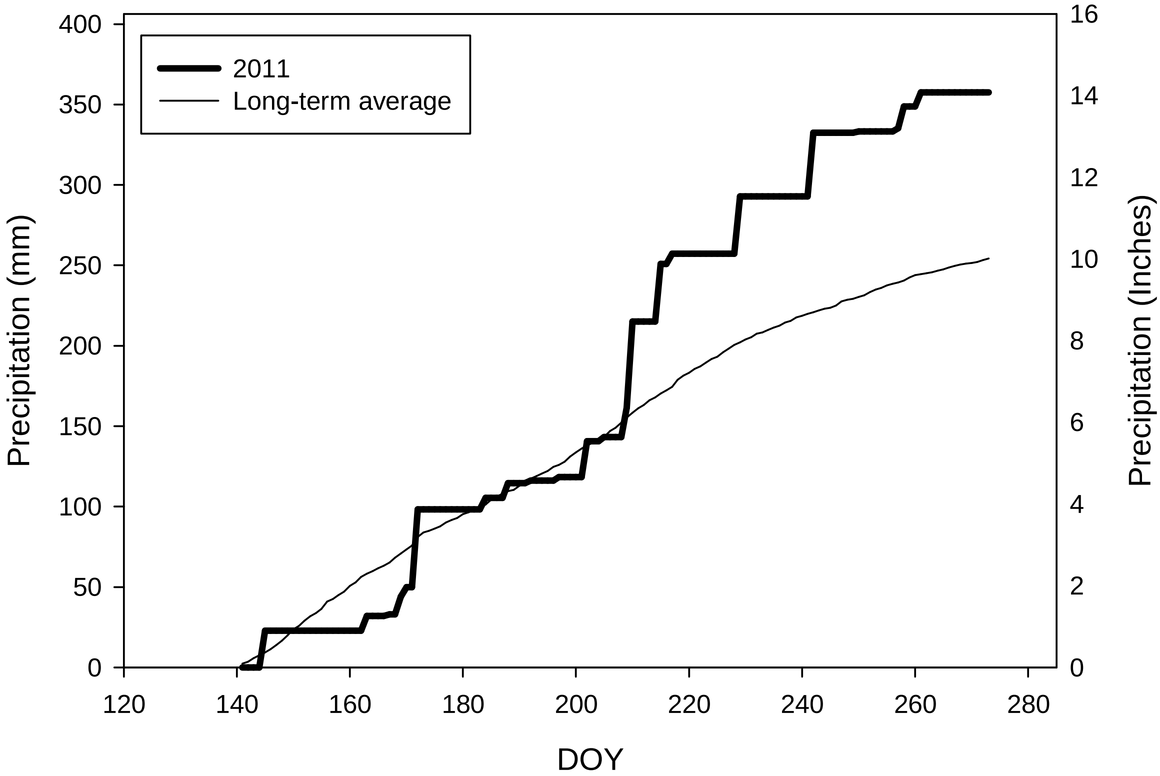

Figure 1.21 - Cumulative corn growing season precipitation, Tribune, Kansas, 2009-2011.

Biomass, stover, grain yield, and harvest index.

Across years, planting geometry (P<0.0001) and seeding rate (P=0.0545) affected above-ground biomass (Table 1.33). Corn planted in a P2S2 configuration resulted in between 8 and 12% less above-ground biomass than any other treatment. Above-ground biomass increased with increasing plant density (Table 1.33). Corn planted at the highest seeding rate produced more above-ground biomass than the other two rates.

Stover production was affected by both planting geometry ($P<0.0001$) and seeding rate ($P<0.0001$) across years (Table 1.33). Corn planted in a conventional configuration produced the highest level of stover. Clump and cluster geometries were no different and produced on average 4.72 Mg ha^{-1} (4210 lb ac^{-1}) of stover, 7% less than the conventional treatment and 6 and 13% more than the P1S1 and P2S2 treatments, respectively. Stover production increased by 650 kg ha^{-1} (570 lb ac^{-1}) or 15% as seeding rate increased (Table 1.33).

A geometry x seeding rate interaction affected grain yield ($P=0.0235$) (Table 1.33). The top LSD group of yields included all geometries other than P2S2 at the lowest seeding rate, clump and cluster geometries at the middle seeding rate, and P1S1 and cluster geometries at the high seeding rate (Figure 1.22). At the lowest seeding rate, P2S2 produced grain yields lower than the clump, conventional, or P1S2 geometries. At the intermediate seeding rate, clump planted corn was higher than corn in a P1S1 configuration. At the highest seeding rate, corn in a P1S1 configuration produced grain yields higher than corn in a P2S2, conventional, or clump configuration. Response to increasing seeding rate varied among geometries. Corn planted in a clump or P2S2 configuration exhibited a quadratic yield response with increasing seeding rate, although the clump treatment resulted in higher yields than P2S2 at the low and middle seeding rate and equivalent yields at the highest seeding rate (Figure 1.22). Corn planted in a cluster configuration did not respond to changes in plant density (Figure 1.22). Yields for the P1S1 treatment were lowest at the intermediate seeding rate, likely driven by the abnormal yields for that treatment observed in 2010. Grain yield for corn planted in a conventional configuration declined linearly as seeding rate increased (Figure 1.22).

Table 1.33 - Effect of planting geometry and seeding rate on corn biomass, grain yield, and yield components, Tribune, Kansas 2009-2011.

Geometry	Seeding rate	Above-ground biomass†	Stover	Grain yield	Harvest index	Kernels plant^{-1}	Kernel rows	Kernels ear row^{-1}	Ears plant^{-1}	Kernel weight	Yield plant^{-1}
	plants m^{2} (1000 plants ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (bu ac^{-1})						mg	g
Clump		10.3 (9210) a‡	4.69 (4190) b†	6.66 (106) a	0.54 a	627 a	17.2 a	39.6 a	1.01 ab	233 c	149 a
Cluster		10.3 (9180) a	4.75 (4230) b	6.56 (104) a	0.53 a	594 ab	17.2 a	38.6 b	1.04 a	237 bc	144 a
Conventional		10.4 (9310) a	5.09 (4540) a	6.33 (101) ab	0.50 b	589 b	17.3 a	38.7 b	1.00 b	232 c	140 ab
P1S1		10.1 (8990) a	4.44 (3960) c	6.67 (106) a	0.54 a	584 b	16.9 b	38.1 b	0.97 b	242 ab	145 a
P2S2		9.33 (8320) b	4.18 (3730) d	6.09 (97) b	0.54 a	528 c	16.9 b	35.8 c	0.99 b	246 a	132 b
	3.0 (12.3)	9.9 (8830) b§	4.34 (3880) c	6.57 (105)	0.56 a	700 a	17.4 a	42.5 a	1.03 a	258 a	182 a
	4.0 (16.2)	10.0 (8940) b	4.55 (4060) b	6.47 (103)	0.53 b	580 b	17.1 b	38.1 b	1.00 b	235 b	138 b
	5.1 (20.6)	10.4 (9240) a	4.99 (4450) a	6.34 (101)	0.50 c	473 c	16.8 c	33.8 c	0.98 b	221 c	106 c
Clump	3.0 (12.3)	10.2 (9120)	4.41 (3940)	6.87 (109) abc	0.57 a	739 a§	17.5	44.2 a	1.01	260 a	193 a
	4.0 (16.2)	10.6 (9420)	4.61 (4110)	7.04 (112) ab	0.56 ab	658 bc	17.3	40.0 cd	1.00	230 bc	152 bc
	5.1 (20.6)	10.2 (9090)	5.06 (4510)	6.06 (97) de	0.49 ef	485 fg	16.8	34.6 g	1.01	208 e	101 g
Cluster	3.0 (12.3)	9.9 (8860)	4.35 (3890)	6.60 (105) abcde	0.56 ab	690 ab	17.3	42.0 b	1.07	258 a	180 a
	4.0 (16.2)	10.2 (9060)	4.68 (4180)	6.48 (103) abcde	0.53 bcd	583 d	17.5	38.7 de	1.03	235 b	139 cd
	5.1 (20.6)	10.8 (9620)	5.20 (4640)	6.59 (105) abcde	0.51 cde	509 ef	16.9	35.0 fg	1.02	218 cde	112 fg
Conventional	3.0 (12.3)	10.7 (9560)	4.98 (4440)	6.79 (108) abcd	0.52 bcde	731 a	17.6	44.0 a	1.06	254 a	189 a
	4.0 (16.2)	10.3 (9170)	4.94 (4410)	6.31 (101) bcde	0.50 de	581 d	17.3	38.0 e	0.99	227 bcd	133 de
	5.1 (20.6)	10.3 (9210)	5.34 (4760)	5.88 (94) e	0.46 f	455 gh	17.1	34.1 g	0.94	214 de	98 g
P1S1	3.0 (12.3)	9.8 (8770)	4.16 (3710)	6.71 (107) abcd	0.57 a	701 ab	17.3	42.4 b	1.01	263 a	186 a
	4.0 (16.2)	9.6 (8580)	4.37 (3900)	6.21 (99) cde	0.52 cde	548 de	16.8	37.6 e	0.95	234 b	131 de
	5.1 (20.6)	10.8 (9630)	4.79 (4270)	7.10 (113) a	0.54 abc	502 efg	16.6	34.5 g	0.96	231 bc	118 ef
P2S2	3.0 (12.3)	8.8 (7860)	3.82 (3410)	5.90 (94) e	0.56 ab	639 c	17.2	40.1 c	1.01	252 a	164 b
	4.0 (16.2)	9.5 (8440)	4.14 (3690)	6.30 (100) bcde	0.56 ab	528 ef	16.8	36.2 f	1.01	251 a	133 de
	5.1 (20.6)	9.7 (8670)	4.58 (4080)	6.07 (97) de	0.50 de	416 h	16.7	31.0 h	0.95	235 b	101 g
LSD = 0.05											
Geometry		0.5 (440)	0.19 (170)	0.43 (7)	0.02	34	0.2	0.8	0.04	8	9
Population		0.4 (340)	0.15 (130)	0.33 (5)	0.02	27	0.2	0.6	0.03	6	7
Geometry x Seeding Rate		0.9 (770)	0.33 (290)	0.75 (12)	0.04	59	0.4	1.3	0.06	13	15
				ANOVA P>F							
Effect											
Geometry		<0.0001	<0.0001	0.0383	<0.0001	<0.0001	<0.0001	<0.0001	0.0054	0.0008	0.0058
Seeding Rate		0.0545	<0.0001	0.3997	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001
Geometry x Seeding Rate		0.1182	0.7174	0.0235	0.0414	0.0791	0.5066	0.0053	0.3233	0.0087	0.0082

† Table values are least square means and may differ from across-years arithmetic means.
‡ Letters within a column and an effect represent differences at LSD (0.05) unless noted otherwise
§ Letters within a column and an effect represent differences at LSD (0.10)

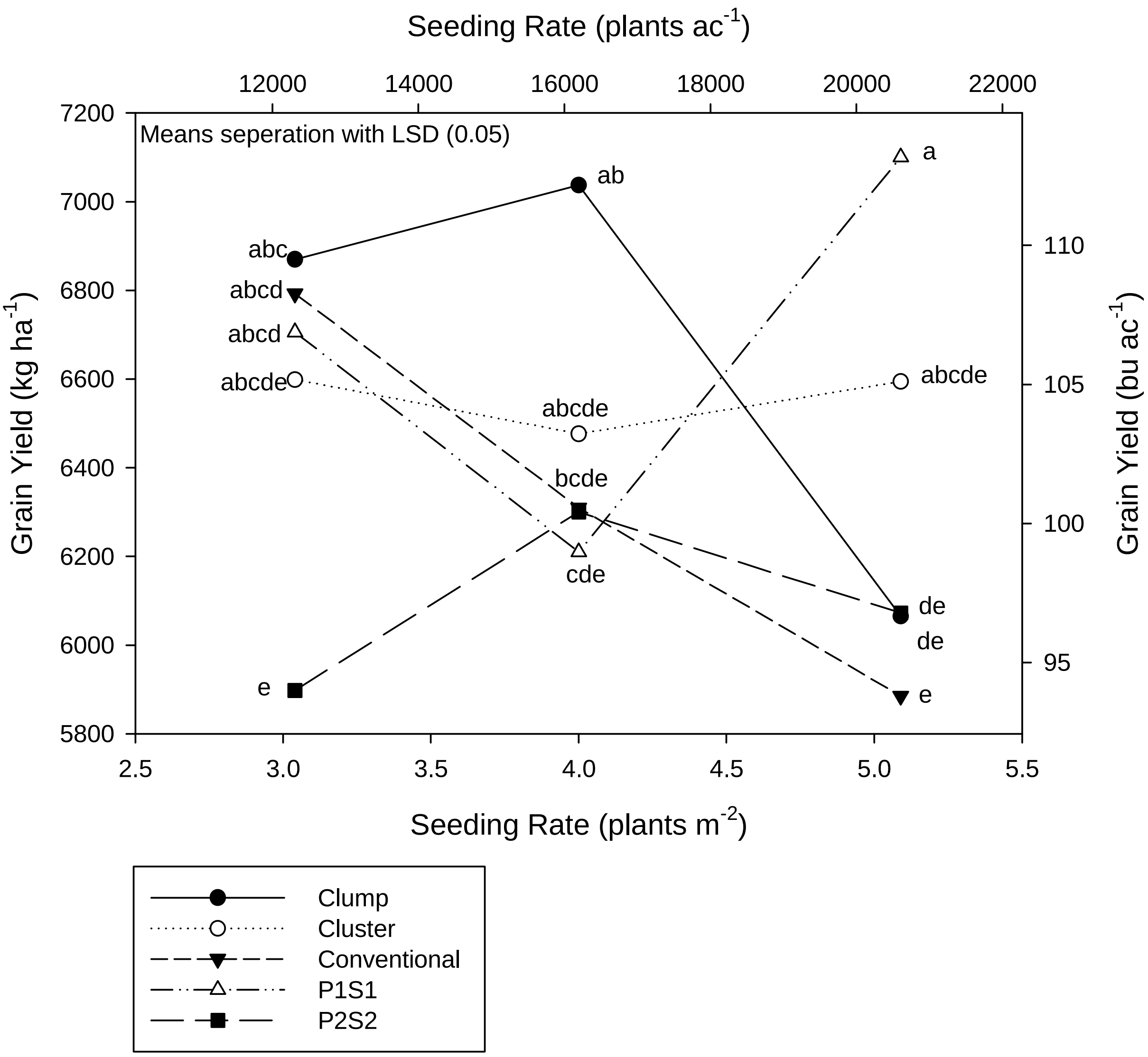

Figure 1.22 - Effect of planting geometry and seeding rate on corn grain yield, Tribune, Kansas, 2009-2011

Harvest index was affected by a geometry x seeding rate interaction (0.0414) (Table 1.33). In general, harvest index declined for all geometries as seeding rates increased from the low to high seeding rate (Figure 1.23). The highest class of HI values was observed for all geometries except P2S2 at the lowest seeding rate, the clump and P2S2 geometries at the intermediate seeding rate, and the P1S1 geometry at the high seeding rate. Corn planted in the conventional configuration resulted in the lowest HI at each level of seeding rate (Figure 1.23). Corn planted in the cluster and P1S1 configurations had the smallest change in HI with respect to seeding rate. As seeding rate increased from the low to the intermediate level, P1S1, conventional, and cluster all exhibited declines in HI while clump P2S2 treatments remained relatively unaffected (Figure 1.23). As seeding rates increased form the intermediate to the high level HI values decreased for all geometries other than P1S1 (Figure 1.23). The P1S1 harvest index response to seeding rate is partially characterized by a relatively low value at the intermediate seeding rate, likely an artifact of 2010 data.

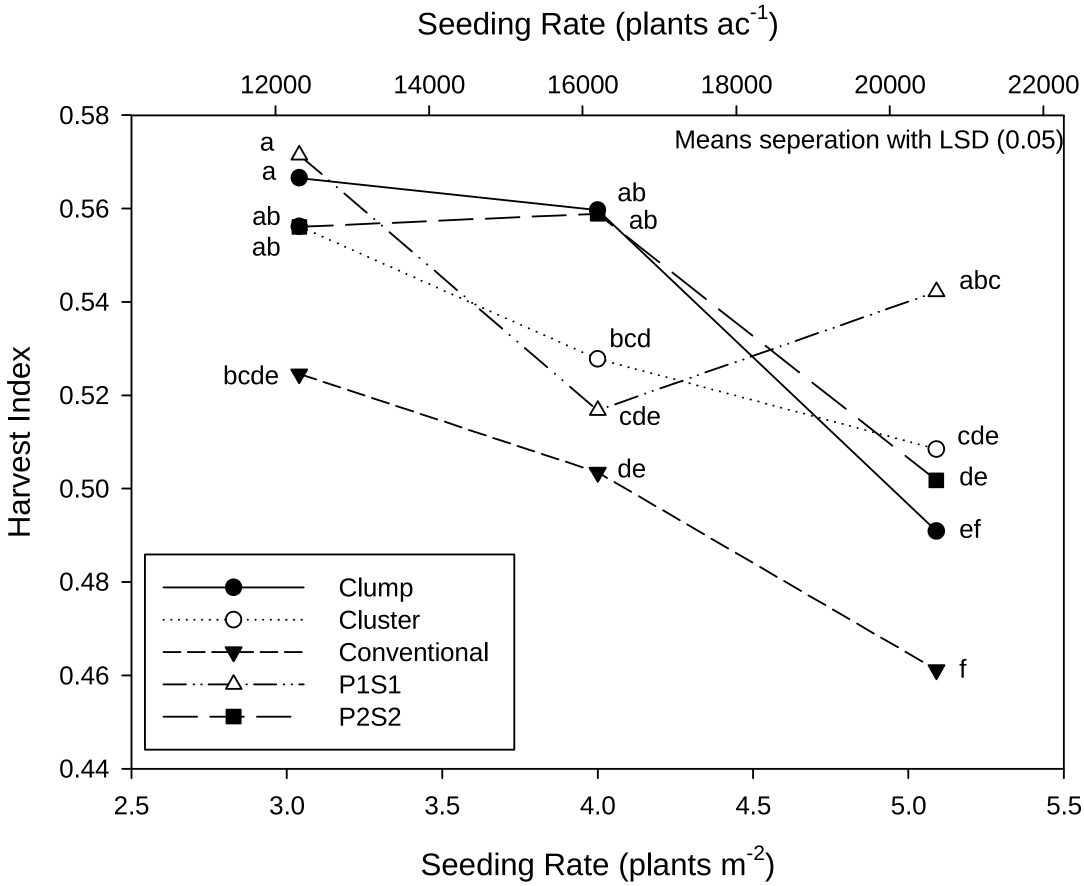

Figure 1.23 - Effect of planting geometry and seeding rate on corn harvest index, Tribune, Kansas, 2009-2011.

Yield components

Kernels plant^{-1} was affected by a geometry x seeding rate interaction (P=0.0791) (Table 1.33). In general, KP declined for all geometries as seeding rates increased (Figure 1.24).

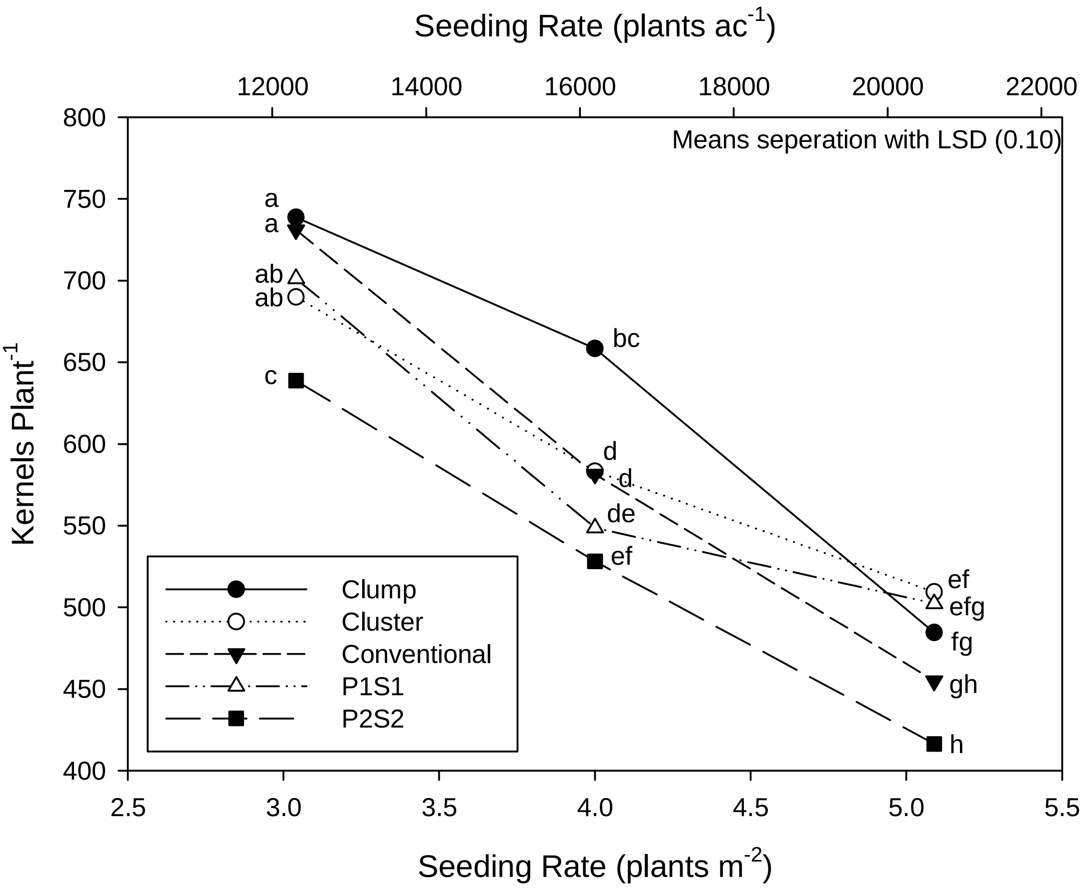

Figure 1.24 - Effect of planting geometry and seeding rate on corn kernels plant-1, Tribune, Kansas 2009-2011.

The highest values for KP were produced by all geometries other than P2S2 at the lowest seeding rate. Corn planted in a P2S2 configuration resulted in lower KP than all other geometries at the lowest seeding rate. At the intermediate seeding rate, corn planted in the clump configuration resulted in the highest KP (Figure 1.24). At the highest seeding rate, the lowest KP values were produced by corn planted in the conventional and P2S2 configurations. Corn planted in either a cluster or P1S1 configuration resulted in the highest KP at the highest seeding rate, while clump and conventional were not distinguishable from either the upper or lower group (Figure 1.24). If the main effect for seeding rate is examined it becomes apparent that KP on average declines with increasing seeding rate. The main effect for geometry ($P<0.0001$) shows KP when averaged across seeding rates is highest for the clump configuration (Table 1.33). P2S2 results in the lowest KP with conventional and P1S1 producing higher values. Corn in the cluster configuration numerically produced lower KP than clump and higher than conventional or P1S1 but is statistically indistinguishable from either.

Kernel rows were affected by both geometry ($P<0.0001$) and seeding rate ($P<0.0001$) main effects across years (Table 1.33). Kernel rows for the clump, cluster, and conventional geometries averaged 17.3, higher than either of the skip-row treatments, which averaged 16.9. Kernel rows declined 0.6 as seeding rate increased from low to high rates.

A geometry x seeding interaction was present in analysis of KER ($P=0.0053$) (Table 1.33). Kernels ear row^{-1} declined with increasing seeding rate for all planting geometries (Figure 1.25). Corn planted in a clump or conventional configuration resulted in the highest value for KER at the low seeding rate followed by the P1S1 and cluster configurations. At the middle seeding rate, clump and cluster planted corn produced the highest KER followed by the conventional and P1S1 treatments, which were not different than the cluster treatment. At the highest seeding rate, all geometries except P2S2 produced a similar KER. Corn planted in a P2S2 configuration resulted in the lowest KER at every level of seeding rate (Figure 1.25). The largest reduction in KER with increasing plant density was observed in the conventional geometry, a reduction of 9.9 kernels. The smallest reduction, 7 kernels, was observed in the cluster treatment. When each level of treatment is evaluated as main effects, underlying themes seen in the interaction persist with clump producing the highest and P2S2 the lowest KER values when averaged across seeding rates and a reduction in KER with increasing seeding rate when averaged across geometries (Table 1.33).

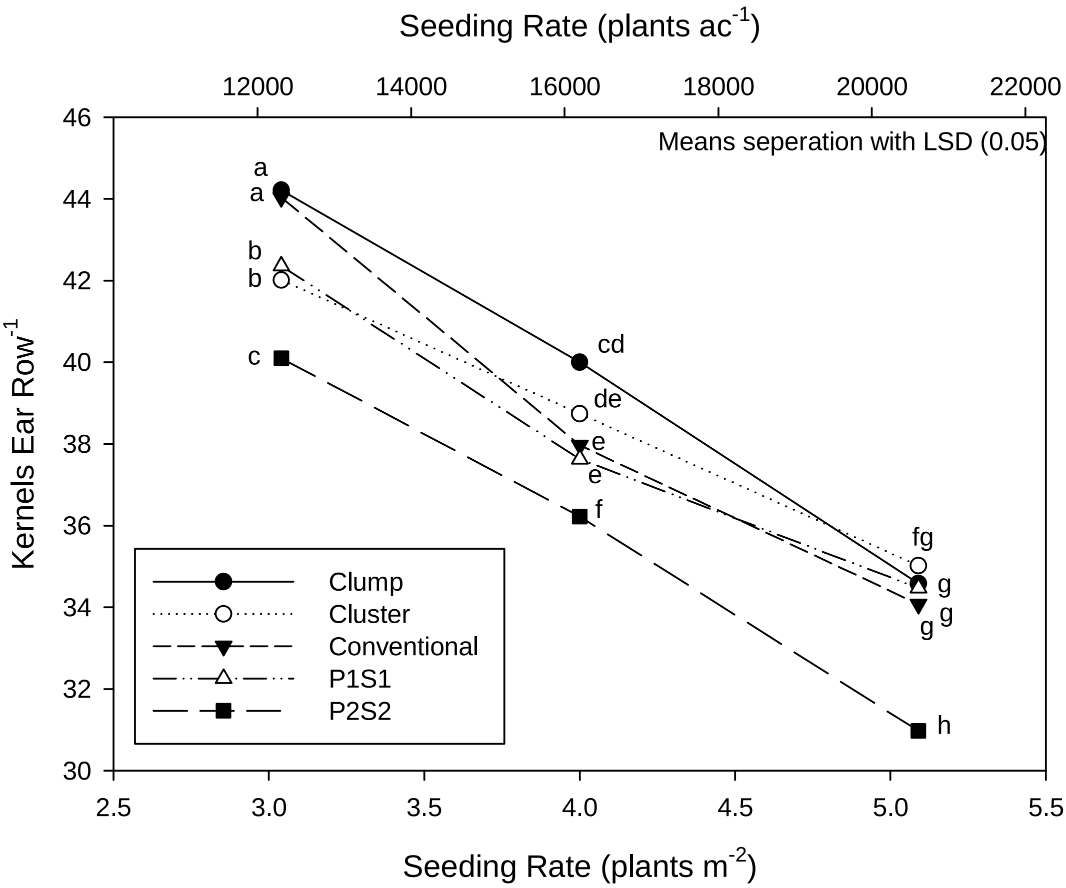

Figure 1.25 - Effect of planting geometry and seeding rate on corn kernels ear row^{-1}, Tribune, Kansas, 2009-2011.

Ears plant^{-1} was affected by both planting geometry (P=0.0054) and seeding rate (P=0.0004) treatments (Table 1.33). Corn planted in a cluster configuration resulted in higher ears plant^{-1} than corn in a conventional, P1S1, or P2S2 configuration. Corn planted in a clump configuration had ears plant^{-1} numerically less than cluster and higher than the other geometries, but could not be distinguished statistically from either. As seeding rate increased from low to high rates, ears plant^{-1} averaged across geometries decreased from 1.03 to 0.98, a 5% reduction.

A planting geometry x seeding rate interaction was evident in the analysis for kernel weight (P=0.0087) (Table 1.33). No differences among planting geometries were evident at the lowest seeding rate (Figure 1.26). In general, kernel weight declined as seeding rate increased. As seeding rate increased from low to intermediate, kernel weight declined for all planting geometries except P2S2 which had no response. At the intermediate seeding rate, P2S2 produced higher kernel weight than all other treatments (Figure 1.26). As seeding rate increased to the high rate, kernel weight declined for all planting geometries and resulted in P2S2 and P1S1 having the largest kernel weight and clump the smallest. Corn planted in the clump configuration had the most responsive kernel weight to changes in plant density, declining 52 mg over the range of plant densities. Corn planted in a P2S2 configuration had the smallest response, a decline of 17 mg (Figure 1.26).

Yield plant^{-1} was affected by a geometry x seeding rate interaction (P=0.0082) (Table 1.33). At the lowest seeding rate, corn in a P2S2 configuration had lower yield plant^{-1} than all other treatments. In general as seeding rates increased yield plant^{-1} decreased (Figure 1.27). At the intermediate seeding rate, corn in a clump configuration produced the highest yield plant^{-1} and the conventional, P1S1, and P2S2 geometries produced the lowest. The yield plant^{-1} of clump planted corn at the intermediate seeding rate was equal to yield plant^{-1} of corn in the P2S2 configuration at the lowest seeding rate (Figure 1.27). Yield plant^{-1} for the cluster treatment at the intermediate seeding rate was indistinguishable from any other treatment statistically. At the high plant density, corn planted in a P1S1 configuration resulted in the highest kernel weight values with clump, conventional, and P2S2 producing the lowest. Corn in a cluster configuration produced lower kernel weights than P1S1 but higher than the other treatments numerically at the high seeding rate (Figure 1.27).

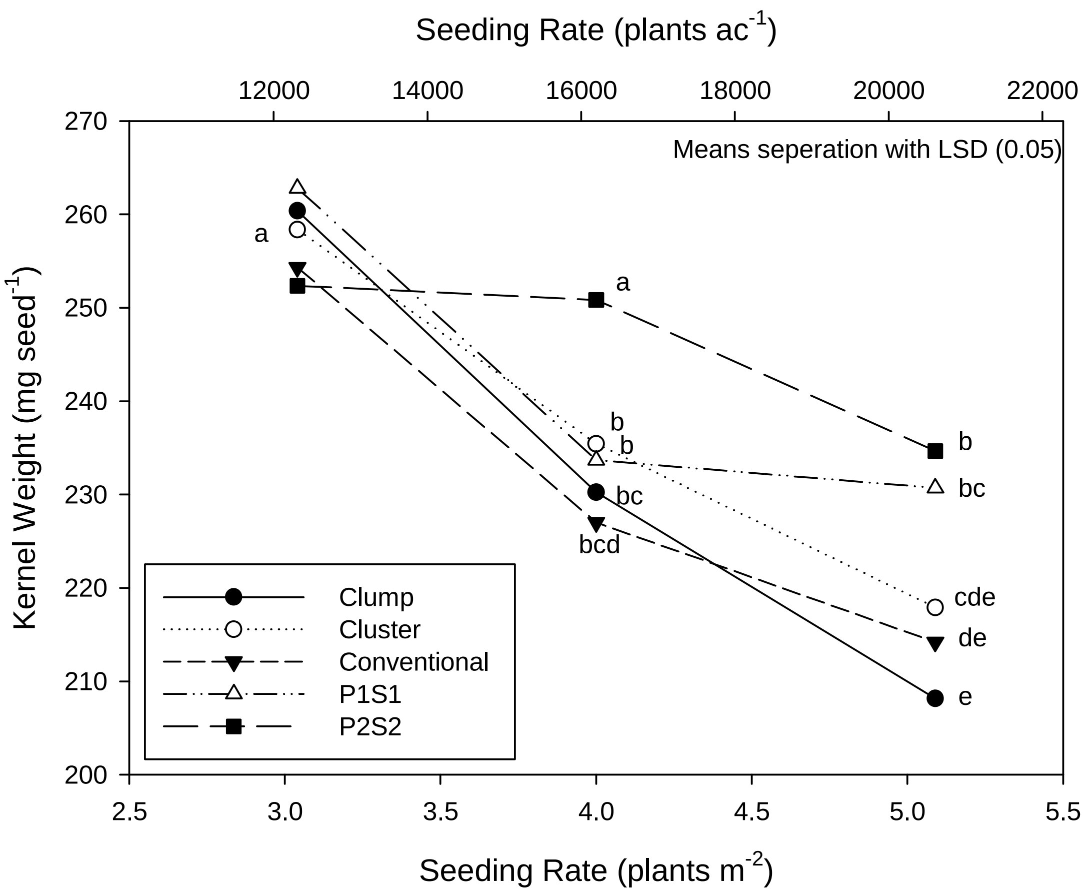

Figure 1.26 - Effect of planting geometry and seeding rate on corn kernel weight, Tribune, Kansas, 2009-2011.

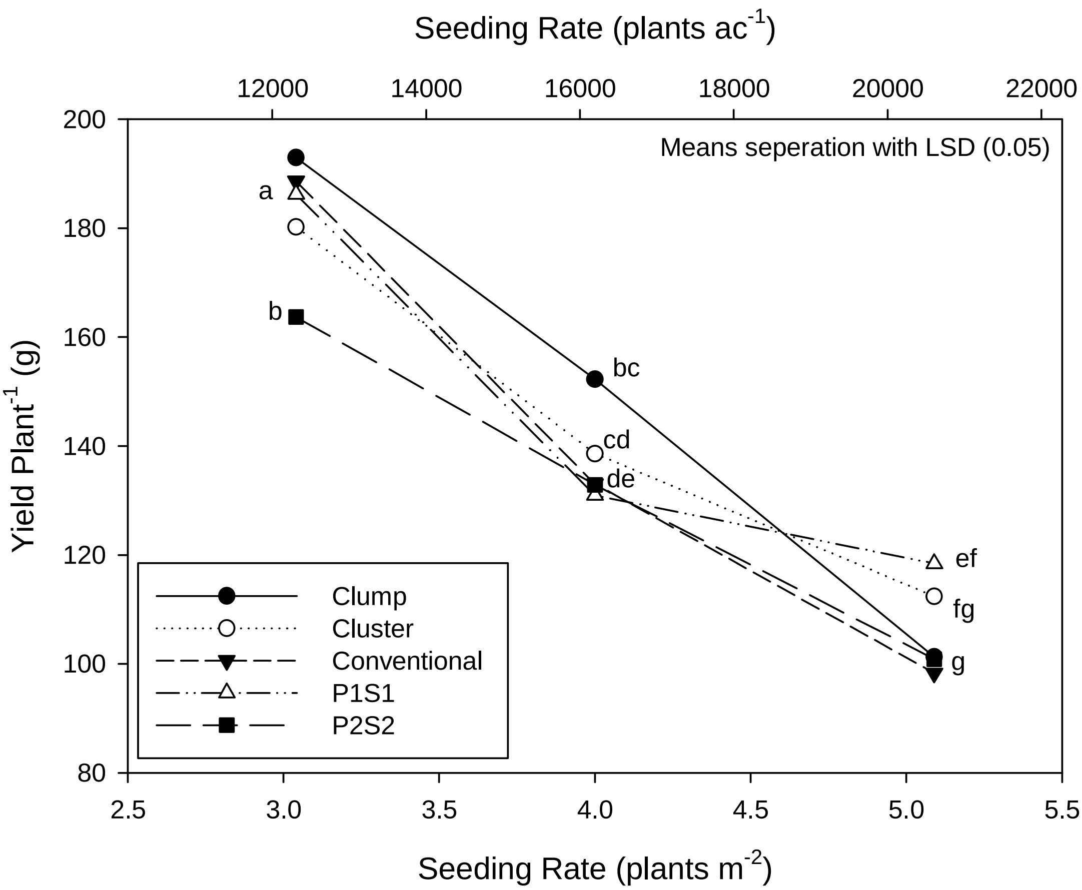

Figure 1.27 - Effect of planting geometry and seeding rate on corn grain yield plant^{-1}, Tribune, Kansas, 2009-2011.

Light interception and grain nutrient content

Across two years of measurement, 2010 and 2011, corn planting geometry affected IPAR ($P<0.0001$) (Table 1.34). Corn planted in a conventional or clump configuration resulted in the highest values for IPAR. Corn planted in a cluster configuration had higher values for IPAR than either of the skip-row treatments and was not different than corn planted in a clump configuration. Corn planted in either a P1S1 or P2S2 configuration produced the lowest values for IPAR, an average of 0.518, a reduction of 26% from the average IPAR of the conventional and clump geometries of 0.696.

Table 1.34 - Effect of corn planting geometry on intercepted photosynthetically active radiation (IPAR), Tribune, Kansas 2010-2011.

Geometry	Fraction of PAR intercepted (θ)	
Clump	0.678	ab†‡
Cluster	0.651	b
Conventional	0.715	a
P1S1	0.538	c
P2S2	0.498	c
LSD = 0.05		
Geometry	0.052	
ANOVA P>F		
Effect		
Geometry	<0.0001	

† Table values are least square means and may differ from across-years arithmetic means.
‡ Letters within a column represent differences at LSD (0.05)

Grain N content across years of measurement, 2010-2011, was affected by planting geometry (P=0.0119) (Table 1.35). The highest grain N contents came from corn planted in a conventional configuration. Corn planted in a cluster, P1S1 or P2S2 configuration resulted in lower grain N contents, averaging 12.7 g kg^{-1} (1.27%) Corn planted in a clump configuration resulted in grain N contents less than that of conventional but higher than any other treatment. N removal was affected by a geometry x seeding rate interaction (P=0.0239) (Table 1.35). While grain N content across years was affected by geometry, the larger driving factor in N removal was grain yields.

Table 1.35 - Effect of planting geometry and seeding rate on corn grain N and P content and removal, Tribune, Kansas, 2010-2011.

Geometry	Seeding rate	Grain N content†		N removal			Grain P content	P removal		
	plants m^2 (1000 plants ac^{-1})	$g\ kg^{-1}$		$kg\ ha^{-1}$ ($lb\ ac^{-1}$)			$g\ kg^{-1}$	$kg\ ha^{-1}$ ($lb\ ac^{-1}$)		
Clump		13.2	ab‡	71	64	a	3.1	17	15	a§
Cluster		12.7	b	68	60	ab	3.1	17	15	a
Conventional		13.6	a	66	59	b	3.1	15	14	ab
P1S1		12.8	b	66	59	ab	3.1	16	14	a
P2S2		12.7	b	61	54	c	3.1	15	13	b
	3.0 (12.3)	12.9		68	60		3.1	16	15	
	4.0 (16.2)	13.0		66	59		3.1	16	14	
	5.1 (20.6)	13.2		65	58		3.1	16	14	
Clump	3.0 (12.3)	13.1		74	66	a	3.1	18	16	a§
	4.0 (16.2)	12.9		73	65	ab	3.1	17	15	ab
	5.1 (20.6)	13.7		67	60	abcde	3.1	15	13	bcdef
Cluster	3.0 (12.3)	12.5		65	58	bcdef	3.0	16	14	abcde
	4.0 (16.2)	12.9		68	61	abcde	3.1	16	15	abcd
	5.1 (20.6)	12.7		69	62	abcd	3.2	17	16	a
Conventional	3.0 (12.3)	13.8		74	66	ab	3.1	17	15	ab
	4.0 (16.2)	13.5		64	57	cdef	3.2	15	14	bcdef
	5.1 (20.6)	13.6		60	54	def	3.0	14	12	ef
P1S1	3.0 (12.3)	12.4		68	61	abcde	3.1	17	15	abc
	4.0 (16.2)	13.2		61	55	cdef	3.1	15	13	cdef
	5.1 (20.6)	12.9		70	62	abc	3.1	17	15	abcd
P2S2	3.0 (12.3)	12.5		57	51	f	3.0	13	12	f
	4.0 (16.2)	12.4		65	58	bcdef	3.0	16	14	abcde
	5.1 (20.6)	13.2		60	53	ef	3.2	15	13	def
LSD = 0.05										
Geometry		0.6		5	5		0.1	2	1	
Population		0.5		4	4		0.1	1	1	
Geometry x Seeding Rate		1.1		9	8		0.2	3	2	
		ANOVA P>F								
Effect										
Geometry		0.0119		0.0035			0.9201	0.0522		
Seeding Rate		0.3584		0.4619			0.8688	0.4493		
Geometry x Seeding Rate		0.6933		0.0239			0.5844	0.0604		

† Table values are least square means and may differ from across-years arithmetic means.
‡ Letters within the column and effect represent differences at LSD (0.10)
§ Letters within the column represent differences at LSD (0.10)

Soil water, water use, and water use efficiency

Profile water totals across measurement positions

Measurements of available soil water were grouped by crop developmental stage for across-years analysis across tube position and geometry (Table 1.36). Differences among sampling position were evident at each time of measurement. Group 1 represented early vegetative growth stages with measurements taken around an average of 1008 GDD after planting. At the early vegetative stage across-years, the lowest levels of available soil water, indicating the highest amounts of soil water extraction, were found in-row in the conventional treatment, and in-row and in between rows of the P2S2 treatment. The highest level of available water was found in the middle of the skip of the P2S2 treatment, which was not different than the 95 cm (37.5 inch) position in the P2S2 treatment or the 38 or 76 cm (15 or 30 inch) positions in the P1S1 or cluster treatments. Group 2 included measurements taken at the R1 (tassel-silk) growth stage, with measurements taken at an average of 1603 GDD after planting. The highest level of soil water was observed in the middle of the P2S2 skip followed by the 95 cm (37.5 inch) position in the P2S2 the 38 and 76 cm (15 and 30 inch) position in the P1S1 and the 76 cm (30 inch) position in the cluster. The lowest levels were observed in-row in the conventional treatment (Table 1.36). Group 3 included measurements taken at harvest, after physiological maturity had occurred. The highest levels of soil water were again observed in the middle of the P2S2 skip followed by the 95 cm (37.5 inch) position in P2S2, all positions in the clump treatment, and the 76 cm (30 inch) position in the P2S1 geometry. The lowest water contents were similar among all other positions and treatments.

Table 1.36 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in corn planting geometries. Tribune, Kansas, 2009-2011.

Geometry	Tube position	Early vegetative 1008 GDD			Tassel / silk 1603 GDD			Harvest		
	cm (inches)	Available soil water, mm (inches)								
Clump	0	141	(5.57)	cde	89	(3.52)	cde	70	(2.75)	bc
	38 (15)	142	(5.61)	cde	90	(3.55)	cde	72	(2.83)	bc
	76 (30)	142	(5.61)	cde	92	(3.63)	cde	72	(2.83)	bc
Cluster	0	145	(5.70)	bcd	89	(3.49)	cde	65	(2.56)	bcd
	38 (15)	150	(5.90)	abc	95	(3.75)	cd	67	(2.62)	bcd
	76 (30)	153	(6.02)	abc	100	(3.92)	bc	68	(2.70)	bcd
Conventional	0	124	(4.89)	f	75	(2.94)	f	55	(2.16)	d
	38 (15)	132	(5.19)	def	80	(3.16)	ef	60	(2.36)	cd
P1S1	0	144	(5.68)	bcd	95	(3.74)	cd	67	(2.64)	bcd
	38 (15)	150	(5.92)	abc	101	(3.97)	bc	68	(2.69)	bcd
	76 (30)	157	(6.18)	ab	110	(4.33)	b	70	(2.75)	bc
P2S2	0	127	(5.00)	f	81	(3.18)	ef	58	(2.30)	cd
	38 (15)	129	(5.06)	ef	84	(3.32)	def	61	(2.40)	cd
	95 (37.5)	151	(5.96)	abc	108	(4.27)	b	76	(2.98)	b
	152 (60)	160	(6.31)	a	147	(5.77)	a	94	(3.70)	a
LSD = 0.10										
	Tube Position	14	(0.56)		13	(0.51)		14	(0.54)	
		ANOVA P>F								
Effect										
	Tube Position	0.0001			<0.0001			0.0050		

† Letters within a column and an effect represent differences at LSD (0.10) unless noted otherwise

Cross-section analysis of soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. Soil water measurements were taken as close to planting as possible in all years, however in 2011 collection took place much later. An across years analysis of 2009 and 2010 data at postemergence (average of 693 GDD after planting) revealed no discernible differences among treatments (Table 1.37). At this sampling, soil water in the conventional geometry was the lowest numerically, a trend that would be persistent throughout the season.

Data from all three years were used in describing soil water at the early vegetative growth stages (average of 1008 GDD after planting). Profile water content was numerically lowest for the conventional treatment but not discernible from other treatments (P=0.1163) (Table 1.37). The largest range in soil water contents within the profile was attributed to the P2S2 geometry and the smallest range to the conventional geometry. Cumulative water use differed among planting geometries with the highest amounts of water use attributable to the conventional and clump geometries, which were similar to the P2S1 geometry. Corn in cluster and P2S2 geometries had the lowest water use and were similar to the P1S1 geometry.

Soil water measurements taken at the tassel-silk growth stage, which on average occurred 1603 GDD after planting, showed that geometry affected profile water content (P=0.0115) (Table 1.37). The lowest level of soil water was observed in the conventional geometry, which was similar to clump. The profile underlying the P2S2 configuration had the highest level of soil water and was similar to the P1S1 and cluster configurations. The profile under the P2S2 treatment had the largest range and SD for soil moisture contents while conventional resulted in the smallest. These correspond with the degree of spatial uniformity of soil water content and extraction. Other treatments produced intermediate values. Cumulative water use at tassel-silk was highest for the clump treatment, which was similar to the cluster and conventional treatments. The lowest cumulative water use was in the P2S2 geometry with P1S1 resulting in an intermediate value similar to cluster and conventional. Water use for the interval of early vegetative to tassel-silk was not different among geometries (P=0.1524). Numerically the largest spread was between the P2S2 treatment and all others, which would coincide with observations in profile water.

No differences among geometries were evident at harvest with respect to profile water content (Table 1.37), although numerically the largest spread was between conventional and all other treatments, consistent with observations of water use and water content earlier in the season. Cumulative water use (measured from early vegetative) was similar among all treatments. Interval water use varied among treatments ($P<0.0001$) with the highest use in the P2S2 geometry followed by cluster with P1S1 similar to both. The lowest water use values from tassel-silk to harvest were observed in the clump and conventional geometries.

Table 1.37 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated soil water values, and water use as affected by corn planting geometry. Tribune, Kansas 2009-2011.

Geometry	Postemergence (693 GDD)‡			Early vegetative (1008 GDD)			
	Profile available water	Range	SD	Profile available water	Range	SD	Cumulative water use
	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)
Clump	188 (7.39)	0.107	0.033	144 (5.68)	0.093 bc	0.026	48 (1.89) a
Cluster	183 (7.21)	0.111	0.032	152 (5.98)	0.101 b	0.024	38 (1.51) b
Conventional	168 (6.62)	0.118	0.038	132 (5.18)	0.091 c	0.026	46 (1.82) a
P1S1	180 (7.08)	0.108	0.035	153 (6.02)	0.097 bc	0.025	42 (1.65) ab
P2S2	174 (6.85)	0.123	0.034	146 (5.75)	0.123 a	0.028	38 (1.49) b
LSD = 0.10							
Geometry	21 (0.84)	0.023	0.008	14 (0.57)	0.009	0.003	7 (0.29)
				ANOVA P>F			
Effect							
Geometry	0.5708	0.7395	0.7682	0.1163	<0.0001	0.2655	0.1036

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

‡ Includes data from 2009 and 2010

Geometry	Tassel / silk (1603 GDD)					Harvest				
	Profile available water	Range	SD	Cumulative water use	Interval water use	Profile available water	Range	SD	Cumulative water use	Interval water use
	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)
Clump	91 (3.58) bc	0.068 b	0.018 b	144 (5.65) a	82 (3.23)	72 (2.82)	0.082 b	0.020	324 (12.8)	120 (4.71) c
Cluster	95 (3.74) ab	0.072 b	0.016 bc	141 (5.53) ab	82 (3.22)	67 (2.62)	0.080 b	0.020	331 (13.0)	127 (4.98) b
Conventional	78 (3.09) c	0.060 c	0.016 c	142 (5.59) ab	82 (3.24)	58 (2.28)	0.080 b	0.020	324 (12.8)	117 (4.60) c
P1S1	102 (4.00) ab	0.072 b	0.017 bc	137 (5.41) b	80 (3.17)	68 (2.68)	0.084 b	0.021	333 (13.1)	130 (5.13) ab
P2S2	105 (4.12) a	0.113 a	0.023 a	125 (4.91) c	76 (3.00)	72 (2.84)	0.098 a	0.022	319 (12.6)	136 (5.34) a
LSD = 0.10										
Geometry	13 (0.50)	0.007	0.002	6 (0.24)	5 (0.18)	15 (0.57)	0.011	0.002	11 (0.4)	6 (0.25)
					ANOVA P>F					
Effect										
Geometry	0.0115	<0.0001	<0.0001	<0.0001	0.1524	0.4793	0.0357	0.5596	0.2667	<0.0001

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Water use / Water use efficiency

In the across-years analysis, water use differences among treatments were not observed (Table 1.38). No differences were observed among treatments with regard to grain water use efficiency however, the clump treatment was the most separated from the other treatments numerically. Biomass water use efficiency was affected by planting geometry with the clump and conventional configurations producing the highest values, which were similar to those of the cluster configuration. Corn in the skip-row configurations resulted in the lowest levels for biomass water use efficiency.

Table 1.38 - Corn water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb) as affected by planting geometry. Tribune, Kansas, 2009-2011.

Geometry	Water Use†		WUEg		WUEb		
	mm (in)		$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)		$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)		
Clump	324	(12.8)	18.4	(417)	32.7	(741)	a‡
Cluster	331	(13.0)	16.7	(377)	30.9	(699)	ab
Conventional	324	(12.8)	17.0	(384)	32.4	(735)	a
P1S1	333	(13.1)	16.0	(362)	29.2	(661)	b
P2S2	319	(12.6)	16.8	(380)	29.8	(674)	b
LSD = 0.05							
Geometry	11	(0.4)	1.7	(38)	2.4	(54)	
			ANOVA P>F				
Effect							
Geometry	0.2667		0.1910		0.0576		

† Table values are least square means and may differ from across-years arithmetic means.

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Discussion

Inter-plant competition

Within-row plant to plant spacing is consistent among the conventional, P1S1, and P2S2 configurations, as well as two-thirds of the plants in the cluster configuration, however, the across-row spacing varies considerably. Corn plants in a P1S1 or cluster configuration are 152 cm (60 inches) to the next across-row plant, while plants in the P2S2 configuration are 76 cm (30 inches) in one direction and 229 cm (90 inches) in another, resulting in the same average across-row distance. However, plant competition effects are typically described as exponential in nature (Wiley and Heath, 1970), thus, these spatial arrangements likely have different effects.

Differences in rate of decline for all yield components with increasing seeding rate indicates that as seeding rate increases, the inter-plant competition effects on each plant vary greatly. Each corn plant in a conventional planting geometry experiences an equal increase in inter-plant competition as plant density increases. This is in contrast to the cluster geometry where the plant at each end of the cluster experiences a change in inter-plant competition but the four plants within the center of the cluster experience relatively little change. A similar case exists for corn in a clump configuration. The two outside plants in the clump experience the largest changes in inter-plant competition as seeding rates change. In the clump configuration, compared to the cluster configuration, there are fewer plants, one compared to four, which can buffer the effect of increased inter-plant competition. The skip-row configurations result in little change in inter-plant competition as seeding rates increase. These relationships are somewhat characterized by the rectangularity of the various planting geometries with increasing seeding rate (Figure 1.28). Using this measure, a value of 1 would represent a perfect equidistant pattern. As the index increases it indicates a more uneven pattern with regard to inter-row and intra-row plant spacing, and presumably plant competition. The rectangularity values for the clump and cluster configurations are the average of the values for individual plants within a clump or cluster. The ClumpDiag values use the diagonal distance to the next closest clump in the adjoining row rather than the distance straight across 152 cm (60 inches) to the next clump. Corn in a clump geometry typically produced individual yield components at the upper end of observations, but also produced some of the steepest declines as plant density increased. This is possibly due to the comparatively more rapid increase in rectangularity as seeding rate increases.

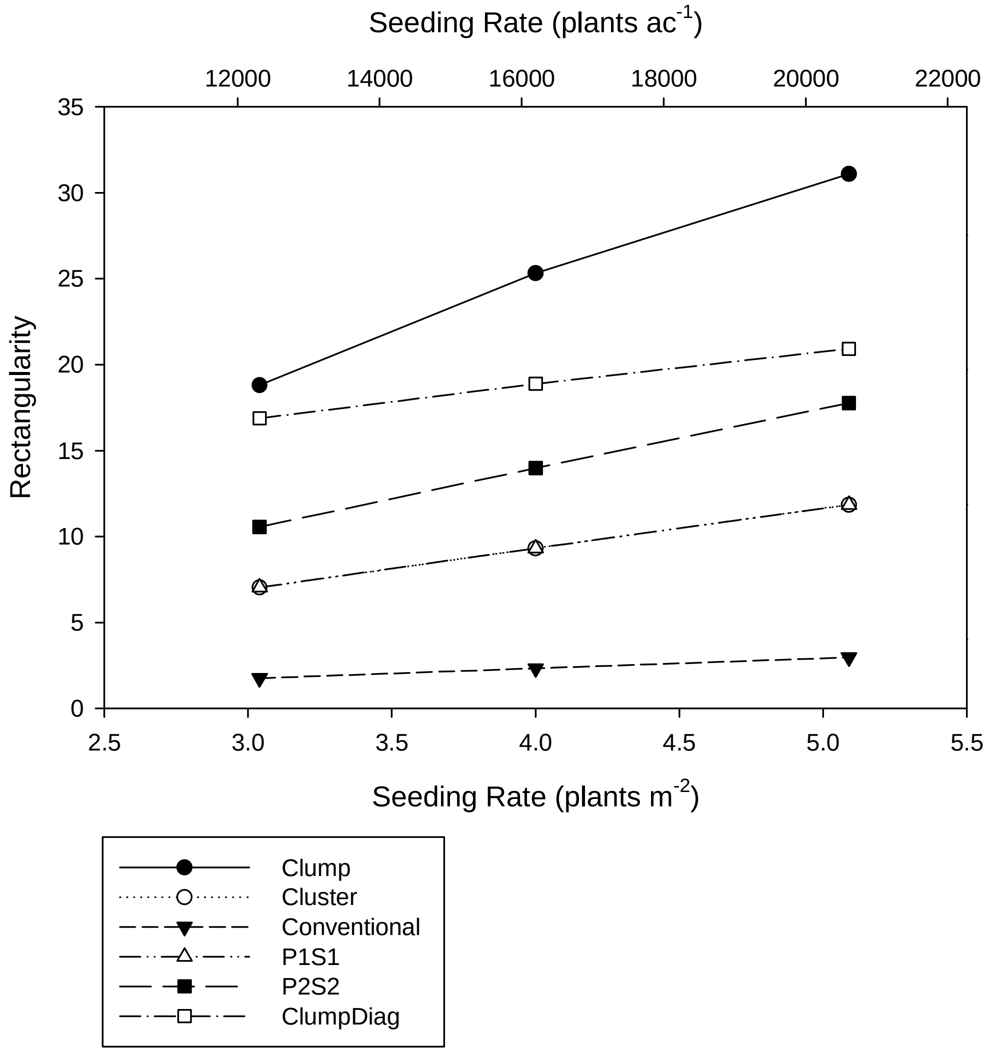

Figure 1.28 - Rectangularity of planting geometries and plant densities used. Tribune, Kansas, 2009-2011.

Light interception

Planting geometry affected light interception at tassel-silk. Corn in a P2S2 geometry intercepted the least amount of light in both years. Light interception in 2010 and in the across-years analysis for corn in a P1S1 configuration was comparable to P2S2. Maximum light interception occurred in the conventional and clump geometries in both years, and the cluster geometry in 2010. The spatial arrangement of plants plays a larger role in light interception at low plant densities, such as those used in High Plains dryland production. Maddonni et al. (2001)

reported that the effect of row spacing on light interception was much greater at plant densities of 3 to 4.5 plants m^{-2} (12 to 18,000 plants ac^{-1}) than at densities of 9 to 12 plants m^{-2} (36 to 49,000 plants ac^{-1}). While skip-row configurations allow more light to reach deeper into the canopy longer into the season (Ottman and Welch, 1989) much like wider row spacing, leaves lower in the canopy have lower photosynthetic capacity, and at the time of critical growth rates for kernel set provide little assimilate (Dwyer and Stewart, 1986). In the case of the skip-row geometries, less light is intercepted on a land-area basis not only due to the presence of skips but also the high level of mutual shading among leaves due to reduced plant spacing within the planted row. The mutual shading among plants within the planted rows of P2S2 further reduces light interception as compared to a P1S1 configuration. The lowest level of light interception in the P2S2 configuration, together with reduced soil volume exploration and root water uptake, resulted in a reduction in biomass production. Crop growth rate, which is largely dependent on light interception, is critical for kernel set around tassel-silk (R1). Data collected in this study would suggest that reduced light interception in the skip-row treatments contributed to reduced kernel set.

Above-ground biomass

Above-ground biomass was affected by geometry in every year of the study. Total above-ground biomass was similar amongst clump, cluster, and conventional planting geometries which differed by 560 kg ha^{-1} (500 lb ac^{-1}) in 2010 and only 153 and 215 kg ha^{-1} (137 and 192 lb ac^{-1}) in 2011 and 2009, respectively. The similarity in total biomass production among these treatments is despite differences that existed in early-season light interception and plant growth due to spatial arrangement under non-limiting water and light conditions. The lower harvest index and high level of stover in the conventional geometry, as compared to the alternative geometries, is likely the result of higher crop growth rate in the conventional geometry during early vegetative stages followed by equal growth rates amongst the geometries during kernel set and grain fill. This is supported by known effects of inter-plant competition on early growth. Corn in a conventional geometry is more equidistant than the alternative geometries when evaluated in terms of its rectangularity (Wiley and Heath, 1970) (Figure 1.28). This arrangement minimizes inter-plant competition and promotes growth when resources are non-limiting. While holding plant density constant, Bullock et al. (1988) reported that plants in a more equidistant pattern, obtained by narrow row spacing of 38 cm (15 inches) compared to 76 cm (30 inches), had a higher crop relative growth rate prior to 400 GDD and thus more biomass. Corn in the narrow rows (more equidistant) maintained an advantage in crop growth rate until around 1100 GDD and resulted in higher levels of total above-ground biomass. Tollenaar et al. (2006) reported 16% higher biomass and leaf area at five weeks after planting for plants on equal intra-row spacing than for plants in a clump. The difference between plant spacing treatments in the Tollenaar et al. (2006) study remained apparent in total biomass two weeks after silking. The advantage to the equally spaced plants was maintained due to having an equivalent growth rate as the irregularly spaced plants from two weeks post-silking until maturity. In the Texas Panhandle, less leaf area in clump planted corn compared to conventional has been reported at 60 days after planting (Kapanigowda et al., 2010b) and at the V6 and V13 growth stages (Mohammed et al., 2012). Kapanigowda et al. (2010b) also reported higher water use at 60 days after planting for corn planted in a conventional geometry compared to clump. Although not documented in their studies, the LAI and water use observations would indicate increased early season biomass production. In this study, corn in a conventional geometry had the lowest levels of profile available water at the early vegetative and tassel-silk measurement times (Table 1.37) and was the lowest numerically at postemergence measurement. These observations support the notion of increased biomass production prior to kernel set and grain fill.

In this study differences in total above-ground biomass were not observed between the conventional and clump geometries. This is similar to one-year of observations from the Texas Panhandle by Mohammed et al. (2012) whose above-ground biomass yields were similar to those observed in 2010. Kapanigowda et al. (2010b) however reported 16% higher total above-ground biomass for corn in a clump configuration in a 2-year study in the Texas Panhandle. Availability of soil water during early season growth is a possible explanation for differences among these observations. In order for differential growth and water use to occur there would need to be sufficient water to allow the conventional planted corn to utilize its light interception advantage. Average profile soil water at first measurement was very similar in 2009 and 2010 in this study measuring 17.8 and 17.9 cm (7.00 and 7.06 inches), respectively, (Table 1.9, and Table 1.20). Profile water at first measurement in 2011 was less, 13.8 cm (5.44 inches) (Table 1.31), however, the measurement was taken much later in the season, after additional crop water use had occurred.

No treatments similar to the cluster geometry in this study were found in the literature for comparison. Other than producing more above-ground biomass than corn in a P2S2 treatment, no consistent trends relative to other treatments were observed. The next highest levels of total above-ground biomass were typically found in the P1S1 treatment. Other than in 2009 when it was in the top LSD grouping along with the conventional geometry, corn in a P1S1 configuration has tended to produce levels of above-ground biomass higher than P2S2 but lower than the other geometries. While these levels were not always distinguishable from the other treatments, they would coincide with relative differences in light interception (Table 1.12) and soil water use (Table 1.9, Table 1.20, Table 1.31, Table 1.37).

Total above-ground biomass was consistently lowest for corn planted in a P2S2 configuration. The spatial arrangement of plants in this configuration limits light interception (Table 1.12) as well as access to soil water as evidenced by lack of water extraction from the inter-row skip and relatively higher levels of available water at most measurement times. While imposing artificial limitations on resource availability, specifically with a time component, is an objective of alternative planting geometries, it would appear in this study that P2S2 may be too aggressive of an approach. Light and water resources were limited to the point where significant reductions in dry matter accumulation occurred which translated into reduced grain yields. The spatial arrangement of plants in the P2S2 configuration limited light and water interception and thus plant growth. This reduction in biomass contrasts with findings in other locations. Simons et al. (2008) in Australia reported no differences in above ground biomass between conventional, P2S1, and P2S2 configurations. In the northern Great Plains corn in a P2S1 configuration resulted in 12% higher biomass (Allen, 2012).

Effect of seeding rate on total above-ground biomass was not apparent in any year, although the numerical trend was for increasing biomass with increasing seeding rate in two of three years. These trends observed in individual years were apparent in the across-years analysis. Increasing biomass with increasing seeding rate is consistent with the observations of Hashemi et al. (2005).

Stover and harvest index

Harvest index, averaged across all treatments, was smallest in 2010 with an average of 0.45. Harvest indices in 2009 and 2011 averaged 0.55 and 0.59, respectively. Total above-ground biomass and grain yields were also the lowest in 2010. In all three years of the study, and in an across-years analysis, HI declined as seeding rate increased with the highest seeding rate always having the lowest HI. Declining HI along with numerically increasing total above-ground biomass resulted in increasing levels of stover as seeding rate increased. Declines in HI with increasing plant density are evident in the literature (Tollenaar, 1989; DeLoughery and Crookston, 1979; Tollenaar, 1992b) including dryland conditions (Allen, 2012).

Planting geometry affected the rate of HI decline associated with increased seeding rate in this study. Corn planted in a clump configuration resulted in the highest rate of decline with increasing plant density, a reduction of 0.08 (Table 1.33). Harvest index for corn in a conventional or P2S2 geometry declined 0.06 over the range of populations, and declines of 0.05 and 0.03 were observed for the cluster and P1S1 geometries, respectively. The reduced sensitivity of the P1S1 geometry contributed to the geometry x seeding rate interaction present in the 2010 and across years analysis, and was evident numerically in 2009 and 2011. The presence of a planting geometry x seeding rate interaction revealed that planting geometry could affect how plants respond to increases in plant density in their partitioning of dry matter into grain.

Corn planted in a conventional configuration resulted in the lowest HI in 2010, 2011, and across-years. The consistently lower HI value for corn in a conventional configuration resulted as a combination of above-ground biomass yields that were higher than the average of all geometry treatments in every year while producing grain yields at or below the average of all geometry treatments in every year. Corn in a clump or cluster configuration tended to have similar values of above-ground biomass as conventional corn, but had reduced levels of stover and increased HI. Overall, the alternative geometries were able to partition a larger portion of a smaller total biomass accumulation into grain.

Harvest index values for corn in a P1S1 or P2S2 configuration were always higher than the conventional, often equal and sometimes greater than clump and cluster geometries. Simons et al. (2008) in Australia reported higher harvest index for P1S1 compared to conventional while Allen (2012) observed no difference between conventional and a P2S1 configuration in the northern Great Plains. Harvest index for the clump geometry was always numerically higher than the conventional, and was substantially higher in 2010, the lowest yielding year, and in the across-years analysis. The across-years analysis shows an 8% improvement in HI for clump planting compared to conventional geometry. Kapanigowda et al. (2010b) and Mohammed et al.

(2012) reported harvest indices of 10 to 33% higher for clump planted corn compared to conventional geometry. Hybrid x seeding rate x planting geometry interactions have been shown to affect HI (Ottman and Welch 1989) which could explain the variability of results. In 2009, corn in a P1S1 configuration produced a HI similar to clump and higher than cluster (Table 1.2). In 2009 corn in a P1S1 configuration had the highest HI resulting in less stover production compared to conventional which produced a similar amount of total above-ground biomass. In 2010, 2011, and when analyzed across-years, corn in a P1S1 configuration produced less stover than conventional, cluster, or clump, but higher levels of stover than corn in a P2S2 configuration. Stover production was consistently lowest in all years and across-years for corn in a P2S2 configuration. Although HI in P2S2 was higher than in conventional and comparable to other geometries, it was not enough to compensate for reduced total biomass, thus consistently resulting in the lowest levels of stover production.

In none of the years, or in the across-years analysis, was stover affected by a geometry x seeding rate interaction, while geometry and seeding rate main effects were consistently observed.

Grain yield

Grain yields were affected by treatments in 2009 and 2010. Seeding rate alone never affected yields but was expressed through a geometry x seeding rate interaction in 2010 and in the across-years analysis. Lyon et al. (2009) reported a geometry x seeding rate interaction at only one of 23 site-years when evaluating skip-row geometries. The study of Lyon et al. (2009) contained a wide variety of hybrids which could contribute to finding no interaction, while this study contained only one hybrid. However the hybrid used in this study was also used in a number of the site-years included in Lyon et al. (2009).

The range of HI and total above-ground biomass was very small in 2011 and the responses to geometry and seeding rate were largely offsetting, resulting in no effect on grain yields, and a very minor effect on yield components. The hybrid used in this study is considered a medium maturity, flex-ear, typically non-prolific, with above average drought tolerance and is popular in the High Plains region due to these characteristics and its performance in dryland situations. In all years, and in the across-years analysis all yield components were affected by planting geometry, seeding rate, or both.

Yields in 2010 were most representative of average yield expectations for the study site. In 2010, corn planted in a clump configuration resulted in more grain yield than corn in a conventional geometry at the intermediate seeding rate. Corn planted in a clump configuration maintained grain yields as seeding rate increased from the low to intermediate level whereas grain yield of corn in the conventional geometry declined.

For clump planted corn in 2010 there was no difference between the low and intermediate seeding rates, the increase in plant density overcame reductions in KP through KR and KER, ears plant^{-1} and KW. In 2010 yield declined significantly in the clump geometry as seeding rate increased from the intermediate to the high rate. A similar trend of reduced yield at the highest seeding rate was observed numerically in 2011. The partitioning of yield reduction among yield components was similar in both years with reductions of 33%, 14%, and 7% for KP, KER, and KW, respectively, in 2010. It is clear that the KER yield component in clump planted corn is sensitive to changes in overall plant density. Data from this study, with one hybrid, suggest that increasing plant density beyond an optimum in clump geometries may result in reductions in key yield components and grain yield.

Corn planted in a cluster configuration had a much flatter response to seeding rate than the other planting geometries. This resulted from a relatively flat responsiveness of most yield components. Corn planted in a cluster configuration with this hybrid expressed prolificacy. This additional flexible yield component added additional buffering to changes in sink:source relationships with increasing seeding rate, thus keeping yield component responses subtle. While there was no apparent optimum seeding rate for corn planted in a cluster configuration, the use of a hybrid that is strictly non-prolific or one more prolific, would likely alter the response.

Corn planted in a P2S2 configuration generally did not respond to seeding rate. Corn in P2S2 configuration was never in the top LSD group for grain yield other than the intermediate seeding rate in 2010. Low yields for the P2S2 configuration in 2009 were the result of reductions in KER compared to other planting geometries. When evaluated across-years, P2S2 remained in the lowest LSD grouping for yield across the entire range of planting densities.

The negative response to corn in a P2S2 geometry is not necessarily contrary to existing work due to the yield levels observed in this study. It has been stated that yields of corn in a conventional configuration would need to be below 3500 kg ha^{-1} (56 bu ac^{-1}) (Vigil et al, 2008) or 4600 kg ha^{-1} (74 bu ac^{-1}) (Lyon et al., 2009) to expect a positive response with the P2S2 configuration. The data collected in this study correspond with a large multi-year, multi-location study summarized by Lyon et al. (2009) in which the mean yields of sites with a positive response to skip-row plants was 2760 kg ha^{-1} (44 bu ac^{-1}), while mean yields of 5460 kg ha^{-1} (87 bu ac^{-1}) resulted in no response. Lyon et al. (2009) reported that locations with negative responses had a mean yield of 8470 kg ha^{-1} (135 bu ac^{-1}) and that neutral or negative responses to P2S2 were expected at yield levels above 4140 kg ha^{-1} (74 bu ac^{-1}). In the present study, negative responses were observed at conventional yield levels of 7080 kg ha^{-1} (112.9 u ac^{-1}) in 2009 with a corresponding P2S2 yield of 6510 kg ha^{-1} (103.8 bu ac^{-1}). However, in that same year a positive response to the P1S1 configuration was observed. This study tended to see a negative response to a P2S2 configuration and a positive response to a P1S1 configuration. This contrasts other work in the immediate vicinity by Schlegel (2007) and Olson et al. (2010) and in the northern plains (Allen, 2012) all of whom reported no difference in grain yields. Lyon et al. (2009) stated that that positive response to a P1S1 configuration would be found at conventional yields below 5660 kg ha^{-1} (101 bu ac^{-1}). The results of this study would suggest that the breakpoint may be higher than that.

Responses to clump planting in this study were generally neutral and smaller in magnitude than those reported in the Texas Panhandle. Kapanigowda et al. (2010b) reported grain yield increases of 13-55% for clump planted corn at a similar plant density as the intermediate level in this study. While both the present study and that of Kapanigowda et al. (2010b) reported higher values in harvest index, and kernels $plant^{-1}$ (as calculated from their data) there were several contrasts. Kapanigowda et al. (2010b) reported higher kernel weight and above-ground biomass for clump planted corn whereas we found no difference. The results of Mohammed et al. (2012) closely mirror those of the present study where corn in a clump configuration resulted in higher harvest index and numerically higher grain yields, but was not statistically differentiable. The yield levels present in the data of Mohammed et al. (2012) most closely resemble those experienced in 2010 of the present study.

Although consistent responses were difficult to identify, it is important to note that when evaluated across seeding rates, grain yield was not lowered due to use of an alternative planting geometry other than P2S2.

Yield components – Ears plant^{-1}

Ears plant^{-1} was the only yield component unaffected by a geometry x seeding rate interaction although geometry clearly contributed to observed trends. Ears plant^{-1} declined numerically with increasing seeding rate in 2009, and was different between the high and low seeding rates in 2010, 2011, and in the across-years analysis. An increase in ears plant^{-1} at the lowest seeding rate was driven by apparent prolificacy in the cluster treatment while decreased ears plant^{-1} at the highest seeding rate was contributed by barrenness in the skip-row geometry, and occasionally the conventional geometry. Declines in ears plant^{-1} were also observed in a similar study in the Texas Panhandle (data calculated from Mohammed et al., 2012).

The ears plant^{-1} treatment means for planting geometry would further indicate that in the cluster configuration some plants are prolific. In 2009, assuming no barrenness existed on any plant, which is consistent with field observation; approximately 8% of the plants in the cluster treatment were prolific. Field observation through the seasons noted this and that prolific plants were the outside plants of a cluster. These plants, which represent 1/3 of the total plants seeded, would have the lowest level of inter-plant competition of any plants in the entire study (within a seeding rate). This reduction in inter-plant competition and perhaps increased resource availability at the per-plant level likely influenced this response (Prior and Russell, 1975). Light quality as defined by R:FR ratio was likely higher in the cluster configuration which has been shown to promote tillering and prolificacy (Moulia et al., 1999). Ears plant^{-1} means of less than one for the P2S2 skip-row treatment in 2009, 2011, and across-years, indicates by definition that some level of barrenness was occurring in these treatments. In data calculated from Mohammed et al. (2012), corn planted in a clump configuration resulted in higher ears plant^{-1} than corn in a conventional geometry, which is supported by a numerical trend in this work. However, it is apparent from their data that the hybrid used by Mohammed et al. (2012) was more prolific than the hybrid used in this study. Under highly stressed conditions in the region, barrenness can result in the ears plant^{-1} yield component having a large effect on grain yields. In southwest Kansas, Norwood (2001) reported that 26-34% of the yield was attributed to the ears plant^{-1} yield component variability in a study involving multiple hybrids and seeding rates. The ears plant^{-1} mean for the P1S1 treatment in the across-years analysis is driven by the abnormal data of the P1S1 treatment at the middle seeding rate.

Yield components - Kernel rows

Kernel rows (KR) is generally the least flexible yield component and is influenced heavily by genotype. In this study it was apparent that plant density played a role, as in every year KR decreased with increasing plant density agreeing with observations of Hashemi et al. (2005) and Tetio-Kagho and Gardner (1988b). As integer counts were performed on the ears the means declining between 18 and 16 indicate an increasing number of ears with 16 kernel rows compared to 18 kernel rows as seeding rate increased. In 2011 and the across-years analysis, KR for the skip-row treatments were less than the conventional, cluster, or clump. A similar numerical trend existed in 2009. Differences among geometries on KR in 2010, the lowest yielding year were minimal. The high inter-plant competition due to small intra-row plant spacing appeared to affect ear development at the time of KR determination in the skip-row configurations more drastically than in the clump or cluster configuration.

Yield components - Kernels ear row^{-1}

Kernels ear row^{-1} (KER) consistently declined with increasing seeding rate in every year of the study. In 2010 and 2011 the nature of that decline was affected by planting geometry. The lowest KER was consistently observed for corn planted in a P2S2 configuration with corn in a P1S1 the next lowest. Corn in a clump configuration typically produced the highest numerical KER when averaged across seeding rates and was consistently in the top LSD group at any seeding rate in any year. In 2009 the decline in KER for any geometry other than P2S2 was greatest as seeding rate increased from the low to the intermediate level. From the intermediate to the high level of seeding rate, the rate of KER decline increased for the P2S2 configuration, decreased for the clump and conventional geometries, and was flat for the cluster and P1S2 configurations. Similar to responses in 2010, rates of decline in KER were greatest for the conventional geometry as seeding rates increased from the low to the intermediate level. All other geometries had steeper declines in KER from the intermediate to the high seeding rate, a contrasting response to 2010. The largest spread in KER between conventional and clump geometries occurred at the intermediate seeding rate which was an important contributing factor to the difference in grain yield at that seeding rate.

Although corn in a conventional geometry likely went into the kernel set and grain fill period with the highest amount of accumulated biomass, it consistently produced the lowest values for harvest index. Monneveux et al. (2005) found no relationship between above-ground biomass at anthesis and yield, indicating that an increase in vegetative reserves does not necessarily increase stress tolerance. It has been shown that less than 10% of the assimilate used during kernel set and grain fill is produced prior to silking (Swank et al., 1982; Simmons and Jones, 1985) and that plant competition during vegetative growth has little or no effect on final grain yield (Hashemi et al., 2005). The limited ability to reallocate assimilate from stored carbohydrate reserves in the plant places almost all source requirements of kernel set and grain fill on concurrent photosynthesis and assimilate production especially when the corn plant is under water stress (Schussler and Westgate, 1991). Kernel number determination is driven by plant growth rate in a time period bracketing flowering (Edmeades and Daynard, 1979; Andrade et al., 1993; Tollenaar, 1992a; Kiniry and Knievel 1995; Otegui and Bonhomme, 1998). Plant growth rate is determined by light interception and radiation use efficiency (Sinclair and Muchow, 1999a) which can be reduced by heat and water stress (Earl and Davis, 2003) and perhaps evaporative demand of the environment expressed as vapor-pressure deficit (Stockle and Kiniry, 1990; Kiniry et al., 1998; Sinclair and Muchow, 1999b; Kiniry, 1999). Higher photosynthetic rates and crop growth would allow for more kernels, up to the genetic capacity of the plant, to be set thus raising the maximum attainable grain yield. Data in this study indicate that light interception, and thus likely plant growth, was lowest for the P2S2 geometry, followed by P1S1. This corresponds with trends in KP. It is reasonable to assume that some of the alternative geometries exhibited a higher plant growth rate during kernel set than the conventional geometry, especially the clump treatment which tended to have higher KP and KER, notably in 2010 (Table 1.4).

Working in western Nebraska, Pavlista et al. (2010) reported higher KP though a longer primary ear for corn grown in a P2S2 configuration in three of four years. That contrasts the results of this study which measured consistently lower KER for corn in a P2S2 configuration while corn in a P1S1 generally resulted in equivalent KER as corn in a conventional geometry. Corn planted in clump, cluster, or conventional geometries tended to produce equivalent KER with the clump configuration typically resulting in the highest values as evidenced in the across-years analysis. Pavlista et al. (2010) reported that when corn in a P2S2 configuration outperformed corn in a conventional geometry it was primarily due to increased ear length along with kernel weight. Data collected in this study also contrasts calculated kernels ear^{-1} from the data of Mohammed et al. (2012). Their data indicated higher kernels ear^{-1} for corn planted in a conventional geometry as opposed to clumps of 3 or 4 plants although they reported higher kernel weight for clump planted corn, the opposite of responses observed in the present study. It is important to note that the data of Mohammed et al. (2012) is from a one-year study, and that environmental conditions for that year could have affected the observed responses. The data of Pavlista et al. (2010) was collected on a hybrid that was clearly prolific and the data suggest that the axillary ears changed the dynamics of kernel set and grain fill.

Yield components - Kernel weight

Although it was not evaluated in this study, previous work has reported that management effects on KW are a result of differences in grain fill duration and not necessarily grain fill rate (Jones and Simmons, 1983; Poneleit and Egli, 1979; NeSmith and Ritchie, 1992). Changes in KW as plant density increased varied among geometries for all years of the study. At the lowest seeding rate in all years, except the P2S2 geometry in 2010, kernel weights were equal and likely represented the maximum attainable kernel weight for that particular site-year.

Kernel weight responded to a geometry x seeding rate interaction in 2009, 2011, and in the across-years analysis. Data from 2009 and 2011 are similar and two distinct responses are evident, the response of the skip-row treatments and the response of the conventional and clump treatments. Response of the cluster treatment varied by year. In two higher yielding years of the study, 2009 and 2011, corn planted in either of the skip-row configurations had the largest average KW and also the smallest change in KW as plant density increased. In 2009, the smallest changes in KW were 14 and 15 mg $seed^{-1}$ for the P2S2 and P1S1 geometries, respectively. In 2011, the smallest changes in KW were again for the P2S2 and P1S1 treatments with reductions of 24 and 47 mg $seed^{-1}$.

Kernel weight of corn planted in either a conventional or clump configuration was more responsive to changes in plant density in 2009 and 2011. The largest responsiveness for any geometry occurred in 2011 when KW of corn planted in a clump configuration declined 97 mg $seed^{-1}$ as seeding rate decreased. Corn in clump and conventional configurations had nearly identical declines in kernel weight as plant density increased (Figure 1.7, Figure 1.19).

In 2009 and 2011, corn in a P2S2 configuration had the highest mean KW, different however is the quadratic response of KW with increasing seeding rate. Biomass and grain yields were the lowest in 2010 of any year in the study due to in-season stress. Reductions in RUE caused by plant stress may have limited plant growth rate and assimilate production relative to potential sink capacity, resulting in all treatments filling kernels in a source-limited manner. The reduction in KW with increasing seeding rate resulted form inadequate assimilate production. This response was also evident in other yield components which declined linearly with increasing plant density.

When evaluating the 2009 and 2011 data, the relationships of KW, KP, light interception, and water use in this study would indicate that the larger KW and lack of KW response to increasing plant density in the skip-row treatments result from a sink limited grain-fill process. The relatively lower values for kernel weight, especially under increasing plant densities for the clump and conventional geometries likely result from a source-limited grain fill process.

In the skip-row configurations, reductions in kernel set reduced the strongest sink for assimilate and increased the assimilate available for grain fill on a per kernel basis. Harder et al. (1982) and Claassen and Shaw (1970) reported that if KP was reduced early by stress, within one to two weeks post-silking, and conditions remained favorable thereafter, there could be increased KW with decreasing KP. Estimates of the critical time frame for plant growth rate and kernel set referenced to silking include -15 to +15 days (Andrade et al., 1993); -7 to +21 days (Tollenaar, 1992a); and 0 to +10 days (Kiniry and Knievel (1995). Otegui and Bonhomme (1998) defined the window in thermal time which in practice placed more emphasis on the time prior to silking, typically 2.5 to 3 weeks and approximately one week post-silking. The windows critical to kernel set combined with the findings of Harder et al. (1982) would support the scenario of reduced kernel set followed by assimilate production at a relative high per kernel rate, thus resulting in heavier kernels such as those seen in the skip-row treatments, especially P2S2. Sink-limited grain fill for the skip-row treatments results in the relative lack of responsiveness in KW to increases in plant density. Kernel weight declines in the skip-row treatments with increasing plant density as assimilate production declines due to resource competition, even though it is declining at a faster rate than reductions in sink size. Overall the sink:source relationship in the skip-row treatments results in higher KW at the mid and high seeding rates.

As discussed in a prior section, corn in the conventional or clump geometry produced higher KP relative to the skip row and cluster treatments as plant density increased (except cluster in 2010), predominantly through the KER yield component. Reduced KW compared to the skip-row treatments are supported by Uribelarrea et al. (2008) who reported that when kernel number increased through management, kernel weight declined due to less assimilate availability per kernel. Reductions in KW within the conventional and clump treatments as seeding rate increased are similar to responses observed by Tollenaar (1992a) and Monneveux et al. (2005). Tollenaar (1992a) and Monneveux et al. (2005) reported that in source limited conditions, such as increasing plant density, kernel weight declines when the potential assimilate sink remains relatively unchanged or declines at a rate slower than source availability. Hashemi et al. (2005) reported a negative trend in kernel weight with increasing plant density and speculated that downward adjustments in kernel number with increasing plant density, specifically KER allowed remaining kernels to grow at higher grain-filling rates than would otherwise occur. In this study, average kernel weight at the low plant density was highest in 2011, the year of steepest declines with increasing seeding rate. This illustrates that in years with higher potential, the affect of source limited grain fill on kernel weight is more apparent in the conventional and clump configurations.

Kernel weight for corn in a cluster geometry declined on the same magnitude as conventional and clump in 2009, although a greater portion of the decline came as seeding rate increased from the low to intermediate rate. In 2011 however, the decline in kernel weight for cluster planting was greater than that of conventional or clump, the additional decline occurring as seeding rates increased from the mid to high rate (Figure 1.19). The cluster planting geometry resulted in prolificacy that was evident throughout the study. The level of prolificacy was much higher in 2009 with a mean of 1.08 ears plant^{-1} across seeding rates. The additional ears provided an assimilate sink in addition to kernels. As a result the cluster treatment was more source limited in 2009 much like the clump and conventional geometries. Prolificacy in the cluster treatment was not evident at the mid and high seeding rates in 2011. Reduced prolificacy resulted in plants being more sink limited than source limited in 2011, however increased KP relative to the skip-row treatments provided additional assimilate sink. This resulted in a response to increasing plant density that lies between the source-limited response of the clump and conventional treatments and the sink-limited response of the skip-row treatments.

As in this study, Pavlista et al. (2010) found increased kernel weight from corn planted in a P2S2 configuration, however he did not observe a geometry x seeding rate interaction or a seeding rate main effect. Increased KW was a factor in a site-year where corn in a P2S2 configuration produced higher grain yields than corn in a conventional geometry (Pavlista et al., 2010). While not a direct comparison, Maddonni et al. (2006) reported that kernel weight in wide rows was less affected by increases in plant density. Corn planted in a clump geometry in this study produced equivalent kernel weight to that in a conventional configuration. This is in contrast to findings of Mohammed et al. (2012) and Kapanigowda et al. (2010b) who reported higher kernel weights for clump compared to conventionally planted corn grown in the Texas Panhandle.

Contrary to the findings of Pavlista et al. (2010); Tetio-Kagho and Gardner, (1988a); and Ahmadi et al. (1993) we consistently observed reductions in kernel weight with increasing plant density in every year of this study, except for within the skip-row configurations.

Grain nutrient content

Grain N content for corn in a P2S2 configuration was consistently in the bottom LSD grouping while grain N content for corn in a conventional configuration was consistently in the top LSD grouping. Based on water extraction patterns of the geometries in this study it is intuitive that access to water-soluble nutrients in the soil profile, such as N, would be affected. Corn in a conventional geometry resulted in the most even and complete exploration of the soil profile while corn in a P2S2 configuration represented the opposite scenario. Stickler (1964) reported that under water-limiting conditions more equidistant plant spacing resulted in higher grain N concentration, presumably through more thorough soil profile exploration. Along with root exploration and N uptake, treatment related differences in kernel fill rate and duration, and thus kernel weight, could affect grain N content via different levels of dilution with carbohydrate starch. Harder et al. (1982) and Jurgens et al. (1978) reported increased grain N content when kernel weight was reduced due to water stress. The effect of incomplete profile exploration by the roots, and thus N uptake, combined with having the largest kernel weights, likely contributed to low grain N contents in the P2S2 configuration. Grain P content did not appear to be correlated with any other measurement obtained in this study for aid in explanation of differences amongst geometry treatments.

Water use and water use efficiency (WUE) of grain and biomass production

Water use was only affected by geometry in one year of the study, 2011 (Table 1.32). Corn in a P1S1 configuration resulted in a higher water use than other geometries but was similar to corn in a cluster configuration. It is important to note that seasonal crop water use being the highest for the P1S1 geometry resulted from having the highest water use, along with P2S2, for the interval of grain fill to harvest (Table 1.31). The P2S2 followed a similar pattern. During this interval, cluster and clump used less water than the skip row treatments while corn in a conventional geometry used the least. This pattern was evident in 2009 and 2010 as well (Table 1.9 and Table 1.20). In this study no differences were observed in water use between the clump and conventional geometries which agrees with the findings in the Texas Panhandle by Kapanigowda et al. (2010b). Likewise, this study did not find differences in water use between conventional and skip-row which mirrors the findings in Australia presented by Simons et al. (2008).

Biomass WUE and grain WUE were lower for corn in a P1S1 configuration than any other geometry in 2010, the year of lowest biomass and grain yields. This should be interpreted with caution however as the unexplainable outlier of the intermediate seeding rate in the P1S1 geometry was an influence. However, with respect to biomass WUE, corn in a P2S2 configuration produced the lowest numerical value by some distance in 2009 and 2011. These numerical differences manifest themselves in the across-years analysis where corn planted in clump or conventional geometries results in a biomass WUE higher than corn planted in either of the skip-row configurations while the cluster geometry was intermediate in nature. Allen (2012) reported increased PUE with a P2S1 configuration in the Northern Great Plains. The calculations of Allen (2012) did not take into account soil water depletion so it is not directly comparable. In the present study, no differences in seasonal water use were observed between conventional and skip-row. If that finding was assumed for the Allen (2012) study then it would imply higher biomass WUE for skip-row, a finding in contrast with the findings of this study.

In 2010, P1S1 data aside, grain WUE was higher for the clump and P2S2 treatments compared to the cluster and conventional treatments. This conflicts with the findings of Baumhardt (2010) who evaluated P2S2 under limited irrigation in the Texas Panhandle and found reduced grain WUE compared to conventional planting. In all years, corn in a clump configuration resulted in the highest numerical water use efficiency. Kapanigowda et al. (2010b) reported grain WUE for clump planted corn of 14.37 kg ha^{-1} mm^{-1} (5.8 bu ac^{-1} in^{-1}) compared to 13.86 kg ha^{-1} mm^{-1} (5.6 bu ac^{-1} in^{-1}) for conventional. This relationship was generated in the lower yielding year of a two-year study with yields ranging from 2280 to 5100 kg ha^{-1} (36.3 to

81.3 bu ac^{-1}). In the second year of the study yields ranged from 2970 to 7030 kg ha^{-1} (47.3 to 112.0 bu ac^{-1}) with conventional corn having a grain WUE of 26.35 kg ha^{-1} mm^{-1} (10.7 bu ac^{-1} in^{-1}) compared to 19.71 kg ha^{-1} mm^{-1} (7.4 bu ac^{-1} in^{-1}) for clump planted corn in the higher yielding year of the study. When their dataset is combined across-years, conventionally planted corn maintains a higher grain WUE. However, key to note are lower intercepts under clump planting. That is, it takes less water use to produce the first kernel of grain, resulting in higher grain yields under lower water levels. This is an important point in dryland cropping systems where attaining threshold ET is a key step in the success of a crop producing economical yield.

Soil water

While planting geometry did not always affect water use, WUE, or average soil water content across the soil profile cross section, it is apparent that planting geometry affected the spatial distribution of water extraction by plants and water contents in the soil profile.

Water extraction among treatments was not equal in quantity or spatial distribution at most times of measurement. These differences were evident in analysis of profile water by measurement location across geometries, analysis of water content by measurement location within geometries and depths, and through analysis of interpolated profile cross-sections.

For all geometries, maximum soil water depletion occurred closest to the planted row and declined as measurement location was moved away from the planted row. The relative differences in depletion between measurement position declined as the growing season progressed indicating lateral root expansion, although some soil water redistribution may have played a role. This is consistent with the observations of Yao and Shaw (1964b) who reported that water depletion declined as you moved away from the planted row in a 107 cm (42 inch) row spacing. However, higher levels of depletion in the P2S2 treatment were observed in-between the planted rows than within the planted row (Table 1.36).

Differences in soil water content by depth were much less apparent in 2010 than in 2009 or 2011. It is possible that root growth was less in 2010 than other years, or perhaps more lateral root growth occurred thus minimizing differences between measurement locations. The 2010 study was on a different soil type which may have affected root growth and soil water redistribution characteristics differently than in 2009 and 2011. In 2009, the progression of water extraction by roots was very apparent through the season and lower water contents were found under the planted rows with progressing depth. In all years, the time of measurement when the most number of soil water differences were detected varied by geometry.

The most pronounced differences were in the P2S2 geometry, with differences detected at deeper depths as the season progressed and between most measurement positions. Differences between the area directly under the planted rows and the middle of skip were apparent for the entire depth of the profile, 183 cm (72 inches) in 2009 and 2011 (Table 1.8 and Table 1.30), but only to a depth of 122 cm (48 inches) in 2010 although the numerical trend existed through the entire depth (Table 1.19). Corn planted in either a P1S1 or P2S2 configuration in general rooted to deeper depths more quickly than corn planted in any of the other geometries.

When profile total water is evaluated, a common trend both statistically and numerically of less profile soil water in the conventional treatment compared to others, especially at tassel-silk. This supports the observations of overall increased biomass and stover production in conventional geometry of this study, and would be an outcome of increased early-season vegetative growth which data in this study support. When evaluating profile water totals by tube position across geometries at tassel-silk, the lowest values were consistently observed directly under the planted row in the conventional treatment followed by the inter-row position in the conventional treatment (Table 1.3, Table 1.14, Table 1.25, and Table 1.36). The clump and cluster treatments had more soil water available to them at tassel-silk and based on measures of range, SD, depth of observed differences, and visual interpretation of soil water content, and appeared to have root systems exploring a similar soil volume as the conventional treatment. These differences in soil water could explain the observed reductions in HI and kernel set in the conventional treatment.

Total biomass growth, cross-section analysis of change in soil water, and ending values of soil water content all support that corn grown in a P2S2 configuration did not fully explore the soil profile over the course of the growing season. A hypothesized objective of skip-row planting is to artificially limit soil water availability as a function of time via plant and root growth. However, it is counter-productive to reduce the effective use of water (EUW) (Blum, 2009) by leaving soil water in the profile at the expense of plant growth and partitioning into yield. Water left in the profile is subject to evaporation losses at the surface, and/or loss to deep percolation should enough precipitation be received prior to use by a subsequent crop. Similar lack of profile extraction was observed in skip-row dryland corn production by other researchers in the central

High Plains, (Vigil et al., 2008) as well as in Australia (Robertson et al., 2003). In the findings of Robertson et al. (2003) only 29% of soil water was extracted at a distance of 120 cm (47 inches) into the skip away from the planted row. Under limited irrigation on graded furrows in the Texas Panhandle, Musick and Dusek (1982) reported that corn roots were able to extract water 75 cm (30 inches) away from the row, the center point of a one-row skip in their study, but were unable to extract water 113 cm (44.5 inches) away, the center point of a two-row skip. In Australia, Simons et al. (2008) speculated that a P2S2 configuration had too wide of a skip for water extraction. In contrast to the aforementioned findings, Pavlista et al., (2010), working in the Nebraska Panhandle, did not measure soil water, but did observe root growth in the middle of the skip in a P2S2 configuration with most roots located in the top 50 cm and some present to a depth of 76 cm, much shallower than the depths of depletion observed in this study. It is known that root architecture can be affected by genotype (Vamerali et al., 2003; Campos et al., 2004; Lorens et al., 1987; Vincet and Woolley, 1972; Hammer et al., 2009), particularly through the genetically control expression of root angle (Giuliani et al., 2005), which could explain variability in observations from studies utilizing different hybrids. Pavlista et al. (2010) did not quantify root density or water extraction, nor did this study measure the physical presence of roots. It is possible that roots were present into the skip but extracted relatively small amounts of water.

With the exception of the P2S2 configuration, in which lack of root exploration across the entire soil volume limited water use, soil water contents and total cumulative water use among geometry treatments tended to be equalized between either tassel-silk or grain fill and harvest. Barbieri et al. (2012) reported increased water use for narrow vs. wide rows in a corn row spacing study, however soil water differences dissipated as the season progressed. Late season water use in the P2S2 geometry was the highest among geometries (Table 1.9, Table 1.20, Table 1.31, and Table 1.37) and was likely driven by evaporation as evidenced by spatial position of soil water depletion in graphical plots (Figure A.241 through Figure A.245). This was more pronounced in years where data were available to evaluate water use from grain fill to harvest such as 2009 (Figure A.101 through Figure A.105), and 2011 (Figure A.201 through Figure A.205). This high rate of water use relative to the other treatments equalized total water use among geometries when evaluated across the entire season. The harvest measurement was the only time of measurement where P2S2 was consistently no different than the other geometries with respect to profile water, even though spatial distribution of that water within the profile remained quite different.

Evaporation component of water use – concerns and management

A potential concern for alternative planting geometries is that a reduction in light interception by leaves increases solar radiation available for interception at the soil surface. In dryland corn in western Nebraska, Todd et al. (1991) reported the effect of canopy shading on reducing soil surface evaporation to be substantially higher than the placement of 6700 kg ha^{-1} (5980 lb ac^{-1}) of small grains residue on the surface. In the present study it has been apparent through reductions of near surface soil water contents that surface evaporation is greater as the point of measurement is moved away from the planted row, clump, or cluster. It is likely in this study that evaporative losses have affected the E:ET ratio, especially for the skip-row configurations, which have resulted in reduced biomass and grain water use efficiencies. Differences in light interception observed in this study due to planting geometry (Table 1.34) indicate that differing levels of solar energy would be available to drive surface evaporation. This same effect was found with various row spacings in grain sorghum by Adams et al. (1976). The final measurement in 2010 occurred after a prolonged period without precipitation. The lowest values of soil water in the near-surface measurement were observed 76 cm (30 inches) away from the plants in the cluster and P1S1 configurations, an area more exposed to evaporative demand, mostly though solar energy, but also possibly through wind movement (Tolk et al., 1995) and the processes of advection, which in semi-arid areas has been shown to be a significant source of heat for the ET process (Hanks et al., 1971). The effects of evaporation are especially apparent in the last measurement interval of any season, which consistently resulted in higher rates of water use for the P1S1 and P2S2 treatments. Lack of accompanying yield and yield component responses in these treatments combined with soil water reductions in the near surface layers and in the skips of these treatments support evaporative losses as a major factor in late season water use. By the end of the growing season, surface residues from the previous crop have broken down and are reduced from their initial levels, thus providing less protection against evaporative demand. Less crop water use, and thus less competition from crop roots, offers little competition to evaporation for late season precipitation. Additionally, as leaves senesce more of the soil surface is subject to intercepting solar radiation energy.

Having adequate levels of surface residue is key in minimizing the affect of increased solar radiation interception by the soil surface if alternative geometries are to be implemented. Adams et al. (1976) showed soil surface evaporation rates during first stage drying as high as 93% of potential evaporation in between widely-spaced rows of grain sorghum in Texas. Adding as little as 2000 kg ha^{-1} (1785 lb ac^{-1}) of small grains residue resulted in substantial reductions in evaporation, and similar results have been described by others (Russel, 1939; Bond and Willis, 1969; Bond and Willis, 1970). In the present study, adequate levels of surface residue in the form of wheat stubble were present in every year of the study. Residue levels were not quantified but should be of concern when implementing a planting geometry that will result in more solar energy reaching the soil surface at any point in the growing season. Adapting technology such as stripper headers to leave more residue in place and in an upright architecture may further reduce evaporative losses (Baumhardt et al., 2002).

Conclusions

Several strategies are implemented through the utilization of alternative planting geometries This includes spacing of plants to leave areas of the soil profile available for root exploration later in the growing season and the reduction of leaf area and light interception per unit of available water supply to better match water and light resources in order to reduce stress induced reductions in radiation use efficiency (RUE), dry matter accumulation and partitioning into grain yield components.

When evaluated across-years, above-ground biomass, grain yield, harvest index, and most yield components were affected by a geometry x seeding rate interaction, showing that planting geometry can create differences in dry matter accumulation and how corn plants partition dry matter into various yield components as overall plant density on a land area basis changes.

Water use and stover production measurements in this study, along with observations in the literature, would indicate that corn in a conventional planting geometry produced more biomass relative to the alternative geometries prior to kernel set and grain fill. Clump, cluster and conventional configurations produced similar levels of total above-ground biomass, larger than the biomass production of the skip-row treatments. Corn planted in a P2S2 geometry consistently produced the least above-ground biomass due to the restrictions imposed on light interception and water extraction. In this study, the purposeful implementation of crowding stress via alternative planting geometries increased HI relative to a more equidistant plant spacing pattern. As seeding rate increased, harvest index declined at different rates depending upon planting geometry.

Grain yields were affected by geometry or geometry x seeding rate in two of three years. Although no clear advantage to a particular planting geometry and seeding rate emerged, it is important to note that other than the P2S2 configuration, yields were not reduced compared to conventional planting at relatively high yield levels for the region. The inability of corn planted in a P2S2 geometry to fully explore the soil volume, and reduced levels of light interception, resulted in less total biomass production.

Kernel rows ear^{-1} were reduced by the skip-row geometries indicating that high levels of inter-plant competition affected plant growth at the time of KR determination. Reduced kernel set in the skip-row treatments relative to others was likely due to reduced light interception and thus plant growth rate during the critical time bracketing silking for kernel set. Kernels ear row^{-1} declined with increasing plant density regardless of planting geometry, although the rate of decline varied with geometry and year. Corn planted in a clump or conventional configuration tended to have the highest rates of decline in two of three years. Corn planted in a clump geometry tended to produce higher levels of KER. Kernel weights were highest for the skip-row treatments and had minimal reductions with increasing plant density. Increased KW was most likely due to reduced kernel set, thus grain-fill in these treatments became a sink-limited process. In conventional and clump planted corn, KW declined with increasing seeding rate, most likely due to reduced assimilate production on a per-kernel basis, in other words source-limited grain fill. In the cluster geometry KW dynamics were influenced by prolificacy.

Differences in total water use and water use efficiency were not frequently apparent. Corn planted in a conventional geometry had the lowest levels of profile soil water at tassel-silk. Profile water content located directly under the planted row in a conventional geometry was the lowest of any measurement position in the study all three years. In an across-years analysis, corn planted in clump or conventional geometry results in a biomass WUE higher than corn planted in either of the skip-row configurations.

Progression of soil water extraction varied by measurement position, geometry, and year. The most pronounced differences in soil water content throughout the season and remaining at harvest were in the P2S2 geometry. Soil water contents and season water use among the geometry treatments (other than P2S2) were equalized between tassel-silk or grain-fill and harvest.

Commercialization recommendations

Corn planted in a cluster configuration typically had higher HI than conventional and responded similarly to environment and seeding rate as clump and conventional. For many producers implementation of the cluster geometry would be difficult, especially those utilizing auto-swath and individual row clutches. Currently, technology to properly synchronize plate position between rows while using row clutches is not widely available to producers. Without synchronization and proper placement of the planted clusters and the open portions of row there is no management control over the intended objectives of regulating light interception and soil water extraction. Additionally, yield component responses of the cluster configuration were complicated by a typically non-prolific hybrid expressing prolificacy. It would seem that this geometry may be especially sensitive to hybrid selection. For these reasons, and equally or more promising results from other alternative geometries, it is the opinion of the author that cluster geometry is likely not the best alternative for commercial adoption.

Planting corn in a P2S2 configuration resulted in less than necessary light interception and incomplete extraction of soil water resulting in reduced dry matter accumulation which translated into reduced grain yields. For the site-years evaluated in this study, the P2S2 configuration was an overly defensive strategy. Late season reductions of soil water in the P2S2 geometry near the soil surface, and in the skip, indicated elevated levels of water loss to evaporation. While the findings of this study do not discount the potential response of skip-row systems at lower yield potentials as reported by Vigil et al. (2008), Lyon et al. (2009) and Pavlista et al. (2010), it does raise concern that in many environments the P2S2 configuration is overly defensive and that in moderate yielding site-years may be detrimental to grain yields as compared to conventional planting. Producers considering adoption of a skip-row alternative planting geometry should consider a P1S1 configuration. The data in this study showed no advantages to P2S2 relative to any other treatment. Yields and most yield components minimized with this treatment, other than KW. Even in the driest year of the study, no advantage was observed relative to conventional geometry corn and P2S2 was numerically lower relative to the other alternative geometries. Soil water data consistently shows uneven water distribution at the end of the growing season.

Based on the results in this study and current planting technologies, clump and P1S1 planting geometries appear to be the most viable for commercial implementation and evaluation in further research efforts. These two treatments consistently produced similar values of total above-ground biomass and higher values of harvest index than corn planted in a conventional geometry and resulted in grain yields that were equal or better than conventionally planted corn. Additional consideration may be warranted for the clump geometry as the KP yield component tended to be higher than in P1S1, although KW tended to be less. The ears plant^{-1} yield component tended to show some level of prolificacy in the clump treatment while barrenness was common in the P1S1 configuration. Implementation of the P1S1 geometry requires no equipment investment on the part of the producer. If a producer were to implement P1S1 on all his acres, planter row units could be removed from service thus reducing maintenance and replacement costs. Adoption of the clump planting geometry will involve the purchase of another set of metering devices, i.e. seed discs, finger wheels, plates, etc.

Should a producer implement an alternative geometry? Data collected in this study show that for the yield levels experienced, conventional corn yields of 4.23 to 7.74 Mg ha^{-1} (67 to 123 bu ac^{-1}), the clump and P1S1 alternative geometries performed equal to or better than corn planted in a conventional geometry, with any advantage being inconsistent and occurring at specific seeding rates. In cases where yield differences were not detected, differences in yield components indicated that corn planted in alternative geometries responded as though it were under less stress and was more effective at partitioning biomass into grain.

There was no overwhelming evidence to suggest that changing planting geometry would necessitate large changes in seeding rate. In general, corn in a P1S1 configuration responded to increases in plant density in 2 of 3 years. Increasing seeding rate from the intermediate to high level reduced grain yield in clump planted corn in all three years of the study. Corn planted in a conventional geometry tended to perform best at the lowest seeding rate, although in 2009 a high yielding year, the intermediate seeding rate produced the largest numerical grain yield. A potential concern is reaching the limit of yield components that are increased through use of an alternative planting geometry. Seeding rates should be maintained at a level high enough to ensure some yield component flexibility remains both in the upward and downward directions.

Seeding at a lower than optimal rate may result in various yield components, most notably KER and KW, limiting out at their genetic potential, thus capping yields and the ability of the plant to flex upward under better than normal growing conditions.

Any commercial implementation of an alternative planting geometry should only occur within the context of cropping systems that maximize surface residue, i.e. no-till and planting corn into small-grains stubble or heavy row-crop stubble. Situations where surface residue is lacking, when combined with the open areas of alternative planting geometries will be prone to increased weed pressure and surface evaporation losses. Evaporation losses will negatively affect WUE and PUE of the entire cropping system, and losses at some level will negate any potential gains in productivity attained via planting geometry.

Avenues for future research

Many avenues for future research efforts exist in the area of alternative planting geometries. The results of this study established differences in IPAR at the R1 growth stage. While it gives a snapshot glimpse into light interception at a very critical time for kernel set and grain fill, it leaves many questions unanswered as to how plant growth and leaf area development from emergence until R1 affects light interception. A time-series study of light interception and growth analysis would allow further investigation of these mechanisms and evaluation of the effects of planting geometry on RUE. Characterization of leaf profile within the canopy and the development of extinction coefficients for light interception would create opportunities in crop modeling where geometries and seeding rates could be evaluated for light interception and coupled with split-component ET models to evaluate the partitioning of E:ET under various scenarios (Lascano et al., 1987 and Gardiol et al., 2003).

In addition to research with IPAR and RUE, measurements of R:FR light ratio at various locations in the canopy may provide data relating plant responses to inter-plant competition. Measurements of R:FR light ratio at perpendicular locations away from a planted row in the P2S2 system may indicate at what distance neighboring across-row plants are detectable and could explain differences between the P2S2, P1S1, and cluster systems, which for the most part share a common intra-row plant to plant spacing.

This study was performed with a single hybrid, albeit a well understood hybrid that has performed well in dryland environments. Although, it exhibits the traits that future hybrids adapted to High Plains dryland corn production would likely have, it is still a relevant question if a hybrid x geometry x seeding rate interaction may exist. Hybrid x row spacing and hybrid x seeding rate interactions are well documented in the literature. It is well known that hybrids respond differently to many of the components involved in alternative planting geometries including leaf orientation plasticity in response to changes in R:FR light ratio via interplant competition (Maddonni et al., 2001), yield stability under drought stress via breeding method (Guillen-Portal et al., 2003), harvest index with respect to changes in plant density and row spacing (Ottman and Welch, 1989), light interception via differences in leaf architecture (Ottman and Welch, 1989; Maddonni and Otegui, 1996), stomatal closure with respect to limited soil water (Ray and Sinclair, 1997), and root architecture (Vamerali et al., 2003; Campos et al., 2004; Lorens et al., 1987; Vincet and Woolley, 1972; Hammer et al., 2009, Giuliani et al., 2005). The rate of new hybrid introduction into the market would make evaluation of individual hybrids unfeasible. However, evaluating hybrid groups representative of phenotypical characteristics such as prolificacy, ear-flex, maturity, rooting angle, etc. may provide generalized data that would be more robust as specific hybrids change.

While planting in skip-row configurations, particularly P2S2, appeared to be too defensive of an approach for the environmental conditions encountered by this study, there may be value to it from a systems approach. Previous work in the High Plains region has been mixed regarding second-year or continuous row cropping. The soil water left in the skip of a skip-row system may be particularly valuable in ensuring the economic success of a subsequent row crop planted into the previous years skip. Improving the probability of success of a subsequent row crop would help mitigate the economic losses due to yield reductions of corn in a P2S2 configuration in a good year. In this study however, a portion of the soil water not used in the P2S2 configuration for crop growth was lost late in the season via evaporation. Management improvements to further minimize evaporative losses would be necessary for this approach to be viable. Observations regarding grain nutrient content and soil water extraction patterns may be the basis for research questions regarding the proper placement of water soluble nutrients such as N to ensure that corn planted in alternative geometries has sufficient nutrient availability.

The effect of various spatial arrangements of plants on micro-climatic conditions is not well understood. It is theorized that the clumping of plants may reduce the apparent vapor-pressure deficit within the clump as it appears to the leaf surface, thus reducing transpirational demand (B.A. Stewart, personal communication). This study was conducted in relatively large plots in terms of field research, but yet small with respect to production fields. It is quite possible that large areas of a particular geometry would result different micrometeorological conditions within the plant community. The effects of planting geometry on wind movement through the canopy and its effect on evaporative demand need to be evaluated. This is especially true in the skip-row systems where the skip provides an open “run” for which dryer air can be moved through rapidly, thus potentially keeping VPD at the leaf surface relatively high.

While data were generated from this study, more questions worthy of future investigation are apparent if the mechanisms at work are to be understood. A better understanding of these mechanisms may open the doors to planting geometry and plant density recommendations that are more specific to environmental conditions resulting in dryland production systems that maximize economic returns while minimizing risk.

References

Abunyewa, A.A., R.B. Ferguson, C.S. Wortman, D.J. Lyon, S.C. Mason, and R.N. Klein. 2010. Skip-row and plant population effects on sorghum grain yield. Agron. J. 102:296-302.

Abunyewa, A.A., R.B. Ferguson, C.S. Wortman, D.J. Lyon, S C. Mason, S. Irmak, and R.N. Klein. 2011. Grain sorghum water use with skip-row configuration in the Central Great Plains of the USA. African J. of Agric. Res. 23:5328-5338.

Adams, J.E., G.F. Arkin, and J.T. Ritchie. 1976. Influence of row spacing and straw mulch on first stage drying. SSSAJ 40:436-442.

Ahmadi, M, W.J. Wiebold, J.E. Beuerlein, D.J. Eckert, and J. Schoper. 1993. Agronomic practices that affect corn kernel characteristics. Agron. J. 85:615-619.

Allen, B.L. 2012. Dryland corn yield affected by row configuration and seeding rate in the northern Great Plains. J. of Soil and Water Cons. 67:32-41.

Andrade, F.H., P. Calvino, A. Cirilo, and P. Barbieri. 2002. Yield responses to narrow rows depend on increased radiation interception. Agron. J. 94:975-980.

Andrade, F.H., S.A. Uhart, M.I. Frugone. 1993. Intercepted radiation at flowering and kernel number in maize: Shade versus plant density effects. Crop Sci. 33:482-485.

Anonymous. 1975. Report of Progress – Colby Branch Experiment Station. Kansas State Univ. Agric. Exp. Stn.

Aubertin, G.M. and D.B. Peters. 1961. Net radiation determinations in a corn field. Agron. J. 53:269-272.

Babalola, O. and C. Oputa. 1981. Effects of planting patterns and population on water relations of maize. Expl. Agric. 17:97-104.

Bandaru, V., B.A. Stewart, R.L Baumhardt, S. Ambati, C.A. Robinson, and A. Schlegel. 2006. Growing dryland grain sorghum in clumps to reduce vegetative growth and increase yield. Agron. J. 98:1109-1120.

Barbieri, P., L. Echarte, A. Della Maggiora, V.O. Sadras, H. Echeverria, and F.H. Andrade. 2012. Maize evapotranspiration and water-use efficiency in response to row spacing. Agron. J. 104:939-944.

Bauder, T. and R. Waskom. 2003. Best management practices for Colorado corn. Bull. XCM574A. Colorado St. Univ. Coop. Ext. Svc. Ft. Collins, CO.

Baumhardt, R.L. 2010. Can you harvest grain from deficit irrigated corn if you plant using skip-row? Ogallala Aquifer Program 2009 Final Report. USDA-ARS Conservation and Production Research Laboratory. Bushland, TX.

Baumhardt, R.L., R.C. Schwartz, and R.W. Todd. 2002. Effects of taller wheat residue after stripper header harvest on wind run, irradiant energy interception, and evaporation. In E. Van Santen (ed.) Proc. Of 25th Annual Southern Conservation Tillage Conf. Auburn, AL. 24-26 June 2002.

Bean, B. 2007. Dryland corn in the Texas Panhandle. AREC Publication 07-18. Texas Agricultural Experiment Station, Amarillo, TX.

Bean, B. and T. Gerik. 2005. Evaluating corn row spacing and plant population in the Texas Panhandle. Result Demonstration Report from TAES-Amarillo. Available at http://amarillo.tamu.edu/files/2010/11/Evaluationofcorn.pdf. (accessible 12 January, 2013)

Blum, A. 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res. 112:119-123.

Blum, A., and M. Naveh. 1976. Improved water-use efficiency in dryland grain sorghum by promoted plant competition. Agron. J. 68:111-116.

Blumenthal, J.M., D.J. Lyon, and W.W. Stroup. 2003. Optimal plant population and nitrogen fertility for dryland corn in western Nebraska. Agron. J. 95:878-883.

Bond, J.J., and W.O. Willis. 1969. Soil water evaporation: Surface residue rate and placement effects. SSSAJ 33:445-448.

Bond, J.J., and W.O. Willis. 1970. Soil water evaporation: First stage drying as influenced by surface residue and evaporation potential. SSSAJ 34:924-928.

Bullock, D.G., R.L. Nielsen, and W.E. Nyquist. 1988. A growth analysis comparison of corn grown in conventional and equidistant plant spacing. Crop Sci. 28:254-258.

Campos, H., M. Cooper, J.E. Habben, G.O. Edmeades, and J.R. Schussler. 2004. Improving drought tolerance in maize: A view from industry. Field Crops Res. 90:19-34.

Claassen, M.M. and R.H. Shaw. 1970. Water deficit effects on corn. II. Grain components. Agron. J. 62:652-655.

DeLoughery, R.L., and R. K. Crookston. 1979. Harvest index of corn affected by population density, maturity rating, and environment. Agron. J. 71:577-580.

Denmead, O.T., and R.H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J. 52:272-274.

Dhuyvetter, K.C., C.R. Thompson, C.A. Norwood, and A.D. Halvorson. 1996. Economics of dryland cropping systems in the Great Plains: A review. J. Prod. Agric. 9:216–222.

Dwyer, L.M., and D.W. Stewart. 1986. Effect of leaf age and position on net photosynthetic rates in maize. Agric. for Meteorol. 37:29-46.

Earl, H.J., and R.F. Davis. 2003. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. Agron. J. 95:688-696.

Eck, H.V. 1986. Effects of water deficits on yield, yield components, and water use efficiency of irrigated corn. Agron. J. 78:1035-1040.Edmeades, G.O., and T.B. Daynard. 1979. The relationship between final yield and photosynthesis at flowering in individual maize plants. Can. J. Plant Sci. 59:585-601.

Farahani, H.J., G.A. Peterson, D.G. Westfall, L.A. Sherrod, and L.R. Ahuja. 1998. Soil water storage in dryland cropping systems: The significance of cropping intensification. Soil Sci. Soc. Am J. 62:984–991.

Farnham, D.E. 2001. Row spacing, plant density, and hybrid effects on corn grain yield and moisture. Agron. J. 93:1049-1053.

Fjell, D. 2005. Crop management – plant population. Internal extension materials. Kansas St. Univ. Agric. Exp. Stn. and Coop. Ext. Svc., Manhattan.

Fulton, J.M. 1970. Relationships among soil moisture stress, plant populations, row spacing and yield of corn. Can. J. Plant Sci. 50:31-38.

Gallow, K.P. and C.S.T. Daughtry. 1986. Techniques for measuring intercepted and absorbed photosynthetically active radiation in corn canopies. Agron. J. 78:752-756.

Gardiol, J.M., L.A. Serio, A.I. Della Maggiora. 2003. Modeling evapotranspiration of corn (Zea mays) under different plant densities. J. of Hydrology. 271:188-196.

Giuliani, S., M.C. Sanguineti, R. Tuberosa, M. Bellotti, S. Salvi, and P. Landi. 2005. Root-ABA2, a major constitutive QTL, affects maize root architecture and leaf ABA concentration at different water regimes. J. Exp. Bot. 56:3061-3070.

Grant, R.F., B.S Jackson, J.R. Kiniry, and G.F. Arkin. 1989. Water deficit timing effects on yield components in maize. Agron. J. 84:61-65.

Guillen-Portal, F.R., W.K. Russell, D.D. Baltensperger, K.M. Eskridge, N.E. D'Croz-Mason, and L.A. Nelson. 2003. Best types of maize hybrids for the western high plains of the USA. Crop Sci. 43:2065-2070.

Haag, L.A., and A. J. Schlegel. 2009. Yield and dry matter partitioning of grain sorghum grown in clumps. Southwest Research-Extension Center Report of Progress No. 1014. Kansas State Univ. Agric. Exp. Stn. and Coop. Ext. Svc.

Hammer, G.L. Z. Dong, G. McLean, A. Doherty, C. Messina, J. Schussler, C. Zinselmeier, S. Paszkiewicz, and M. Cooper. 2009. Can changes in canopy and/or root system architecture explain historical maize yield trends in the U.S. Corn Belt? Crop Sci. 49:299-312.

Hanks, R.J., L.H. Allen, and H.R. Gardner. 1971. Advection and evapotranspiration of wide-row sorghum in the central Great Plains. Agron. J. 63:520-527

Hashemi, A.M., S.J. Herbert, and D.H. Putnam. 2005. Yield response of corn to crowding stress. Agron. J. 97:839-846.

Havlin, J.L., and F.R. Lamm. 1988. Management of dryland corn for the central Great Plains. p. 837-838. In P.W. Unger et al. (ed.) Challenges in Dryland Agriculture – A Global perspective. Proc. Intl. Conf. on Dryland Farming, Amarillo, TX. 15-17 Aug. Texas Agric. Exp Stn, College Station.

Harder, H.J., R.E. Carlson, and R.H. Shaw. 1982. Yield, yield components, and nutrient content of corn grain as influenced by post-silking moisture stress. Agron. J. 74:275-278.

Hashemi, A.M., S.J. Herbert, and D.H. Putnam. 2005. Yield response of corn to crowding stress. Agron. J. 97:839-846.

Holtzer, T.O., R.L. Anderson, M.P. McCullen, and F.B. Peairs. 1996. Integrated pest management of insects, plant pathogens, and weeds in dryland cropping systems of the Great Plains. J. Prod. Agric. 9(2):200–208.

Hons, F.M. and B.L. McMichael. 1986. Planting pattern effects on yield, water use and root growth of cotton. Field Crops Res. 13:147-158.

Johnson, G.A., T.R. Hoverstad, and R.E. Greenwald. 1998. Integrated weed management using narrow corn row spacing, herbicides, and cultivation. Agron. J. 90:40-46.

Jones, R.J., and S.R. Simmons. 1983. Effect of altered source-sink ratio on growth of maize kernels. Crop Sci. 23:129-134.

Jurgens, S.K., R.R. Johnson, and J.S. Boyer. 1978. Dry matter production and translocation in maize subjected to drought during grain fill. Agron. J. 70:678-682.

Kandelous, M.M., J. Simunek, M.T. Van Genuchten, K. Malek. 2011. Soil water content distributions between two emitters of a subsurface drip irrigation system. SSSAJ 75:488-497.

Kapanigowda, M, M. Schneider, and B.A. Stewart. 2010a. Dryland grain sorghum tillering: clump vs. uniform planting geometries. J. of Crop Improv. 24:271-280.

Kapanigowda, M., B.A. Stewart, T.A. Howell, H. Kadasrivenkata, R.L. Baumhardt. 2010b. Growing maize in clumps as a strategy for marginal climatic conditions. Field Crops Res. 118:115-125.

Kiniry, J.R. 1999. Response to questions raised by Sinclair and Muchow. Field Crops Res. 62:245-247.

Kiniry, J.R., and D.P. Knievel. 1995. Response of maize seed number to solar radiation intercepted after anthesis. Agron. J. 87:228-234.

Kiniry, J.R., J.A. Landivar, M. Witt, T.J. Gerik, J. Cavero, L.J. Wade. 1998. Radiation-use efficiency response to vapor pressure deficit for maize and sorghum. Field Crops Res. 56:265-270.

Klein, R.N. and D.J. Lyon. 2011. Recommended seeding rates and hybrid selection for rainfed (Dryland) corn in Nebraska. NebGuide G2068. Univ. of Nebr. Coop. Ext. Svc., Lincoln, NE.

Krishnareddy, S.R., B.A. Stewart, W.A. Payne, and C.A. Robinson. 2010. Grain sorghum tiller production in clump and uniform planting geometries. J. of Crop Improv. 24:1-11.

Lascano, R.J., C.H.M VanBavel, J.L. Hatfield, and D.R. Upchurch. 1987. Energy and water balance of a sparse crop: simulated and measured soil and crop evaporation. Soil Sci.

Lee, C.D. 2006. Reducing row widths to increase yield: Why it does not always work. Crop Management. doi:10.1094/CM-2006-0227-04-RV.

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. SAS for Mixed Models, Second Edition. SAS Institute. Cary, NC.

Loomis, R.S. 1983. Crop manipulation for efficient use of water: An overview. Pg. 345-374. In Limitations to Efficient Use in Crop Production. (H.M. Taylor, W.R. Jordan, T.R. Sinclair, editors).

Lorens, G.F., J.M. Bennett, and L.B. Loggale. 1987. Differences in drought resistance between two corn hybrids. I. Water relations and root length density. Agron. J. 79:802-807.

Lyon, D.L., and D. D. Baltensperger. 1995. Cropping systems control winter annual grass weeds in winter wheat. J. Prod. Agric. 8(4):535–539.

Lyon, D.J., G.L. Hammer, G.B. McLean, and J.M. Blumenthal. 2003. Simulation supplements field studies to determine no-till dryland corn population recommendations for semiarid western Nebraska. Agron. J. 95:884-891.

Lyon, D.J., A.D. Pavlista, G.W. Hergert, R.N. Klein, C.A. Shapiro, S. Knezevic, S.C. Mason, L.A. Nelson, D.D. Baltensperger, R.W. Elmore, M.F. Vigil, A.J. Schlegel, B.L. Olson, and R.M. Aiken. 2009. Skip-row planting patterns stabilize corn grain yields in the central Great Plains [online]. Crop Manage., doi:10.1094/CM-2009-0224-02-RS, Available at http://www.plantmanagementnetwork.org/cm/.

Maddonni, G.A. and M.E. Otegui. 1996. Leaf area, light interception, and crop development in maize. Field Crops Res. 48:81-87.

Maddonni, G.A., A.G. Cirilo, and M.E. Otegui. 2006. Row width and maize grain yield. Agron. J. 98:1532-1543.

Maddonni, G.A., M.E. Otegui, and A.G. Cirilo. 2001. Plant population density, row spacing and hybrid effects on maize canopy architecture and light attenuation. Field Crops Res. 71:183-193.

MathWorks. 2012. Matlab technical computing language software. Version R2012b. Natick, MA.McGee, E.A., G.A. Peterson, and D.G. Westfall. 1997. Water storage efficiency in no-till dryland cropping systems. J. Soil and Water Cons. 52:131–136.

McMaster, G.S. and W.W. Wilhelm. 1997. Growing degree-days: one equation, two interpretations. Agric. and Forest Meteorology. 87:291-300.

Milliken, G.A., and D.E. Johnson. 2009. Analysis of messy data – volume 1: designed experiments. 2nd ed. CRC Press. Boca Raton, FL.

Mohammed, S., B.C. Blaser, B.A. Stewart. 2012. Planting geometry and plant population affect dryland maize grain yield and harvest index. J. of Crop Improv. 26:130-139.

Monneveux, P., P.H. Zaidi, and C. Sanchez. 2005. Population density and low nitrogen effects yield-associated traits in tropical maize. Crop Sci. 45:535-545.

Moulia, B., C. Loup, M. Chartier, J.-M. Allirand, and C. Edelin. 1999. Dynamics of architectural development of isolate plants of maize (Zea mays L.), in a non-limiting environment: The branching potential of modern maize. Ann. Bot (Lond.) 84:645-656.

Musick, J.T. and D.A. Dusek. 1972. Irrigation of grain sorghum and winter wheat in alternating double-bed strips. J. of Soil and Water Cons. 27:17-20.

Musick, J.T. and D.A. Dusek. 1982. Skip-row planting and irrigation of graded furrows. Trans. ASAE 25:82-87, 92.

NASS. 2013. Online query of crop production survey data. Available online at http://www.nass.usda.gov. Verified, 4 Aug. 2013.

NeSmith, D.S., and J.T. Ritchie. 1992. Maize response to a sever soil water-deficit during grain-filling. Field Crops Res. 29:23-35.

Nielsen, D.C., M.F. Vigil, J.G. Benjamin. 2009. The variable response of dryland corn grain yield to soil water content at planting. Agric. Water Manage. 96:330-336.

Nielsen, D.C., P.W. Unger, and P.R. Miller. 2005. Efficient water use in dryland cropping systems in the Great Plains. Agron J. 97:364–372.

Nielsen, D.C., A.D. Halvorson, and M.F. Vigil. 2010. Critical precipitation period for dryland maize production. Field Crops Res. 118:259-263.

Nielsen, R.L. 1988. Influence of hybrids and plant density on grain yield and stalk breakage in corn grown in 15-inch row spacing. J. Prod. Agric. 1:190-195.

Norwood, C.A. 2001. Dryland corn in western Kansas: Effects of hybrid maturity, planting date, and plant population. Agron. J. 93:540-547.

Norwood, C.A. and R.S. Currie. 1996. Tillage, planting date, and plant population effects on dryland corn. J. Prod. Agric. 9:119-122.

Olson, B.L., A.J. Schlegel, and J.D. Holman. 2010. Comparison of skip-row grain sorghum and corn in western Kansas. Agronomy Field Research Report of Progress No. 1030. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Otegui, M.E., and R. Bonhomme. 1998. Grain yield components in maize I. Ear growth and kernel set. Field Crops Res. 56:247-256.

Ottman, M.J. and L.F. Welch. 1989. Planting patterns and radiation interception, plant nutrient concentration, and yield in corn. Agron. J. 81:167-174.

Pavlista, A.D., D.J. Lyon, D.D. Baltensperger, and G.W. Hergert. 2010. Yield components as affected by planting dryland maize in a double-skip row pattern. J. of Crop Improv. 24:131-141.

Peterson, G.A., A.J. Schlegel, D.L. Tanaka, and O.R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage systems. J. Prod. Agric. 9:180–186.

Pidaran, K., R. Aiken, M.B. Kirkham, K. Roozeboom, A. Schlegel, J.D. Holman, and B.L. Olson. 2011. Planting geometry effects on sorghum productivity in the Central High Plains. Agronomy Field Research Report of Progress No. 1048. Kansas State Univ. Agric. Exp. Stn. and Coop Ext. Svc., Manhattan, KS.

Poneleit, C.G., and D.B. Egli. 1979. Kernel growth rate and duration in maize as affected by plant density and genotype. Crop Sci. 19:385-388.

Porter, P.M., D.R. hicks, W.E. Lueschen, J.H. Ford, D.D. Warnes, and T.R. Hoverstad. 1997. Corn response to row width and plant density in the northern Corn Belt. J. Prod. Agric. 10:293-300.

Prior, C.L., and W.A. Russell. 1975. Yield performance of non-prolific and prolific maize hybrids at six plant densities. Crop Sci. 15:482-486.

Ray, J.D., and T.R. Sinclair. 1997. Stomatal closure of maize hybrids in response to drying soil. Crop Sci. 37:803-807.

Robertson, M.J., S. Cawthray, C. Birch, R. Bidstrup, M. Crawford, N.P. Dalgleish, G.L. Hammer. 2003. Managing risk of growing dryland maize in the northern region. In 5th Australian maize conference: Versatile maize, golden opportunities. (Eds. C.J. Birch, S. Wilson). Pg 112-119. Maize Association of Australia. Darlington Point, NSW.

Robins, J.S., and C.E. Domingo. 1953. Some effects of severe soil moisture deficits at specific growth stages in corn. Agron. J. 45:618-621.

Roozeboom, K.L., D.L. Fjell, and R.L. Vanderlip. 2007. Corn Production Handbook. Pub. C560. Kansas State Univ. Agric. Exp. Stn. and Coop. Ext. Svc., Manhattan, KS.

Routley, R., I. Broad, G. McLean, J. Whish, and G. Hammer. 2003. The effect of row configuration on yield reliability in grain sorghum: I. Yield, water use efficiency and soil water extraction. Online. Proc. Of the 11 Aust. Agron. Conf. Australian Soc. Of Agron., Gosford, Australia.

Russel, J.C. 1939. The effect of surface cover on soil moisture losses by evaporation. SSSAJ 3:831-837.

Sandwell, D.T., 1987. Biharmonic spline interpolation of GEOS-3 and SEASAT altimeter data. Geophysical Research Letters. 14(2):139-142.

Saxton, A.M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. In Proc. 23rd SAS Users Group Intl., SAS Institute, Cary, NC, p.1243-1246.

Schlegel, A.J. 2007. Skip row corn for improved drought tolerance. Southwest Research-Extension Center Report of Progress No. 980. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Schlegel, A.J., T.J. Dumler, and C.R. Thompson. 2002. Feasibility of four-year crop rotations in the central High Plains. Agron J. 94:509–517.

Schussler, J.R., and M.E. Westgate. 1991. Maize kernel set at low water potential: I. Sensitivity to reduced assimilates during early kernel growth. Crop Sci. 31:1189-1195.

Shapiro, C.A. and C.S. Wortmann. 2006. Corn response to nitrogen rate, row spacing, and plant density in Eastern Nebraska. Agron. J. 98:529-535

Sharratt, B.S. and D.A. McWilliams. 2005. Microclimatic and rooting characteristics of narrow-row versus conventional-row corn. Agron. J. 97:1129-1135.

Simmons, S.R., and R.J. Jones. 1985. Contributions of pre-silking assimilate to grain yield in maize. Crop Sci. 25:1004-1006.

Simons, S., D. K. Tan, S. Belfield, and B. Martin. 2008. Plant populations to improve yield of dryland maize in northwest NSW. Proceedings of the 14th Australian Agronomy Conference. Sept. 2008, Adelaide, South Australia.

Sinclair, T.R., and R.C. Muchow. 1999a. Radiation use efficiency. Adv. In Agron. 65:215-265.

Sinclair, T.R., and R.C. Muchow. 1999b. Occam's razor, radiation-use efficiency, and vapor-pressure deficit. Field Crops Res. 62:239-243

Smika, D.E. 1990. Fallow management practices for wheat production in the Central Great Plains. Agron. J. 82:319–323.

Staggenborg, S.A., W.B. Gordon, V.L. Martin, D.L. Fjell, T. Dumler, G. Kilgore, R.K. Taylor. 2001. Narrow row corn production in Kansas. Pub. MF-2516. Kansas State Univ. Agric. Exp. Stn and Coop. Ext. Svc. Manhattan, KS.

Stickler, F.C. 1964. Row width and plant population studies with corn. Agron. J. 56:438-441.

Stockle, C.O., J.R. Kiniry. 1990. Variability in crop radiation-use efficiency associated with vapor-pressure deficit. Field Crops Res. 25:171-181.

Stroup, W.W., P. S. Baenziger, and D.K. Mulitze. 1994. Removing spatial variation from wheat yield trials: a comparison of methods. Crop Sci. 86:62-66.

Swank, J.C., F.F. Below, R.J. Lambert, and R.H. Hageman. 1982. Interaction of carbon and nitrogen metabolism in the productivity of maize. Plant Physiol. 70:1185-1190.

Teasdale, J.R., C.B. Coffman, and R.W Mangum. 2007. Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agron. J. 99:1297-1305.

Tetio-Kagho, F. and F.P. Gardner. 1988a. Reponses of maize to plant population density. I. Canopy development, light relationships, and vegetative growth. Agron. J. 80:930-935.

Tetio-Kagho, F., and F.B. Gardner. 1988b. Responses of maize to plant population density. II. Reproductive development, yield, and yield adjustments. Agron J. 80:935-940.

Thelen, K. D. 2006. Interaction between row spacing and yield: Why it works. Online. Crop Management doi:10.1094/CM-2006-0227-03-RV.

Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agron. J. 59:240-243.

Todd, R.W., N.L Klocke, G.W. Hergert, A.M. Parkhurst. 1991. Evaporation from soil influenced by crop shading, crop residue, and wetting regime. Trans. of the ASAE 34:461-466.

Tolk, J.A., T.A. Howell, J.L. Steiner, and D.R. Krieg. 1995. Aerodynamic characteristics of corn as determined by energy balance techniques. Agron. J. 87:464-473.

Tollenaar, M. 1989. Genetic improvement in grain yield of commercial maize hybrids grown in Ontario from 1959 to 1988. Crop Sci. 29:1365-1371.

Tollenaar, M. 1992a. Ear and kernel formation in maize hybrids representing three decades of grain yield improvement in Ontario. Crop Sci. 32:432-438.

Tollenaar, M. 1992b. Is low plant density a stress in maize? Maydica 37:305-311.

Tollenaar, M., W. Deen, L. Echarte, and W. Liu. 2006. Effect of crowding stress on dry matter accumulation and harvest index in maize. Agron. J. 98:930-937.

Uribelarrea, M., J. Carcova, L. Borras, and M.E. Otegui. 2008. Enhanced kernel set promoted by synchronous pollination determines a tradeoff between kernel number and kernel weight in temperate maize hybrids. Field Crops Res. 105:172-181.

Vamerali, T., M. Saccomani, S. Bona, G. Mosca, M. Guarise, and A. Ganis. 2003. A comparison of root characteristics in relation to nutrient and water stress in two maize hybrids. Plant and Soil 255:157-167.

Van Roekel, R.J. and J.A. Coulter. 2012. Agronomic responses of corn hybrids to row width and plant density. Agron. J. 104:612-620

Vigil, M.F., B. Henry, F.J. Calderon, D. Poss, D.C. Nielsen, J.G. Benjamin, and R. Klein. 2008. A use of skip-row planting as a strategy for drought mitigation in the west-central Great Plains. Proceedings of the Great Plains soil fertility conference Vol. 12 (A. Schlegel, editor). Denver, CO March 4-5, 2008.

Vincent, G.B., and D.G. Woolley. 1972. Effect of moisture stress at different stages on growth: II. Cytoplasmic male-sterile corn. Agron. J. 64:599-602.

Westgate, M.W., F. Forcella, D.C. Reicosky, J. Somen. 1997. Rapid canopy closure for maize production in the northern US corn belt: Radiation-use efficiency and grain yield. Field Crops Res. 49:249-258.

Wicks, G.A., and D.E. Smika. 1973. Chemical fallow in a winter wheat-fallow rotation. Weed Sci. 21(2):97–102.

Widdicombe, W.D. and K.D. Thelen. 2002. Row width and plant density effects on corn grain production in the Corn Belt. Agron. J. 94:1020-1023.

Wiley, R.W., and S.B. Heath. 1970. The quantitative relationships between plant population and crop yield. Adv. Agon. 21:281-321.

Yao, A.Y.M. and R.H. Shaw. 1964a. The effect of plant population and planting pattern of corn on net radiation. Agron. J. 56:165-169.

Yao, A.Y.M. and R.H. Shaw. 1964b. Effect of plant population and planting pattern of corn on water use and yield. Agron. J. 56:147-152.

Chapter 2 - Evaluation of alternative planting geometries on dryland grain sorghum production

Introduction

Grain sorghum [*Sorghum bicolor* (L.) Monech] is a staple crop of dryland cropping systems in the central and southern High Plains. Harvested acreage has varied by year and has declined recently (Figure 2.1). However, it still occupies a significant amount of dryland cropland in the High Plains. Grain sorghum has been one of the key summer annual crops that have played a role in intensifying cropping systems beyond a wheat-fallow system (Hansen et al., 2012; Nielsen et al., 2005; Peterson et al., 1996; Schlegel et al., 2002) which has improved precipitation use efficiency (PUE) and economic returns (Norwood and Dhuyvetter, 1993; Dhuyvetter et al., 1996; Schlegel et al., 2002). Although dryland corn has gained popularity in the region, sorghum may have an advantage in lower yielding environments (Norwood and Currie, 1997; Staggenborg et al., 2008). Grain sorghum responds to increasing levels of available soil water at planting as well as in-season precipitation (Stone and Schlegel, 2006). This characteristic allows grain sorghum to benefit from cropping systems which reduce tillage and increase levels of surface residue resulting in more available soil water at planting and less in-season evaporative losses. From 1939 to 1997 sorghum yields on the southern High Plains increased 139%. Unger and Baumhardt (1999) reported that 93% of the increase was due to increased levels of soil water at planting.

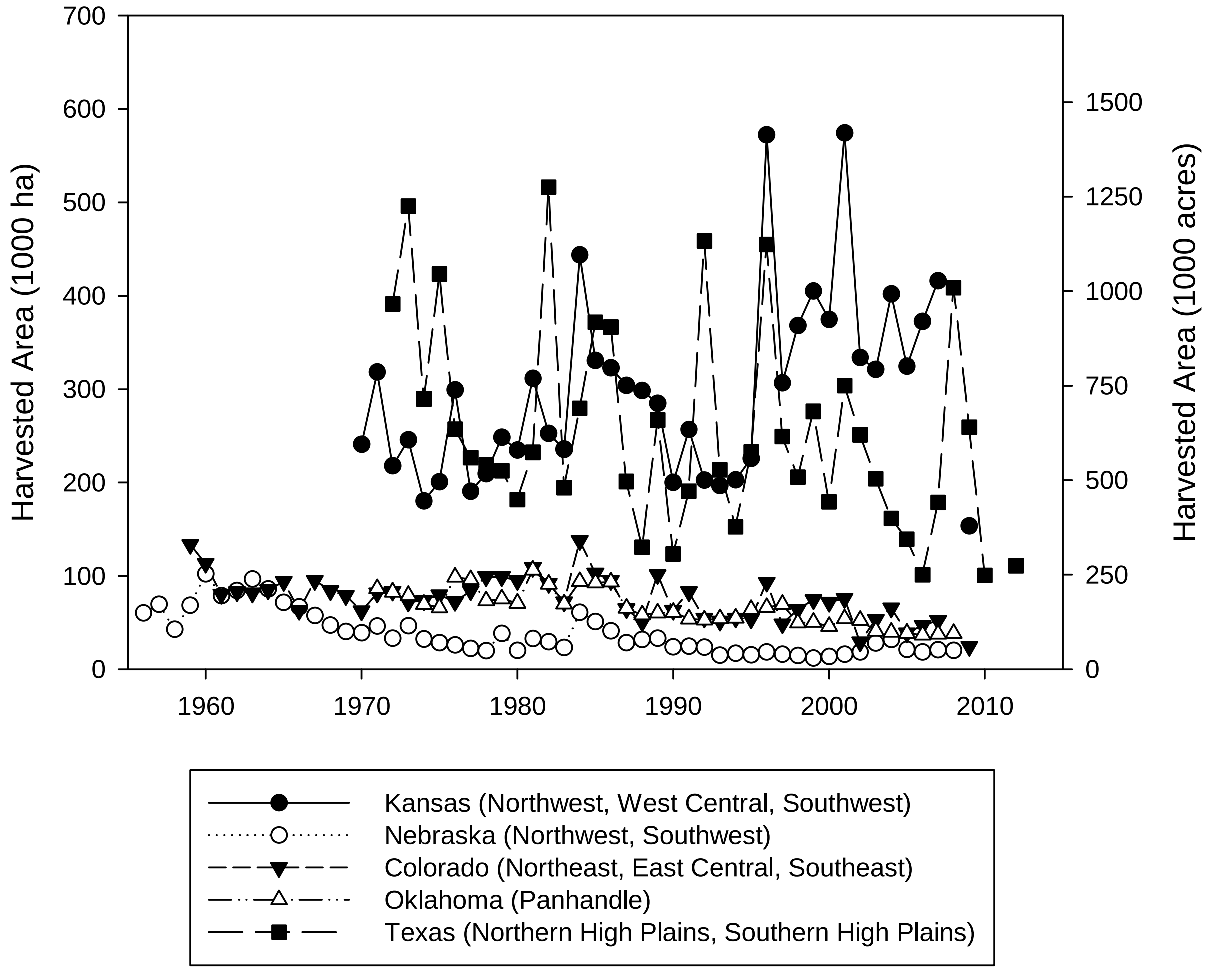

Figure 2.1 - High Plains dryland grain sorghum harvest acres, 1956-2012.

In semi-arid environments, crop growth and development is limited by available water resources, especially stored soil water that must carry the plant through times of sparsely spaced precipitation events that are unable to fully meet crop evapotranspiration (ET). Sorghum production is most reliable when the crop enters the heading stage with sufficient supplies of available soil water. Harvest index (HI) of grain sorghum increases as available soil water at planting increases (Bond et al., 1964; Brown and Shrader, 1959). Cultural practices which tend to stimulate early-season water use are undesirable (Bond et al., 1964) as they reduce available soil water at booting and flowering, a critical time for yield determination (Craufurd et al., 1993; Krieg and Lascano, 1990). In the worst cases, a shortage of soil water in conjunction with lack of precipitation can result in the production of only stover and a HI of zero (Brown and Shrader, 1959). Reductions in pre-anthesis water use can increase post-anthesis water use and thus yield potential (van Oosterom et al., 2008). Early season water use and soil water depletion is higher with narrower rows in grain sorghum (Steiner, 1986; Chin Choy and Kanemasu, 1974; McGowan et al., 1991; Peters, 1960) leading to symptoms of plant stress such as increased stomatal resistance (Steiner, 1986; Sanabria et al., 1995). Limited water resources lead to the plant undergoing heat and drought stress and thus reducing radiation-use efficiency (RUE), dry-matter accumulation, and dry matter partitioning to grain through reductions in HI (Prihar and Stewart, 1990, 1991).

Alterations in planting geometry, specifically row spacing and plant density, reduced tillering, leaf-area index (LAI), light interception, net radiation, and water use during the vegetative stage. Steiner (1986) and Blum and Naveh (1976) reported lower LAI when sorghum was planted in wider rows or skip-row configurations. This reduction in LAI is accompanied by a reduction in transpiration. Sorghum planted in wide rows intercepts less light (Witt et al., 1972; Clegg et al., 1974). Due to the effect of row spacing on light interception and thus water use, optimum row spacing depends on expected yield (Myers and Foale, 1981; Thomas et al., 1981). In the High Plains, expected yield is regulated by growing season water supply. In environments with ample growing season water supply, decreased row spacing may result in higher levels of productivity (Staggenborg et al., 1999). Decreased row spacing my also have an advantage in environments with limited or no surface residues to reduce evaporation (Steiner, 1987). Research conducted in western Kansas on narrow-row sorghum has shown yield advantages when growing season water supply is adequate (Thompson, 1982; Norwood, 1982). Narrow-row, high seeding rate, grain sorghum can be beneficial in dryland cropping systems due to the nature of the surface residue that remains. However, as moisture becomes more limiting optimal row spacing becomes wider (Bond et al., 1964; Brown and Shrader, 1959; Steiner, 1986).

In addition to altering the spacing of regular rows and plant-to-plant spacing within a row via plant density, alternative approaches using non-regular geometries such as skip-rows and planting in clumps have been evaluated. Blum and Naveh (1976) demonstrated the use of altering planting geometry to induce inter-plant competition for the purposes of reducing water use. This followed from work that showed reductions in soil water use prior to grain fill when management reduced LAI (Blum, 1972). Blum and Naveh (1976) arranged plants in plant-two skip-three skip-row configuration on 40 cm row spacing and compared those to plants in an every-row 40 cm row spacing at equal plant densities. They reported reduced LAI, total biomass, and tillering while grain yields were increased in two of four trials through both the kernels panicle^{-1} and kernel weight yield components. Yield increases in the skip-row treatment were attributed to higher levels of available soil water at the boot to full bloom growth stages.

Planting grain sorghum in a skip-row configuration has become an accepted practice in dryland regions of Australia (Thomas et al., 1981; Fukai and Foale, 1988; Routley et al., 2003) where datasets have been sufficient to allow the modification and calibration of crop models (Whish et al., 2005; McLean et al., 2003). Research trials of skip-row sorghum have also shown potential in semi-arid areas of Ethiopia (Mesfin et al., 2010).

Across the High Plains, skip-row techniques were implemented in crops other than sorghum. In the southern High Plains skip-row planting of dryland cotton (Hons and McMichael, 1986) is a common practice, while the evaluation of skip-row planting of corn is a relatively new area of investigation in the central High Plains (Lyon et al., 2009). Limited work with skip-row sorghum has been conducted on the southern High Plains. Wide unplanted areas adjacent to sorghum rows have been suggested for use in delaying the onset of moisture stress and reducing irrigation requirements (Musick and Dusek, 1972). Clark and Knight (1996) reported that skip-row planting resulted in more stable yields but lower net returns than sorghum planted in conventional rows. Jones and Johnson (1991), working at the same location reported decreased yields from a plant-one skip-one (P1S1) configuration in two of three years.

Work in the central High Plains on skip-row sorghum has produced mixed findings. Vigil et al. (2008) reported in northeast Colorado that grain sorghum planted in a plant-two rows skip-two rows (P2S2) arrangement yielded better than conventionally planted sorghum in a two-year study irrespective of a 4.9 or 9.9 plants m^{-2} (20 or 40,000 plants ac^{-1}) seeding rate, while a plant-one row skip-one row (P1S1) arrangement performed better than conventional in one of those years. Olson et al. (2010) found that sorghum planted in a conventional configuration produced higher grain yields than P2S2 planted sorghum across seven site-years in western Kansas. In years of optimal conditions the difference was as large as 3.9 Mg ha^{-1} (62 bu ac^{-1}). Abunyewa et al. (2010), working in central and western Nebraska, reported that the relative response of skip-row planting to conventional planting depended upon the yield environment.

In addition to using a skip-row system, recent work in the region has tested planting sorghum in clumps to achieve similar objectives. Planting grain sorghum in clumps has been evaluated in the central and southern High Plains and has shown under some conditions to improve grain yield. Working in the Texas Panhandle and in western Kansas, Bandaru et al. (2006) reported that clump planting reduced biomass, leaf area, leaf temperature, and tillering, while increasing grain yields through increased HI at yield levels of less than 3000 kg ha^{-1} (48 bu ac^{-1}). A reduction in tillers plant^{-1} and increased partitioning of dry matter to reproductive use was also reported by Haag and Schlegel (2009) in the central High Plains. Kapanigowda et al. (2010), working in the southern High Plains, reported reduced tillering for clump planted sorghum, fewer leaves per tiller, and that the tillers present were more likely to produce grain.

While the aforementioned methods have been evaluated in different scenarios previously, a study with direct comparisons for the High Plains region had not been conducted. The objective of this study was to evaluate multiple aspects of growing grain sorghum in conventional, skip-row, clump, and cluster planting geometries under central High Plains growing conditions.

Materials and Methods

Production management

Plots were established in 2009, 2010, and 2011 at the K-State Southwest Research-Extension Center near Tribune, Kansas. This site is located in the central High Plains with a long-term annual precipitation of 429 mm (16.9 inches). A significant portion of the precipitation (48%) falls during the months of May, June, and July. Throughout the study, temperature and solar radiation were recorded by an automated weather station located no further than 853 meters (2,800 feet) from the study location. Growing degree days were calculated with an upper temperature threshold, described as method 2 in McMaster and Wilhelm (1997), using a base temperature of 10° C (50° F) and a maximum temperature of 37.8° C (100° F).

The study included five planting geometries (Figure 2.2). All geometries were planted in 76 cm (30 inch) row spacing. Geometries evaluated included conventional rows in which plants were equidistantly spaced within rows, clumps of four plants each, clusters where six plants were planted sequentially alternating between two rows, plant-one skip-one skip row (P1S1), and plant-two skip-two skip rows (P2S2). All geometries were seeded at a density of 8.7 plants m^{-2} (35,200 plants ac^{-1}).

Plots measuring 8 rows in width by 12 m (40 feet) in length were no-till planted into wheat stubble from the previous year using a Case-IH 1200 vacuum planter (CNH North

America, Racine, WI). Blank plates were machined in-house to the author's design for metering the desired plant geometries. Sorghum was typically planted to a depth of 5 cm (2 inches). Additional details regarding cultural practices are presented in Table 2.1.

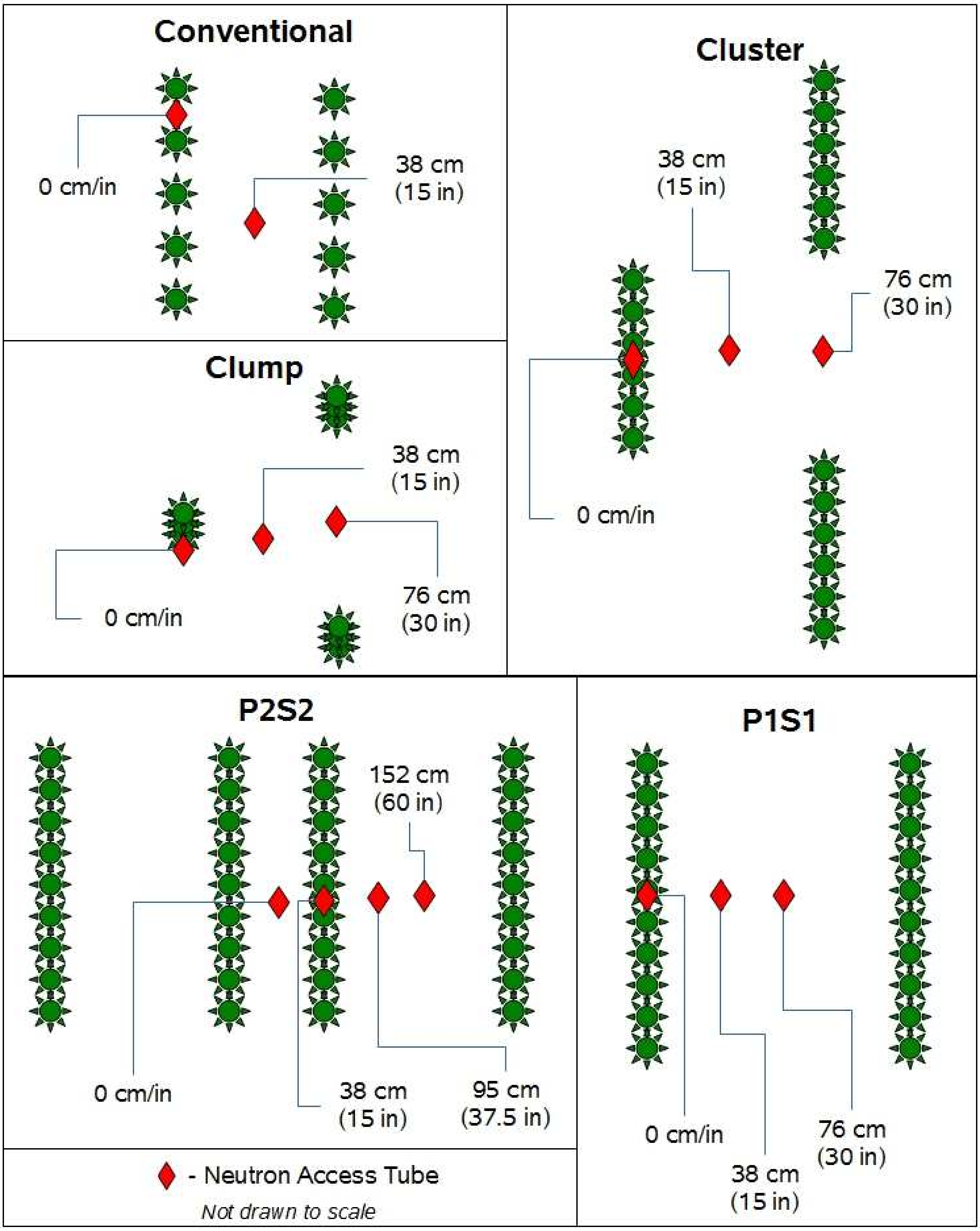

Figure 2.2 - Spatial arrangement of plants and neutron access tubes in grain sorghum planting geometries under evaluation.

Table 2.1 - Production practices for grain sorghum planting geometry study. Tribune, Kansas, 2009-2011.

Year	2009	2010	2011
Location	Dixon Dryland Annex, SWREC-Tribune Irrigation Field	SWREC-Tribune Dryland Station	Dixon Dryland Annex, SWREC-Tribune Irrigation Field
Soil Type	Ulysses Silt Loam	Richfield Silt Loam / Ulysses Silt Loam	Ulysses Silt Loam
Soil Description	Fine-silty, mixed, superactive, mesic Aridic Haplustolls	Fine, smectitic, mesic Aridic Argiustolls	Fine-silty, mixed, superactive, mesic Aridic Haplustolls
Planting Date	5/26/2009 (DOY 146)	5/26/2010 (DOY 146)	5/21/2011 (DOY 141)
Fertility	90 kg ha^{-1} (80 lb ac^{-1}) N applied 5/12/09 (DOY 132)	90 kg ha^{-1} (80 lb ac^{-1}) N applied 5/12/09 (DOY 82) 56 l ha^{-1} (6 gal ac^{-1}) 10-34-0 at planting	90 kg ha^{-1} (80 lb ac^{-1}) N applied 4/6/2011 (DOY 96)
Hybrid	Pioneer 87P06	Pioneer 87P06	Pioneer 87P06
Seeding Rate	8.7 plants m^{-2} (35,200 plants ac^{-1})	8.7 plants m^{-2} (35,200 plants ac^{-1})	8.7 plants m^{-2} (35,200 plants ac^{-1})
Harvest Date	9/30/2009 (DOY 273)	9/28/2010 (DOY 271)	10/27/11 (DOY 300) Hard Freeze, -5° C (23° F) 11/22/2011 (DOY 326) Harvest

Soil water

Volumetric soil water contents were determined for each geometry by neutron attenuation. Access tubes were placed in an effort to represent a repeatable cross-section perpendicular to a given geometry for interpolation that would be representative of the true soil water status (Figure 2.2). Neutron attenuation readings were recorded at 15 cm (6 inch) intervals to a depth of 183 cm (6 feet) at various times throughout the season. At a minimum, measurements were taken as near to planting as possible, typically representing an early vegetative growth stage, at boot to flowering, and at harvest after reaching physiological maturity. In some years additional measurements were made during the growing season. Existing calibrations and unavailable soil water values from other experiments at the experiment station were used to calculate volumetric plant-available water from the ratio of raw neutron counts to the average seasonal standard count.

Values of profile available soil water were calculated for each tube at each measurement time from the neutron data. Analysis of variance was used to test for differences with respect to tube position. This analysis utilized geometry by tube position combinations in a one-way analysis to test if differences in profile soil water across the entire study area were affected by tube location. Values of available water content were also evaluated within geometry and depth with respect to tube position to test if spatial differences in available soil water existed within a given geometry. As soil water dynamics can involve both drainage from the soil profile as well as water uptake by roots, comparisons were made within a given depth, as a depth x tube position interaction would inherently occur without necessarily being representative of treatment effects.

Calculated volumetric soil water measurements from neutron attenuation measurements were used as the input for a spatial interpolation procedure to obtain a more complete cross-sectional representation of soil water status (Kandelous et al., 2011). Interpolation was conducted using the griddata procedure with the v4 method in Matlab (MathWorks, 2012). This procedure uses biharmonic spline interpolation to estimate values at desired interpolation points (Sandwell, 1987). Interpolation was conducted on a domain measuring in width equal to the repeatable pattern of each geometry and depth to the deepest point of soil water measurement, 183 cm (72 inches) for all geometries. Cells in the interpolated domain were 2.54 x 2.54 cm (1 inch x 1 inch) in dimension.

Volumetric water content for each combination of plot by time of measurement was calculated by computing the mean volumetric water content of the cells in the interpolated domain. Total profile water was calculated by multiplying the volumetric water content for each plot by time of measurement combination by the profile depth. Total water use for each combination of plot by time of measurement was calculated by subtracting profile water at planting or other beginning period of interest from the profile total of the ending measurement then adding precipitation. This method is inclusive of both evaporation (E) and transpiration (T) components while assuming zero water loss due to runoff and deep percolation. Change in soil water with respect to spatial location was calculated by subtracting grid cell values of the two interpolated cross-sections of interest. For ease of visual interpretation and display, each interpolated cross-section was mirrored as necessary to generate a cross section measuring 305 cm (120 inches) across, the smallest common factor among the various individual cross sections.

Plot harvest and data collection

At physiological maturity plants were harvested at ground level from an area measuring 2.32 m^2 (25.0 ft^2) for the conventional, P1S2, and P2S2 treatments. In the cluster geometry 18 plants (3 clusters) were harvested representing 2.28 m^2 (24.5 ft^2), and 20 plants (5 clumps) from the clump treatment representing 2.04 m^2 (22.0 ft^2). Plants were harvested from areas having uniform stand as per the treatment intentions. Counts were made of plants and tillers. Tillers $plant^{-1}$ was calculated by dividing the tiller count by the plant count. Plant population was calculated by dividing plant count by harvest area. Panicles with harvestable grain were removed, counted, and mechanically threshed. Panicle population was calculated by dividing panicle count by harvest area. Panicles $plant^{-1}$ was calculated by dividng panicle count by plant count. Grain weight and oven-dry panicle weight less grain was recorded. Grain samples were analyzed for moisture and test weight (GAC2100, Dickey John Auburn, IL, USA). A subsample of grain was dried at 60° C for a minimum of 72 hours. Kernel weight (KW) was determined by counting 300 seeds from the subsample, drying, and reweighing. Kernels $panicle^{-1}$ was calculated by dividing oven-dry plot grain weight by kernel weight and then dividing by panicle count. Grain from the subsample was ground using a sample mill for use in determining N and P concentration in the grain. Grain concentrations for N and P were obtained by the sulfuric acid – hydrogen peroxide digestion method (Thomas et al., 1967) and were performed by the K-State Soil Testing Lab, Manhattan, Kansas. Above ground biomass, grain, was dried at 60° C for a minimum of 1 week and weighed to obtain stover weight. Grain yields were corrected to 135 g kg^{-1} (13.5%) moisture content for analysis, total above ground biomass is the sum of the stover and grain on a dry matter basis. Harvest index was calculated by dividing grain yield by total above ground biomass, both components on a dry matter basis. Yield plant^{-1} was calculated by dividing oven dry grain weight by plant population.

Statistical analysis

Statistical analysis was completed using the PROC MIXED procedure is SAS 9.2. Denominator degrees of freedom were obtained using the containment method. Variance component estimation was performed with the restricted maximum likelihood technique (REML). In instances where variance components were estimated as near zero or negative the NOBOUND option was invoked to attempt completion of a G matrix that was positive definite.

Invoking NOBOUND in these situations provides better control of the Type I error rate and better power in estimates of whole-plot error variances (Littell et al., 2006). Statistical analysis of soil water data was performed on profile totals or within a given depth. Data were analyzed as individual years with replication taken as a random effect term. Data were also analyzed across years with year and replication within year taken as random effects terms. Means separation was performed using LSD on the LSMEANS output utilizing the PDMIX800 macro (Saxton, 1998).

All reported means are least square means (LSMEANS) resulting from a mixed-model analysis. Each analysis fits the optimal mixed-model for that specific dataset and its variance-covariance structure. As a result, means presented in the across-years analysis will differ slightly than the arithmetic means of the individual years. In addition to each analysis being fit with a unique model, the across-years analysis uses a model with a different structure of random effects. Each unique model results in unique estimates for the LSMEANS. The across-years analysis also results in an unbalanced design due to five replications in 2010 and four replications in 2009 and 2011. The use of LSMEANS from the PROC MIXED procedure is the most appropriate way to handle unbalanced data (Milliken and Johnson, 2009). Reports of other agronomic research have shown LSMEANS to differ from arithmetic means when conducting across-years analysis with unbalanced data (Teasdale et al., 2007).

Results

2009

Growing conditions in 2009 were characterized by above normal precipitation throughout the course of the growing season (Figure 2.3), with a total in-season precipitation of 354 mm (13.92 inches) (Figure 2.4). Heat unit accumulation closely resembling the long-term average (Figure 2.5).

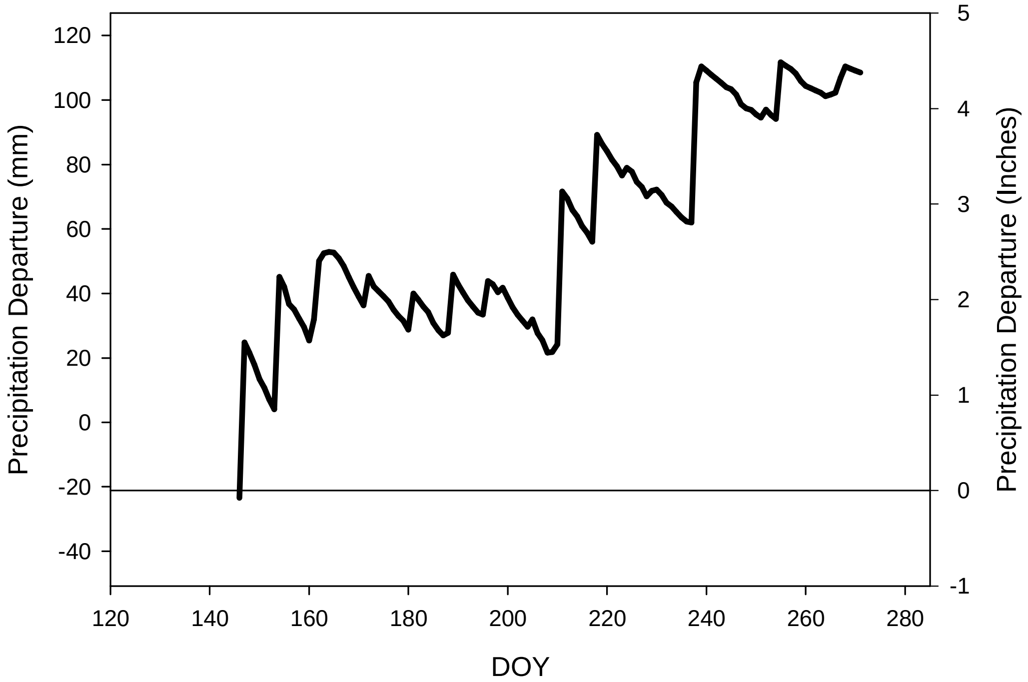

Figure 2.3 - Precipitation departure from normal during grain sorghum growing season. Tribune, Kansas, 2009.

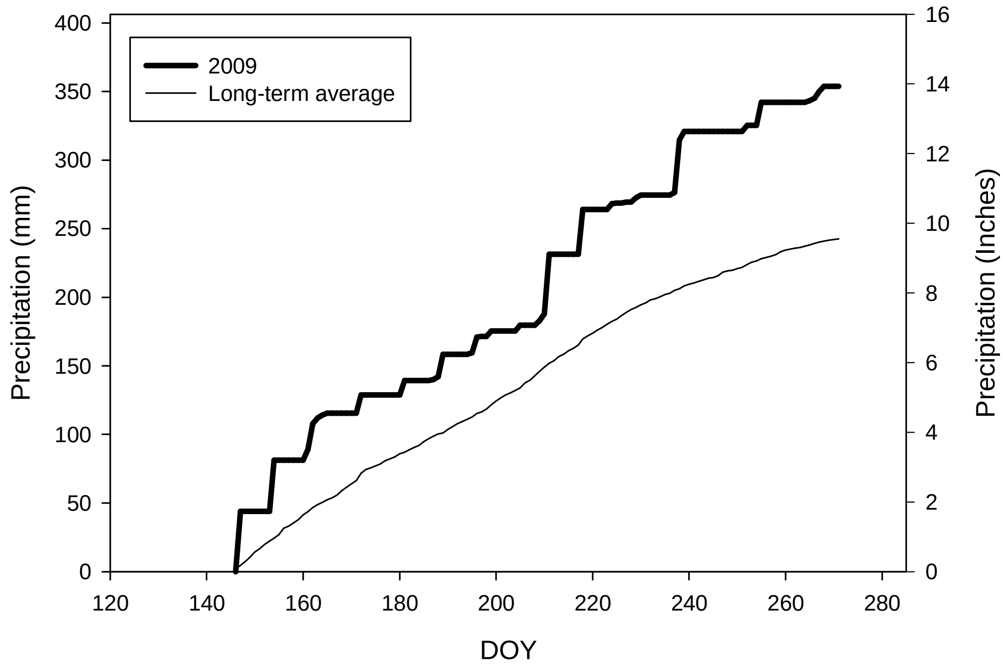

Figure 2.4 - Cumulative precipitation during grain sorghum growing season. Tribune, Kansas, 2009.

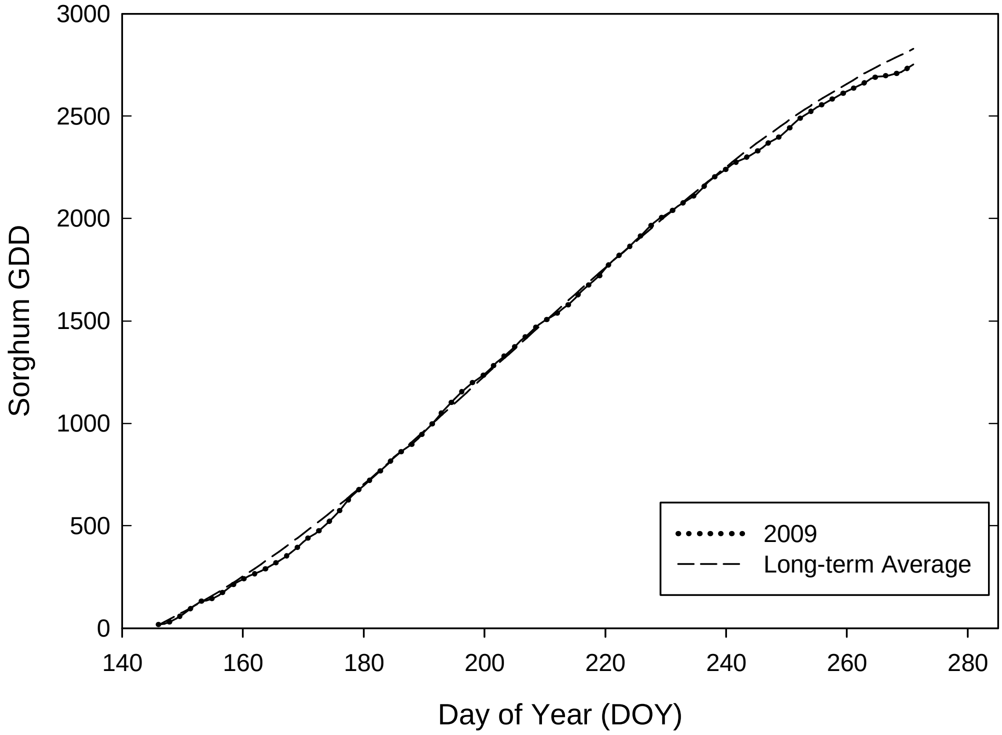

Figure 2.5 - Cumulative heat units during grain sorghum growing season. Tribune, Kansas 2009.

Yield, yield components, water use, and water use efficiency

Total above-ground biomass in 2009 was affected by planting geometry ($P<0.0001$) (Table 2.2). Sorghum planted in a clump or conventional geometry produced the highest levels of biomass, 29% more than the lowest levels which were produced by the P1S2 and P2S2 treatments. Sorghum planted in a cluster configuration produced an intermediate amount of above-ground biomass. Stover production was higher for sorghum planted in a clump or conventional geometry than all other configurations (Table 2.2). Sorghum grain yields followed the same trend as above-ground biomass ($P<0.0001$), with the highest yields produced by the clump and conventional configurations, the lowest by the skip-row configurations, and an intermediate yield from the cluster configuration. The same trend being evident both in above-ground biomass and grain yields was indicative of no treatment effects on harvest index (HI) (Table 2.2). Tillers plant^{-1} were affected by planting geometry ($P=0.0070$). Sorghum in a conventional or cluster geometry produced the greatest number of tillers plant^{-1}, averaging 2.4

(Table 2.2). Sorghum planted in a clump geometry produced the lowest number of tillers, 1.6 and was comparable to sorghum in a P1S1 geometry. Harvestable panicles plant^{-1} was affected by planting geometry ($P<0.0001$). Sorghum planted in a cluster configuration resulted in the largest number of panicles with grain while sorghum planted in either of the skip-row configurations produced the fewest number of harvestable panicles per plant (Table 2.2). Final plant stand was lower for sorghum in a cluster configuration than any other geometry (Table 2.2). This was a unique occurrence in 2009 and in-season observations would suggest it is likely due to a planter configuration error. Final panicle population was higher for clump, cluster, and conventional geometries than the skip-row configurations (Table 2.2). Yield per plant was highest for sorghum in the cluster geometry. This was driven by reduced plant stand and subsequent compensation evidenced by increases in the panicles plant^{-1}, kernels panicle^{-1}, and kernel weight yield components. This indicates that despite the alternative geometry some plasticity in yield components is still evident in the event of reduced stands. No differences were observed in total water use (Table 2.3), this combined with differences in total biomass production and grain yield, resulted in geometry affecting water use efficiency for grain production (WUEg) ($P<0.0001$) and water use efficiency for biomass production (WUEb) ($P<0.0001$). Sorghum planted in a clump or conventional geometry resulted in WUEg higher than any other treatment while sorghum planted in either of the skip-row configurations resulted in the lowest WUEg. A similar trend was evident in WUEb (Table 2.3).

Table 2.2- Effect of planting geometry on grain sorghum biomass, grain yield, and yield components. Tribune, Kansas, 2009.

Geometry	Above-ground biomass			Stover			Grain yield			Harvest index	Tillers plant^{-1}		Panicles plant^{-1}		Kernels panicle^{-1}	Plant population			Panicle population			Kernel weight	Yield plant^{-1}	
	Mg ha^{-1} (lb ac^{-1})			Mg ha^{-1} (lb ac^{-1})			Mg ha^{-1} (bu ac^{-1})			g g^{-1}						1000 ha^{-1} (1000 ac^{-1})			1000 ha^{-1} (1000 ac^{-1})			mg	g	
Clump	9.53	(8500)	a†	3.42	(3050)	a	7.06	(112)	a	0.52	1.6	c	2.2	b	1811	70.6	(28.6)	a	155.6	(63.0)	a	21.7	87	b
Cluster‡	7.55	(6740)	b	2.72	(2420)	b	5.59	(89)	b	0.52	2.1	ab	2.7	a	1899	41.7	(16.9)	b	111.6	(45.2)	b	22.9	118	a
Conventional	9.34	(8340)	a	3.49	(3110)	a	6.77	(108)	a	0.51	2.3	a	2.1	b	1751	74.3	(30.1)	a	153.9	(62.3)	a	21.8	79	b
P1S1	6.74	(6010)	c	2.54	(2270)	b	4.85	(77)	c	0.51	1.9	bc	1.4	c	1749	82.7	(33.5)	a	106.2	(43.0)	b	22.7	53	c
P2S2	6.59	(5880)	c	2.46	(2190)	b	4.78	(76)	c	0.51	1.9	b	1.3	c	1719	81.2	(32.9)	a	106.0	(42.9)	b	22.8	52	c
LSD = 0.05																								
Geometry	0.71	(640)		0.30	(260)		0.56	(9)		0.02	0.3		0.4		169	16.3	6.6		12.4	5.0		0.4	18	
											ANOVA P>F													
Effect																								
Geometry	<0.0001			<0.0001			<0.0001			0.3016	0.0070		<0.0001		0.2125	0.0009			<0.0001			0.2854	<0.0001	

† Letters within a column represent differences at LSD (0.05)

‡ Potentially affected by a planting error in 2009.

Table 2.3 - Effect of planting geometry on grain sorghum water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb). Tribune, Kansas, 2009.

Geometry	Water use		WUEg			WUEb		
	mm (in)		kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})			kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})		
Clump	369	(14.5)	16.5	(375)	a†	25.8	(585)	a
Cluster‡	357	(14.1)	13.6	(307)	b	21.2	(480)	b
Conventional	350	(13.8)	16.7	(379)	a	26.7	(605)	a
P1S1	354	(14.0)	11.9	(269)	c	19.0	(431)	c
P2S2	340	(13.4)	12.1	(275)	c	19.4	(439)	bc
LSD = 0.05								
Geometry	19	(0.7)	1.4	(31)		2.0	(46)	
			ANOVA P>F					
Effect								
Geometry	0.0572		<0.0001			<0.0001		

† Letters within a column represent differences at LSD (0.05)

‡ Potentially affected by a planting error in 2009.

Soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. Differences in profile water among tube positions were not observed in 2009 (Table 2.4). Relatively few differences among sampling positions within depths and geometries were observed in 2009 for the clump geometry (Table 2.5). Soil water contents tended to be highest near the cluster at measurements made later in the season (Table 2.6), particularly at depths of 15 to 76 cm (6 to 30 inches). In the conventional geometry, the only differences observed were located near the surface with the lowest soil water contents detected in-row early in the growing season and in-between rows later in the season (Table 2.7). Differences among tube position in the P1S1 geometry were most apparent at the harvest measurement where soil water content increased as measurement moved from the planted row to the middle of the skip (Table 2.8). Differences among tube positions with respect to depth were most apparent in the P2S2 geometry in 2009 (Table 2.9). Soil water contents early in the season were generally highest near the planted rows. However as the season progressed the highest water contents were generally found in the skip. On the 22 July measurement, soil water contents were higher in the skip than under the planted rows at seven depths.

Differences were detected in water use from 10 July to 22 July (P=0.0099) (Table 2.10) with P2S2 having the lowest rate of water use, 36 mm (1.41 inches), and clump, conventional, and P1S1 averaging a water use of 44 mm (1.74 inches). Sorghum in a cluster configuration was intermediate relative to the other treatments and used 42 mm (1.64 inches).

Table 2.4 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in grain sorghum planting geometries. Tribune, Kansas, 2009.

Geometry	Tube position	06/26/09		07/10/09		07/22/09		08/04/09		08/17/09		10/28/09	
	cm (inches)	Available soil water, mm (inches)											
Clump	0	177	(6.97)	173	(6.83)	153	(6.02)	131	(5.17)	109	(4.28)	94	(3.71)
	38 (15)	177	(6.98)	170	(6.70)	144	(5.68)	126	(4.97)	106	(4.18)	90	(3.52)
	76 (30)	180	(7.10)	176	(6.92)	152	(5.97)	132	(5.21)	108	(4.27)	94	(3.70)
Cluster	0	162	(6.38)	157	(6.18)	137	(5.38)	121	(4.77)	96	(3.77)	83	(3.25)
	38 (15)	162	(6.38)	158	(6.22)	135	(5.31)	114	(4.50)	94	(3.69)	80	(3.14)
	76 (30)	161	(6.34)	158	(6.22)	134	(5.29)	112	(4.41)	91	(3.59)	74	(2.93)
Conventional	0	174	(6.86)	169	(6.66)	145	(5.71)	134	(5.26)	113	(4.46)	103	(4.07)
	38 (15)	173	(6.81)	171	(6.72)	141	(5.53)	128	(5.04)	109	(4.29)	99	(3.91)
P1S1	0	170	(6.68)	163	(6.41)	143	(5.63)	127	(5.01)	102	(4.02)	87	(3.41)
	38 (15)	173	(6.81)	168	(6.63)	144	(5.65)	128	(5.04)	106	(4.16)	86	(3.39)
	76 (30)	177	(6.99)	175	(6.88)	153	(6.02)	135	(5.33)	111	(4.35)	90	(3.53)
P2S2	0	177	(6.96)	166	(6.56)	139	(5.45)	122	(4.82)	108	(4.25)	105	(4.13)
	38 (15)	173	(6.81)	166	(6.55)	146	(5.73)	131	(5.15)	113	(4.45)	107	(4.23)
	95 (37.5)	172	(6.76)	170	(6.68)	155	(6.11)	139	(5.49)	121	(4.78)	109	(4.28)
	152 (60)	164	(6.45)	162	(6.38)	153	(6.04)	144	(5.67)	127	(4.98)	102	(4.02)
LSD = 0.10													
	Tube Position	21	(0.82)	20	(0.77)	18	(0.70)	19	(0.77)	20	(0.78)	19	(0.77)
		ANOVA P>F											
Effect													
	Tube Position	0.9054		0.8892		0.5767		0.3901		0.2517		0.1008	

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Table 2.5 - Soil water by depth in grain sorghum planted in clump geometry. Tribune, Kansas 2009.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
06/26/2009	15 (6)	0.0870	0.254	b†	0.258	a	0.258	a
	30 (12)	0.6073	0.276		0.275		0.272	
	46 (18)	0.6365	0.258		0.265		0.265	
	61 (24)	0.5287	0.243		0.247		0.250	
	76 (30)	0.3012	0.237		0.239		0.242	
	91 (36)	0.6574	0.226		0.230		0.229	
	107 (42)	0.8368	0.219		0.222		0.221	
	122 (48)	0.6691	0.204		0.210		0.208	
	137 (54)	0.9729	0.197		0.196		0.197	
	152 (60)	0.2207	0.195		0.184		0.190	
	168 (66)	0.4819	0.193		0.184		0.192	
	183 (72)	0.7983	0.194		0.189		0.192	
07/10/2009	15 (6)	0.4750	0.249		0.241		0.245	
	30 (12)	0.6523	0.267		0.264		0.261	
	46 (18)	0.3682	0.250		0.254		0.261	
	61 (24)	0.2310	0.235		0.238		0.246	
	76 (30)	0.0776	0.230	b	0.231	b	0.237	a
	91 (36)	0.4926	0.221		0.221		0.225	
	107 (42)	0.6192	0.214		0.218		0.215	
	122 (48)	0.7513	0.207		0.210		0.207	
	137 (54)	0.9292	0.200		0.201		0.202	
	152 (60)	0.3359	0.200		0.190		0.197	
	168 (66)	0.2287	0.200		0.188		0.197	
	183 (72)	0.7179	0.201		0.195		0.196	
07/22/2009	15 (6)	0.1179	0.227		0.206		0.213	
	30 (12)	0.2252	0.241		0.230		0.235	
	46 (18)	0.4773	0.225		0.219		0.231	
	61 (24)	0.4910	0.213		0.213		0.219	
	76 (30)	0.3090	0.213		0.214		0.219	
	91 (36)	0.6434	0.209		0.212		0.212	
	107 (42)	0.5664	0.209		0.210		0.206	
	122 (48)	0.7135	0.203		0.206		0.202	
	137 (54)	0.9796	0.199		0.199		0.200	
	152 (60)	0.3371	0.200		0.189		0.199	
	168 (66)	0.3249	0.199		0.188		0.197	
	183 (72)	0.7082	0.200		0.195		0.196	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.5 (continued)- Soil water by depth in grain sorghum planted in clump geometry. Tribune, Kansas 2009.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
08/04/2009	15 (6)	0.0798	0.235	a†	0.226	b	0.225	b
	30 (12)	0.1766	0.228		0.223		0.224	
	46 (18)	0.4788	0.202		0.201		0.208	
	61 (24)	0.1708	0.184		0.185		0.207	
	76 (30)	0.0485	0.185	b	0.184	b	0.195	a
	91 (36)	0.9227	0.187		0.188		0.189	
	107 (42)	0.6909	0.191		0.191		0.188	
	122 (48)	0.4847	0.192		0.195		0.190	
	137 (54)	0.9434	0.194		0.194		0.195	
	152 (60)	0.5293	0.197		0.188		0.194	
	168 (66)	0.3760	0.200		0.190		0.193	
	183 (72)	0.5993	0.201		0.197		0.195	
08/17/2009	15 (6)	0.6090	0.213		0.212		0.211	
	30 (12)	0.8287	0.221		0.221		0.219	
	46 (18)	0.5408	0.195		0.198		0.202	
	61 (24)	0.2867	0.175		0.178		0.181	
	76 (30)	0.2608	0.172		0.173		0.177	
	91 (36)	0.7239	0.169		0.170		0.171	
	107 (42)	0.9138	0.170		0.171		0.170	
	122 (48)	0.6848	0.172		0.175		0.172	
	137 (54)	0.5985	0.179		0.179		0.176	
	152 (60)	0.1583	0.189		0.178		0.185	
	168 (66)	0.4282	0.195		0.185		0.191	
	183 (72)	0.4572	0.198		0.191		0.191	
10/28/2009	15 (6)	0.2974	0.264		0.258		0.253	
	30 (12)	0.1226	0.240		0.231		0.239	
	46 (18)	0.1850	0.193		0.190		0.202	
	61 (24)	0.1293	0.166		0.167		0.172	
	76 (30)	0.3158	0.160		0.161		0.163	
	91 (36)	0.4078	0.155		0.157		0.157	
	107 (42)	0.4342	0.154		0.154		0.152	
	122 (48)	0.3391	0.152		0.155		0.153	
	137 (54)	0.9016	0.155		0.156		0.156	
	152 (60)	0.3593	0.164		0.156		0.163	
	168 (66)	0.5215	0.172		0.164		0.170	
	183 (72)	0.6001	0.179		0.173		0.174	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.6 - Soil water by depth in grain sorghum planted in cluster geometry. Tribune, Kansas 2009.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
06/26/2009	15 (6)	0.0034	0.260	b†	0.270	a	0.263	b
	30 (12)	0.2713	0.275		0.273		0.271	
	46 (18)	0.1746	0.266		0.262		0.261	
	61 (24)	0.9346	0.242		0.240		0.241	
	76 (30)	0.7823	0.230		0.229		0.227	
	91 (36)	0.6890	0.216		0.216		0.218	
	107 (42)	0.3135	0.203		0.203		0.208	
	122 (48)	0.6940	0.185		0.183		0.188	
	137 (54)	0.9192	0.173		0.173		0.174	
	152 (60)	0.6310	0.175		0.179		0.177	
	168 (66)	0.5374	0.182		0.182		0.179	
	183 (72)	0.3432	0.191		0.190		0.185	
07/10/2009	15 (6)	0.4221	0.245		0.251		0.252	
	30 (12)	0.1973	0.268		0.264		0.263	
	46 (18)	0.8813	0.253		0.255		0.255	
	61 (24)	0.9846	0.233		0.233		0.234	
	76 (30)	0.2382	0.228		0.222		0.221	
	91 (36)	0.1575	0.215		0.210		0.214	
	107 (42)	0.1149	0.203		0.204		0.208	
	122 (48)	0.4982	0.194		0.193		0.198	
	137 (54)	0.9930	0.181		0.182		0.182	
	152 (60)	0.4036	0.176		0.183		0.178	
	168 (66)	0.2366	0.181		0.185		0.179	
	183 (72)	0.7627	0.188		0.190		0.187	
07/22/2009	15 (6)	0.5866	0.223		0.224		0.221	
	30 (12)	0.3220	0.242		0.234		0.234	
	46 (18)	0.7926	0.228		0.223		0.225	
	61 (24)	0.8578	0.209		0.205		0.207	
	76 (30)	0.8352	0.207		0.206		0.204	
	91 (36)	0.4408	0.201		0.200		0.203	
	107 (42)	0.3768	0.196		0.197		0.199	
	122 (48)	0.4573	0.191		0.190		0.194	
	137 (54)	0.9379	0.184		0.185		0.186	
	152 (60)	0.7248	0.179		0.183		0.179	
	168 (66)	0.5326	0.182		0.183		0.179	
	183 (72)	0.4856	0.190		0.190		0.185	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.6 (continued)- Soil water by depth in grain sorghum planted in cluster geometry. Tribune, Kansas 2009.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
08/04/2009	15 (6)	0.0090	0.237	a†	0.233	a	0.219	b
	30 (12)	0.0253	0.231	a	0.222	b	0.217	b
	46 (18)	0.1809	0.208		0.200		0.202	
	61 (24)	0.5563	0.185		0.179		0.180	
	76 (30)	0.6262	0.181		0.178		0.176	
	91 (36)	0.6043	0.180		0.176		0.179	
	107 (42)	0.1966	0.183		0.177		0.182	
	122 (48)	0.7531	0.184		0.181		0.182	
	137 (54)	0.7862	0.184		0.181		0.184	
	152 (60)	0.7875	0.180		0.183		0.181	
	168 (66)	0.6258	0.184		0.185		0.181	
	183 (72)	0.4912	0.194		0.189		0.187	
08/17/2009	15 (6)	0.0259	0.218	a	0.220	a	0.209	b
	30 (12)	0.1030	0.223		0.217		0.214	
	46 (18)	0.4142	0.197		0.193		0.193	
	61 (24)	0.7098	0.171		0.170		0.168	
	76 (30)	0.3912	0.166		0.164		0.162	
	91 (36)	0.7660	0.161		0.160		0.160	
	107 (42)	0.9901	0.160		0.160		0.160	
	122 (48)	0.3772	0.162		0.159		0.163	
	137 (54)	0.8529	0.166		0.166		0.167	
	152 (60)	0.6039	0.171		0.175		0.175	
	168 (66)	0.7140	0.179		0.179		0.177	
	183 (72)	0.6232	0.189		0.186		0.185	
10/28/2009	15 (6)	0.0347	0.268	a	0.261	a	0.248	b
	30 (12)	0.0181	0.233	a	0.221	b	0.211	c
	46 (18)	0.0037	0.193	a	0.188	b	0.183	c
	61 (24)	0.8584	0.164		0.162		0.162	
	76 (30)	0.0820	0.158	a	0.155	ab	0.152	b
	91 (36)	0.4902	0.149		0.151		0.151	
	107 (42)	0.1127	0.146		0.147		0.149	
	122 (48)	0.8838	0.147		0.147		0.146	
	137 (54)	0.9420	0.147		0.148		0.148	
	152 (60)	0.3437	0.149		0.153		0.152	
	168 (66)	0.7357	0.156		0.158		0.155	
	183 (72)	0.8844	0.167		0.165		0.165	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.7 - Soil water by depth in grain sorghum planted in conventional geometry. Tribune, Kansas 2009.

Date	Depth	ANOVA P>F	Tube position			
			0		38 cm (15 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}			
06/26/2009	15 (6)	0.0276	0.255	b†	0.258	a
	30 (12)	0.5495	0.270		0.265	
	46 (18)	0.9897	0.258		0.258	
	61 (24)	0.7227	0.242		0.238	
	76 (30)	0.8206	0.228		0.229	
	91 (36)	0.9463	0.222		0.222	
	107 (42)	0.6643	0.214		0.215	
	122 (48)	0.9624	0.204		0.204	
	137 (54)	0.8808	0.195		0.196	
	152 (60)	0.8566	0.195		0.196	
	168 (66)	0.8671	0.196		0.195	
	183 (72)	0.3593	0.199		0.195	
07/10/2009	15 (6)	0.5433	0.230		0.233	
	30 (12)	0.6259	0.259		0.254	
	46 (18)	0.7654	0.253		0.249	
	61 (24)	0.9277	0.233		0.232	
	76 (30)	0.5507	0.223		0.226	
	91 (36)	0.5473	0.219		0.221	
	107 (42)	0.2378	0.213		0.215	
	122 (48)	0.7694	0.209		0.208	
	137 (54)	0.2878	0.200		0.207	
	152 (60)	0.5171	0.198		0.205	
	168 (66)	0.9339	0.201		0.202	
	183 (72)	0.5176	0.207		0.203	
07/22/2009	15 (6)	0.5952	0.209		0.207	
	30 (12)	0.6335	0.228		0.221	
	46 (18)	0.5475	0.220		0.211	
	61 (24)	0.4654	0.209		0.199	
	76 (30)	0.5980	0.204		0.200	
	91 (36)	0.8137	0.203		0.202	
	107 (42)	0.7340	0.204		0.203	
	122 (48)	0.8908	0.202		0.203	
	137 (54)	0.5173	0.199		0.203	
	152 (60)	0.6370	0.198		0.202	
	168 (66)	0.9781	0.202		0.202	
	183 (72)	0.5013	0.208		0.204	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.7 (continued) - Soil water by depth in grain sorghum planted in conventional geometry. Tribune, Kansas 2009.

Date	Depth	ANOVA P>F	Tube position			
			0		38 cm (15 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}			
08/04/2009	15 (6)	0.0129	0.235	a†	0.229	b
	30 (12)	0.3631	0.230		0.219	
	46 (18)	0.7606	0.206		0.202	
	61 (24)	0.6188	0.186		0.182	
	76 (30)	0.6268	0.180		0.178	
	91 (36)	0.3861	0.184		0.180	
	107 (42)	0.9189	0.187		0.187	
	122 (48)	0.5378	0.194		0.192	
	137 (54)	0.7974	0.195		0.196	
	152 (60)	0.8579	0.199		0.201	
	168 (66)	0.9580	0.203		0.202	
	183 (72)	0.3272	0.211		0.205	
08/17/2009	15 (6)	0.9512	0.214		0.214	
	30 (12)	0.6648	0.223		0.219	
	46 (18)	0.9025	0.202		0.204	
	61 (24)	0.8635	0.180		0.178	
	76 (30)	0.8554	0.171		0.170	
	91 (36)	0.4664	0.170		0.167	
	107 (42)	0.3328	0.172		0.169	
	122 (48)	0.1414	0.176		0.173	
	137 (54)	0.6166	0.179		0.177	
	152 (60)	0.8407	0.187		0.186	
	168 (66)	0.6589	0.196		0.193	
	183 (72)	0.5334	0.204		0.200	
10/28/2009	15 (6)	0.2722	0.262		0.254	
	30 (12)	0.5251	0.231		0.227	
	46 (18)	0.9656	0.201		0.201	
	61 (24)	0.8467	0.176		0.174	
	76 (30)	0.8877	0.163		0.164	
	91 (36)	0.9515	0.161		0.161	
	107 (42)	0.6835	0.161		0.160	
	122 (48)	0.8135	0.162		0.162	
	137 (54)	0.9913	0.164		0.164	
	152 (60)	0.9537	0.169		0.168	
	168 (66)	0.5965	0.176		0.172	
	183 (72)	0.1562	0.186		0.179	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.8 - Soil water by depth in grain sorghum planted in plant-1 skip-1 (P1S1) geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cn (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
06/26/2009	15 (6)	0.1979	0.250		0.261		0.259	
	30 (12)	0.5869	0.265		0.272		0.271	
	46 (18)	0.8156	0.252		0.256		0.253	
	61 (24)	0.7036	0.239		0.239		0.242	
	76 (30)	0.5979	0.232		0.229		0.229	
	91 (36)	0.9295	0.224		0.223		0.223	
	107 (42)	0.0522	0.218	a†	0.213	b	0.220	a
	122 (48)	0.1536	0.206		0.206		0.211	
	137 (54)	0.0506	0.195	b	0.197	b	0.203	a
	152 (60)	0.1840	0.191		0.191		0.198	
	168 (66)	0.3643	0.189		0.192		0.193	
	183 (72)	0.0879	0.188	b	0.192	ab	0.197	a
07/10/2009	15 (6)	0.1978	0.233		0.247		0.249	
	30 (12)	0.4569	0.252		0.262		0.263	
	46 (18)	0.2183	0.241		0.247		0.253	
	61 (24)	0.2096	0.231		0.229		0.238	
	76 (30)	0.9714	0.223		0.223		0.224	
	91 (36)	0.6506	0.220		0.217		0.218	
	107 (42)	0.0114	0.213	b	0.210	c	0.216	a
	122 (48)	0.2493	0.206		0.208		0.210	
	137 (54)	0.0605	0.200	b	0.202	ab	0.206	a
	152 (60)	0.1434	0.196		0.197		0.203	
	168 (66)	0.2593	0.194		0.198		0.201	
	183 (72)	0.1428	0.193		0.199		0.201	
07/22/2009	15 (6)	0.9443	0.217		0.218		0.221	
	30 (12)	0.3120	0.225		0.229		0.240	
	46 (18)	0.3047	0.212		0.214		0.223	
	61 (24)	0.0863	0.207	b	0.204	b	0.215	a
	76 (30)	0.9880	0.207		0.206		0.206	
	91 (36)	0.8723	0.207		0.207		0.208	
	107 (42)	0.1220	0.207		0.203		0.209	
	122 (48)	0.1220	0.202		0.203		0.207	
	137 (54)	0.0004	0.198	b	0.198	b	0.205	a
	152 (60)	0.1664	0.197		0.196		0.201	
	168 (66)	0.3676	0.196		0.199		0.201	
	183 (72)	0.4380	0.196		0.199		0.202	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.8 (continued)- Soil water by depth in grain sorghum planted in plant-1 skip-1 (P1S1) geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position 0		38 cn (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
08/04/2009	15 (6)	0.7599	0.232		0.231		0.228	
	30 (12)	0.8938	0.223		0.224		0.227	
	46 (18)	0.8601	0.198		0.199		0.202	
	61 (24)	0.0873	0.183	b†	0.186	ab	0.191	a
	76 (30)	0.2975	0.184		0.181		0.186	
	91 (36)	0.2735	0.187		0.182		0.189	
	107 (42)	0.1595	0.192		0.187		0.195	
	122 (48)	0.0320	0.191	b	0.192	b	0.199	a
	137 (54)	0.0416	0.192	b	0.194	b	0.200	a
	152 (60)	0.2041	0.194		0.196		0.201	
	168 (66)	0.1654	0.194		0.199		0.202	
	183 (72)	0.2310	0.199		0.202		0.205	
08/17/2009	15 (6)	0.6128	0.212		0.216		0.215	
	30 (12)	0.5768	0.213		0.218		0.221	
	46 (18)	0.8714	0.191		0.194		0.193	
	61 (24)	0.5000	0.174		0.175		0.179	
	76 (30)	0.9164	0.170		0.169		0.170	
	91 (36)	0.2828	0.169		0.167		0.172	
	107 (42)	0.0513	0.172	a	0.167	b	0.174	a
	122 (48)	0.0421	0.171	b	0.169	b	0.178	a
	137 (54)	0.1186	0.174		0.176		0.181	
	152 (60)	0.5073	0.181		0.184		0.186	
	168 (66)	0.1710	0.185		0.193		0.192	
	183 (72)	0.2296	0.193		0.199		0.199	
10/28/2009	15 (6)	0.2578	0.257		0.258		0.249	
	30 (12)	0.8954	0.227		0.222		0.224	
	46 (18)	0.9794	0.187		0.185		0.187	
	61 (24)	0.8371	0.166		0.166		0.168	
	76 (30)	0.4061	0.160		0.157		0.159	
	91 (36)	0.5332	0.156		0.153		0.155	
	107 (42)	0.0665	0.154	a	0.151	b	0.155	a
	122 (48)	0.0041	0.152	b	0.153	b	0.156	a
	137 (54)	0.0011	0.153	b	0.153	b	0.160	a
	152 (60)	0.0743	0.157	b	0.159	ab	0.163	a
	168 (66)	0.0394	0.162	b	0.165	ab	0.168	a
	183 (72)	0.0930	0.172	b	0.176	ab	0.179	a

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.9 - Soil water by depth in grain sorghum planted in plant-2 skip-2 (P2S2) geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position							
			0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$							
06/26/2009	15 (6)	0.5250	0.258		0.252		0.258		0.258	
	30 (12)	0.3292	0.274		0.270		0.271		0.268	
	46 (18)	0.0605	0.268	a†	0.255	b	0.261	ab	0.254	b
	61 (24)	0.0778	0.250	a	0.238	b	0.239	b	0.234	b
	76 (30)	0.7755	0.230		0.228		0.227		0.225	
	91 (36)	0.3614	0.213		0.216		0.219		0.211	
	107 (42)	0.7666	0.207		0.208		0.211		0.207	
	122 (48)	0.6036	0.209		0.207		0.205		0.202	
	137 (54)	0.1361	0.204		0.202		0.200		0.189	
	152 (60)	0.0487	0.199	a	0.200	a	0.193	ab	0.185	b
	168 (66)	0.0436	0.192	ab	0.197	a	0.188	b	0.187	b
	183 (72)	0.1153	0.189		0.196		0.188		0.191	
07/10/2009	15 (6)	0.0035	0.226	b	0.231	b	0.252	a	0.253	a
	30 (12)	0.4721	0.249		0.258		0.267		0.263	
	46 (18)	0.1794	0.257		0.248		0.257		0.249	
	61 (24)	0.0892	0.242	a	0.231	b	0.232	b	0.228	b
	76 (30)	0.7882	0.225		0.220		0.222		0.222	
	91 (36)	0.8235	0.211		0.214		0.215		0.214	
	107 (42)	0.8107	0.206		0.208		0.211		0.208	
	122 (48)	0.5629	0.208		0.205		0.205		0.202	
	137 (54)	0.0204	0.207	a	0.204	a	0.206	a	0.192	b
	152 (60)	0.0368	0.205	a	0.204	a	0.198	a	0.187	b
	168 (66)	0.0465	0.200	ab	0.204	a	0.192	bc	0.189	c
	183 (72)	0.1185	0.190		0.199		0.192		0.192	
07/22/2009	15 (6)	0.0008	0.202	d	0.214	c	0.227	b	0.239	a
	30 (12)	0.0017	0.225	b	0.233	b	0.246	a	0.255	a
	46 (18)	0.0102	0.216	b	0.217	b	0.237	a	0.241	a
	61 (24)	0.0237	0.205	b	0.206	b	0.220	a	0.217	a
	76 (30)	0.0145	0.199	b	0.207	a	0.212	a	0.214	a
	91 (36)	0.0157	0.197	b	0.205	a	0.211	a	0.209	a
	107 (42)	0.0379	0.198	c	0.201	bc	0.207	a	0.205	ab
	122 (48)	0.6668	0.203		0.202		0.201		0.199	
	137 (54)	0.0206	0.203	a	0.201	a	0.203	a	0.191	b
	152 (60)	0.0580	0.204	a	0.202	a	0.200	a	0.189	b
	168 (66)	0.1124	0.200		0.202		0.194		0.190	
	183 (72)	0.1119	0.192		0.200		0.195		0.191	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.9 (continued)- Soil water by depth in grain sorghum planted in plant-2 skip-2 (P2S2) geometry. Tribune, Kansas, 2009.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$							
08/04/2009	15 (6)	0.4191	0.222		0.228		0.226		0.230	
	30 (12)	0.0004	0.223	c†	0.228	c	0.236	b	0.244	a
	46 (18)	0.0104	0.207	bc	0.202	c	0.216	ab	0.226	a
	61 (24)	0.0015	0.184	c	0.186	c	0.195	b	0.209	a
	76 (30)	0.0005	0.175	c	0.183	c	0.191	b	0.207	a
	91 (36)	0.0003	0.173	c	0.186	b	0.195	a	0.202	a
	107 (42)	0.0028	0.179	c	0.189	b	0.199	a	0.200	a
	122 (48)	0.2777	0.189		0.193		0.199		0.197	
	137 (54)	0.0460	0.193	bc	0.196	ab	0.200	a	0.191	c
	152 (60)	0.0721	0.199	a	0.201	a	0.200	a	0.190	b
	168 (66)	0.2314	0.199		0.200		0.195		0.191	
	183 (72)	0.1400	0.192		0.200		0.197		0.194	
08/17/2009	15 (6)	0.1973	0.208		0.213		0.222		0.218	
	30 (12)	0.3254	0.224		0.222		0.230		0.232	
	46 (18)	0.1771	0.208		0.197		0.208		0.213	
	61 (24)	0.4180	0.184		0.179		0.186		0.190	
	76 (30)	0.0606	0.169	b	0.173	b	0.178	ab	0.187	a
	91 (36)	0.0030	0.165	c	0.173	b	0.178	b	0.188	a
	107 (42)	0.0006	0.168	c	0.173	c	0.182	b	0.189	a
	122 (48)	0.0159	0.175	c	0.178	bc	0.182	b	0.189	a
	137 (54)	0.2191	0.179		0.183		0.188		0.185	
	152 (60)	0.2993	0.183		0.190		0.192		0.188	
	168 (66)	0.1992	0.190		0.198		0.189		0.193	
	183 (72)	0.0250	0.188	c	0.198	a	0.194	ab	0.193	b
10/28/2009	15 (6)	0.0667	0.263	a	0.264	a	0.261	a	0.250	b
	30 (12)	0.0023	0.248	a	0.249	a	0.239	a	0.222	b
	46 (18)	0.1186	0.209		0.202		0.205		0.194	
	61 (24)	0.7008	0.179		0.174		0.177		0.174	
	76 (30)	0.9720	0.165		0.165		0.166		0.167	
	91 (36)	0.4605	0.159		0.161		0.165		0.166	
	107 (42)	0.0342	0.157	c	0.162	bc	0.165	ab	0.168	a
	122 (48)	0.0742	0.163	c	0.163	bc	0.168	ab	0.169	a
	137 (54)	0.2905	0.165		0.166		0.171		0.167	
	152 (60)	0.5144	0.169		0.174		0.175		0.170	
	168 (66)	0.5933	0.172		0.178		0.175		0.176	
	183 (72)	0.2366	0.173		0.182		0.181		0.181	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.10 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated values, and water use as affected by grain sorghum planting geometry. Tribune, Kansas, 2009.

Geometry	06/26/2009			07/10/2009				07/22/2009				
	Profile available water	Range	SD	Profile available water	Range	SD	Cumulative water use	Profile available water	Range	SD	Cumulative water use	Interval water use
	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)
Clump	183 (7.19)	0.105	0.030	175 (6.89)	0.089	0.024	37 (1.47)	148 (5.84)	0.065	0.014	81 (3.20)	44 (1.73) ab
Cluster	168 (6.60)	0.112	0.036	162 (6.38)	0.099	0.030	35 (1.39)	137 (5.41)	0.072	0.019	77 (3.03)	42 (1.64) b
Conventional	180 (7.08)	0.094	0.028	174 (6.83)	0.091	0.022	36 (1.42)	144 (5.68)	0.072	0.015	82 (3.24)	46 (1.82) a
P1S1	178 (7.02)	0.101	0.028	172 (6.77)	0.081	0.021	36 (1.42)	147 (5.78)	0.061	0.012	78 (3.08)	42 (1.66) ab
P2S2	176 (6.94)	0.099	0.028	171 (6.73)	0.089	0.023	35 (1.39)	152 (5.99)	0.086	0.016	71 (2.79)	36 (1.41) c
LSD = 0.10												
Geometry	23 (0.90)	0.019	0.008	21 (0.82)	0.020	0.007	5 (0.18)	18 (0.72)	0.020	0.005	7 (0.29)	4 (0.17)
						ANOVA P>F						
Effect												
Geometry	0.8087	0.5305	0.2960	0.8197	0.6379	0.2222	0.9211	0.6940	0.2903	0.2716	0.1118	0.0099

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Geometry	08/04/2009					08/17/2009					10/28/2009				
	Profile available water	Range	SD	Cumulative water use	Interval water use	Profile available water	Range	SD	Cumulative water use	Interval water use	Profile available water	Range	SD	Cumulative water use	Interval water use
	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)
Clump	131 (5.16)	0.071	0.018	154 (6.07)	73 (2.88)	108 (4.27)	0.068	0.019	218 (8.59)	64 (2.52)	99 (3.88)	0.137 b	0.039	362 (14.2)	144 (5.66)
Cluster	119 (4.68)	0.075	0.021	152 (5.97)	75 (2.93)	96 (3.77)	0.073	0.022	216 (8.49)	64 (2.52)	88 (3.46)	0.162 a	0.042	357 (14.1)	142 (5.58)
Conventional	133 (5.24)	0.075	0.020	149 (5.88)	67 (2.64)	112 (4.43)	0.081	0.021	211 (8.32)	62 (2.44)	107 (4.21)	0.135 b	0.037	350 (13.8)	139 (5.48)
P1S1	132 (5.19)	0.069	0.018	149 (5.86)	71 (2.78)	107 (4.22)	0.071	0.019	215 (8.46)	66 (2.60)	94 (3.70)	0.140 b	0.039	362 (14.2)	147 (5.79)
P2S2	138 (5.44)	0.078	0.017	141 (5.54)	70 (2.74)	120 (4.72)	0.077	0.018	200 (7.88)	59 (2.34)	114 (4.48)	0.133 b	0.037	340 (13.4)	140 (5.51)
LSD = 0.10															
Geometry	23 (0.91)	0.023	0.006	12 (0.48)	9 (0.35)	23 (0.90)	0.013	0.003	15 (0.57)	5 (0.21)	22 (0.87)	0.018	0.005	16 (0.6)	7 (0.29)
								ANOVA P>F							
Effect															
Geometry	0.6551	0.9554	0.7545	0.3984	0.6192	0.4756	0.4739	0.1724	0.2595	0.3089	0.2960	0.0863	0.2807	0.1256	0.3883

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

2010

In-season precipitation during the 2010 season was below normal until DOY 204 and was above normal for the rest of the season (Figure 2.6), although the departure never exceeded 69 mm (2.73 inches). Cumulative in-season precipitation was 337 mm (13.28 inches) (Figure 2.7). Heat unit accumulation was above normal for the entire 2010 growing season ending 278 GDD above normal (Figure 2.8).

Yield, yield components, water use, and water use efficiency

Grain sorghum planted in either of the skip-row configurations resulted in the lowest above-ground biomass in 2010 ($P<0.0001$). The mean above-ground biomass for the skip-row treatments was 32% less than sorghum planted in either a clump or conventional geometry (Table 2.11). Sorghum planted in the cluster geometry was intermediate in above-ground biomass. Stover production followed a similar trend as above-ground biomass ($P=0.0004$) despite differences in harvest index. Sorghum planted in a clump, conventional, or cluster configuration resulted in an average grain yield of 8.46 Mg ha^{-1} (135 bu ac-1), 37% higher than grain yield of the P1S1 configuration and 64% higher than the P2S2 ($P<0.0001$). The large yield reduction of the P2S2 resulted both from reduced above-ground biomass and a reduction in HI compared to all other geometries ($P=0.0143$) (Table 2.11). Tillers $plant^{-1}$ was reduced in the skip-row geometries compared to the clump or conventional geometry. Final panicle population was reduced by 27% in the skip-row configurations ($P=0.0046$). The cumulative differences in yield components for the P2S2 configuration are further evident in a 29% reduction of yield $plant^{-1}$ ($P=0.0334$) (Table 2.11) relative to the clump or cluster geometry. Water use efficiency for both grain and total biomass was lowest for the skip-row configurations, highest for the clump and conventional configurations, and intermediate for sorghum planted in a cluster geometry (Table 2.12). Sorghum planted in a skip-row configuration resulted in decreased water use efficiencies of 34 and 31% for grain and biomass, respectively, compared to clump and conventional planting (Table 2.12).

Grain nutrient contents in 2010 were unaffected by planting geometry (Table 2.13) coinciding with no effect on kernel weight. Differences in nutrient removal were driven by differences in grain yield.

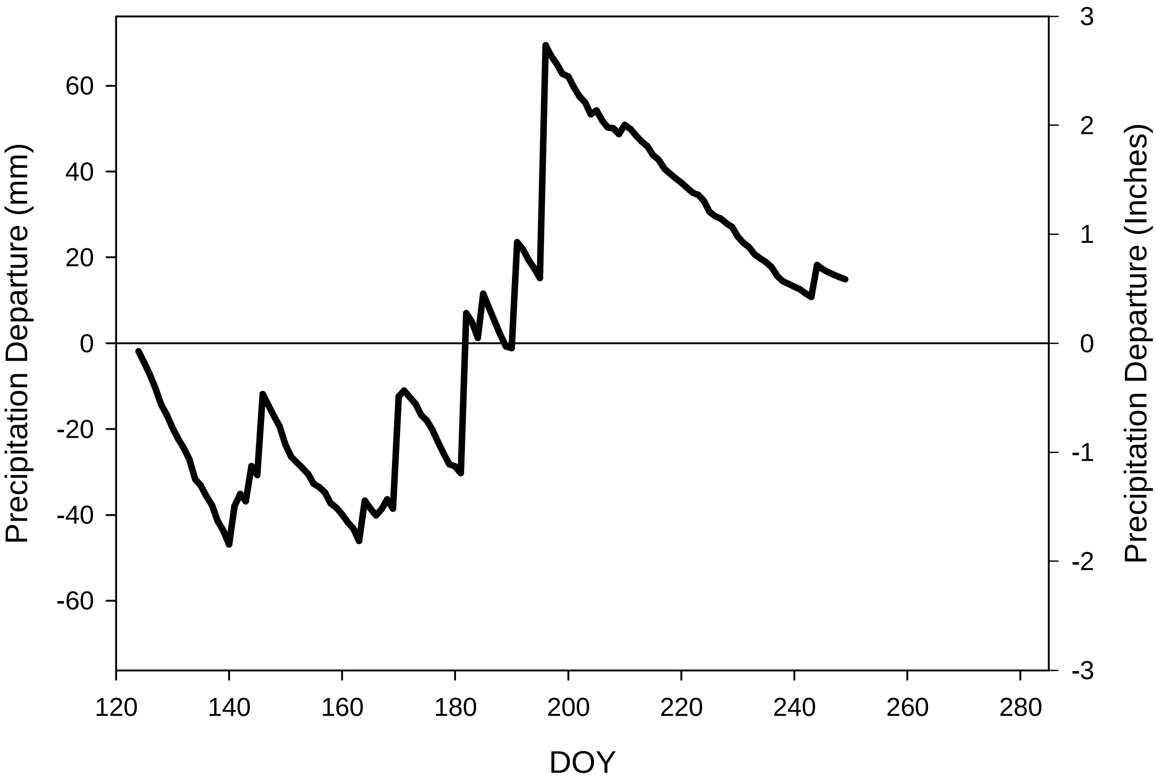

Figure 2.6 - Precipitation departure from normal during grain sorghum growing season. Tribune, Kansas, 2010.

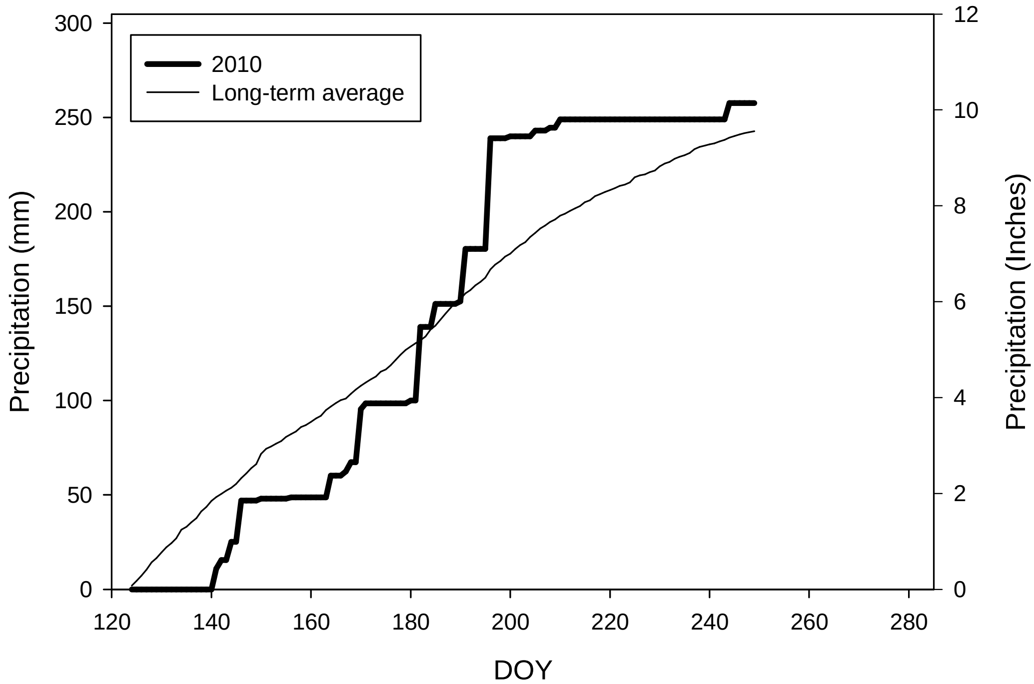

Figure 2.7 - Cumulative precipitation during grain sorghum growing season. Tribune, Kansas, 2010.

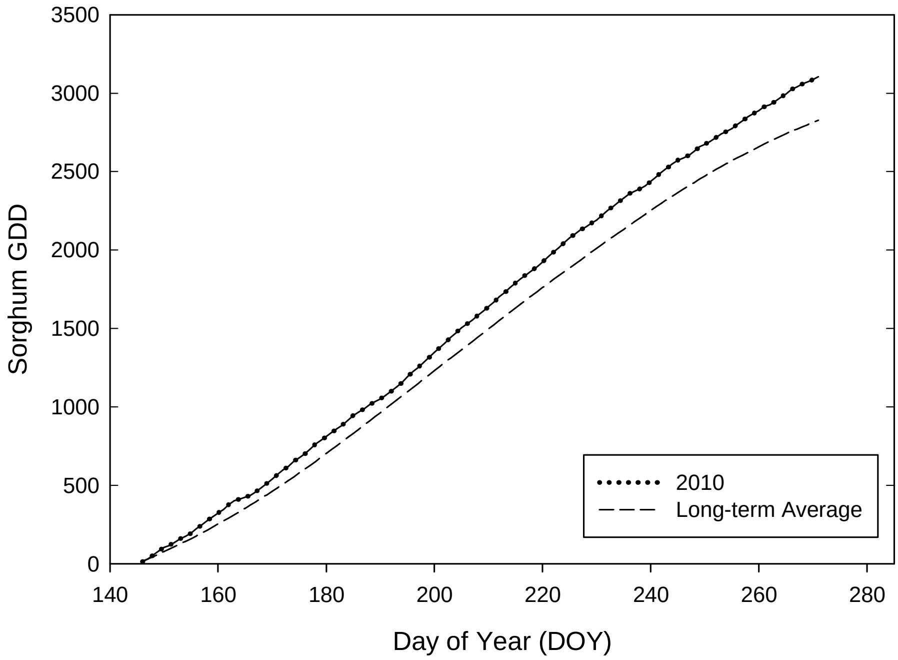

Figure 2.8 - Cumulative heat units during grain sorghum growing season. Tribune, Kansas 2010.

Table 2.11 - Effect of planting geometry on grain sorghum biomass, grain yield, and yield components. Tribune, Kansas, 2010.

Geometry	Above-ground biomass	Stover	Grain yield	Harvest index	Tillers $plant^{-1}$	Panicles $plant^{-1}$	Kernels $panicle^{-1}$	Plant population	Panicle population	Kernel weight	Yield $plant^{-1}$
	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (bu ac^{-1})	g g^{-1}				1000 ha^{-1} (1000 ac^{-1})	1000 ha^{-1} (1000 ac^{-1})	mg	g
Clump	12.8 (11,400) ab†	5.50 (4910) ab	8.45 (135) a	0.53 a	2.6 a	3.1	1551	64.1 (25.9) b	200.2 (81.0) a	22.8	114 a
Cluster	12.2 (10,900) b	5.17 (4610) b	8.17 (130) a	0.53 a	3.0 a	3.3	1535	62.9 (25.4) b	203.6 (82.4) a	23.4	114 a
Conventional	13.8 (12,300) a	6.25 (5580) a	8.77 (140) a	0.51 ab	2.6 ab	2.5	1452	90.4 (36.6) a	227.1 (91.9) a	23.2	85 b
P1S1	9.6 (8,580) c	4.26 (3800) c	6.19 (99) b	0.52 a	2.1 b	2.6	1367	65.7 (26.6) b	158.2 (64.0) b	24.0	85 b
P2S2	8.6 (7,650) c	4.11 (3660) c	5.17 (82) c	0.49 b	2.1 b	2.6	1349	58.1 (23.5) b	148.5 (60.1) b	24.0	81 b
LSD = 0.05											
Geometry	1.5 (1,340)	0.86 (770)	0.89 (14)	0.03	0.5	0.8	235	13.9 (5.6)	39.4 (15.9)	0.4	26
					ANOVA P>F						
Effect											
Geometry	<0.0001	0.0004	<0.0001	0.0143	0.0116	0.2661	0.2796	0.0022	0.0046	0.2900	0.0334

† Letters within a column represent differences at LSD (0.05)

Table 2.12 - Effect of planting geometry on grain sorghum water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb). Tribune, Kansas, 2010.

Geometry	Water use		WUEg			WUEb		
	mm (in)		kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})			kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})		
Clump	245	(9.7)	29.5	(668)	a	51.1	(1158)	a
Cluster	241	(9.5)	27.8	(629)	a	47.4	(1075)	a
Conventional	257	(10.1)	29.3	(663)	a	51.2	(1161)	a
P1S1	250	(9.8)	20.5	(464)	b	36.1	(817)	b
P2S2	255	(10.0)	17.4	(394)	b	32.6	(739)	b
LSD = 0.05								
Geometry	28	(1.1)	5.4	(122)		10.2	(231)	
	ANOVA P>F							
Effect								
Geometry	0.7127		0.0008			0.0038		

† Letters within a column represent differences at LSD (0.05)

Table 2.13 - Effect of planting geometry on sorghum grain nutrient content and nutrient removal. Tribune, Kansas, 2010.

Geometry	Grain N content	N removal			Grain P content	P removal		
	g kg^{-1}	kg ha^{-1} (lb ac^{-1})			g kg^{-1}	kg ha^{-1} (lb ac^{-1})		
Clump	17.2	125	(112)	ab†	3.8	28	(25)	a
Cluster	16.1	114	(102)	b	3.9	28	(25)	a
Conventional	17.2	130	(116)	ab	3.8	29	(26)	a
P1S1	17.3	92	(82)	c	3.9	21	(18)	b
P2S2	17.2	77	(69)	c	4.2	19	(17)	b
LSD = 0.05								
Geometry	1.2	15	(14)		0.4	3	(3)	
		ANOVA P>F						
Effect								
Geometry	0.2494	<0.0001			0.2647	<0.0001		

† Letters within a column represent differences at LSD (0.05)

Soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. Profile soil water differed among tube positions at all times of measurement in 2010 (Table 2.14). At the earliest measurement, 15 July, the highest levels of soil water were observed mid-skip of the P2S2 geometry (P=0.0176) and were similar to observed values at the 38 and 76 cm (15 and 37.5 inch) P2S2 positions and the 76 cm (30 inch) P1S1 position. The lowest level was observed at the 76 cm (30 inch) cluster position and was similar to the in-row and 38 cm (15 inch) cluster positions. At the second in-season measurement, which occurred at flowering / early grain fill, the highest profile water content was located mid-skip in the P2S2 geometry (P=0.0038) and was similar to observations in the other P2S2 positions and the 38 and 76 cm (15 and 30 inch) positions in the P1S1 geometry. The lowest profile total was the 76 cm (30 inch) cluster position along with the other cluster positions and in-row in the conventional geometry. At harvest the highest profile totals existed in the 38 and 95 cm (15 and 37.5 inch) P2S2 positions (P=0.0115) and were similar to many other positions (Table 2.14). The lowest profile water totals were observed in all three of the cluster positions as well as both of the conventional positions.

Few differences in soil water content with respect to depth and tube position were evident in the clump geometry (Table 2.15). When differences were present, soil water contents tended to be highest immediately adjacent to the clump. Differences were evident in the cluster treatment as the season progressed (Table 2.16) however their trends did not appear to be stable spatially or temporally. Differences present at the 168 cm (66 inch) depth were present from the beginning and appear to be artifacts of the plot location. At harvest, water content at the 61 and 76 cm (24 and 30 inch) depths increased as measurement moved away from the cluster. A difference in soil water content among tube positions was only found at one depth and one measurement time in the conventional geometry indicating a uniform extraction of water from the soil profile (Table 2.17). The 15 July measurement in the P1S1 treatment indicated lower levels of soil water, likely through root extraction, near the planted row (Table 2.18). Differences were observed at many depths on the 15 July and 11 August measurements in the P2S2 geometry, generally indicating higher levels of soil water were present in the skip away from the planted rows (Table 2.19). No differences were clearly evident at the harvest measurement. The higher occurrence of differences in the clump and skip-row treatments was also reflected in the highest ranges of soil water content in the interpolated data (Table 2.20). Differences in total profile water and water use were not evident however.

Only the range of interpolated soil water contents at harvest was affected by planting geometry in 2010 (Table 2.20). The range of soil water values found in the cross-section underlying the P1S1, P2S2, and clump treatments at harvest was larger than cluster or conventional. This indicates a less uniform soil profile, i.e. higher spatial variability with regard to soil water content. The increased range is accompanied by numerical increases in SD as well.

Table 2.14 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in grain sorghum planting geometries. Tribune, Kansas, 2010.

Geometry	Tube position	07/15/10			08/11/10			09/27/10		
	cm (inches)	Available soil water, mm (inches)								
Clump	0	154	(6.06)	b	125	(4.91)	bc	72	(2.83)	ab
	38 (15)	146	(5.76)	bcd	122	(4.79)	bc	66	(2.60)	abc
	76 (30)	145	(5.71)	bcd	123	(4.83)	bc	66	(2.59)	abc
Cluster	0	123	(4.84)	de	101	(3.98)	cd	50	(1.97)	d
	38 (15)	129	(5.08)	cde	97	(3.81)	cd	49	(1.95)	d
	76 (30)	120	(4.74)	e	91	(3.59)	d	48	(1.88)	d
Conventional	0	147	(5.79)	bcd	120	(4.73)	bcd	57	(2.24)	cd
	38 (15)	152	(5.98)	bc	131	(5.14)	b	58	(2.28)	bcd
P1S1	0	152	(6.00)	bc	134	(5.27)	b	71	(2.79)	abc
	38 (15)	152	(5.97)	bc	144	(5.68)	ab	70	(2.74)	abc
	76 (30)	159	(6.27)	ab	141	(5.54)	ab	68	(2.67)	abc
P2S2	0	154	(6.06)	b	146	(5.75)	ab	70	(2.75)	abc
	38 (15)	158	(6.24)	ab	143	(5.62)	ab	76	(3.01)	a
	95 (37.5)	161	(6.32)	ab	142	(5.59)	ab	73	(2.88)	a
	152 (60)	181	(7.11)	a	169	(6.65)	a	71	(2.80)	abc
LSD = 0.10										
	Tube Position	24	(0.95)		29	(1.14)		14	(0.56)	
		ANOVA P>F								
Effect										
	Tube Position	0.0176			0.0038			0.0115		

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Table 2.15 - Soil water by depth in grain sorghum planted in clump geometry. Tribune, Kansas 2010.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
07/15/2010	15 (6)	0.3203	0.228		0.211		0.215	
	30 (12)	0.1589	0.240		0.227		0.228	
	46 (18)	0.0822	0.227	a†	0.221	b	0.219	b
	61 (24)	0.2595	0.225		0.214		0.221	
	76 (30)	0.8031	0.232		0.229		0.230	
	91 (36)	0.8403	0.230		0.232		0.230	
	107 (42)	0.9615	0.223		0.224		0.222	
	122 (48)	0.8427	0.212		0.215		0.213	
	137 (54)	0.2895	0.205		0.204		0.198	
	152 (60)	0.1504	0.180		0.181		0.175	
	168 (66)	0.3773	0.171		0.167		0.166	
	183 (72)	0.8771	0.171		0.170		0.169	
08/11/2010	15 (6)	0.9793	0.220		0.221		0.222	
	30 (12)	0.7726	0.227		0.232		0.235	
	46 (18)	0.4426	0.208		0.211		0.206	
	61 (24)	0.8733	0.198		0.194		0.195	
	76 (30)	0.7100	0.198		0.194		0.196	
	91 (36)	0.5704	0.195		0.193		0.195	
	107 (42)	0.6710	0.191		0.188		0.192	
	122 (48)	0.8769	0.191		0.190		0.190	
	137 (54)	0.4867	0.191		0.189		0.189	
	152 (60)	0.3093	0.182		0.180		0.178	
	168 (66)	0.1163	0.176		0.172		0.172	
	183 (72)	0.3401	0.174		0.169		0.171	
09/27/2010	15 (6)	0.3061	0.169		0.144		0.156	
	30 (12)	0.0818	0.191	a	0.192	a	0.187	b
	46 (18)	0.7525	0.182		0.183		0.181	
	61 (24)	0.1897	0.172		0.167		0.171	
	76 (30)	0.4871	0.170		0.167		0.168	
	91 (36)	0.8229	0.158		0.160		0.159	
	107 (42)	0.3919	0.149		0.153		0.150	
	122 (48)	0.9616	0.151		0.151		0.151	
	137 (54)	0.4834	0.160		0.160		0.156	
	152 (60)	0.2515	0.165		0.161		0.156	
	168 (66)	0.1665	0.169		0.164		0.163	
	183 (72)	0.4699	0.171		0.167		0.168	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.16 - Soil water by depth in grain sorghum planted in cluster geometry. Tribune, Kansas 2010.

Date	Depth	ANOVA P>F	Tube position 0		Tube position 38 cm (15 inches)		Tube position 76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
07/15/2010	15 (6)	0.8019	0.213		0.209		0.210	
	30 (12)	0.6590	0.222		0.225		0.219	
	46 (18)	0.0615	0.210	b†	0.219	a	0.214	ab
	61 (24)	0.2832	0.205		0.211		0.209	
	76 (30)	0.3516	0.214		0.219		0.214	
	91 (36)	0.2732	0.216		0.214		0.211	
	107 (42)	0.2919	0.212		0.213		0.207	
	122 (48)	0.0825	0.204	b	0.210	a	0.201	b
	137 (54)	0.3514	0.187		0.193		0.187	
	152 (60)	0.4981	0.163		0.170		0.166	
	168 (66)	0.0477	0.150	ab	0.154	a	0.145	b
	183 (72)	0.3636	0.146		0.144		0.141	
08/11/2010	15 (6)	0.1327	0.205		0.223		0.208	
	30 (12)	0.1031	0.223		0.212		0.211	
	46 (18)	0.7847	0.199		0.195		0.197	
	61 (24)	0.4153	0.183		0.178		0.181	
	76 (30)	0.4729	0.183		0.180		0.182	
	91 (36)	0.6342	0.179		0.178		0.176	
	107 (42)	0.1896	0.178		0.179		0.173	
	122 (48)	0.0551	0.187	a	0.183	ab	0.178	b
	137 (54)	0.3887	0.181		0.177		0.175	
	152 (60)	0.1237	0.169		0.163		0.159	
	168 (66)	0.0316	0.159	a	0.152	b	0.147	b
	183 (72)	0.0598	0.152	a	0.149	ab	0.146	b
09/27/2010	15 (6)	0.0296	0.164	a	0.155	b	0.154	b
	30 (12)	0.3084	0.183		0.181		0.179	
	46 (18)	0.3305	0.169		0.172		0.172	
	61 (24)	0.0740	0.155	b	0.158	ab	0.162	a
	76 (30)	0.0668	0.156	b	0.157	ab	0.158	a
	91 (36)	0.2716	0.151		0.152		0.152	
	107 (42)	0.5837	0.145		0.146		0.145	
	122 (48)	0.1849	0.149		0.149		0.146	
	137 (54)	0.6645	0.147		0.149		0.148	
	152 (60)	0.3334	0.148		0.149		0.146	
	168 (66)	0.0124	0.148	a	0.147	a	0.143	b
	183 (72)	0.1290	0.148		0.144		0.144	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.17 - Soil water by depth in grain sorghum planted in conventional geometry. Tribune, Kansas 2010.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$			
07/15/2010	15 (6)	0.2671	0.225		0.213	
	30 (12)	0.9233	0.220		0.220	
	46 (18)	0.4142	0.211		0.220	
	61 (24)	0.3922	0.216		0.219	
	76 (30)	0.6869	0.227		0.224	
	91 (36)	0.3607	0.229		0.226	
	107 (42)	0.7956	0.224		0.223	
	122 (48)	0.4920	0.218		0.214	
	137 (54)	0.7391	0.208		0.211	
	152 (60)	0.1042	0.192		0.201	
	168 (66)	0.1651	0.170		0.190	
	183 (72)	0.3910	0.158		0.172	
08/11/2010	15 (6)	0.2537	0.215		0.231	
	30 (12)	0.3292	0.231		0.236	
	46 (18)	0.8221	0.205		0.207	
	61 (24)	0.8645	0.195		0.196	
	76 (30)	0.0770	0.195	b†	0.201	a
	91 (36)	0.4158	0.194		0.200	
	107 (42)	0.4376	0.187		0.194	
	122 (48)	0.6179	0.191		0.195	
	137 (54)	0.7132	0.192		0.195	
	152 (60)	0.3519	0.184		0.190	
	168 (66)	0.1248	0.172		0.179	
	183 (72)	0.1379	0.163		0.168	
09/27/2010	15 (6)	0.3090	0.162		0.153	
	30 (12)	0.3584	0.191		0.193	
	46 (18)	0.6970	0.174		0.174	
	61 (24)	0.6808	0.161		0.162	
	76 (30)	0.1465	0.158		0.161	
	91 (36)	0.9048	0.157		0.157	
	107 (42)	0.5438	0.147		0.148	
	122 (48)	0.4410	0.148		0.149	
	137 (54)	0.7785	0.150		0.151	
	152 (60)	0.1255	0.151		0.155	
	168 (66)	0.2989	0.153		0.155	
	183 (72)	0.8681	0.156		0.157	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.18 - Soil water by depth in grain sorghum planted in plant-1 skip-1 (P1S1) geometry. Tribune, Kansas, 2010.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cn (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
07/15/2010	15 (6)	0.7837	0.225		0.226		0.230	
	30 (12)	0.0335	0.237	b†	0.231	b	0.249	a
	46 (18)	0.0028	0.225	b	0.229	b	0.240	a
	61 (24)	0.0471	0.224	b	0.225	b	0.236	a
	76 (30)	0.1231	0.232		0.230		0.240	
	91 (36)	0.7680	0.233		0.231		0.235	
	107 (42)	0.5053	0.224		0.220		0.221	
	122 (48)	0.0602	0.217	a	0.216	a	0.210	b
	137 (54)	0.2855	0.204		0.203		0.196	
	152 (60)	0.8535	0.182		0.180		0.181	
	168 (66)	0.4587	0.168		0.169		0.173	
	183 (72)	0.0309	0.164	b	0.169	a	0.170	a
08/11/2010	15 (6)	0.0536	0.225	b	0.246	a	0.231	b
	30 (12)	0.8073	0.244		0.247		0.242	
	46 (18)	0.6125	0.220		0.227		0.226	
	61 (24)	0.5676	0.204		0.208		0.210	
	76 (30)	0.1425	0.202		0.209		0.211	
	91 (36)	0.0538	0.203	b	0.207	ab	0.209	a
	107 (42)	0.5900	0.198		0.201		0.201	
	122 (48)	0.1567	0.197		0.204		0.196	
	137 (54)	0.0302	0.193	b	0.201	a	0.194	b
	152 (60)	0.3505	0.181		0.186		0.185	
	168 (66)	0.6593	0.175		0.175		0.178	
	183 (72)	0.2753	0.170		0.171		0.174	
09/27/2010	15 (6)	0.0078	0.172	a	0.156	b	0.143	c
	30 (12)	0.4849	0.192		0.191		0.195	
	46 (18)	0.3634	0.180		0.181		0.183	
	61 (24)	0.2221	0.166		0.166		0.171	
	76 (30)	0.5312	0.164		0.164		0.167	
	91 (36)	0.8819	0.160		0.160		0.161	
	107 (42)	0.8582	0.153		0.153		0.152	
	122 (48)	0.1049	0.152		0.154		0.148	
	137 (54)	0.3183	0.160		0.166		0.156	
	152 (60)	0.9031	0.163		0.163		0.163	
	168 (66)	0.7814	0.168		0.166		0.168	
	183 (72)	0.7670	0.170		0.172		0.172	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.19 - Soil water by depth in grain sorghum planted in plant-2 skip-2 (P2S2) geometry. Tribune, Kansas, 2010.

Date	Depth	ANOVA P>F	Tube position							
			0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}							
07/15/2010	15 (6)	0.0042	0.204	c†	0.211	bc	0.226	b	0.255	a
	30 (12)	0.0022	0.229	c	0.236	bc	0.241	b	0.264	a
	46 (18)	0.0023	0.223	c	0.226	bc	0.233	b	0.249	a
	61 (24)	0.0095	0.213	b	0.218	b	0.235	a	0.242	a
	76 (30)	0.0118	0.228	b	0.231	b	0.242	a	0.247	a
	91 (36)	0.0121	0.239	b	0.240	b	0.241	b	0.251	a
	107 (42)	0.0389	0.231	b	0.232	b	0.225	b	0.239	a
	122 (48)	0.3581	0.220		0.221		0.221		0.225	
	137 (54)	0.3543	0.211		0.217		0.209		0.215	
	152 (60)	0.1119	0.197		0.198		0.182		0.193	
	168 (66)	0.2801	0.179		0.174		0.167		0.176	
	183 (72)	0.3770	0.169		0.170		0.167		0.163	
08/11/2010	15 (6)	0.0055	0.235	b	0.216	c	0.230	b	0.248	a
	30 (12)	0.0214	0.257	a	0.248	a	0.232	b	0.260	a
	46 (18)	0.2631	0.232		0.232		0.219		0.239	
	61 (24)	0.3454	0.209		0.207		0.209		0.224	
	76 (30)	0.0702	0.205	b	0.207	b	0.214	ab	0.226	a
	91 (36)	0.0012	0.208	b	0.211	b	0.214	b	0.232	a
	107 (42)	0.0051	0.202	b	0.201	b	0.205	b	0.224	a
	122 (48)	0.0043	0.196	c	0.196	c	0.207	b	0.219	a
	137 (54)	0.0345	0.195	b	0.203	b	0.204	b	0.214	a
	152 (60)	0.0983	0.192	ab	0.193	ab	0.188	b	0.200	a
	168 (66)	0.1900	0.185		0.184		0.177		0.185	
	183 (72)	0.0693	0.176	a	0.174	a	0.168	b	0.173	a
09/27/2010	15 (6)	0.1589	0.143		0.161		0.151		0.145	
	30 (12)	0.4768	0.197		0.197		0.197		0.192	
	46 (18)	0.2228	0.189		0.186		0.185		0.182	
	61 (24)	0.2088	0.170		0.173		0.170		0.166	
	76 (30)	0.9697	0.168		0.169		0.167		0.166	
	91 (36)	0.1960	0.166		0.168		0.165		0.171	
	107 (42)	0.3005	0.158		0.159		0.156		0.162	
	122 (48)	0.4782	0.150		0.153		0.155		0.155	
	137 (54)	0.5413	0.158		0.162		0.166		0.163	
	152 (60)	0.2912	0.162		0.166		0.165		0.168	
	168 (66)	0.2375	0.165		0.170		0.169		0.166	
	183 (72)	0.2087	0.168		0.171		0.168		0.165	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.20 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated values, and water use as affected by grain sorghum planting geometry. Tribune, Kansas, 2010.

Geometry	07/15/2010				08/11/2010						09/27/2010								
	Profile available water		Range	SD	Profile available water		Range	SD	Cumulative water use		Profile available water		Range		SD	Cumulative water use		Interval water use	
	mm (in)		$v\ v^{-1}$	$v\ v^{-1}$	mm (in)		$v\ v^{-1}$	$v\ v^{-1}$	cm (in)		mm (in)		$v\ v^{-1}$		$v\ v^{-1}$	mm (in)		mm (in)	
Clump	151	(5.95)	0.108	0.027	126	(4.97)	0.092	0.024	107	(4.19)	65	(2.54)	0.108	ab	0.023	245	(9.66)	139	(5.47)
Cluster	131	(5.18)	0.107	0.028	102	(4.03)	0.096	0.025	111	(4.37)	49	(1.95)	0.074	c	0.017	241	(9.49)	130	(5.12)
Conventional	157	(6.17)	0.093	0.022	132	(5.20)	0.092	0.024	106	(4.19)	59	(2.31)	0.090	bc	0.020	257	(10.1)	151	(5.93)
P1S1	158	(6.23)	0.112	0.031	147	(5.78)	0.105	0.027	93	(3.66)	67	(2.64)	0.117	a	0.023	250	(9.84)	157	(6.18)
P2S2	167	(6.57)	0.121	0.029	151	(5.96)	0.105	0.025	97	(3.83)	71	(2.81)	0.122	a	0.023	255	(10.0)	157	(6.19)
LSD = 0.10																			
Geometry	28	(1.09)	0.021	0.006	32	(1.25)	0.020	0.004	13	(0.50)	14	(0.57)	0.019		0.004	23	(0.89)	24	(0.93)
									ANOVA P>F										
Effect																			
Geometry	0.2714		0.2567	0.1892	0.1073		0.5872	0.7500	0.1319		0.1323		0.0044		0.1177	0.7127		0.2322	

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

2011

In-season precipitation in the 2011 season was near or below normal for the first half of the growing season until a large precipitation event on DOY 210 (Figure 2.9). Another large event was received late in the growing season resulting in an ending in-season precipitation of 156 mm (6.14 inches) above normal, although it played no role in crop growth and development. Cumulative in-season precipitation in 2011 was 434mm (17.09 inches) (Figure 2.10). Heat unit accumulation was above normal throughout the 2011 growing season, ending 500 GDD above normal (Figure 2.11).

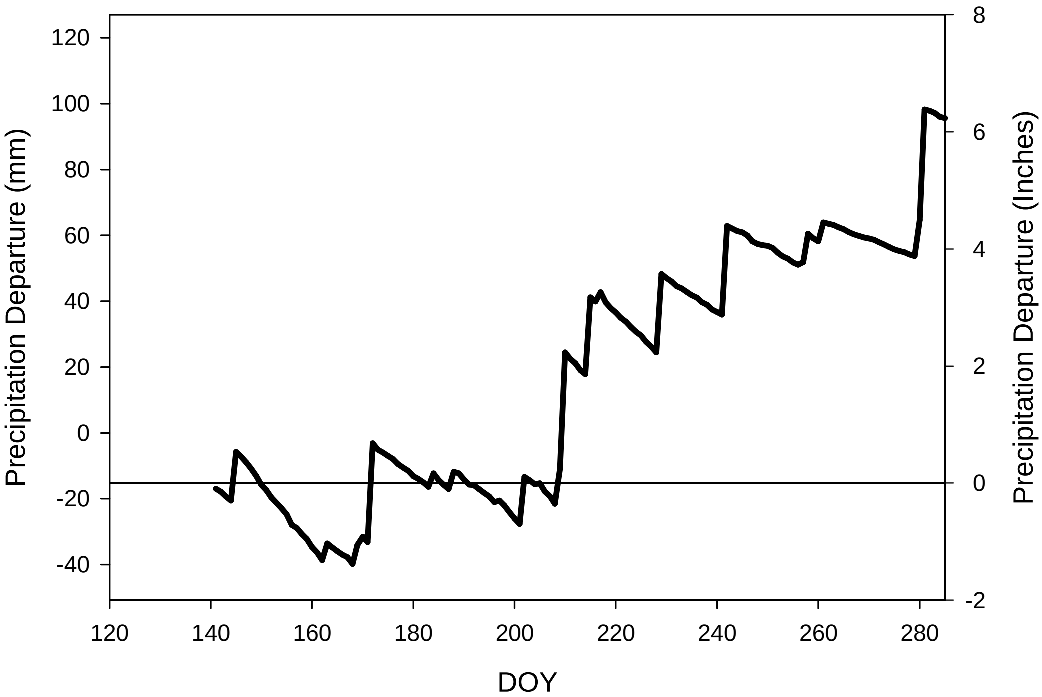

Figure 2.9 - Precipitation departure from normal during grain sorghum growing season. Tribune, Kansas, 2011.

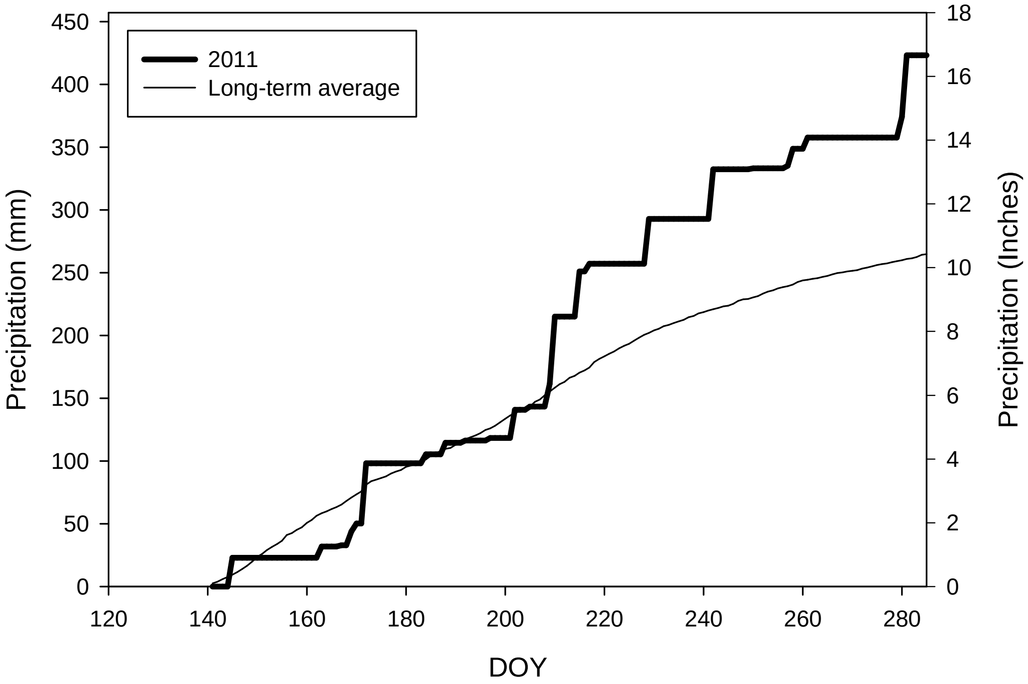

Figure 2.10 - Cumulative precipitation during grain sorghum growing season. Tribune, Kansas, 2011.

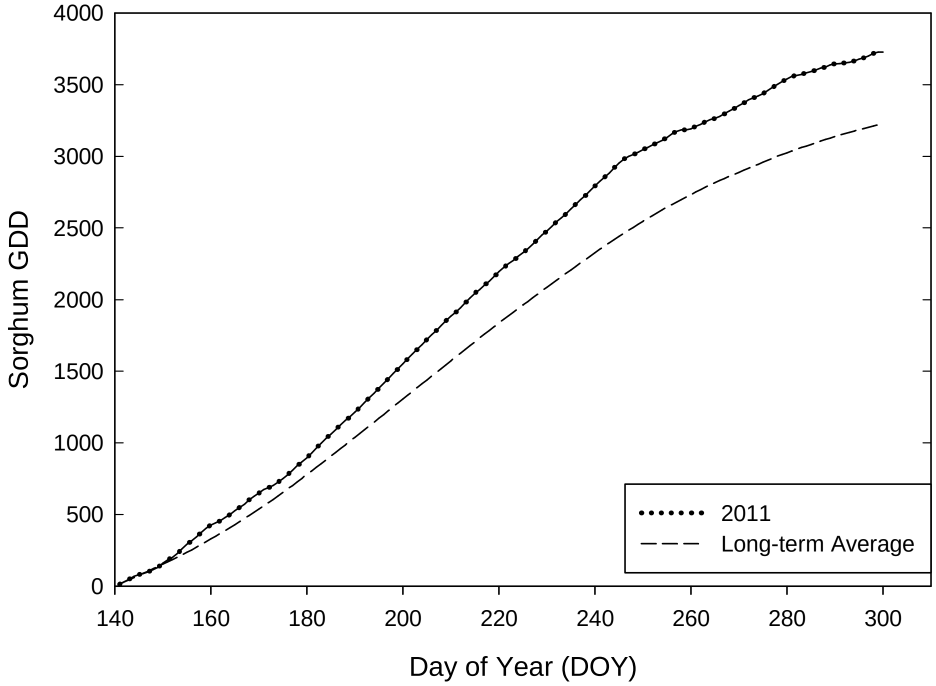

Figure 2.11 - Cumulative heat units during grain sorghum growing season. Tribune, Kansas 2011.

Yield, yield components, water use, and water use efficiency

Above-ground biomass was highest for the cluster and conventional geometries in 2011 (P=0.0023), averaging 12.3 Mg ha^{-1} (11,000 lb ac^{-1}), and lowest for the skip-row geometries with a mean of 9.35 Mg ha^{-1} (8340 lb ac^{-1}), a reduction of 24% (Table 2.21). Sorghum planted in a clump configuration produced an intermediate level of biomass, 10.7 Mg ha (9590 lb ac^{-1}). Stover production followed a similar trend as there was no difference in HI. Grain yields were reduced by 25% in the skip-row treatments and 8% in the clump treatment relative to the conventional and cluster configurations (Table 2.21). Tillers plant^{-1} was reduced an average of 38% (P=0.0366) when sorghum was planted in a skip-row configuration relative to the other geometries (Table 2.21). Kernels panicle^{-1} was highest for sorghum in a conventional or cluster geometry, lowest for the skip-row treatments, and intermediate for sorghum in a clump geometry. Reductions in kernels panicle^{-1} were somewhat offset by increased kernel weight for treatments with reduced kernel number, particularly the skip-row treatments. However, yield plant^{-1} was larger for treatments with more kerenels panicle^{-1}. Although tillering was reduced in the skip-row treatments, the concurrent reduction in kernels panicle^{-1} suggest that relative to the other geometries, yield was not limited by reductions in potential kernel number. Trends in yield plant^{-1} resembled those found in grain yield except that clump was in the top LSD grouping of yield plant^{-1} but not grain yield.. Season water use was unaffected by planting geometry, however both WUEg and WUEb responded to planting geometry (P=0.0018 and P=0.001, respectively) (Table 2.22). Water use efficiency for grain production was maximized when sorghum was planted in a cluster, conventional, or clump geometry and was the least for sorghum planted in skip-row configurations. Sorghum planted in a skip-row configuration resulted in a WUEb lower than the other geometries, while the highest values of WUEb were obtained with sorghum planted in a cluster or conventional configuration (Table 2.22).

Grain N content was on average 12% higher for sorghum planted in the skip-row geometries than the other treatments (P=0.0066) (Table 2.23), while grain P content was 19% higher (P=0.0140). These differences in grain nutrient content were not of large enough magnitude to overcome the reductions in grain yield for the associated treatments to result in detectable effects in nutrient removal.

Table 2.21 - Effect of planting geometry on grain sorghum biomass, grain yield, and yield components. Tribune, Kansas, 2011.

Geometry	Above-ground biomass			Stover			Grain yield			Harvest index	Tillers plant^{-1}		Panicles plant^{-1}	Kernels panicle^{-1}		Plant population		Panicle population			Kernel weight		Yield plant^{-1}	
	Mg ha^{-1} (lb ac^{-1})			Mg ha^{-1} (lb ac^{-1})			Mg ha^{-1} (bu ac^{-1})			g g^{-1}						1000 ha^{-1} (1000 ac^{-1})		1000 ha^{-1} (1000 ac^{-1})			mg		g	
Clump	10.7	(9,590)	bc†	4.34	(3870)	bc	7.47	(119)	b	0.55	1.2	a	2.0	1890	bc	71.4	(28.9)	147.2	(59.6)	a	23.4	c	92	a
Cluster	12.3	(11,000)	a	5.16	(4600)	a	8.16	(130)	a	0.54	1.3	a	2.0	2113	a	74.0	(30.0)	141.8	(57.4)	ab	23.7	bc	83	a
Conventional	12.3	(11,000)	ab	4.87	(4350)	ab	8.15	(130)	a	0.56	1.3	a	1.7	2018	ab	89.3	(36.2)	150.2	(60.8)	a	23.4	c	98	ab
P1S1	10.0	(8,880)	cd	4.15	(3700)	c	6.44	(103)	c	0.54	0.8	b	1.7	1724	cd	79.7	(32.2)	129.7	(52.5)	b	25.0	a	73	b
P2S2	8.8	(7,800)	d	3.71	(3310)	c	5.86	(93)	c	0.54	0.8	b	1.6	1693	d	79.2	(32.1)	112.5	(45.5)	c	24.6	ab	66	b
LSD = 0.05																								
Geometry	1.6	(1,430)		0.63	(560)		0.69	(11)		0.02	0.4		0.4	173		14.9	(6.0)	16.7	(6.8)		0.3		19	
											ANOVA P>F													
Effect																								
Geometry	0.0023			0.0032			<0.0001			0.2885	0.0366		0.0584	<0.0001		0.1340		0.0004			0.0045		0.0236	

† Letters within a column represent differences at LSD (0.05)

Table 2.22 - Effect of planting geometry on grain sorghum water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb). Tribune, Kansas, 2011.

Geometry	Water use		WUEg			WUEb		
	mm (in)		kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})			kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})		
Clump	377	(14.9)	17.0	(385)	ab	28.5	(645)	bc
Cluster	383	(15.1)	18.8	(425)	a	32.2	(730)	a
Conventional	388	(15.3)	19.1	(433)	a	31.6	(717)	ab
P1S1	385	(15.2)	15.1	(341)	bc	25.8	(585)	cd
P2S2	382	(15.1)	13.2	(299)	c	22.9	(519)	d
LSD = 0.05								
Geometry	8	(0.3)	2.5	(57)		3.7	(84)	
			ANOVA P>F					
Effect								
Geometry	0.1155		0.0018			0.0011		

† Letters within a column represent differences at LSD (0.05)

Table 2.23 - Effect of planting geometry on sorghum grain nutrient content and nutrient removal. Tribune, Kansas, 2011.

Geometry	Grain N content		N removal		Grain P content		P removal	
	$g\ kg^{-1}$		$kg\ ha^{-1}$ ($lb\ ac^{-1}$)		$g\ kg^{-1}$		$kg\ ha^{-1}$ ($lb\ ac^{-1}$)	
Clump	13.7	c†	88	(78)	2.5	c	16	(14)
Cluster	13.2	c	95	(85)	2.7	bc	20	(17)
Conventional	14.1	bc	104	(93)	2.7	c	20	(18)
P1S1	15.2	ab	88	(79)	3.1	ab	17	(16)
P2S2	15.5	a	83	(74)	3.2	a	17	(15)
LSD = 0.05								
Geometry	1.2		20	(18)	0.4		4	(3)
			ANOVA P>F					
Effect								
Geometry	0.0066		0.2356		0.0140		0.1659	

† Letters within a column represent differences at LSD (0.05)

Soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. Sampling positions resulted in differing levels of profile soil water for all times in 2011 (Table 2.24). At the first measurement, on 13 July, the highest levels of profile water were present in the skip area of the P2S2 geometry (P=0.0004) with the lowest levels present at all positions of the clump, cluster, and conventional geometries, and the 0 and 38 cm (0 and 15 inch) tube positions of the P1S1 configuration. At the in-season measurement on 27 July, the mid-skip position in P2S2 had a higher level of profile water than any other position (P<0.0001). The lowest observed profile total was the 38 cm (15 inch) clump position. This was similar to all other positions in the clump, cluster, and conventional geometries. At harvest the highest levels of soil water were found in the four P2S2 positions (P=0.0001). The lowest levels of profile water occurred at the 38 and 76 cm (15 and 30 inch) cluster positions and was similar to observations from all other cluster positions, all clump and conventional positions, and the 38 and 76 cm (15 and 30 inch) P1S1 positions (Table 2.24).

Table 2.24 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in grain sorghum planting geometries. Tribune, Kansas, 2011.

Geometry	Tube position	07/13/11			07/27/11			11/22/11		
	cm (inches)	Available soil water, mm (inches)								
Clump	0	123	(4.85)	f	88	(3.47)	fgh	76	(3.00)	cd
	38 (15)	123	(4.85)	f	85	(3.35)	h	74	(2.93)	cd
	76 (30)	125	(4.92)	ef	86	(3.38)	gh	80	(3.14)	cd
Cluster	0	130	(5.12)	def	89	(3.50)	fgh	76	(2.98)	cd
	38 (15)	126	(4.96)	ef	87	(3.44)	fgh	73	(2.89)	d
	76 (30)	132	(5.21)	cdef	94	(3.69)	defgh	73	(2.88)	d
Conventional	0	130	(5.14)	def	88	(3.48)	fgh	77	(3.05)	cd
	38 (15)	134	(5.26)	cdef	91	(3.58)	efgh	73	(2.86)	de
P1S1	0	131	(5.14)	def	99	(3.90)	cdefg	86	(3.37)	bc
	38 (15)	135	(5.32)	cdef	103	(4.06)	cde	81	(3.20)	cd
	76 (30)	142	(5.60)	cd	109	(4.30)	c	78	(3.07)	cd
P2S2	0	146	(5.74)	bc	107	(4.20)	cd	95	(3.74)	ab
	38 (15)	138	(5.44)	cde	101	(3.99)	cdef	95	(3.75)	ab
	95 (37.5)	158	(6.23)	ab	130	(5.13)	b	106	(4.17)	a
	152 (60)	165	(6.48)	a	154	(6.05)	a	105	(4.13)	a
LSD = 0.10										
	Tube Position	14	(0.55)		14	(0.56)		12	(0.48)	
		ANOVA P>F								
Effect										
	Tube Position	0.0004			<0.0001			0.0001		

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Very few differences between tube positions within depths and geometry were observed in the measured soil water data for the clump (Table 2.25), cluster (Table 2.26), and conventional (Table 2.27) geometries. Differences in the skip-row treatments were more apparent. Soil water contents in the P1S1 configuration increased with distance away from the planted row (Table 2.28). Near-surface soil water contents were lower in the skip-row area at the harvest measurement, likely due to evaporative losses. Soil water contents in the P2S2 geometry were notably different by tube position across seven depths on the 27 July measurement (Table 2.29), with higher water contents found in the middle of the skip area. These differences persisted through harvest at the deeper depths of the profile.

Analysis of the interpolated profile cross-section data revealed higher total profile water available in the P2S2 geometry than any other treatment at the 13 July (P=0.0620), 27 July (P=0.0030), and 22 November (P=0.0103) measurements (Table 2.30). At the 27 July measurement, total profile water in the P1S1 configuration was less than in P2S2 but higher than conventional, clump, or cluster. Water use from 13 July through 27 July was highest for the conventional and cluster geometries followed by the clump geometry, and lowest for the skip-row geometries, however, from 27 July through the harvest measurement, the skip-row treatments had higher water use than the other geometries. At the 27 July measurement, the highest range and SD of interpolated values was observed in the P2S2 configuration, indicating spatially variable soil water extraction.

Table 2.25 - Soil water by depth in grain sorghum planted in clump geometry. Tribune, Kansas 2011.

Date	Depth	ANOVA P>F	Tube position 0		38 cm (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}					
07/13/2011	15 (6)	0.4631	0.192		0.204		0.194	
	30 (12)	0.0313	0.213	b†	0.208	b	0.222	a
	46 (18)	0.3285	0.216		0.215		0.221	
	61 (24)	0.8940	0.221		0.222		0.220	
	76 (30)	0.3737	0.218		0.211		0.212	
	91 (36)	0.4140	0.206		0.201		0.208	
	107 (42)	0.8938	0.199		0.198		0.200	
	122 (48)	0.7512	0.188		0.185		0.186	
	137 (54)	0.9918	0.174		0.174		0.174	
	152 (60)	0.6792	0.170		0.172		0.170	
	168 (66)	0.1577	0.171		0.174		0.171	
	183 (72)	0.0934	0.176	b	0.180	a	0.176	b
07/27/2011	15 (6)	0.2595	0.172		0.182		0.174	
	30 (12)	0.2733	0.177		0.175		0.184	
	46 (18)	0.3774	0.166		0.167		0.171	
	61 (24)	0.6959	0.169		0.164		0.166	
	76 (30)	0.1102	0.178		0.162		0.165	
	91 (36)	0.4121	0.179		0.170		0.174	
	107 (42)	0.9138	0.183		0.181		0.182	
	122 (48)	0.8490	0.185		0.183		0.183	
	137 (54)	0.6487	0.178		0.176		0.174	
	152 (60)	0.4833	0.173		0.176		0.173	
	168 (66)	0.8518	0.174		0.175		0.174	
	183 (72)	0.7422	0.178		0.181		0.178	
11/22/2011	15 (6)	0.7823	0.229		0.234		0.232	
	30 (12)	0.0287	0.225	a	0.215	b	0.233	a
	46 (18)	0.0410	0.202	a	0.189	b	0.210	a
	61 (24)	0.2136	0.178		0.168		0.178	
	76 (30)	0.1374	0.156		0.148		0.155	
	91 (36)	0.5494	0.145		0.145		0.147	
	107 (42)	0.8633	0.145		0.146		0.146	
	122 (48)	0.1071	0.145		0.148		0.147	
	137 (54)	0.1523	0.146		0.150		0.148	
	152 (60)	0.1341	0.150		0.154		0.150	
	168 (66)	0.1055	0.153		0.159		0.153	
	183 (72)	0.2449	0.162		0.167		0.159	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.26 - Soil water by depth in grain sorghum planted in cluster geometry. Tribune, Kansas 2011.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cn (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
07/13/2011	15 (6)	0.3426	0.199		0.197		0.206	
	30 (12)	0.1418	0.222		0.214		0.220	
	46 (18)	0.4218	0.222		0.218		0.222	
	61 (24)	0.6001	0.218		0.221		0.218	
	76 (30)	0.8372	0.213		0.215		0.215	
	91 (36)	0.5703	0.207		0.199		0.208	
	107 (42)	0.2242	0.203		0.195		0.206	
	122 (48)	0.2393	0.198		0.193		0.199	
	137 (54)	0.3396	0.185		0.180		0.185	
	152 (60)	0.8363	0.175		0.174		0.174	
	168 (66)	0.6822	0.172		0.175		0.172	
	183 (72)	0.5278	0.175		0.180		0.179	
07/27/2011	15 (6)	0.2211	0.176		0.179		0.183	
	30 (12)	0.8032	0.177		0.176		0.177	
	46 (18)	0.8323	0.167		0.167		0.168	
	61 (24)	0.7116	0.164		0.164		0.168	
	76 (30)	0.7779	0.166		0.165		0.169	
	91 (36)	0.2334	0.174		0.170		0.179	
	107 (42)	0.4392	0.187		0.184		0.191	
	122 (48)	0.0761	0.189	ab†	0.184	b	0.192	a
	137 (54)	0.0645	0.186	a	0.180	b	0.187	a
	152 (60)	0.1913	0.180		0.176		0.179	
	168 (66)	0.5467	0.175		0.179		0.176	
	183 (72)	0.4325	0.175		0.183		0.180	
11/22/2011	15 (6)	0.8504	0.233		0.233		0.235	
	30 (12)	0.1096	0.226		0.218		0.219	
	46 (18)	0.0335	0.203	a	0.196	b	0.192	b
	61 (24)	0.1359	0.174		0.170		0.163	
	76 (30)	0.4261	0.153		0.149		0.149	
	91 (36)	0.8258	0.145		0.143		0.144	
	107 (42)	0.5303	0.146		0.143		0.148	
	122 (48)	0.4656	0.146		0.144		0.148	
	137 (54)	0.1164	0.146		0.145		0.149	
	152 (60)	0.1878	0.149		0.151		0.150	
	168 (66)	0.0904	0.151	b	0.159	a	0.154	ab
	183 (72)	0.4361	0.159		0.167		0.163	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.27 - Soil water by depth in grain sorghum planted in conventional geometry. Tribune, Kansas 2011.

Date	Depth	ANOVA P>F	Tube position			
			0		38 cm (15 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}			
07/13/2011	15 (6)	0.2908	0.192		0.203	
	30 (12)	0.2832	0.216		0.220	
	46 (18)	0.7132	0.223		0.224	
	61 (24)	0.6201	0.218		0.220	
	76 (30)	0.8397	0.215		0.216	
	91 (36)	0.2376	0.208		0.212	
	107 (42)	0.7338	0.204		0.205	
	122 (48)	0.8709	0.196		0.196	
	137 (54)	0.9113	0.186		0.186	
	152 (60)	0.6731	0.178		0.176	
	168 (66)	0.7941	0.175		0.175	
	183 (72)	0.3222	0.180		0.178	
07/27/2011	15 (6)	0.3466	0.178		0.182	
	30 (12)	0.7517	0.181		0.182	
	46 (18)	0.1454	0.168		0.171	
	61 (24)	0.6118	0.161		0.163	
	76 (30)	0.9801	0.164		0.163	
	91 (36)	0.7248	0.170		0.172	
	107 (42)	0.3172	0.180		0.184	
	122 (48)	0.2413	0.186		0.189	
	137 (54)	0.8360	0.187		0.186	
	152 (60)	0.9883	0.181		0.181	
	168 (66)	0.8371	0.178		0.178	
	183 (72)	0.1954	0.183		0.179	
11/22/2011	15 (6)	0.9843	0.234		0.234	
	30 (12)	0.0545	0.231	a†	0.224	b
	46 (18)	0.0494	0.208	a	0.197	b
	61 (24)	0.0379	0.178	a	0.169	b
	76 (30)	0.1523	0.151		0.149	
	91 (36)	0.2864	0.143		0.144	
	107 (42)	0.0633	0.142	b	0.144	a
	122 (48)	0.5273	0.144		0.144	
	137 (54)	0.4926	0.148		0.147	
	152 (60)	0.6750	0.151		0.149	
	168 (66)	0.7883	0.152		0.152	
	183 (72)	0.0917	0.160	a	0.158	b

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.28 - Soil water by depth in grain sorghum planted in plant-1 skip-1 (P1S1) geometry. Tribune, Kansas, 2011.

Date	Depth	ANOVA P>F	Tube position					
			0		38 cn (15 inches)		76 cm (30 inches)	
	cm (inches)		Volumetric water content, $cm^3\ cm^{-3}$					
07/13/2011	15 (6)	0.0184	0.199	b†	0.207	b	0.223	a
	30 (12)	0.0396	0.224	b	0.225	b	0.238	a
	46 (18)	0.0076	0.221	b	0.226	b	0.235	a
	61 (24)	0.0573	0.220	b	0.225	ab	0.229	a
	76 (30)	0.1730	0.216		0.220		0.221	
	91 (36)	0.9176	0.208		0.209		0.210	
	107 (42)	0.4177	0.200		0.204		0.204	
	122 (48)	0.2633	0.193		0.197		0.198	
	137 (54)	0.7359	0.184		0.188		0.185	
	152 (60)	0.9877	0.175		0.174		0.174	
	168 (66)	0.7979	0.174		0.171		0.173	
	183 (72)	0.9886	0.177		0.176		0.176	
07/27/2011	15 (6)	0.7891	0.185		0.189		0.187	
	30 (12)	0.4688	0.187		0.187		0.190	
	46 (18)	0.0077	0.176	b	0.180	b	0.188	a
	61 (24)	0.0166	0.176	b	0.179	b	0.189	a
	76 (30)	0.0023	0.178	c	0.186	b	0.195	a
	91 (36)	0.0480	0.183	b	0.190	a	0.193	a
	107 (42)	0.1705	0.187		0.193		0.196	
	122 (48)	0.2905	0.188		0.192		0.194	
	137 (54)	0.5926	0.185		0.187		0.188	
	152 (60)	0.6840	0.180		0.177		0.180	
	168 (66)	0.6441	0.178		0.173		0.175	
	183 (72)	0.8347	0.181		0.179		0.178	
11/22/2011	15 (6)	0.0032	0.239	a	0.226	b	0.214	c
	30 (12)	0.0064	0.234	a	0.225	b	0.209	c
	46 (18)	0.0777	0.210	a	0.206	a	0.190	b
	61 (24)	0.1120	0.189		0.184		0.174	
	76 (30)	0.5378	0.166		0.163		0.161	
	91 (36)	0.2624	0.149		0.150		0.153	
	107 (42)	0.1440	0.148		0.148		0.153	
	122 (48)	0.0553	0.148	b	0.151	ab	0.155	a
	137 (54)	0.1431	0.148		0.150		0.155	
	152 (60)	0.0749	0.151	b	0.150	b	0.156	a
	168 (66)	0.2124	0.154		0.153		0.159	
	183 (72)	0.2784	0.159		0.000		0.166	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.29 - Soil water by depth in grain sorghum planted in plant-2 skip-2 (P2S2) geometry. Tribune, Kansas, 2011.

Date	Depth	ANOVA P>F	Tube position							
			0		38 cm (15 inches)		95 cm (37.5 inches)		152 cm (60 inches)	
	cm (inches)		Volumetric water content, cm^3 cm^{-3}							
07/13/2011	15 (6)	0.0003	0.199	b†	0.192	b	0.236	a	0.234	a
	30 (12)	0.0001	0.219	b	0.215	b	0.247	a	0.251	a
	46 (18)	0.0019	0.226	c	0.219	c	0.236	b	0.249	a
	61 (24)	0.0099	0.227	b	0.217	c	0.229	b	0.242	a
	76 (30)	0.6339	0.224		0.219		0.224		0.227	
	91 (36)	0.4995	0.219		0.212		0.222		0.216	
	107 (42)	0.3780	0.212		0.208		0.215		0.212	
	122 (48)	0.7154	0.212		0.206		0.205		0.207	
	137 (54)	0.8091	0.199		0.199		0.200		0.204	
	152 (60)	0.9361	0.190		0.190		0.192		0.193	
	168 (66)	0.8174	0.183		0.182		0.184		0.189	
	183 (72)	0.5197	0.179		0.181		0.182		0.190	
07/27/2011	15 (6)	0.0014	0.186	c	0.185	c	0.204	b	0.227	a
	30 (12)	0.0006	0.180	c	0.185	c	0.206	b	0.242	a
	46 (18)	0.0005	0.175	c	0.176	c	0.201	b	0.234	a
	61 (24)	0.0044	0.174	c	0.167	c	0.198	b	0.228	a
	76 (30)	0.0243	0.182	bc	0.170	c	0.201	ab	0.213	a
	91 (36)	0.0227	0.185	b	0.175	b	0.203	a	0.208	a
	107 (42)	0.0360	0.192	b	0.188	b	0.206	a	0.205	a
	122 (48)	0.5598	0.199		0.196		0.201		0.204	
	137 (54)	0.4936	0.196		0.190		0.198		0.200	
	152 (60)	0.4260	0.192		0.192		0.198		0.194	
	168 (66)	0.8301	0.187		0.188		0.188		0.192	
	183 (72)	0.4225	0.186		0.186		0.185		0.195	
11/22/2011	15 (6)	0.7127	0.237		0.225		0.239		0.225	
	30 (12)	0.4127	0.231		0.235		0.230		0.224	
	46 (18)	0.5634	0.213		0.219		0.206		0.207	
	61 (24)	0.8569	0.193		0.196		0.187		0.192	
	76 (30)	0.9982	0.173		0.174		0.174		0.174	
	91 (36)	0.1058	0.159		0.158		0.171		0.165	
	107 (42)	0.0111	0.155	b	0.154	b	0.168	a	0.167	a
	122 (48)	0.3101	0.159		0.158		0.166		0.168	
	137 (54)	0.0222	0.155	b	0.154	b	0.168	a	0.171	a
	152 (60)	0.0381	0.157	b	0.159	b	0.173	a	0.170	a
	168 (66)	0.0785	0.160	c	0.162	bc	0.171	ab	0.176	a
	183 (72)	0.1567	0.166		0.167		0.176		0.182	

† Letters within a row represent differences within a geometry, time, and depth at LSD (0.10)

Table 2.30 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated values, and water use as affected by grain sorghum planting geometry. Tribune, Kansas, 2011.

Geometry	07/13/2011			07/27/2011				11/22/2011				
	Profile available water	Range	SD	Profile available water	Range	SD	Cumulative water use	Profile available water	Range	SD	Cumulative water use	Interval water use
	mm (in)	v v^{-1}	v v^{-1}	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)	v v^{-1}	v v^{-1}	mm (in)	mm (in)
Clump	125 (4.92) b	0.076	0.019	86 (3.38) c	0.052 b	0.012 ab	66 (2.60) b	81 (3.21) b	0.103	0.033	377 (14.9)	311 (12.3) b
Cluster	129 (5.09) b	0.064	0.018	89 (3.51) c	0.039 c	0.010 b	67 (2.64) ab	80 (3.14) b	0.112	0.034	383 (15.1)	316 (12.5) b
Conventional	135 (5.32) b	0.074	0.019	91 (3.57) c	0.039 c	0.011 b	71 (2.81) a	81 (3.18) b	0.103	0.036	388 (15.3)	317 (12.5) b
P1S1	138 (5.43) b	0.078	0.020	105 (4.12) b	0.037 c	0.009 b	60 (2.37) c	87 (3.41) b	0.097	0.031	385 (15.2)	325 (12.8) a
P2S2	154 (6.06) a	0.082	0.019	123 (4.86) a	0.079 a	0.015 a	59 (2.31) c	106 (4.17) a	0.102	0.029	382 (15.1)	324 (12.8) a
LSD = 0.10												
Geometry	15 (0.59)	0.015	0.006	13 (0.52)	0.020	0.003	5 (0.19)	11 (0.43)	0.019	0.005	7 (0.3)	6 (0.2)
						ANOVA P>F						
Effect												
Geometry	0.0620	0.3331	0.9671	0.0030	0.0007	0.0717	0.0048	0.0103	0.3882	0.1561	0.1155	0.0061

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

2009-2011 Across-years

Yield, yield components, water use, and water use efficiency

When evaluated across years, sorghum planted in either of the skip-row configurations resulted in 26% less above-ground biomass relative to the mean of the other geometries ($P<0.0001$) (Table 2.31). Harvest index was unaffected by planting geometry, thus differences in grain yield ($P<0.0001$) mirrored the response of above-ground biomass (Table 2.31). Reduced grain yields in the skip row treatment resulted from reductions in panicles plant^{-1} ($P=0.0160$) and kernels panicle^{-1} ($P=0.0044$) despite having increased kernel weight ($P=0.0046$) (Table 2.31). Plant population was affected by geometry, although the reduced value for the cluster treatment is driven by the planter mechanical error in 2009. Differences in panicle population among treatments were more influential in grain yield than differences in plant population. Sorghum planted in either of the skip-row treatments had 23% less harvestable panicles than sorghum planted in the clump or conventional geometry ($P=0.0002$) (Table 2.31). Yield plant^{-1} was reduced 34% in the skip-row geometries relative to the clump and cluster geometries. Plant population was numerically higher for conventionally planted sorghum in two of the three years, resulting in an intermediate value for yield plant^{-1}. Water use efficiency for grain production was minimized with sorghum planted in either of the skip-row treatments relative to the other geometries ($P=0.0022$) (Table 2.32). Water use efficiency for biomass production was highest ($P=0.0210$) for sorghum grown in a clump or conventional geometry, lowest in a P2S2 geometry, and intermediate for the P1S1 and cluster geometries.

Grain nutrient contents across years were unaffected by planting geometry (Table 2.33), although the affects of differences in grain N content in 2011 are evident in the across-years means. Differences in nutrient removal were driven primarily by differences in grain yield and not grain nutrient content (Table 2.33) despite numerically higher means for grain nutrient content resulting from the 2011 crop year.

Table 2.31 - Effect of planting geometry on grain sorghum biomass, grain yield, and yield components. Tribune, Kansas, 2009-2011.

Geometry	Above-ground biomass[†]	Stover	Grain yield	Harvest index	Tillers plant^{-1}	Panicles plant^{-1}	Kernels panicle^{-1}	Plant population	Panicle population	Kernel weight	Yield plant^{-1}
	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (lb ac^{-1})	Mg ha^{-1} (bu ac^{-1})	g g^{-1}				1000 ha^{-1} (1000 ac^{-1})	1000 ha^{-1} (1000 ac^{-1})	mg	g
Clump	11.2 (9,960) a[‡]	4.50 (4020) ab	7.66 (122) a	0.53	1.8	2.5 ab	1757 ab	68.5 (27.7) bc	163.4 (66.1) a	22.8 b	98 a
Cluster[§]	10.8 (9,660) a	4.41 (3930) ab	7.56 (120) a	0.53	2.1	2.7 a	1878 a	59.3 (24.0) c	150.5 (60.9) ab	23.4 ab	110 a
Conventional	12.0 (10,700) a	4.98 (4440) a	8.01 (128) a	0.52	2.1	2.1 bc	1774 ab	84.5 (34.2) a	171.1 (69.2) a	22.9 b	83 b
P1S1	8.8 (7,880) b	3.70 (3300) bc	5.99 (96) b	0.52	1.6	1.9 c	1610 bc	75.8 (30.7) ab	131.7 (53.3) bc	24.1 a	70 bc
P2S2	7.9 (7,090) b	3.44 (3070) c	5.34 (85) b	0.51	1.7	1.9 c	1573 c	71.9 (29.1) b	125.6 (50.8) c	24.0 a	65 c
LSD = 0.05											
Geometry	1.6 (1450)	0.95 (850)	0.68 (11)	0.02	0.6	0.5	172	11.2 (4.5)	21.8 (8.8)	0.2	15
					ANOVA P>F						
Effect											
Geometry	<0.0001	0.0143	<0.0001	0.1577	0.2171	0.0160	0.0044	0.0008	0.0002	0.0046	<0.0001

† Table values are least square means and may differ from across-years arithmetic means.
† Letters within a column represent differences at LSD (0.05)
‡ Potentially affected by a planting error in 2009.

Table 2.32 - Effect of planting geometry on grain sorghum water use, grain water use efficiency (WUEg), and biomass water use efficiency (WUEb). Tribune, Kansas, 2009-2011.

Geometry	Water use		WUEg			WUEb		
	mm (in)		$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)			$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)		
Clump	324	(12.7)	21.4	(486)	a	36.0	(816)	a
Cluster‡	320	(12.6)	20.5	(464)	a	34.5	(781)	ab
Conventional	325	(12.8)	22.1	(502)	a	37.4	(847)	a
P1S1	323	(12.7)	16.2	(368)	b	27.8	(631)	bc
P2S2	313	(12.3)	14.8	(336)	b	26.1	(591)	c
LSD = 0.05								
Geometry	45	(1.8)	4.2	(95)		8.0	(181)	
			ANOVA P>F					
Effect								
Geometry	0.9872		0.0022			0.0210		

† Letters within a column represent differences at LSD (0.05)

‡ Potentially affected by a planting error in 2009.

Table 2.33 - Effect of planting geometry on sorghum grain nutrient content and nutrient removal. Tribune, Kansas, 2010-2011.

Geometry	Across Years							
	Grain N content†	N removal			Grain P content	P removal		
	g kg^{-1}	kg ha^{-1} (lb ac^{-1})			g kg^{-1}	kg ha^{-1} (lb ac^{-1})		
Clump	15.6	109	(97)	a‡	3.3	23	(20)	ab
Cluster	14.9	106	(94)	ab	3.4	24	(22)	a
Conventional	15.8	119	(106)	a	3.3	25	(22)	a
P1S1	16.4	90	(81)	bc	3.5	19	(17)	b
P2S2	16.7	78	(69)	c	3.8	18	(16)	b
LSD = 0.05								
Geometry	1.6	16	(14)		0.6	5	(4)	
	ANOVA P>F							
Effect								
Geometry	0.1909	0.0001			0.3400	0.0269		

† Table values are least square means and may differ from across-years arithmetic means.
‡ Letters within a columnrepresent differences at LSD (0.05)

Soil water

Interpolated cross-sectional figures that visually present soil water content and soil water changes can be found in the appendix. Measurements of profile soil water from individual years were grouped by cumulative GDD since planting and sorghum developmental stage to perform an across-years analysis. At the early vegetative timing, which on average occurred 1298 GDD after planting, differences between tube positions were observed (Table 2.34). The highest level of profile soil water was present in the middle of the skip of the P2S2 geometry followed by the 95 cm (37.5 inch) P2S2 position. The lowest level of profile water occurred at the (30 inch) cluster position, similar to the cluster 0 and 38 cm (0 and 15 inch) positions and the clump 38 cm (15 inch) position. At the flower / grain fill time of measurement, typically around 1826 GDD, the highest level of soil water was present in the middle of the skip of the P2S2 geometry (Table 2.34). The lowest values were present in all clump, cluster, and conventional positions as well as the P1S1 in-row and P2S2 between-rows positions. At harvest the highest levels of profile soil water occurred at all four positions of the P2S2 geometry (Table 2.34). The lowest levels of soil water occurred in the three positions of the cluster treatment.

Table 2.34 - Available soil water in 183 cm (72 inch) profile as affected by sampling position in grain sorghum planting geometries. Tribune, Kansas, 2009-2011.

Geometry	Tube position	Early vegetative (1298 GDD)			Flower / grain fill (1826 GDD)			Harvest		
	cm (inches)	Available soil water, mm (inches)								
Clump	0	143	(5.64)	cd	110	(4.32)	de	81	(3.18)	bc
	38 (15)	138	(5.43)	def	106	(4.16)	de	77	(3.02)	cd
	76 (30)	141	(5.53)	de	109	(4.29)	de	80	(3.14)	c
Cluster	0	130	(5.12)	ef	105	(4.14)	de	69	(2.73)	de
	38 (15)	130	(5.12)	ef	101	(3.97)	e	68	(2.66)	e
	76 (30)	129	(5.08)	f	103	(4.05)	de	65	(2.56)	e
Conventional	0	141	(5.54)	cd	111	(4.37)	cde	79	(3.12)	c
	38 (15)	142	(5.59)	cd	109	(4.31)	de	77	(3.02)	cd
P1S1	0	142	(5.59)	cd	113	(4.46)	cde	81	(3.19)	bc
	38 (15)	143	(5.65)	cd	116	(4.55)	cd	79	(3.11)	c
	76 (30)	152	(5.97)	bc	122	(4.82)	bc	78	(3.09)	c
P2S2	0	145	(5.73)	cd	113	(4.46)	cde	90	(3.53)	ab
	38 (15)	147	(5.81)	bcd	116	(4.55)	cd	93	(3.66)	a
	95 (37.5)	157	(6.19)	ab	133	(5.24)	ab	95	(3.75)	a
	152 (60)	166	(6.52)	a	146	(5.73)	a	92	(3.61)	a
LSD = 0.10										
	Tube Position	11	(0.43)		13	(0.51)		9	(0.35)	
		ANOVA P>F								
Effect										
	Tube Position	<0.0001			<0.0001			<0.0001		

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Analysis of the interpolated soil water contents across years at the early vegetative, flower / grain fill, and harvest timings revealed treatment effects on profile available water and water use (Table 2.35). At the early vegetative timing the highest levels of available water in the profile cross-section were present in the P2S2 configuration (P=0.0378) with similar levels present in the P1S1 and conventional geometries. The lowest levels of available water in the profile cross-section were evident in the clump and cluster geometries. When measured at flower / grain fill, the profile cross-section under sorghum in a P2S2 configuration had 130 mm (5.10 inches), more available soil water than any other treatment except P1S1 (P=0.0342). The lowest amount of soil water was found in the cluster configuration and was similar to clump and conventional with a mean profile available water of 108 mm (4.26 inches). The range in interpolated values was also highest for the P2S2 geometry (P=0.0661), indicating a more uneven spatial distribution of soil water in the profile. Cumulative water use from early vegetative to flowering / grain fill was highest for sorghum in a clump, cluster, or conventional configuration (P=0.0315) compared to the P1S1 and P2S2 geometries. Differences in profile water content remained at harvest time with the highest level found with the P2S2 geometry (P=0.0018). Profile water contents for the clump, conventional, and P1S1 configurations were intermediate in nature and the least available soil water was found under the cluster treatment. Water use from flowering / grain fill through physiological maturity was higher for the skip-row treatments than either clump or cluster (P=0.0438).

Table 2.35 - Available soil water in 183 cm (72 inch) deep cross-section, range and SD of interpolated values, and water use as affected by grain sorghum planting geometry. Tribune, Kansas, 2009-2011.

Geometry	Early vegetative (1187 GDD)			Flower / grain fill (1826 GDD)					Harvest				
	Profile available water	Range	SD	Profile available water	Range	SD	Cumulative water use	Interval water use	Profile available water	Range	SD	Cumulative water use	Interval water use
	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)
Clump	150 (5.92) bc	0.091	0.023	114 (4.51) bc	0.072 b	0.018	109 (4.29) a	73 (2.88)	82 (3.21) b	0.116	0.032	328 (12.92)	198 (7.80) b
Cluster	141 (5.55) c	0.090	0.025	103 (4.07) c	0.070 b	0.019	110 (4.33) a	75 (2.93)	72 (2.85) c	0.116	0.031	327 (12.88)	196 (7.72) b
Conventional	155 (6.11) ab	0.086	0.021	119 (4.67) ab	0.069 b	0.018	109 (4.29) a	67 (2.64)	82 (3.23) b	0.109	0.031	332 (13.07)	202 (7.96) ab
P1S1	156 (6.14) ab	0.090	0.024	128 (5.03) ab	0.070 b	0.018	101 (3.97) b	71 (2.78)	83 (3.25) b	0.118	0.031	332 (13.08)	210 (8.25) a
P2S2	164 (6.44) a	0.098	0.024	137 (5.40) a	0.086 a	0.019	99 (3.88) b	70 (2.74)	97 (3.80) a	0.120	0.030	325 (12.81)	207 (8.15) a
LSD = 0.10													
Geometry	12 (0.46)	0.011	0.003	13 (0.52)	0.011	0.003	6 (0.23)	9 (0.36)	9 (0.35)	0.013	0.003	10 (0.38)	8 (0.33)
							ANOVA P>F						
Effect													
Geometry	0.0378	0.5190	0.3222	0.0016	0.0834	0.9466	0.0028	0.6277	0.0018	0.7082	0.8012	0.7025	0.0438

† Letters within a column represent differences at LSD (0.10) unless noted otherwise

Discussion

Above-ground biomass and grain yield

Planting grain sorghum in a skip-row configuration, particularly P2S2, resulted in less above-ground biomass and grain yield than the other geometries in all years. Reduction of biomass production in skip-row plantings has been observed in several environments abroad (Blum and Naveh, 1976; Fukai and Foale, 1988) as well as the southern High Plains (Jones and Johnson, 1991). In contrast to the findings of Bandaru et al. (2006) and Kapanigowda et al. (2010) there was no reduction in above-ground biomass for the clump geometry relative to the conventional configuration. Bandaru et al. (2006) and Kapanigowda et al. (2010), using several different hybrids including Pioneer 8699 and Dekalb 39Y, reported that the reduction in biomass for the clump treatment resulted primarily from reduced tillering. In this study, the clump geometry was effective in reducing tillering in only one of three years. With no effective reduction in tillering, the mechanism by which clump planting was shown to reduce above-ground biomass was inhibited.

Reduced grain yields in skip-row compared with conventional geometry is not a particularly unique observation. It is well established that wider row spacing or the use of a skip-row system would reduce light interception, net radiation, and thus plant growth and yield when RUE is not limited by water stress (Earl and Davis, 2003). Multi-year average grain sorghum yields at the study site, in the context of a wheat-sorghum-fallow rotation, have been reported as 4.4 Mg ha^{-1} (70 bu ac^{-1}) to 6.2 Mg ha^{-1} (99 bu ac^{-1}) (Schlegel 2013a, 2013b). All three years of the study produced average to above average grain yields for the site with means of 5.81, 7.35, and 7.22 Mg ha^{-1} (93, 117, and 115 bu. ac^{-1}) in 2009, 2010, and 2011, respectively. The yields attained in this study indicate that water supplies were adequate to support a higher level of light interception than accomplished by the skip-row treatments. Other researchers have used the yield of the conventional geometry or the mean of geometries to define the environmental threshold above which skip-row plantings intercept inadequate levels of light to maximize plant growth and yield. In central and western Nebraska, Abunyewa et al. (2010) reported that sorghum in a conventional geometry produced higher yields than several skip-row configurations when the mean yield across geometries exceeded 4.5 Mg ha^{-1} (72 bu ac^{-1}) and recommended skip-row techniques be used when growing season water supply (sum of 120 cm soil profile water at planting and in-season precipitation) was expected to be <675 mm (26.6 inches). Lower thresholds have been reported in Australia with Spackman et al. (2001) and Routley et al. (2003) both placing the threshold at 2.5 Mg ha^{-1} (40 bu ac^{-1}). In Ethiopia, stover and grain yield were reduced by skip row planting when yields of the conventional treatment were near 3 Mg ha^{-1} (48 bu ac^{-1}). Clark and Knight (1996), in the southern High Plains, reported a yield increase with skip-rows at yields of <2 Mg ha^{-1}, but a yield decrease at yield levels of 3 Mg ha^{-1} (48 bu ac^{-1}). Jones and Johnson (1991), also working in the southern High Plains, found no yield difference between conventional and P1S1 at a yield level of 3.4 Mg ha^{-1} (54 bu ac^{-1}), but yields were reduced by skip-row when conventional yields were between 4.5 and 5.6 Mg ha^{-1} (71 and 90 bu ac^{-1}). For the environments and hybrid included in the present study the threshold where skip-row treatments provide an advantage could not be determined but would have been less than a conventional yield of 6.77 Mg ha^{-1} (108 bu ac^{-1}), the lowest conventional yield observed in this study.

The other alternative geometries, clump and cluster, produced similar grain yields to conventional planting, with the exception of clump planted sorghum in 2011. The findings of this study partially agree with the observations of Bandaru et al. (2006) in the southern High Plains, who reported a yield advantage for clump planted sorghum when yields were below 3 Mg ha^{-1} (48 bu ac^{-1}), but no difference to a slight reduction at yields of 5 Mg ha^{-1} (80 bu ac^{-1}). In 2010, there was no difference between conventional and clump planted sorghum with an average yield of 6912 kg ha^{-1} (110 bu ac^{-1}). However, in 2011 conventional yields were (119 bu ac^{-1}) and higher than clump planting. This suggests that the threshold yield for advantage or disadvantage of clump planting relative to conventional may be near this yield level. Additional work in the southern High Plains found no yield differences between clump and conventionally planted sorghum at conventional yield levels of 3.8 Mg ha^{-1} (61 bu ac^{-1}) (Kapanigowda et al., 2010). The results of this study show that relative to conventional planting, the threshold yield between negative and positive response for a clump or cluster configuration is much higher than for skip-row.

Harvest index

Harvest indices in this study were exceptionally high, typically falling near the upper-bound genetic harvest index for grain sorghum of 0.53 (Prihar and Stewart, 1990), indicating that stress had not reduced harvest index (HI). Harvest index was only affected in one of the three study years, 2010, when the P2S2 configuration resulted in a HI less than the clump, P1S1, and conventional geometries. Routley et al. (2003) reported consistently higher HI for skip-row plants, although their yield environments was lower than those encountered in this study. In other studies, at higher yields, HI has been found to be relatively unaffected by skip-row planting (Thomas et al., 1981; Jones and Johnson, 1991). The absence of increased HI for clump compared to conventional planted sorghum is contrary to previous findings in the southern High Plains (Bandaru et al., 2006). However, no differences were observed in another study at this site while using the same hybrid, although numerical trends of higher HI for clump plantings were consistent (Bandaru et al., 2006). Kapanigowda et al. (2010) showed that clump planting reduced tillering and increased the survival rate of remaining tillers. This reduction in tiller biomass and increase in tiller grain production resulted in higher tiller HI while HI of the main culm was unaffected by planting geometry. In other words, the mechanism for increasing HI through clump planting resulted from reduced tillering and increased HI of remaining tillers. In the present study, tillering, even in the conventional treatments, was at a relatively low level. Due to these conditions the mechanism by which HI is increased by clump planting was inhibited.

Tillers plant^{-1}

Tillers plant^{-1} was consistently lower for sorghum planted in either of the skip-row configurations than in a conventional or cluster configuration. This was reflected in reduced panicle population relative to the clump and conventional treatments in all years and to the cluster treatment in 2010. Planting in a skip-row configuration decreases plant-to-plant spacing within the row which has been shown to reduce tillering even when plant density was held constant (Staggenborg et al., 1999; Stickler and Wearden, 1965). The reduction of tillering by planting in a skip-row configuration has been observed by other researchers (Blum and Naveh, 1976; Fukai and Foale, 1988).

Cluster, clump, and conventional geometries produced similar tillers plant^{-1} except in 2009 when the clump treatment produced the lowest tillers plant^{-1} of any geometry. Previous work in the southern High Plains and at the present study location has consistently observed a reduction in tillers plant^{-1} for clump planted sorghum relative to conventional (Bandaru et al., 2006; Haag and Schlegel, 2009; Kapanigowda et al., 2010; Krishnareddy et al, 2010) even when grain yield was unaffected. Several possible explanations exist for the lack of response in the present study. Initiation of tillering in grain sorghum was shown to be regulated by supply and demand of assimilate within the plant (Kim et al., 2010; Lafarge and Hammer, 2002). Available soil water at planting was higher in 2009 than either 2010 or 2011, additionally from planting forward, in-season precipitation was above normal for the growing season, whereas in 2010 and 2011 in-season precipitation was at or below normal through at least DOY 208. With ample supplies of water available, more assimilate would have been produced, thus supporting tiller initiation. Light quality, especially R:RF ratio (Casal et al., 1986) has been shown to affect tillering as well, and is believed to be a driving mechanism resulting from clump planting (Krishnareddy et al., 2010), most likely by regulating cessitation of tiller growth (Lafarge and Hammer, 2002). Additional influence on the light ratio may have been provided by wheat stubble residue, which results in a lower R:FR ratio than soil (Kasperbauer, 1999). The favorable conditions experienced during the time of this study may have resulted in assimilate production within the plant of such supply that light quality influences were insufficient to curtail tiller growth.

The overall level of tillering observed in this study was relatively low, so the question may not be why tillering was not suppressed, but rather, why tillering in the conventional treatment was not more evident. One potential explanation stems from the findings of Lafarge et al. (2002). They reported that tiller initiation on lower axils was driven by surplus assimilate in the main culm while tiller initiation on upper axils was influenced by R:FR light ratio. Data were not collected on the location of tillers in this study, however it is plausible that the tillers present were from lower axils while tillering was inhibited from upper axils due to planting geometry affecting R:FR ratio. This mechanism however fails to explain the low tillering of the conventionally planted sorghum. Additionally, differences among hybrids in their propensity to tiller is well documented (Larsen and Vanderlip, 1994; Caravetta et al., 1990). Short-season hybrids, such as the one used in this study, tend to produce fewer tillers due to less surplus assimilate (Baumhardt and Howell, 2006; Lafarge et al., 2002). It is noteworthy that clump planted sorghum did produce the lowest tillers plant^{-1} of any geometry in 2009, the year of lowest yields, and the year where clump planting possessed a numerical yield advantage over conventional planting. This would be consistent of the responses seen by other researchers. The reduced available plant water in 2010 and 2011 would have likely resulted in less assimilate production within the plant, thus tillering was limited across all geometries due to resource scarcity. Tiller initiation would have occurred during a time of ample plant available water in 2009, allowing planting geometry to play a role in limiting tiller development rather than assimilate availability.

Kernels panicle^{-1} and kernel weight

Reduced grain yields in the clump geometry in 2011 corresponded with a reduction in kernels panicle^{-1} relative to the conventional and cluster configurations and reduced kernel weight relative to the cluster configuration. Kernel number in sorghum is influenced by the rate of dry matter accumulation pre-anthesis (Muchow et al., 1982). When stress occurs pre-anthesis, kernel number is reduced (Krieg and Lascano, 1990). In the absence of water stress kernel number, via dry-matter accumulation rate, would be reduced with reduced light interception as likely happens in the clump treatment. This response, due to decreased light interception, is also evident in reduced kernel number for the skip-row treatments in 2009 and in the across-years analysis. Kernels panicle^{-1} was reduced in the skip-row treatments despite a simultaneous reduction in panicle population via reduced tillering. A reduction in panicles per unit land area is typically accompanied by an increase in kernels panicle^{-1} when resources, principally light, are non-limiting. In other studies with yield responses to planting geometry, kernels panicle^{-1} has been regarded as the most responsive yield component (Thomas et al., 1981). This reduction in kernel number and accompanying reduction in the assimilate sink size at grain fill resulted in a corresponding increase in kernel weight. Kernel weight tended to be highest for the skip row treatments relative to conventional and clump treatments as reflected in the across-years analysis.

Kernel weight was most affected by planting geometry in 2011 while numerical advantages for the skip-row treatments were also evident in 2009 and 2010 and contributed to an across-years response. Thomas et al. (1981) reported higher kernel weights for wide spaced and skip-row configurations in Australia while in the southern High Plains Jones and Johnson (1991) observed no differences in kernel weight between conventional and P1S1. Kernel weight is largely driven by post-anthesis stress (Muchow et al., 1982; Krieg and Lascano, 1990), which likely played a role in the varying responses observed. In all years of this study, precipitation during the grain fill period was above normal and adequate soil water supplies existed. Increased kernel weight for the skip-row treatments was also correlated with increased grain N and P contents. Larger kernels would result in exponentially more starch and protein (Lee et al., 2002) and thus more N and P per unit of waxy seed coat. However, grain yields affected nutrient removal more than grain nutrient content.

Water use, water use efficiency, and soil water

Total water use was not affected by planting geometry in any year. The reduction in biomass and grain yield for the skip-row treatments without an accompanying reduction in water use resulted in reduced WUEg and WUEb for the P1S1 and P2S2 configurations in all years. The reduction of WUEg by skip-row planting given the yield and precipitation levels experienced is supported by observations in the literature. Abunyewa et al. (2011), in central and western Nebraska, found that WUEg was higher with skip-row configurations only when site-year mean growing season precipitation was <2 mm day^{-1} (0.08 inches day^{-1}). In the southern High Plains, Jones and Johnson (1991) reported reduced WUEg for a P1S1 configuration compared to conventional when conventional yields ranged from 4.5 to 5.6 Mg ha^{-1} (71 to 90 bu ac^{-1}).

While season-long differences in water use were not observed, there were differences in timing of water use. In 2011, at flower / grain fill, profile cross-section water use was highest for the conventional geometry and was comparable for the cluster configuration, while water use was lowest among the skip-row configurations. From the time of flowering / grain fill to harvest in 2011, water use was the highest among the skip-row treatments. These same trends were numerically evident in 2010. In the across years analysis, the P2S2 treatment specifically had the lowest water use from early vegetative to flowering / grain fill, while both skip-row treatments, as well as conventional, had similar levels of water use from flowering / grain fill to harvest. Abunyewa et al. (2011) and Routley et al. (2003) reported reduced water use for skip-row systems compared to conventional when measured at anthesis, followed by increased water use until harvest. These differences typically offset and resulted in few season long differences in water use. Musick and Dusek (1972) in the southern High Plains found lateral root growth from a sorghum row into an unplanted area measuring 114 cm (45 inches) at boot and 140 cm (55 inches) at flowering. Continued root growth after flowering (McClure and Harvey, 1962) and water extraction by sorghum roots as far as 114 cm (45 inches) away from the last planted row (Musick and Dusek, 1975) would allow extraction of available soil water as shown in the graphics of interpolated change in soil water.

Differences in measured soil water content among tube positions, both profile totals and at individual depths, were seldom seen in the conventional, clump, and cluster treatments. Lack of differences among tube positions, along with no apparent differences in the range and SD of interpolated water contents, and visual inspection of interpolation results all indicate that the conventional, clump, and cluster configurations extracted water more evenly from the soil profile than the skip-row configurations. Routley et al. (2003) reported a root front velocity of 2 cm day^{-1} (0.79 inches day^{-1}) in all directions from the base of a sorghum plant in dryland conditions. Root front velocity in the vertical axis in a rainfed environment was reported as 2.5 cm day^{-1} (0.98 inches day^{-1}) by Stone et al. (2001). Over a time period of sufficient length, the soil volume explored by roots in conventional, clump, and cluster configurations would be equalized. Visual plots of interpolated data indicate the influence of planting geometry on extraction pattern, with water closest to the planted row generally consumed first. Differences in soil water content by tube position were evident in the skip-row configurations with higher soil water contents found in the skip.

Above normal levels of precipitation in 2009 resulted in masking treatment related differences in soil water content throughout the season when profile cross-section totals were considered. In 2010 and 2011 there were consistently higher levels of soil water present in the skip-row treatments, particularly in the skip area, and these differences were more pronounced as the season progressed. Across-years the P2S2 treatment averaged 18 mm (0.70 inches) more profile water at harvest than the clump, cluster, and conventional treatments. Abunyewa et al. (2011) reported 10 to 35 mm more soil water at harvest in P1S1 and P2S2 configurations than conventional in Nebraska. Their analysis was performed using soil water measurements from the middle of the skip only, which could have overestimated differences. Skip-row configurations were effective at reducing early season water use and storing soil water in the skip. For the conditions encountered in this study, the reduction in water use appeared to be too drastic and thus limited grain yields. While a hypothesized objective of skip-row planting is to purposely limit soil water availability as a function of time via plant and root growth, it is counter-productive to reduce the effective use of water (EUW) (Blum, 2009) by leaving soil water in the profile at the expense of plant growth and partitioning into yield. Water left in the profile is subject to evaporation losses at the surface, and/or loss to deep percolation should enough precipitation be received prior to use by a subsequent crop. It is clear in this study that soil water was being left unused in the skip-row configurations, particularly P2S2. Abunyewa et al. (2011) showed similar differences at many of their site years. In general, differences between planting geometries were minimized at very dry site-years with soil water contents near permanent wilting point (PWP) or wet site-years with soil water contents near field capacity (FC). No differences were observed between clump, cluster, and conventional geometries with respect to profile cross-section available water or profile totals by tube position. This is in contrast to the findings of Bandaru et al. (2006). In their study they reported consistently less available soil water for sorghum in a conventional geometry compared to clump. A key difference is that clump planting reduced tillering and biomass production in the study of Bandaru et al. (2006), whereas in the present study no such reductions occurred, thus no reduction in water use would be expected assuming constant transpiration efficiency.

In the present study, particularly 2010, reductions of near surface soil water contents, likely due to surface evaporation, are greater as the point of measurement is moved away from the planted row, clump, or cluster. It is apparent in this study that evaporative losses have likely affected the E:ET ratio, especially for the skip-row configurations, and may be a cause in the reduction of WUEb and WUEg. Reduced WUEb due to reduced biomass and equal water use implies either reduced transpiration efficiency for skip-row configurations or increased evaporation, the later is the more likely explanation. Canopy shading, a feature absent over a portion of the skip-row configurations, particularly P2S2, can play a large role in reducing evaporative losses in the central High Plains (Todd et al., 1991). Wide row spacing and skipped areas increase water losses to first stage evaporation (Adams et al., 1976). By the end of the growing season, surface residues from the previous crop have broken down and are reduced from their initial levels, thus providing less protection against evaporative demand. Less crop water use, and thus less competition from crop roots, offers little competition to evaporation for use of late season precipitation. Additionally, as leaves senesce more of the soil surface is subject to intercepting solar radiation energy. If alternative geometries are to be implemented, having adequate levels of surface residue is essential in minimizing the effect of increased solar radiation interception by the soil surface and maintaining PUE. Adams et al. (1976) reported soil surface evaporation rates during first stage drying as high as 93% of potential evaporation in between widely-spaced rows of grain sorghum in Texas. Adding as little as 2000 kg ha^{-1} (1785 lb ac^{-1}) of small grains residue resulted in substantial reductions in evaporation. Similar results have been described by others (Russel, 1939; Bond and Willis, 1969; Bond and Willis, 1970). In the present study, adequate levels of surface residue in the form of wheat stubble were present in every year of the study. Residue levels were not quantified but should be of concern when implementing a planting geometry that will result in more solar energy reaching the soil surface at any point during the growing season. Adopting technology such as stripper headers to leave more residue in place and in an upright architecture may further reduce evaporative losses (Baumhardt et al., 2002). Effects resulting from skip row planting were shown in subsequent fallow periods with reductions in fallow efficiency due to decreased average ground cover (Routley et al., 2006). Maintaining surface residues will also be important to help suppress weeds in the absence of shading from the crop canopy. These wide areas would also be more prone to weed pressure as sunlight can reach the surface to aid in weed seedling grown and development. Additionally, if a geometry results in additional soil moisture in the skip, that further invites weed competition.

Conclusions

Planting grain sorghum in a P1S1 or P2S2 configuration reduced total biomass, grain yield, WUEg, and WUEb compared to conventional, clump, or cluster geometries at the yield levels observed in this study. Total water use was unaffected by planting geometry although cumulative water use at flower / grain fill was higher for conventional, clump, and cluster than for skip-row configurations. Water use from flower / grain fill through harvest was higher for the skip-row configurations. In this set of high yielding years, sorghum planted in a conventional geometry was always in the highest grouping of grain yields. Grain yields from sorghum in either a cluster or clump geometry were each in the top yield grouping two of three years. The clump treatment was in the top LSD grouping in both years it was planted correctly. When evaluated across-years, sorghum planted in a clump, cluster, or conventional geometry resulted in similar levels of above-ground biomass, grain yield, WUEg, and WUEb. Due to the set of environments encountered during this study, a test of geometries at low yield levels was not attained for comparison to the findings of improved yields with alternative geometries. However, of the various alternative planting geometries proposed for use in the High Plains, clump or cluster planting appear to have substantially less downside in a high yielding year than skip-row configurations. The findings of this study, along with prior work in the literature, indicate that the threshold yield at which an advantage or disadvantage occurs relative to conventional planting is much higher for cluster or clump planted sorghum than for a skip-row system. Improvements in crop management should improve yields in poor years but also should not limit yields when the highly variable conditions in the High Plains provide an optimal growing environment. Results of this study indicate that of the various proposed alternative planting geometries, the clump and cluster configurations are most worthy of further investigation for the yield environments encountered in the central High Plains. Current mechanical limitations of seeding equipment and adoption of technologies such as automatic planter-row clutch control make clump planting a more feasible option compared to planting in a cluster geometry.

Commercialization recommendations

Should a producer implement an alternative planting geometry for sorghum production? Grain yields attained in this study were at or above average for the region. It is clear that skip-row planting of sorghum resulted in reduced levels of biomass and grain yield due to inadequate light interception for the water supply available. As a result, soil water was left unused for crop production in the profile. While the findings of this study do not discount the potential response of skip-row systems at lower yield potentials, it does clearly demonstrate potential losses at yield levels experienced by producers in the central High Plains. Similarly, this study was unable to show a benefit to planting in a clump configuration as others have, or a cluster configuration which was novel to this study. However, it was shown that when evaluated at LSD=0.05, these geometries did not result in yield reductions at average to above average yield levels for the region. For many producers, implementation of the cluster geometry would be overly difficult, especially those utilizing auto-swath and individual row clutches on their planters. Currently, technology to properly synchronize plate position between rows while using row clutches is not commercially available to producers. There is no management control over the intended objectives of regulating light interception and soil water extraction without synchronization and proper placement of the planted clusters and the open portions of row. There appears to be little downside to the adoption of clump planting. Adoption cost by a producer would be limited to the cost of metering seed disk for their planter, typically $40 to $80 per row for the cost of a generic plate and shop labor for modification.

Any commercial implementation of an alternative planting geometry should only occur within the context of cropping systems that maximize surface residue, i.e. no-till and planting grain sorghum into small-grains stubble or heavy row-crop stubble. Situations where surface residue is lacking, when combined with the open areas of alternative planting geometries, will be prone to increased weed pressure and certainly increased surface evaporation losses. Evaporation losses will negatively affect WUE and PUE of the entire cropping system, and losses at some level will negate any potential gains in economic productivity or risk management gained via planting geometry.

Avenues of future research

The potential interaction of genotype with alternative planting geometries is an avenue for future research. Differences among hybrids with respect to tillering, root architecture, and yield component flex would affect the response to alternative planting geometries. Hybrids differ in their propensity to tillering (Larson and Vanderlip, 1994; Wade et al., 1993; Caravetta et al., 1990). This could certainly affect the responsiveness of a hybrid. Work in Australia has identified genetic variability in sorghum root architecture which may give certain genotypes an advantage in alternative geometries. Singh et al. (2008) reported that nodal root angle, when evaluated across 70 inbred lines and hybrids, ranged from 15 to 50 degrees. This would suggest that variability exists among the commercial hybrids available today, which may help explain some of the variability in findings among studies with regard to overall crop performance and water extraction. Traditionally, sorghum was selected and bred for maximum yield with little regard for how yield potential is partitioned among main culms and tillers. The tillers plant^{-1} yield component is often relied upon to be the most flexible in response to pre-anthesis or flowering stress, while kernel weight provides yield compensation for post-anthesis stress. If alternative planting geometries are going to be used to suppress vegetative growth via reductions in tillering, then the identification of hybrids with greater flexibility in the kernels panicle^{-1} yield component would be useful. Hybrids which respond to pre-anthesis stress, or lack thereof, by flex in kernels panicle^{-1} would allow the plant to still be responsive to negative or positive changes in the environment without the water and assimilate costs associated with producing tiller biomass.

If tillering can be inhibited, as other studies have shown, this may open the door to opportunities for managing plant density on a site-specific basis. Previous efforts with variable rate seeding in tillering crops, such as sorghum, have been largely fruitless due to the compensatory ability through the tillering process. Adopting planting strategies that inhibit tillering would allow producers to implement variable rate seeding strategies that incorporate knowledge of spatial variability in yield potential and thus optimal seeding rate.

References

Abunyewa, A., R.B. Ferguson, C.S. Wortman, D.J. Lyon, S.C. Mason, S. Irmak, and R.N. Klein. 2011. African J. of Agric. Res. 6:5328-5338.

Abunyewa, A., R.B. Ferguson, C.S. Wortman, D.J. Lyon, S.C. Mason, and R.N. Klein. 2010. Skip-row and plant population effects on sorghum grain yield. Agron. J. 102:296-302.

Adams, J.E., G.F. Arkin, and J.T. Ritchie. 1976. Influence of row spacing and straw mulch on first stage drying. SSSAJ 40:436-442.

Bandaru, V., B.A. Stewart, R.L. Baumhardt, S. Ambati, C.A. Robinson, and A. Schlegel. 2006. Growing dryland grain sorghum in clumps to reduce vegetative growth and increase yield. Agron. J. 98:1109-1120.

Baumhardt, R.L., and T.A. Howell. 2006. Seeding practices, cultivar maturity, and irrigation effects on simulated grain sorghum yield. Agron. J. 98:462-470.

Baumhardt, R.L., R.C. Schwartz, and R.W. Todd. 2002. Effects of taller wheat residue after stripper header harvest on wind run, irradiant energy interception, and evaporation. In E. Van Santen (ed.) Proc. Of 25th Annual Southern Conservation Tillage Conf. Auburn, AL. 24-26 June 2002.

Blum, A. 1972. Effect of planting date on water-use and its efficiency in dryland grain sorghum. Agron. J. 64:775-778.

Blum, A. 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res. 112:119-123.

Blum, A., and M. Naveh. 1976. Improved water-use efficiency in dryland grain sorghum by promoted plant competition. Agron. J. 68:111-116.

Bond, J.J., T.J. Army, and O.R. Lehman. 1964. Row spacing, plant populations, and moisture supply as factors in dryland grain sorghum production. Agron. J. 56:3-6.

Bond, J.J., and W.O. Willis. 1969. Soil water evaporation: Surface residue rate and placement effects. SSSAJ 33:445-448.

Bond, J.J., and W.O. Willis. 1970. Soil water evaporation: First stage drying as influenced by surface residue and evaporation potential. SSSAJ 34:924-928.

Brown, P.L., and W.D. Shrader. 1959. Grain yields, evapotranspiration, and water use efficiency of grain sorghum under different cultural practices. Agron. J. 51:339-343.

Caravetta, G.J., J.H. Cherney, and K.D. Johnson. 1990. Within-row spacing influences on diverse sorghum genotypes: I. Morphology. Agron. J. 82:206-210.

Casal, J.J., R.A. Sanchez, V.A. Deregibus. 1986. The effect of plant density on tillering: the involvement of R/FR ratio and the proportion of radiation intercepted per plant. Env. and Exp. Botany 26:365-371.

Chin Choy, E.W., and E.T. Kanemasu. 1974. Energy balance comparisons of wide and narrow row spacings in sorghum. Agron. J. 66:98-100.

Clark, L.E., and T.O. Knight . 1996. Grain production and economic returns from dryland sorghum in response to tillage systems and planting patterns in the semi-arid southwestern USA. J. Prod. Agric. 9:249-256.

Clegg, M.D., W.W. Biggs, J.D. Eastin, J.W. Maranville, and C.Y. Sullivan. 1974. Light transmission in field communities of sorghum. Agron. J. 66:471-476.

Craufurd, P.Q., D.J. Flower, and J.M. Peacock. 1993. Effect of heat and drought stress on sorghum (Sorghum bicolor), I. Panicle development and leaf appearance. Exp Agric. 29:61-76.

Dhuyvetter, K.C., C.R. Thompson, C.A. Norwood, and A.D. Halvorson. 1996. Economics of dryland cropping systems in the Great Plains: A review. J. Prod. Agric. 9:216–222.

Earl, H.J., and R.F. Davis. 2003. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. Agron. J. 95:688-696.

Fukai, S., and M.A. Foale. 1988. Effects of row spacing on growth and grain yield of early and late sorghum cultivars. Aust. J. of Exp. Agric. 28:771-777.

Haag, L.A., and A. J. Schlegel. 2009. Yield and dry matter partitioning of grain sorghum grown in clumps. Southwest Research-Extension Center Report of Progress No. 1014. Kansas State Univ. Agric. Exp. Stn. and Coop. Ext. Svc.

Hansen, N.C., B.L. Allen, R.L. Baumhardt, and D.J. Lyon. 2012. Research achievements and adoption of no-till, dryland cropping in the semi-arid U.S. Great Plains. Field Crops Res. 132:196-203.

Hons, F.M. and B.L. McMichael. 1986. Planting pattern effects on yield, water use and root growth of cotton. Field Crops Res. 13:147-158.

Jones, O.R., and G.L. Johnson. 1991. Row width and plant density effects on Texas High Plains sorghum. J. Prod. Agric. 4:613-621.

Kandelous, M.M., J. Simunek, M.T. Van Genuchten, K. Malek. 2011. Soil water content distributions between two emitters of a subsurface drip irrigation system. SSSAJ 75:488-497.

Kapanigowda, M., M. Schneider, and B.A. Stewart. 2010. Dryland grain sorghum tillering: clumps vs. uniform planting geometries. J. of Crop Improv. 24:271-280.

Kasperbauer, M.J. 1999. Cotton seedling root growth response to light reflected to the shoots from straw-covered versus bare soil. Crop Sci. 39:164-167.

Kim, H.K., E. van Oosterom, M. Dingkuhn, D. Luquet, and G. Hammer. 2010. Regulation of tillering in sorghum: environmental effects. Ann. of Botany 106:57-67.

Krieg, D.R., and R.J. Lascano. 1990. Sorghum. p. 719-739. In B.A. Stewart and D.R. Nielsen (ed) Irrigation of agricultural crops. Agron. Monogr. 30. ASA, CSSA, and SSSA, Madison, WI.

Krishnareddy, S.R., B.A. Stewart, W.A. Payne, and C.A. Robinson. 2010. Grain sorghum tiller production in clump and uniform planting geometries. J. of Crop Improvement. 24:1-11.

Lafarge, T.A., I.J. Broad, and G.L. Hammer. 2002. Tillering in grain sorghum over a wide range of population densities: Identification of a common hierarchy for tiller emergence, leaf area development, and fertility. Ann. of Bot. 90:87-98.

Lafarge, T.A., and G.L. Hammer. 2002. Tillering in grain sorghum over a wide range of population densities: modeling dynamics of tiller fertility. Ann. of Bot. 90:99-110.

Larson, E.J., and R.L. Vanderlip. 1994. Grain sorghum yield response to nonuniform stand reductions. Agron. J. 86:475-477.

Lee, W.J., J.F. Pedersen, and D.R. Shelton. 2002. Relationship of sorghum kernel size to physiochemical, milling, pasting, and cooking properties. Food Res. Intl. 35:643-649.

Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. SAS for Mixed Models, Second Edition. SAS Institute. Cary, NC.

Lyon, D.J., A.D. Pavlista, G.W. Hergert, R.N. Klein, C.A. Shapiro, S. Knezevic, S.C. Mason, L.A. Nelson, D.D. Baltensperger, R.W. Elmore, M.F. Vigil, A.J. Schlegel, B.L. Olson, and R.M. Aiken. 2009. Skip-row planting patterns stabilize corn grain yields in the Central Great Plains. Available at http://www.plantmanagementnetwork.org/cm. Crop Manage. doi:10.1094/CM-2009-0224-02-RS.

MathWorks. 2012. Matlab technical computing language software. Version R2012b. Natick, MA.

McClure, J.W., and C. Harvey. 1962. Use of radiophosphorus in measuring root growth of sorghums. Agron. J. 54:457-459.

McGowan, M., H.M. Taylor, and J. Willingham. 1991. Influence of row spacing on growth, light, and water use by sorghum. J. Agric. Sci. (Cambridge) 116:329-339.

McLean, G., J. Whish, R. Routley, I. Broad, and G. Hammer. 2003. The effect of row configuration on yield reliability in grain sorghum: II. Modeling the effects of row configuration. Proc. 11th Aust. Agron. Conf. Geelong, Victoria. 2-6 Feb. 2003. Available at http://www.regional.org.au/au/asa/2003/c/9/mclean.htm [verified 29 June 2013]. Aust. Soc. Agron., Gosford, Australia.

McMaster, G.S. and W.W. Wilhelm. 1997. Growing degree-days: one equation, two interpretations. Agric. and Forest Meteorology. 87:291-300.

Mesfin, T., G.B. Tesfahunegn, C.S. Wortman, M. Mamo, and O. Nikus. 2010. Skip-row planting and tie-ridging for sorghum production in semiarid areas of Ethiopia. Agron. J. 102:745-750.

Milliken, G.A., and D.E. Johnson. 2009. Analysis of messy data – volume 1: designed experiments. 2nd ed. CRC Press. Boca Raton, FL.

Muchow, R.C., D.B. Coates, G.L. Wilson, and M.A. Foale. 1982. Growth and productivity of irrigated Sorghum bicolor (L. Moench) in Northern Australia. I. Plant density and arrangement effects on light interception and distribution, and grain yield, in the Hybrid Texas 610SR in low and medium latitudes. Aust. J. Agric. Res. 33:773-784.

Musick, J.T., and D.A. Dusek. 1972. Irrigation of grain sorghum and winter wheat in alternating double-bed strips. J. Soil and Water Cons. 27:17-20.

Musick, J.T., and D.A. Dusek. 1975. Limited irrigation of grain sorghum in alternating strips with wheat. Trans. ASAE 18:544-548.

Myers, R.J.K., and M.A. Foale. 1981. Row spacing and population density in grain sorghum - a simple analysis. Field Crops Res. 4:147-154.

NASS. 2013. Online query of crop production survey data. Available online at http://www.nass.usda.gov. Verified, 4 Aug. 2013.Nielsen, D.C., P.W. Unger, and P.R. Miller. 2005. Efficient water use in dryland cropping systems in the Great Plains. Agron J. 97:364–372.

Norwood, C.A., 1982. High population narrow row dryland sorghum for southwest Kansas. Keeping up with research. No. 62. Kansas Agric. Exp. Stn., Manhattan, KS.

Norwood, C.A., and R.S. Currie. 1997. Dryland corn vs. grain sorghum in western Kansas. J. Prod. Agric. 10:152-157.

Norwood, C.A., and K.C. Dhuyvetter. 1993. An economic comparison of the wheat-fallow and wheat-sorghum-fallow cropping systems. J. Prod. Agric. 6:261-266.

Olson, B.L., A.J. Schlegel, and J.D. Holman. 2010. Comparison of skip-row grain sorghum and corn in western Kansas. Agronomy Field Research Report of Progress No. 1030. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Peters, D.B. 1960. Relative magnitude of evaporation and transpiration. Agron. J. 52:536-538.

Peterson, G.A., A.J. Schlegel, D.L. Tanaka, and O.R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage systems. J. Prod. Agric. 9:180–186.

Prihar, S.S., and B.A. Stewart. 1990. Using upper-bound slope through origin to estimate genetic harvest index. Agron. J. 82:1160-1165.

Prihar, S.S., and B.A. Stewart. 1991. Sorghum harvest index in relation to plant size, environment, and cultivar. Agron. J. 83:603-608.

Routley, R., I. Broad, G. McLean, J. Whish, G. Hammer. 2003. The effect of row configuration on yield reliability in grain sorghum: 1. Yield, water use efficiency and soil water extraction. Proc. 11th Aust. Agron. Conf. Geelong, Victoria. 2-6 Feb. 2003. Available at http://www.regional.org.au/au/asa/2003/c/9/routley.htm [verified 29 June 2013]. Aust. Soc. Agron., Gosford, Australia.

Routley, R., B. Lynch, M. Conway. 2006. The effect of sorghum row spacing on fallow cover distribution and soil water accumulation. Proc. 13th Agron. Conf. 2006. 10-14 September 2006. Perth, Western Australia. Available online at: www.regional.org.au/au/asa/2006 Date accessed 6 July 2013.

Russel, J.C. 1939. The effect of surface cover on soil moisture losses by evaporation. SSSAJ 3:831-837.

Sanabria R., J., J.F. Stone, and D.L. Weeks. 1995. Stomatal response to high evaporative demand in irrigated grain sorghum in narrow and wide row spacing. Agron. J. 87:1010-1017.

Sandwell, D.T., 1987. Biharmonic spline interpolation of GEOS-3 and SEASAT altimeter data. Geophysical Research Letters. 14(2):139-142.

Saxton, A.M. 1998. A macro for converting mean separation output to letter groupings in Proc Mixed. In Proc. 23rd SAS Users Group Intl., SAS Institute, Cary, NC, p.1243-1246.

Schlegel, A. 2013a. Large-scale dryland cropping systems. Southwest Research-Extension Center 2013 Field Day Report of Progress No. 1088. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Schlegel, A. 2013b. Effects of wheat stubble height on subsequent corn and grain sorghum crops. Southwest Research-Extension Center 2013 Field Day Report of

Progress No. 1088. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Schlegel, A.J., T.J. Dumler, and C.R. Thompson. 2002. Feasibility of four-year crop rotations in the central High Plains. Agron J. 94:509–517.

Singh, V., G. Hammer, E. van Oosterom. 2008. Variability in structure and function of sorghum root systems. In: Unkovich M. ed. Global Issues, Paddock Action. Proceedings of the 14th Australian Society of Agronomy Conference. Gosford, Australia: The Regional Institute, www.agronomy.org.au.

Spackman, G.B., K.J. McCosker, A.J. Farquharson, and M.J. Conway. 2001. Innovative management of grain sorghum in central Queensland. In B. Rowe et al. (ed.) in Proc. Aust. Agron. Conf., 10th, Hobart, TAS. 29 Jan.-1 Feb. 2001. Aust. Soc. of Agron.

Staggenborg, S.A., K.C. Dhuyvetter, W.B. Gordon. 2008. Grain sorghum and corn comparisons: Yield, economic, and environmental responses. Agron. J. 100:1600-1604.

Staggenborg, S.A., D.L. Fjell, D.L. Devlin, W.B. Gordon, and B.H. Marsh. 1999. Grain sorghum response to row spacings and seeding rates in Kansas. J. Prod. Agric. 12:390-395.

Steiner, J.L. 1986. Dryland grain sorghum water use, light interception, and growth response to planting geometry. Agron. J. 78:720-726.

Steiner, J.L. 1987. Radiation balance of dryland grain sorghum as affected by planting geometry. Agron. J. 79:259-265.

Stickler, F.C., and S. Wearden. 1965. Yield and yield components of grain sorghum as affected by row width and stand density. Agron. J. 57:564-567.

Stone, L.R., D.E. Goodrum, M.N. Jaafar, and A.H. Khan. 2001. Rooting front and water depletion depths in grain sorghum and sunflower. Agron. J. 93:1105-1110.

Stone, L.R., and A.J. Schlegel. 2006. Yield-water supply relationships of grain sorghum and winter wheat. Agron. J. 98:1359-1366.

Teasdale, J.R., C.B. Coffman, and R.W Mangum. 2007. Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agron. J. 99:1297-1305.

Thomas, G.A., R.J.K. Myers, M.A. Foale, A.V. French, B. Hall, F.H. Ladewig, A.A. Dove, G.K. Taylor, E. Lefroy, P. Wylie, and G.D. Stirling. 1981. Evaluation of row spacing and population density effects on grain sorghum over a range of northern Australian environments. Aust. J. Exp. Agric. Anim. Husb. 21:210-217.91:870-875.

Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agron. J. 59:240-243.

Thompson, C.A. 1982. Try some “super thick” sorghum. Keeping up with research. No. 49R. Kansas Agric. Exp. Stn., Manhattan, KS.

Todd, R.W., N.L Klocke, G.W. Hergert, A.M. Parkhurst. 1991. Evaporation from soil influenced by crop shading, crop residue, and wetting regime. Trans. of the ASAE 34:461-466.

Unger, P.W., and R.L. Baumhardt. 1999. Factors related to dryland sorghum yield increases: 1939 through 1997. Agron. J.

van Oosterom, E., G. Hammer, H. Kim, G. McLean, K. Deifel. 2008. Plant design features that improve grain yield of cereals under drought. In: Unkovich M. ed. Global Issues, Paddock Action. Proceedings of the 14th Australian Society of Agronomy Conference. Gosford, Australia: The Regional Institute, www.agronomy.org.au.

Vigil, M.F., B. Henry, F.J. Calderon, D. Poss, D.C. Nielsen, J.G. Benjamin, and R. Klein. 2008. A use of skip-row planting as a strategy for drought mitigation in the west-central Great Plains. Proceedings of the Great Plains soil fertility conference Vol. 12 (A. Schlegel, editor). Denver, CO March 4-5, 2008.

Wade, L.J., A.C.L. Douglas, and K.L. Bell. 1993. Variation among sorghum hybrids in the plant density required to maximize grain yield over environments. Aust. J. of Exp. Agric. 33:185-191.

Whish, J., B. Butler, M. Castor, S. Cawthray, I. Broad, P. Carberry, G. Hammer, G. McLean, R. Routley, and S. Yeates. 2005. Modeling the effects of row configuration on sorghum yield reliability in north-eastern Australia. Aust. J. of Agric. Res. 56:11-23.

Witt, M.D., R.L. Vanderlip, and L.D. Bark. 1972. Effect of row width and orientation on light intercepted by grain sorghum. Trans. Kansas Acad. Sci. 75:29-40

Chapter 3 - Comparing corn and sorghum in alternative planting geometries and implications to net returns.

Introduction

Both corn and grain sorghum have been proposed as summer annual crops for use in intensifying the wheat-fallow rotation on the central High Plains. Notable differences exist among the crops. Corn typically has higher water use efficiency for grain production (WUEg) than sorghum under both dryland (Peterson et al., 1996) and irrigated conditions (Stone et al., 2006). The higher WUE leads to higher potential yields under optimal conditions in Kansas (Staggenborg et al., 2008; Assefa, 2013). However, timing of in-season precipitation is critical to success in producing economic grain yields (Nielsen et al., 2010). Corn is relatively more sensitive to periods of drought stress than grain sorghum, especially during the time period bracketing silking. Additionally, corn has a higher intercept of the yield water-use function than grain sorghum, in other words, more water is consumed in order to produce the first kernel of grain. Stone et al. (2006) reported a threshold ET 57% higher for corn than grain sorghum. These characteristics of dryland corn production lead to yields that are more variable through time.

Significant effort has been expended on the comparison of corn and sorghum in the central High Plains and their suitability in various cropping systems. Staggenborg et al. (2008) evaluated 13 years of grain sorghum and corn yield trials from variety performance tests in Kansas and Nebraska, and concluded that grain sorghum had a yield advantage in environments where corn yields were less than 6.4 Mg ha^{-1} (102 bu ac^{-1}). Grain sorghum-to-corn price ratio was critical in determining the threshold yield at which net returns favored one crop over the other. As grain sorghum prices were evaluated at levels ranging from 70% to 117% of corn price, the threshold corn yield below which sorghum production was preferred increased from 4.6 to 13.6 Mg ha^{-1} (73 to 216 bu ac^{-1}). These results were based on a production cost of \$78 ha^{-1} less for grain sorghum than corn, which could vary widely due to seed and herbicide costs. More recent work by Assefa (2013), using only Kansas performance test data, confirmed the findings of Staggenborg et al. (2008), by reporting a long-term threshold yield of 6.3 Mg ha^{-1} (100 bu ac^{-1}). However, Assefa (2013) also reported that the cutoff value was 8.0 Mg ha^{-1} (127 bu ac^{-1}) when data from 1992-1996 was used compared to 6.0 Mg ha^{-1} (96 bu ac^{-1}) when data from 2007-2012 was used. This indicates that improvements in corn management and genetics may be lowering the threshold yield. Dryland research in southwest Kansas demonstrated higher grain yields and net returns for corn in site-years where corn yields ranged from 5.8 to 7.5 Mg ha^{-1} (93 to 119 bu ac^{-1}) (Norwood and Currie, 1997; 1998). Dryland corn production in western Kansas has increased in importance in recent years and has became an important factor in the cost efficiency of farms (Langemeier et al., 2013).

The purpose of this analysis was to explore the costs of adopting alternative planting geometries and compare corn and sorghum production characteristics within the context of a three-year study that evaluated alternative geometries. The objective was to identify underlying trends at the crop level and to investigate if planting geometry influenced these trends.

Methods

The cultural practices relating to the production management of the research plots has been described in preceding chapters. Data from the two studies were combined and analyzed as a split-plot RCBD design with crop species as the whole plot and planting geometry as the split-plot. Only corn data from the intermediate seeding rate were included in the analysis. A mixed models approach was implemented using PROC MIXED in SAS version 9.2. Crop, geometry, and crop x geometry were taken as fixed effects with replication and replication x crop taken as random effects. In the across-years analysis, year, replication within year, and replication x crop within year were taken as random effects. When necessary, the NOBOUND option was invoked to allow negative estimates of variance components. All means reported are least-squared means (LSMEANS) resulting from a mixed-model analysis. Each analysis fits the optimal mixed-model for that specific dataset and its variance-covariance structure. As a result, means presented in the across-years analysis will differ slightly than the arithmetic means of the individual years for several reasons. The analysis for comparing corn and sorghum is conducted on the data as a split-plot design whereas the analysis in chapters one and two were conducted on each crop as a RCBD. Each approach has a different set of fixed and random effects which result in slightly different linear mixed models being fit to the data, and thus differences in the LSMEANS which are estimated from the fitted model. Additionally, the across-years analysis results in an unbalanced design due to five replications in 2010 and four replications in 2009 and 2011. Also contributing to the imbalance with respect to sorghum, a P2S2 sorghum plot was lost in 2011. The use of LSMEANS from the PROC MIXED procedure is the most appropriate way to handle unbalanced data (Milliken and Johnson, 2009). Reports of other agronomic research have shown LSMEANS to differ from arithmetic means when conducting across-years analysis with unbalanced data (Teasdale et al., 2007).

Net returns were calculated using a modified version of a corn cost-return budget (Dumler and O'Brien, 2013a) and a modified grain sorghum cost-return budget (Dumler and O'Brien, 2013b) that had been developed for dryland producers in western Kansas. Production costs and government program revenue values for the 6.2 Mg ha^{-1} (100 bu ac^{-1}) yield level were used from the budgets in the calculation of net revenue. Grain revenue, harvesting costs, and fertilizer costs (based on crop removal) were calculated on a per-plot basis using plot yields. Phosphorus and nitrogen removal rates in 2009 were calculated using the mean removal rate of 2010 and 2011 for each respective treatment. Removal rates in 2010 and 2011 were from grain nutrient analysis values. Budgets used for the analysis are summarized in Table 3.1.

Profile soil water cross-sections were compared at corn tassel-silk with grain sorghum heading-flowering and at harvest using across-years means. Details regarding the calculation of cross-section profile water contents are discussed in previous chapters.

Table 3.1 - Corn and grain sorghum cost-return budgets used in computation of net returns.

	Corn		Grain Sorghum	
Income	USD ha^{-1}	(USD ac^{-1})	USD ha^{-1}	(USD ac^{-1})
Yield per acre	Per Plot		Per Plot	
Price per bushel	6.49		5.87	
Net government payment	32.54	(13.17)	32.54	(13.17)
Returns/acre	Per Plot	Per Plot	Per Plot	Per Plot
Costs				
Seed	172.41	(69.80)	25.05	(10.14)
Herbicide	61.22	(24.79)	61.22	(24.79)
Insecticide / Fungicide	2.47	(1.00)	-	-
Fertilizer and Lime	Per Plot	Per Plot	Per Plot	Per Plot
Miscellaneous	13.59	(5.50)	13.59	(5.50)
Custom Hire / Machinery Expense				
Fertilizer Application	13.24	(5.36)	13.24	(5.36)
No-Till Planting	38.24	(15.48)	38.24	(15.48)
Herbicide Applications	26.97	(10.92)	26.97	(10.92)
Harvest Base Charge	64.57	(26.14)	53.15	(21.52)
Harvest Flex Charges	Per Plot	Per Plot	Per Plot	Per Plot
Non-machinery Labor	22.52	(9.12)	23.80	(9.64)
Land Charge / Rent	288.99	(117.00)	288.99	(117.00)
SUB TOTAL	Per Plot	Per Plot	Per Plot	Per Plot
Interest on 1/2 Nonland Costs	23.14	(9.37)	18.02	(7.29)
TOTAL YIELD INDEPENDENT COSTS	727.34	(294.47)	562.26	(227.64)

Inputs for per plot expense calculations

	Corn		Grain Sorghum	
N Cost	\$1.43 kg^{-1} (\$0.65 lb^{-1})			
P Cost	\$1.32 kg^{-1} (\$0.60 lb^{-1})			
Harvest Overage	\$20.13 Mg^{-1}	(\$0.207 bu^{-1})	\$19.74 Mg^{-1}	(\$0.203 bu^{-1})
Harvest Overage Threshold	4.64 Mg ha^{-1}	(74 bu ac^{-1})	2.26 Mg ha^{-1}	(36 bu ac^{-1})
Harvest Trucking	\$6.85 Mg^{-1}	(\$0.174 bu^{-1})	\$7.48 Mg^{-1}	(\$0.19 bu^{-1})

Results and Discussion

Cost of adopting alternative planting geometries

Of the geometries evaluated in these studies, the clump and cluster configurations would require the purchase of new seed meter components for implementation. In the case of a vacuum planter meter system, blank seed discs would be purchased and modified to obtain the desired pattern. Blank seed discs currently cost approximately $30.00 each for John Deere planters and $50.00 each for Case-IH planters. The author estimates necessary shop time of approximately ½ hour each for modification. At a shop labor rate of $60.00 hour^{-1} this results in a finished goods cost of approximately $60 to $80 each. The assignment of those cost on a per unit area basis is difficult as a defined service life is not well known for seed metering discs. If a producer desires to attach the full cost to the year of adoption, then planter size and acres planted are obvious factors. Assuming a finished goods cost of $60 disc^{-1}, cost per unit area as a function of planter size and acreage planted is shown in Figure 3.1.

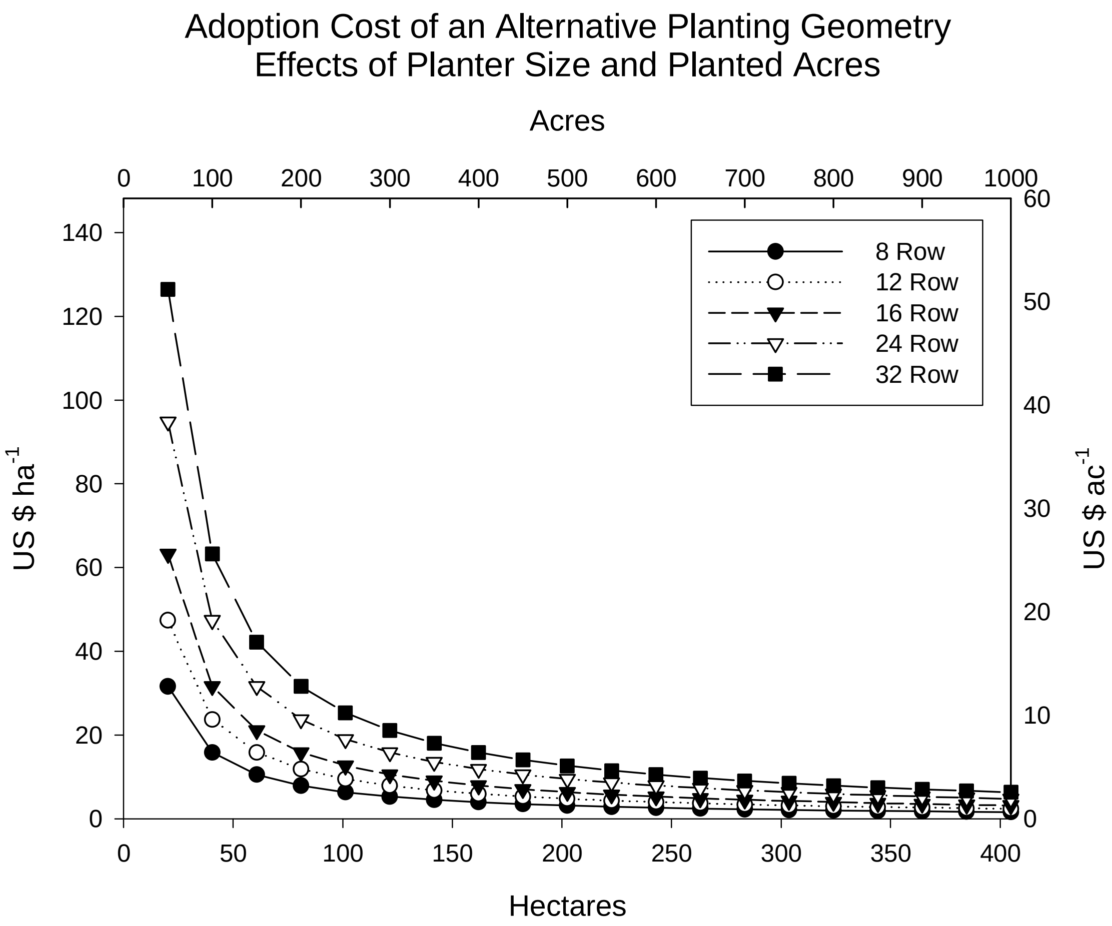

Figure 3.1 - Adoption cost of an alternative planting geometry.

The cost of adoption is relatively minor and decreases rapidly as planted area increases for all planter sizes. As planter size increases the rate of decrease in per unit area cost decreases. Alternative planting geometries may not result in improved yields in every year, but as this analysis shows, a measurable single-year response would be adequate to cover the cost of adoption. However, it is equally possible that in a year that would support exceptional yields, the use of an alternative geometry could result in decreased yields relative to conventional planting. For any size of planter, a yield response of 63 kg ha^{-1} (1 bu ac^{-1}) on 182 ha (450 acres) would cover adoption costs. For an 8-row planter, only 61 ha (150 acres) would be necessary to cover adoption cost with a 63 kg ha^{-1} (1 bu ac^{-1}) yield response. The cost of adoption was not included in the cost-return budgets prepared for the data in this study. Cost of adoption would be very much operation specific with respect to planter size and area planted and as illustrated here, for most commercial situations would be minor relative to other input costs.

2009 Comparison

Corn produced more above-ground biomass than grain sorghum in 2009 (P=0.0024, Table 3.2). When averaged across crops, the most biomass was produced when corn or sorghum was planted in a clump or conventional geometry. Stover production followed a similar trend with corn producing more than sorghum. The most stover was produced by planting corn or sorghum in a clump or conventional geometry, followed by P1S1 and cluster. The lowest levels of stover resulted from planting in a P2S2 geometry. Grain yields followed the same trend as above-ground biomass with higher corn grain yields than sorghum (P=0.0145, Table 3.2) and more grain production occurring in clump and conventional geometries than the others. Water use efficiency for grain production was higher for corn than grain sorghum. Corn or sorghum planted in clump or conventional geometry resulted in higher WUEg and water use efficiency for biomass production (WUEb) than any other geometry. Net returns mirrored the trend of grain yields and WUE with corn producing higher net revenue than sorghum and either crop producing higher net revenue when grown in a conventional or clump geometry.

Table 3.2 - Corn and grain sorghum production and water use characteristics as affected by planting geometry, Tribune, Kansas, 2009.

Crop	Geometry	Above Ground Biomass†	Stover	Grain Yield	Harvest Index	Water Use	WUEg	WUEb	Net Returns
		kg ha^{-1} (lb ac^{-1})	kg ha^{-1} (lb ac^{-1})	kg ha^{-1} (bu ac^{-1})		mm (in)	kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})	kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})	USD ha^{-1} (USD ac^{-1})
Corn		9,900 (8,830)	4520 (4030)	6370 (102)	0.53	326 (12.8)	17.0 (384)	31.0 (702)	747 (302)
Grain Sorghum		10,200 (9,080)	4190 (3740)	6930 (110)	0.53	329 (13.0)	18.5 (420)	31.4 (712)	817 (331)
	Clump	10,800 (9,640) ab‡	4530 (4040) b	7340 (117) a	0.55 a	328 (12.9)	19.7 (447) a	33.9 (768) a	924 (374) a
	Cluster	10,400 (9,310) b	4520 (4030) b	6920 (110) a	0.53 abc	329 (13.0)	18.3 (416) a	32.2 (730) a	840 (340) a
	Conventional	11,100 (9,880) a	4940 (4400) a	7180 (114) a	0.51 c	328 (12.9)	19.3 (438) a	34.5 (781) a	877 (355) a
	P1S1	9,180 (8,190) c	4010 (3580) c	6050 (96.4) b	0.52 bc	331 (13.0)	15.9 (360) b	28.1 (636) b	659 (267) b
	P2S2	8,690 (7,760) c	3780 (3380) c	5760 (91.7) b	0.53 ab	322 (12.7)	15.5 (351) b	27.3 (620) b	608 (246) b
Corn	Clump	10,400 (9,320) b	4580 (4090) abc	6940 (111) bc	0.56 a	324 (12.8)	18.4 (417) abc	32.7 (741) abd	874 (354) abe
Corn	Cluster	10,000 (8,960) bcd	4660 (4160) abc	6380 (102) cd	0.53 b	331 (13.0)	16.7 (377) bcd	30.9 (699) abcd	751 (304) bcdef
Corn	Conventional	10,200 (9,070) bcd	4920 (4390) ac	6210 (99) d	0.50 b	324 (12.8)	17.0 (384) bcd	32.4 (735) abcd	706 (286) dfg
Corn	P1S1	9,510 (8,480) cde	4340 (3880) bd	6110 (97.4) d	0.51 b	333 (13.1)	16.0 (362) d	29.2 (661) cef	686 (278) dfg
Corn	P2S2	9,350 (8,340) de	4110 (3670) de	6200 (98.9) d	0.56 a	319 (12.6)	16.8 (380) bcd	29.8 (674) bcde	716 (290) cdfg
Grain Sorghum	Clump	11,200 (9,970) ab	4480 (4000) cd	7750 (123) ab	0.54 ab	331 (13.0)	21.0 (476) a	35.1 (796) ab	973 (394) abc
Grain Sorghum	Cluster§	10,800 (9,670) bc	4380 (3910) cd	7470 (119) b	0.53 ab	327 (12.9)	20.0 (454) ab	33.6 (762) abc	929 (376) abcd
Grain Sorghum	Conventional	12,000 (10,700) a	4950 (4420) ab	8140 (130) a	0.53 ab	332 (13.1)	21.7 (492) a	36.5 (828) a	1049 (425) a
Grain Sorghum	P1S1	8,840 (7,890) de	3670 (3280) ef	5980 (95.3) cd	0.53 ab	330 (13.0)	15.8 (358) cd	27.0 (611) def	632 (256) efg
Grain Sorghum	P2S2	8,040 (7,170) e	3460 (3080) f	5310 (84.5) d	0.51 b	325 (12.8)	14.2 (322) d	24.9 (565) e	500 (202) f
LSD = 0.05									
Crop		1,600 (1,400)	680 (610)	1200 (19)	0.04	30 (1.2)	4.7 (106)	7.2 (163)	251 (102)
Geometry		610 (550)	250 (220)	480 (8)	0.02	9 (0.3)	1.5 (34)	2.4 (55)	101 (41)
Crop x Geometry		1,300 (1,100)	550 (490)	990 (16)	0.04	22 (0.9)	3.5 (80)	5.5 (124)	209 (85)
				ANOVA P>F					
Source									
Crop		0.7091	0.3074	0.3238	0.8735	0.8347	0.3146	0.6692	0.5540
Geometry		<0.0001	<0.0001	<0.0001	0.0054	0.3481	<0.0001	<0.0001	<0.0001
Crop x Geometry		<0.0001	0.0173	<0.0001	0.0015	0.5512	<0.0001	0.0015	<0.0001

† Table values are least square means and may differ from across-years arithmetic means.
‡ Letters within a column and an effect represent differences at LSD (0.05).
§ Potentially affected by a planting error in 2009.

2010 Comparison

Stress in 2010 severely restricted growth and development of corn as reflected in the collected measurements. Above-ground biomass in 2010 was affected by a crop x planting geometry interaction (Table 3.3). Grain sorghum in a clump or conventional geometry produced the most above-ground biomass, followed by sorghum in cluster geometry. Sorghum planted in either of the skip-row configurations produced a similar level of above-ground biomass as any of the corn geometries other than P1S1 which produced the least biomass of any treatment. Stover production was highest for sorghum in a conventional geometry and lowest for any of the skip-row treatments as well as clump and cluster planted corn. Grain yields were highest for grain sorghum in conventional, clump, and cluster geometries. For any given geometry, corn yields were less than the corresponding sorghum yield (Table 3.3). Harvest index was highest among sorghum treatments as well as corn in clump and P2S2 configurations. Water use was higher for corn than sorghum. The increased water use, when combined with the reductions in above-ground biomass and yield, resulted in WUEg and WUEb generally being less for corn treatments than sorghum. The lowest values for WUEg were produced by corn planted in conventional, P1S1, and cluster geometries. The highest values for WUEg and WUEb were for grain sorghum planted in clump, conventional, and cluster geometries. Only corn planted in a clump resulted in a WUEg high enough to be comparable to any grain sorghum treatments. Net returns were highest for grain sorghum planted in clump, conventional, and cluster geometries. The lowest net returns were for corn planted in a conventional or P1S1 geometry. The highest net returns amongst corn treatments were for the clump and P2S2 geometries which were similar to the grain sorghum skip-row treatments (Table 3.3). Crop selection resulted in much larger differences to net returns than did planting geometry. For example, conventionally planted corn was one of the worst corn treatments, while conventionally planted sorghum was one of the best sorghum treatments (Table 3.3).

Table 3.3 - Corn and grain sorghum production and water use characteristics as affected by planting geometry, Tribune, Kansas, 2010.

Crop	Geometry	Above Ground Biomass	Stover	Grain Yield	Harvest Index	Water Use	WUEg	WUEb	Net Returns
		kg ha^{-1} (lb ac^{-1})	kg ha^{-1} (lb ac^{-1})	kg ha^{-1} (bu ac^{-1})		mm (in)	kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})	kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})	USD ha^{-1} (USD ac^{-1})
Corn		8,330 (7,430) b	4470 (3990)	4570 (73) b	0.45	300 (11.8) a	13.6 (308) b	28.4 (644) b	343 (139) b
Grain Sorghum		11,400 (10,200) a	5060 (4510)	7350 (117) a	0.52	253 (10.0) b	24.9 (564) a	43.8 (992) a	886 (359) a
	Clump	11,000 (9,790) a	5010 (4470) b	6960 (111) a	0.52 a	274 (10.8)	22.6 (512) a	40.9 (926) a	822 (333) a
	Cluster	10,300 (9,230) a	4860 (4340) b	6390 (102) a	0.49 ab	273 (10.7)	20.6 (467) a	37.9 (860) a	702 (284) a
	Conventional	11,100 (9,930) a	5600 (5000) a	6450 (103) a	0.45 c	279 (11.0)	21.3 (483) a	40.9 (926) a	698 (282) a
	P1S1	8,310 (7,410) b	4160 (3710) c	4840 (77) b	0.46 bc	280 (11.0)	15.3 (347) b	29.7 (672) b	380 (154) b
	P2S2	8,610 (7,680) b	4200 (3740) c	5160 (82) b	0.49 ab	277 (10.9)	16.3 (370) b	31.1 (706) b	473 (191) b
Corn	Clump	9,140 (8,150) c	4520 (4030) cde	5470 (87) bc	0.50 ab	300 (11.8)	15.7 (356) bc	30.5 (692) bc	549 (222) bc
Corn	Cluster	8,460 (7,550) c	4560 (4070) cde	4610 (74) cd	0.45 b	301 (11.8)	13.4 (304) cd	28.4 (643) cd	353 (143) cd
Corn	Conventional	8,430 (7,520) c	4950 (4420) bcd	4120 (66) de	0.40 c	298 (11.7)	13.3 (302) cd	30.4 (689) bcd	240 (97) de
Corn	P1S1	6,990 (6,240) d	4050 (3610) e	3480 (56) e	0.39 c	307 (12.1)	10.1 (230) d	23.2 (526) d	96 (39) e
Corn	P2S2	8,640 (7,710) c	4290 (3830) e	5150 (82) bc	0.50 ab	297 (11.7)	15.3 (346) c	29.6 (671) bcd	478 (193) bc
Grain Sorghum	Clump	12,800 (11,400) ab	5500 (4910) b	8450 (135) a	0.53 a	249 (9.8)	29.5 (668) a	51.2 (1160) a	1094 (443) a
Grain Sorghum	Cluster	12,200 (10,900) b	5170 (4610) bc	8170 (130) a	0.53 a	244 (9.6)	27.8 (629) a	47.5 (1077) a	1050 (425) a
Grain Sorghum	Conventional	13,800 (12,300) a	6250 (5580) a	8770 (140) a	0.51 ab	261 (10.3)	29.3 (663) a	51.3 (1163) a	1155 (468) a
Grain Sorghum	P1S1	9,620 (8,580) c	4260 (3800) de	6190 (99) b	0.52 ab	253 (10.0)	20.5 (464) b	36.1 (819) b	664 (269) b
Grain Sorghum	P2S2	8,570 (7,650) c	4110 (3660) de	5170 (82) cd	0.49 ab	258 (10.2)	17.4 (394) bc	32.7 (741) bc	467 (189) bcd
LSD = 0.05									
Crop		1,300 (1,200)	860 (770)	1190 (19)	0.08	23 (0.9)	6.1 (138)	8.3 (188)	278 (113)
Geometry		960 (850)	450 (400)	723 (12)	0.04	16 (0.6)	3.0 (69)	5.2 (117)	156 (63)
Crop x Geometry		1,500 (1,300)	760 (670)	1160 (18)	0.07	23 (0.9)	4.6 (103)	7.5 (169)	256 (104)
				ANOVA P>F					
Source									
Crop		0.0027	0.1326	0.0029	0.0748	0.0129	0.0153	0.0154	0.0056
Geometry		<0.0001	<0.0001	<0.0001	0.0089	0.8411	<0.0001	0.0001	<0.0001
Crop x Geometry		<0.0001	0.0163	<0.0001	0.0029	0.6332	0.0006	0.0067	<0.0001

† Letters within a column and an effect represent differences at LSD (0.05).

2011 Comparison

Total above-ground biomass in 2011 was affected by a crop x geometry interaction. The largest amount of above-ground biomass was produced by corn in the clump, P1S1, and cluster configurations, and grain sorghum in the conventional and cluster configuration. The least above-ground biomass was produced by sorghum either skip-row configuration. Planting geometry affected stover production similarly for both corn and grain sorghum ($P<0.0001$, Table 3.4) with cluster and conventional producing the highest levels of stover and P2S2 the least. Similar grain yields were produced in 2011 by corn in a clump, P1S1, or cluster configuration and grain sorghum in a conventional or cluster configuration. Differences in harvest index, although subject to a crop x geometry interaction, were largely driven by the crop component. Harvest indices were higher in corn than grain sorghum for all geometries other than conventional. Corn in a conventional geometry was comparable to grain sorghum in a conventional treatment and higher than all other sorghum treatments. Total water use was 14% higher for grain sorghum than corn ($P=0.0004$, Table 3.4). When averaged across crops, water use was highest for the P1S1 and cluster geometries and the least for the clump, conventional, and P2S2 geometries. Water use efficiency for grain production was highest for the corn treatments and sorghum grown in either a conventional or cluster configuration. Sorghum grown in either of the skip-row configurations resulted in the lowest values for WUEg. The largest values for WUEb were produced by the corn treatments other than P2S2 and the conventional and cluster sorghum treatments. Net returns were largest for corn grown in clump, P1S1, and cluster configurations and sorghum grown in conventional or cluster geometries. Net returns were least for grain sorghum grown in either skip-row configuration (Table 3.4).

Table 3.4 - Corn and grain sorghum production and water use characteristics as affected by planting geometry, Tribune, Kansas, 2011.

Crop	Geometry	Above Ground Biomass	Stover	Grain Yield	Harvest Index	Water Use	WUEg	WUEb	Net Returns
		kg ha^{-1} (lb ac^{-1})	kg ha^{-1} (lb ac^{-1})	kg ha^{-1} (bu ac^{-1})		mm (in)	kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})	kg ha^{-1} mm^{-1} (lb ac^{-1} in^{-1})	USD ha^{-1} (USD ac^{-1})
Corn		11,100 (9,940)	4470 (3990)	7890 (126)	0.60 a	336 (13.2) b	19.9 (450) a	33.2 (752) a	1099 (445) a
Grain Sorghum		10,800 (9,650)	4450 (3970)	7370 (117)	0.55 b	383 (15.1) a	16.6 (377) b	28.2 (639) b	923 (373) b
	Clump	11,000 (9,830) bc	4420 (3940) bc	7720 (123) ab	0.58	354 (13.9) c	18.8 (425) ab	31.3 (710) ab	1032 (418) ab
	Cluster	12,100 (10,800) a	4980 (4440) a	8340 (133) a	0.57	363 (14.3) ab	19.7 (446) a	33.4 (757) a	1163 (471) a
	Conventional	11,600 (10,300) ab	4740 (4230) ab	7980 (127) ab	0.57	358 (14.1) bc	19.1 (432) a	32.3 (733) a	1072 (434) ab
	P1S1	10,700 (9,550) c	4300 (3840) c	7490 (119) b	0.58	367 (14.5) a	17.5 (397) bc	29.3 (664) bc	985 (399) b
	P2S2	9,480 (8,460) d	3860 (3440) d	6610 (105) c	0.57	355 (14.0) bc	16.1 (366) c	27.1 (614) c	801 (324) c
Corn	Clump	11,300 (10,100) abc	4500 (4010)	8030 (128) abc	0.60 a	330 (13.0)	20.6 (466) a	34.2 (775) ab	1127 (456) ab
Corn	Cluster	11,900 (10,600) ab	4810 (4290)	8370 (133) a	0.59 a	343 (13.5)	20.6 (468) a	34.6 (785) a	1209 (489) a
Corn	Conventional	10,800 (9,670) bcd	4600 (4100)	7390 (118) cd	0.58 b	328 (12.9)	19.0 (431) ab	33.0 (749) ab	982 (397) bc
Corn	P1S1	11,400 (10,200) ab	4460 (3980)	8270 (132) abc	0.61 a	350 (13.8)	20.0 (453) a	32.8 (743) ab	1185 (479) a
Corn	P2S2	10,200 (9,130) cd	4000 (3570)	7380 (118) cd	0.61 a	327 (12.9)	19.0 (432) a	31.3 (709) bc	992 (401) bc
Grain Sorghum	Clump	10,700 (9,590) bcd	4340 (3870)	7410 (118) bcd	0.55 cd	377 (14.9)	17.0 (385) bc	28.5 (645) cd	938 (380) cd
Grain Sorghum	Cluster	12,300 (11,000) a	5160 (4600)	8310 (132) ab	0.54 cd	383 (15.1)	18.8 (425) ab	32.2 (730) ab	1118 (452) abc
Grain Sorghum	Conventional	12,300 (11,000) a	4870 (4350)	8580 (137) a	0.56 bc	388 (15.3)	19.1 (433) a	31.6 (717) ab	1163 (470) ab
Grain Sorghum	P1S1	9,950 (8,880) de	4150 (3700)	6710 (107) de	0.54 cd	385 (15.2)	15.1 (341) cd	25.8 (585) de	785 (318) de
Grain Sorghum	P2S2	8,730 (7,790) e	3720 (3320)	5840 (93) e	0.54 d	382 (15.0)	13.2 (300) d	22.9 (518) e	611 (247) e
LSD = 0.05									
Crop		840 (750)	440 (390)	640 (10)	0.02	9 (0.3)	1.4 (33)	2.5 (56)	131 (53)
Geometry		860 (770)	330 (300)	650 (10)	0.01	9 (0.3)	1.5 (33)	2.3 (51)	135 (55)
Crop x Geometry		1,200 (1,100)	490 (440)	920 (15)	0.02	12 (0.5)	2.1 (47)	3.3 (74)	191 (77)
				ANOVA P>F					
Source									
Crop		0.3111	0.8642	0.0811	0.0019	0.0004	0.0057	0.0076	0.0238
Geometry		<0.0001	<0.0001	0.0003	0.4170	0.0176	0.0005	<0.0001	0.0004
Crop x Geometry		0.0060	0.1448	0.0010	0.0019	0.0508	0.0030	0.0197	0.0010

† Letters within a column and an effect represent differences at LSD (0.05).

Across-years comparison

Most measured variables were affected by a crop x geometry interaction in the across-years analysis (Table 3.5). Grain sorghum planted in a clump or conventional geometry was in the top LSD group for above-ground biomass. The smallest amounts of biomass were produced in the skip-row geometries of both corn and grain sorghum. Grain yields were highest for clump and conventional geometries of grain sorghum. Corn in conventional or skip-row geometries and sorghum in skip-row geometries produced the lowest grain yields. The highest harvest indices were observed in clump and P2S2 planted corn while the lowest were observed in conventional, P1S1, and cluster corn and P2S2 grain sorghum. Water use was not affected by treatments in the across-years analysis (Table 3.5). Water use efficiencies tended to favor grain sorghum. The highest values for WUEg was observed in the clump, conventional, and cluster geometries in grain sorghum and the clump geometry in corn. The lowest values of WUEg were produced by the other corn treatments and the skip-row sorghum treatments. Values of WUEb were highest for corn in clump, conventional, and cluster configurations and for sorghum in clump and conventional configurations. The lowest values for WUEb were observed in the skip-row configurations of both corn and grain sorghum. Net returns were highest for clump planted corn and sorghum in clump, conventional, or cluster geometry. The lowest net returns were generated by the corn treatments other than clump, and the skip-row sorghum treatments (Table 3.5).

Table 3.5 - Corn and grain sorghum production and water use characteristics as affected by planting geometry, Tribune, Kansas, 2009-2011.

Crop	Geometry	Above Ground Biomass†	Stover	Grain Yield	Harvest Index	Water Use	WUEg	WUEb	Net Returns
		$kg\ ha^{-1}$ ($lb\ ac^{-1}$)	$kg\ ha^{-1}$ ($lb\ ac^{-1}$)	$kg\ ha^{-1}$ ($bu\ ac^{-1}$)		mm (in)	$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)	$kg\ ha^{-1}\ mm^{-1}$ ($lb\ ac^{-1}\ in^{-1}$)	$USD\ ha^{-1}$ ($USD\ ac^{-1}$)
Corn		9,900 (8,830)	4520 (4030)	6370 (102)	0.53	326 (12.8)	17.0 (384)	31.0 (702)	747 (302)
Grain Sorghum		10,200 (9,080)	4190 (3740)	6930 (110)	0.53	329 (13.0)	18.5 (420)	31.4 (712)	817 (331)
	Clump	10,800 (9,640) ab‡	4530 (4040) b	7340 (117) a	0.55 a	328 (12.9)	19.7 (447) a	33.9 (768) a	924 (374) a
	Cluster	10,400 (9,310) b	4520 (4030) b	6920 (110) a	0.53 abc	329 (13.0)	18.3 (416) a	32.2 (730) a	840 (340) a
	Conventional	11,100 (9,880) a	4940 (4400) a	7180 (114) a	0.51 c	328 (12.9)	19.3 (438) a	34.5 (781) a	877 (355) a
	P1S1	9,180 (8,190) c	4010 (3580) c	6050 (96.4) b	0.52 bc	331 (13.0)	15.9 (360) b	28.1 (636) b	659 (267) b
	P2S2	8,690 (7,760) c	3780 (3380) c	5760 (91.7) b	0.53 ab	322 (12.7)	15.5 (351) b	27.3 (620) b	608 (246) b
Corn	Clump	10,400 (9,320) b	4580 (4090) abc	6940 (111) bc	0.56 a	324 (12.8)	18.4 (417) abc	32.7 (741) abd	874 (354) abe
Corn	Cluster	10,000 (8,960) bcd	4660 (4160) abc	6380 (102) cd	0.53 b	331 (13.0)	16.7 (377) bcd	30.9 (699) abcd	751 (304) bcdef
Corn	Conventional	10,200 (9,070) bcd	4920 (4390) ac	6210 (99) d	0.50 b	324 (12.8)	17.0 (384) bcd	32.4 (735) abcd	706 (286) dfg
Corn	P1S1	9,510 (8,480) cde	4340 (3880) bd	6110 (97.4) d	0.51 b	333 (13.1)	16.0 (362) d	29.2 (661) cef	686 (278) dfg
Corn	P2S2	9,350 (8,340) de	4110 (3670) de	6200 (98.9) d	0.56 a	319 (12.6)	16.8 (380) bcd	29.8 (674) bcde	716 (290) cdfg
Grain Sorghum	Clump	11,200 (9,970) ab	4480 (4000) cd	7750 (123) ab	0.54 ab	331 (13.0)	21.0 (476) a	35.1 (796) ab	973 (394) abc
Grain Sorghum	Cluster§	10,800 (9,670) bc	4380 (3910) cd	7470 (119) b	0.53 ab	327 (12.9)	20.0 (454) ab	33.6 (762) abc	929 (376) abcd
Grain Sorghum	Conventional	12,000 (10,700) a	4950 (4420) ab	8140 (130) a	0.53 ab	332 (13.1)	21.7 (492) a	36.5 (828) a	1049 (425) a
Grain Sorghum	P1S1	8,840 (7,890) de	3670 (3280) ef	5980 (95.3) cd	0.53 ab	330 (13.0)	15.8 (358) cd	27.0 (611) def	632 (256) efg
Grain Sorghum	P2S2	8,040 (7,170) e	3460 (3080) f	5310 (84.5) d	0.51 b	325 (12.8)	14.2 (322) d	24.9 (565) e	500 (202) f
LSD = 0.05									
Crop		1,600 (1,400)	680 (610)	1200 (19)	0.04	30 (1.2)	4.7 (106)	7.2 (163)	251 (102)
Geometry		610 (550)	250 (220)	480 (8)	0.02	9 (0.3)	1.5 (34)	2.4 (55)	101 (41)
Crop x Geometry		1,300 (1,100)	550 (490)	990 (16)	0.04	22 (0.9)	3.5 (80)	5.5 (124)	209 (85)
				ANOVA P>F					
Source									
Crop		0.7091	0.3074	0.3238	0.8735	0.8347	0.3146	0.6692	0.5540
Geometry		<0.0001	<0.0001	<0.0001	0.0054	0.3481	<0.0001	<0.0001	<0.0001
Crop x Geometry		<0.0001	0.0173	<0.0001	0.0015	0.5512	<0.0001	0.0015	<0.0001

† Table values are least square means and may differ from across-years arithmetic means.

‡ Letters within a column and an effect represent differences at LSD (0.05).

§ Potentially affected by a planting error in 2009.

Variability of net returns through time is important to a producer from a risk-management standpoint. The maximum, minimum, standard deviation, and CV for each main effect and treatment combination across the three years are presented in Table 3.6. These values are calculated from annual treatment means and not individual plots, i.e. n=3. The maximum net return during the study was produced by cluster planted corn in 2011 while the smallest net return was produced by P1S1 corn in 2010. The fact that both the maximum and minimum net returns were observed in corn production is also reflected in the higher standard deviation and CV values observed for corn relative to grain sorghum. Of the corn treatments, the smallest CV for net returns was produced when corn was planted in a clump configuration while the largest CV was for the P1S1 configuration (Table 3.6). In grain sorghum, CV for net return was minimized with a clump configuration and highest with cluster planting. Across crops, planting in a clump configuration resulted in a lower CV for net returns, while P1S1 had the most variability.

Table 3.6 - Maximum, minimum, and variability of net returns for corn and sorghum in various planting geometries, Tribune, Kansas, 2009-2011.

Crop	Geometry	Maximum Net Return		Minimum Net Return		Standard Deviation of Net Return		CV of Net Return
		USD ha^{-1}	(USD ac^{-1})	USD ha^{-1}	(USD ac^{-1})	USD ha^{-1}	(USD ac^{-1})	%
Corn		1099	(445)	343	(139)	386	(156)	50
Grain Sorghum		923	(373)	583	(236)	187	(76)	23
	Clump	1032	(418)	822	(333)	106	(43)	12
	Cluster	1163	(471)	650	(263)	283	(114)	34
	Conventional	1072	(434)	698	(282)	187	(76)	21
	P1S1	985	(399)	380	(154)	303	(123)	45
	P2S2	801	(324)	473	(191)	174	(70)	29
Corn	Clump	1127	(456)	549	(222)	301	(122)	34
Corn	Cluster	1209	(489)	353	(143)	428	(173)	56
Corn	Conventional	982	(397)	240	(97)	426	(172)	58
Corn	P1S1	1185	(479)	96	(39)	562	(228)	78
Corn	P2S2	992	(401)	478	(193)	258	(104)	36
Grain Sorghum	Clump	1094	(443)	819	(331)	138	(56)	15
Grain Sorghum	Cluster†	1118	(452)	550	(223)	310	(125)	34
Grain Sorghum	Conventional	1163	(470)	764	(309)	228	(92)	22
Grain Sorghum	P1S1	785	(318)	400	(162)	197	(80)	32
Grain Sorghum	P2S2	611	(247)	380	(154)	117	(47)	24

† Potentially affected by a planting error in 2009

Soil water content was affected by a crop x geometry interaction when measured at the early vegetative stage (Table 3.7). Profile available water tended to be lower amongst corn treatments with the lowest amounts of profile water present in the clump and conventional treatments in the corn and the cluster treatment in sorghum. The most spatial variability in soil water extraction occurred in the P2S2 treatment as indicated by the widest range of soil water contents (Table 3.7). Profile available water was generally higher in the grain sorghum when compared at each crops reproductive stage. The largest amounts of profile available water were present in the grain sorghum skip-row geometries. The smallest amounts were in the cluster, P1S1 and P2S2 corn treatments and the cluster grain sorghum treatment. Cumulative water use at reproductive stage was higher for corn than grain sorghum (P=0.0026, Table 3.7). Corn or grain sorghum planted in clump, cluster, or conventional geometries had higher cumulative water use at the reproductive stage, followed by P1S1 and P2S2. More profile available water was present in grain sorghum than corn at harvest although cumulative water use was not different. The largest amounts of profile water were found in the P2S2 configuration, indicating incomplete extraction. The range and standard deviation of soil water contents were higher for grain sorghum than corn (Table 3.7) indicating a higher level of spatial variability in soil water extraction.

Table 3.7 - Cross-section profile soil water characteristics as affected by crop and planting geometry, Tribune, Kansas, 2009-2011.

Crop	Geometry	Early Vegetative[†]			Reproductive				Harvest			
		Profile Available Water	Range	SD	Profile Available Water	Range	SD	Cumulative Water Use	Profile Available Water	Range	SD	Cumulative Water Use
		mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)	mm (in)	$v\ v^{-1}$	$v\ v^{-1}$	mm (in)
Corn		143 (5.62) b[‡]	0.101	0.026	92 (3.62) b	0.077	0.018	139 (5.46) a	65 (2.56) b	0.083 b	0.020 b	329 (12.95)
Grain Sorghum		156 (6.12) a	0.091	0.024	124 (4.86) a	0.073	0.018	104 (4.09) b	85 (3.34) a	0.119 a	0.031 a	326 (12.84)
	Clump	147 (5.80)	0.092 b	0.025	103 (4.06) b	0.070 bc	0.018 b	126 (4.96) a	76 (3.01) ab	0.099 b	0.026	326 (12.84)
	Cluster	146 (5.76)	0.096 b	0.025	100 (3.93) b	0.071 b	0.018 b	125 (4.92) a	69 (2.72) b	0.098 b	0.026	329 (12.95)
	Conventional	143 (5.64)	0.089 b	0.024	99 (3.90) b	0.064 c	0.017 b	125 (4.93) a	70 (2.75) b	0.095 b	0.025	328 (12.91)
	P1S1	154 (6.08)	0.094 b	0.025	115 (4.54) a	0.071 b	0.017 b	119 (4.68) b	75 (2.95) b	0.102 ab	0.026	332 (13.09)
	P2S2	155 (6.09)	0.111 a	0.026	122 (4.79) a	0.099 a	0.021 a	111 (4.39) c	84 (3.31) a	0.110 a	0.026	322 (12.68)
Corn	Clump	142 (5.58) cd	0.093 bc	0.026	89 (3.49) fg	0.068 cd	0.018 b	145 (5.70)	69 (2.73)	0.080	0.020	327 (12.88)
Corn	Cluster	149 (5.88) bc	0.101 b	0.024	93 (3.66) ef	0.072 c	0.016 b	142 (5.58)	64 (2.53)	0.078	0.020	333 (13.13)
Corn	Conventional	129 (5.08) d	0.091 bc	0.026	76 (3.00) g	0.060 d	0.016 b	143 (5.64)	56 (2.19)	0.078	0.020	327 (12.87)
Corn	P1S1	150 (5.92) bc	0.097 bc	0.025	99 (3.91) ef	0.072 c	0.017 b	139 (5.45)	66 (2.59)	0.082	0.020	335 (13.21)
Corn	P2S2	144 (5.65) bc	0.123 a	0.028	103 (4.04) e	0.113 a	0.023 a	126 (4.95)	70 (2.75)	0.096	0.022	322 (12.66)
Grain Sorghum	Clump	153 (6.01) bc	0.092 bc	0.023	118 (4.63) cd	0.072 cd	0.018 b	107 (4.22)	83 (3.28)	0.119	0.032	325 (12.81)
Grain Sorghum	Cluster[§]	143 (5.64) cd	0.091 bc	0.025	107 (4.20) de	0.070 cd	0.019 b	108 (4.26)	74 (2.92)	0.119	0.032	324 (12.77)
Grain Sorghum	Conventional	157 (6.20) ab	0.087 c	0.021	122 (4.80) bc	0.069 cd	0.018 b	107 (4.23)	84 (3.30)	0.112	0.031	329 (12.95)
Grain Sorghum	P1S1	158 (6.23) ab	0.091 bc	0.024	131 (5.16) ab	0.070 cd	0.018 b	99 (3.90)	84 (3.32)	0.121	0.031	329 (12.97)
Grain Sorghum	P2S2	166 (6.54) a	0.098 b	0.024	141 (5.53) a	0.085 b	0.019 b	97 (3.83)	98 (3.86)	0.123	0.030	322 (12.69)
LSD = 0.10												
Crop		11 (0.43)	0.012	0.0034	10 (0.38)	0.011	0.0027	16 (0.63)	13 (0.50)	0.020	0.0060	25 (0.97)
Geometry		9 (0.36)	0.007	0.0023	9 (0.36)	0.006	0.0016	4 (0.16)	8 (0.33)	0.008	0.0018	7 (0.29)
Crop x Geometry		14 (0.56)	0.012	0.0038	14 (0.54)	0.011	0.0027	11 (0.44)	14 (0.55)	0.017	0.0045	18 (0.72)
						ANOVA P>F						
Source												
Geometry		0.0616	0.1784	0.2120	0.0001	0.5422	0.8139	0.0026	0.0175	0.0101	0.0079	0.8347
Geometry		0.1584	<0.0001	0.6476	<0.0001	<0.0001	0.0012	<0.0001	0.0347	0.0689	0.9938	0.2239
Crop x Geometry		0.0243	0.0470	0.1190	0.0572	0.0002	0.0073	0.2439	0.2591	0.6245	0.3881	0.6956

† Table values are least square means and may differ from across-years arithmetic means.

‡ Letters within a column and an effect represent differences at LSD (0.10) unless noted otherwise

§ Potentially affected by a planting error in 2009.

Conclusions

Cost of adoption of alternative planting geometries will be unique to a given producer and is a function of planter size and land area planted. In general, cost of adoption would be minor for most commercial producers.

The results of this study reinforce the findings of others in that the relative profitability of dryland corn or grain sorghum in western Kansas is largely dependent on the environment for any given crop year. In years with favorable conditions to corn production, corn tended to surpass sorghum in grain yield, WUEg, WUEb, and net returns. However, in a year when environmental stresses limited corn yields to an average of 4520 kg ha^{-1} (73 bu ac^{-1}), grain sorghum treatments generally had relatively higher above-ground biomass, grain yield, WUEg, WUEb, and net returns. In the third year of the study, yields were maximized equally by producing corn in a clump, P1S1, or cluster configuration and grain sorghum in a conventional or cluster configuration. The highest grain yields when averaged across all years were produced by the conventional and clump sorghum geometries. Net returns however were maximized by conventional, cluster, and clump planted sorghum as well as clump planted corn. Skip-row planting consistently reduced net returns for both crops.

While the results of this study provide some information useful to a producer choosing between corn and grain sorghum and various planting geometry options, caution must be applied, as using the results presented here alone to make inferences is an oversimplification of a producer’s decision making process. The results presented here ignore differences in production costs that may exist among producers. Additionally, not addressed are the implications of crop insurance on minimizing downside risk, the level of which is determined by upside potential as reflected in actual production history (APH). The limitation to downside risk allows producers to choose production alternatives that are more risky than those that would be chosen without the limitation to downside risk. Additionally, in a suboptimal year, if a planting geometry results in marginal yields compared as opposed to complete crop failure, a producer’s net revenue may actually be reduced relative to crop failure due to not collecting insurance indemnities.

References

Assefa, Y. 2013. Corn and grain sorghum comparison: All things considered (morphology and physiology, production trends, yield relationships and functions, resource use efficiency, and effect in crop rotation systems. Post-doctoral research report. Dept. of Agron. Kansas State Univ., Manhattan.

Dumler, T.J., and D.M. O'Brien. 2013a. Corn cost-return budget (W-C-F Rotation) for western Kansas. Farm Management Guide MF-2150. Kansas State Univ. Agric. Exp. Stn. and Coop. Ext. Svc., Manhattan, KS.

Dumler, T.J., and D.M. O'Brien. 2013b. Grain sorghum cost-return budget (W-S-F Rotation) for western Kansas. Farm Management Guide MF-904b. Kansas State Univ. Agric. Exp. Stn. and Coop. Ext. Svc., Manhattan, KS.

Langemeier, M.R., E.A. Yeager, and D. O'Brien. 2013. Cost efficiency and feed grain production in Kansas. Selected paper presentation. Southern Agric. Econ. Ann. Meeting, Orlando, FL, 4-7 Feb., 2013.

Milliken, G.A., and D.E. Johnson. 2009. Analysis of messy data – volume 1: designed experiments. 2nd ed. CRC Press. Boca Raton, FL.

Nielsen, D.C., A.D. Halvorson, M.F. Vigil. 2010. Critical precipitation period for dryland maize production. Field Crops Res. 118:259-263.

Norwood, C.A., and R.S. Currie. 1997. Dryland corn vs. grain sorghum in western Kansas. J. Prod. Agric. 10:152-157.

Norwood, C.A., and R.S. Currie. 1998. An agronomic and economic comparison of the wheat-corn-fallow and wheat-sorghum-fallow rotations. J. Prod. Agric. 11:67-73.

Peterson, G.A., A.J. Schlegel, D.L. Tanaka, and O.R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage systems. J. Prod. Agric. 9:180-186.

Staggenborg, S.A., K.C. Dhuyvetter, and W.B. Gordon. 2008. Grain sorghum and corn comparisons: yield, economic, and environmental responses. Agron. J. 100:1600-1604.

Stone, L.R., A.J. Schlegel., A.H. Kahn, N.L. Klocke, and R.M. Aiken. 2006. Water supply: Yield relationships developed for study of water management. J. of Nat. Res. and Life Sci. Ed. 35:161-173.

Teasdale, J.R., C.B. Coffman, and R.W Mangum. 2007. Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agron. J. 99:1297-1305.

Appendix A - Corn supplemental soil water data

2009 Interpolated soil water content

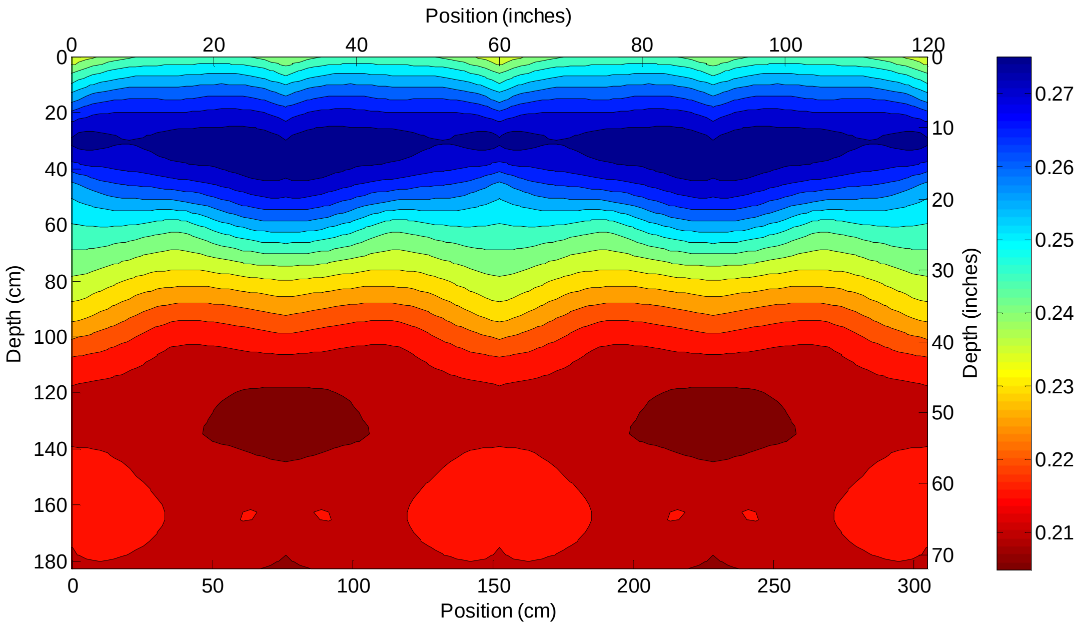

Figure A.1 - 2009 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

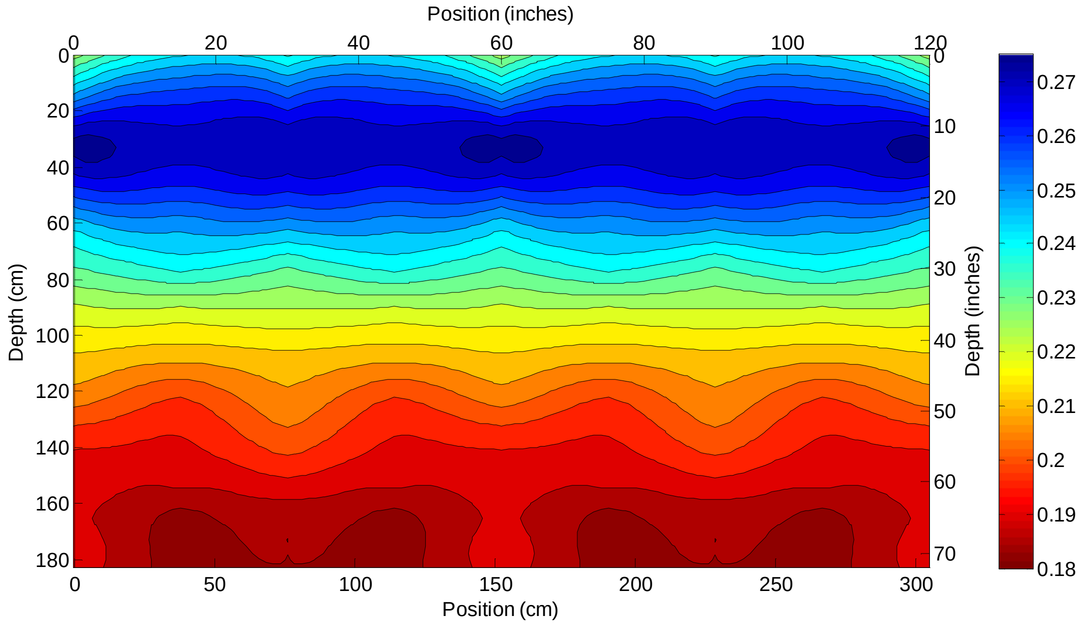

Figure A.2 - 2009 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

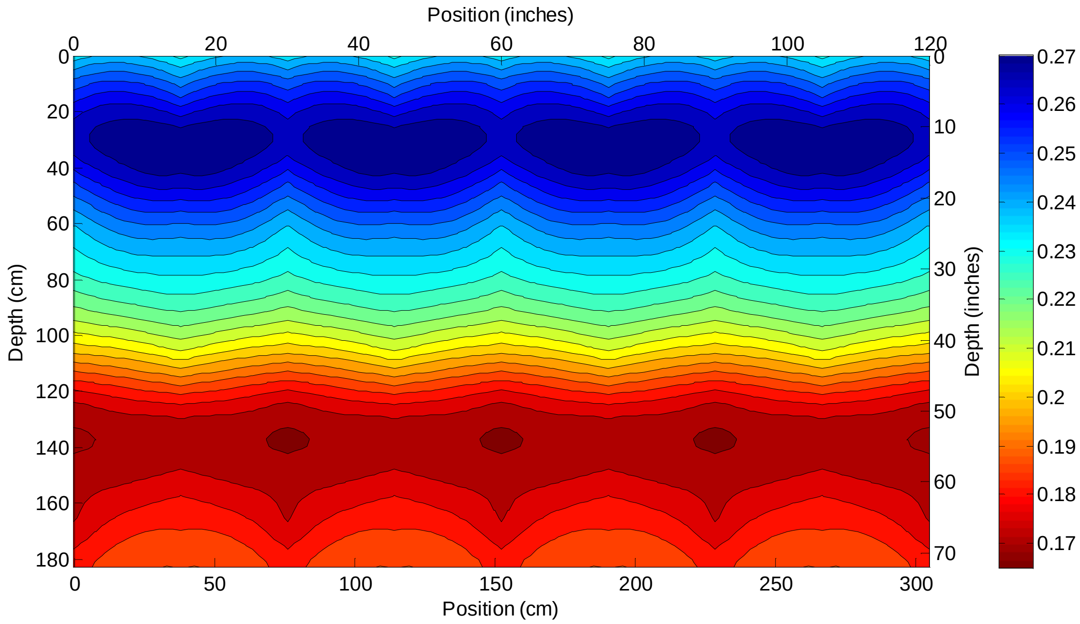

Figure A.3 - 2009 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

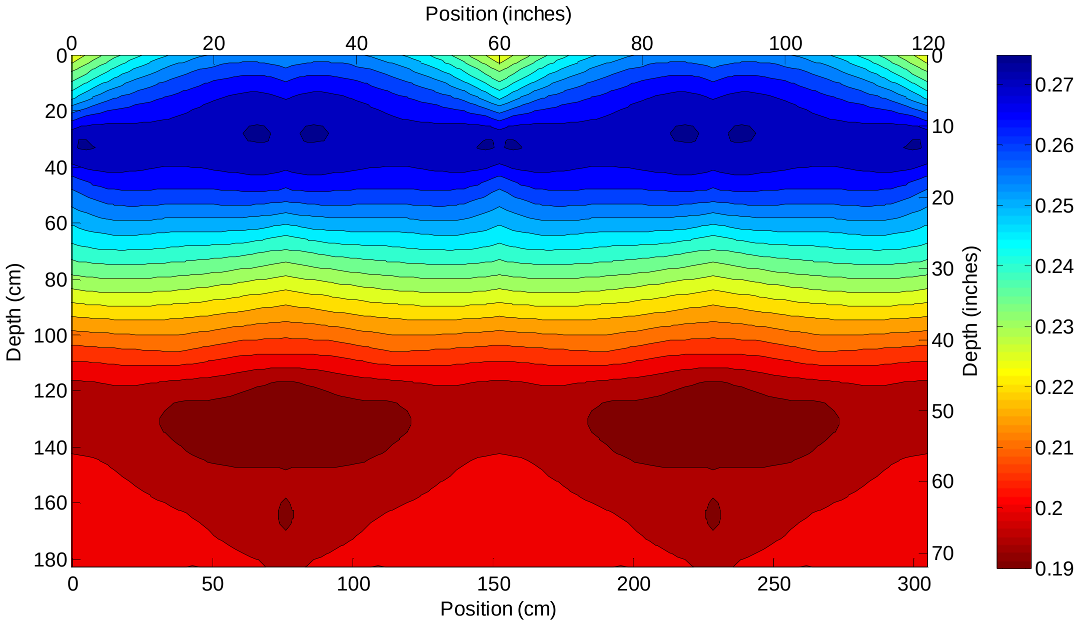

Figure A.4 - 2009 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

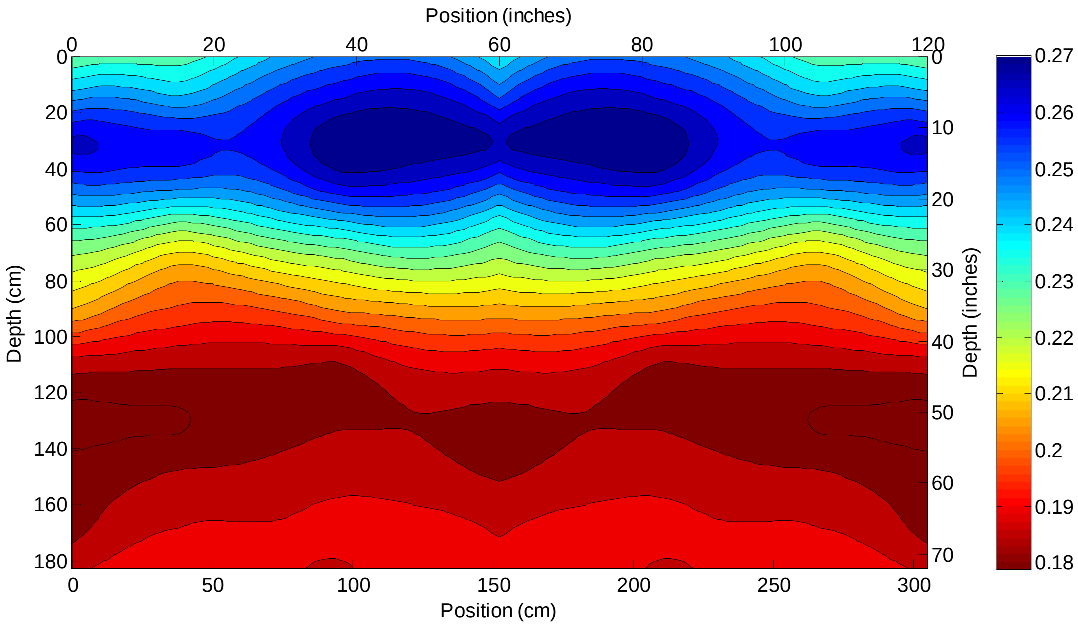

Figure A.5 - 2009 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

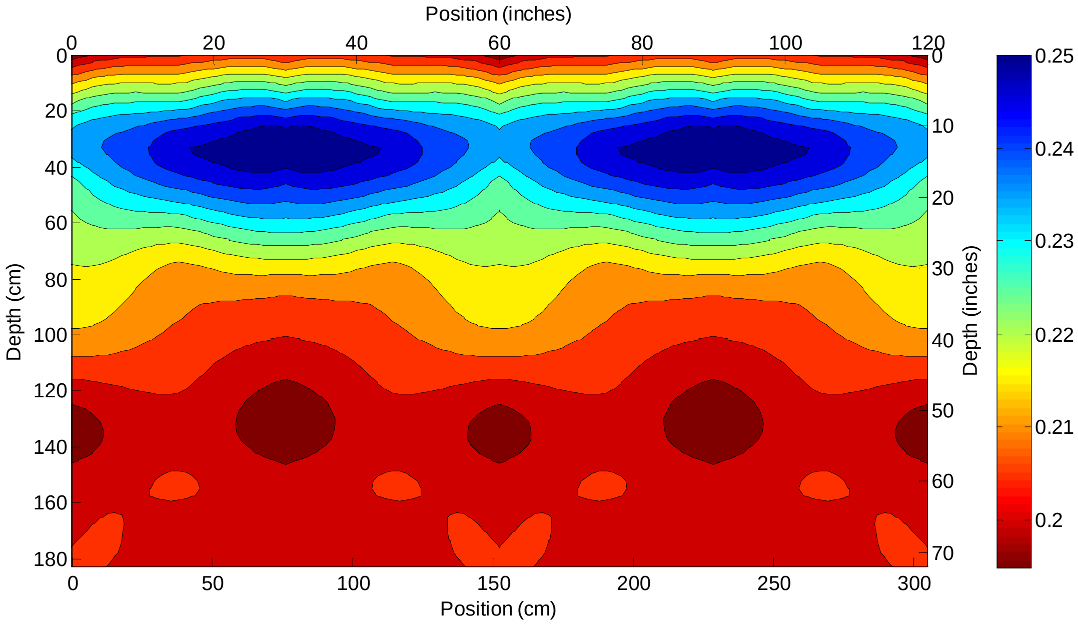

Figure A.6 - 2009 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, clump geometry.

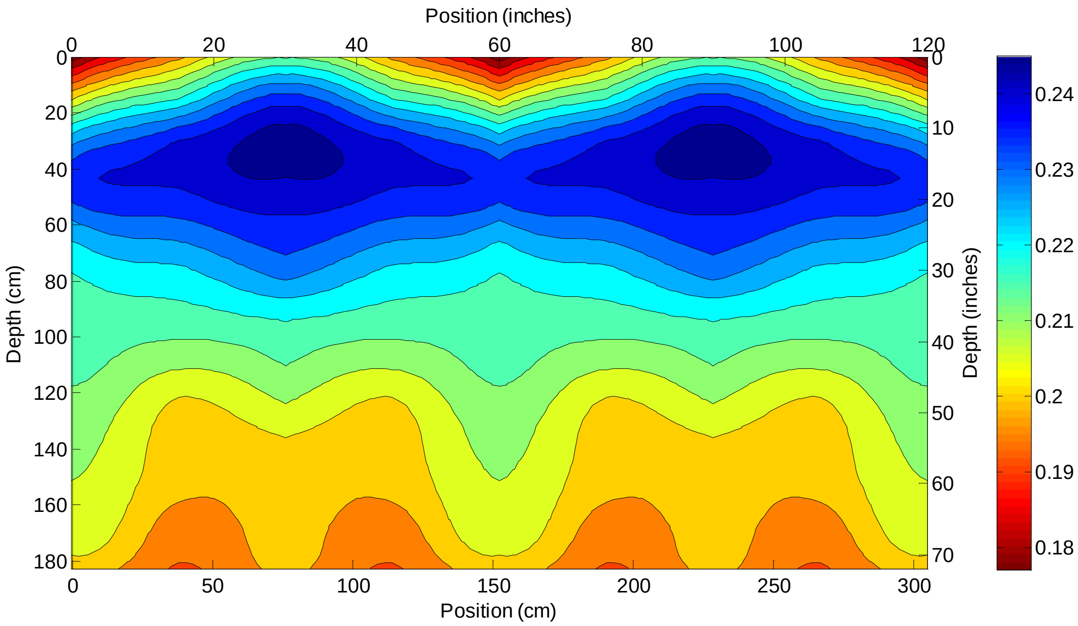

Figure A.7 - 2009 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, cluster geometry.

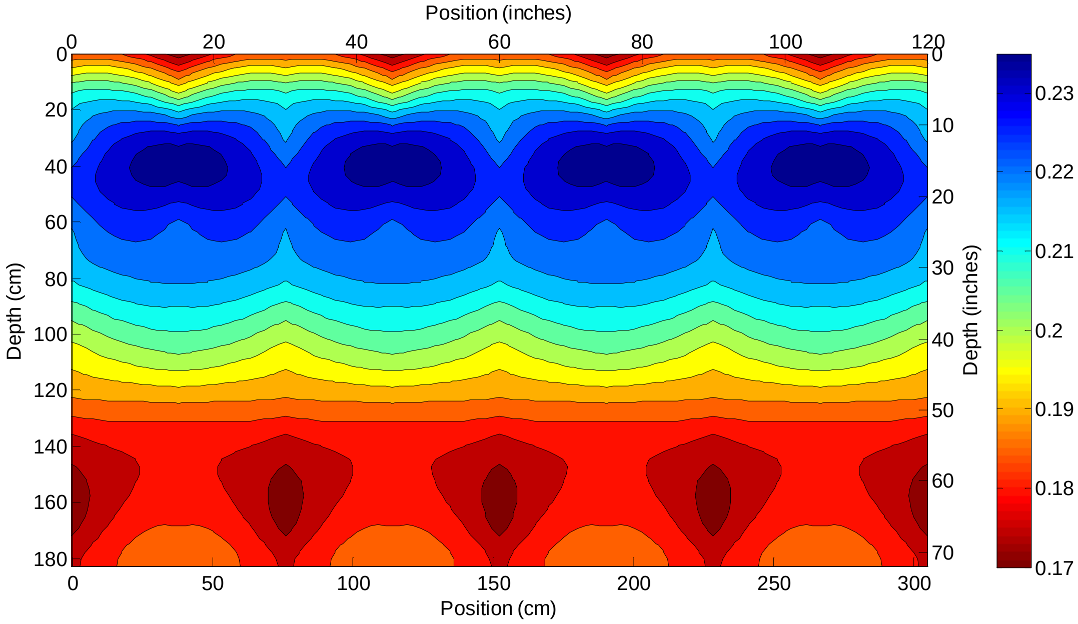

Figure A.8 - 2009 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

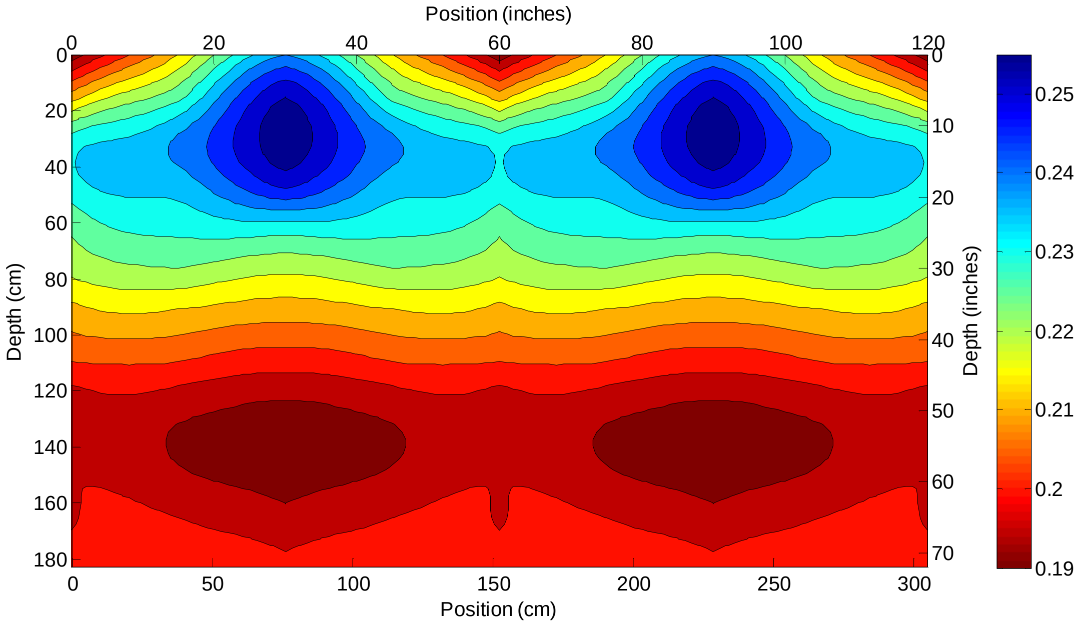

Figure A.9 - 2009 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

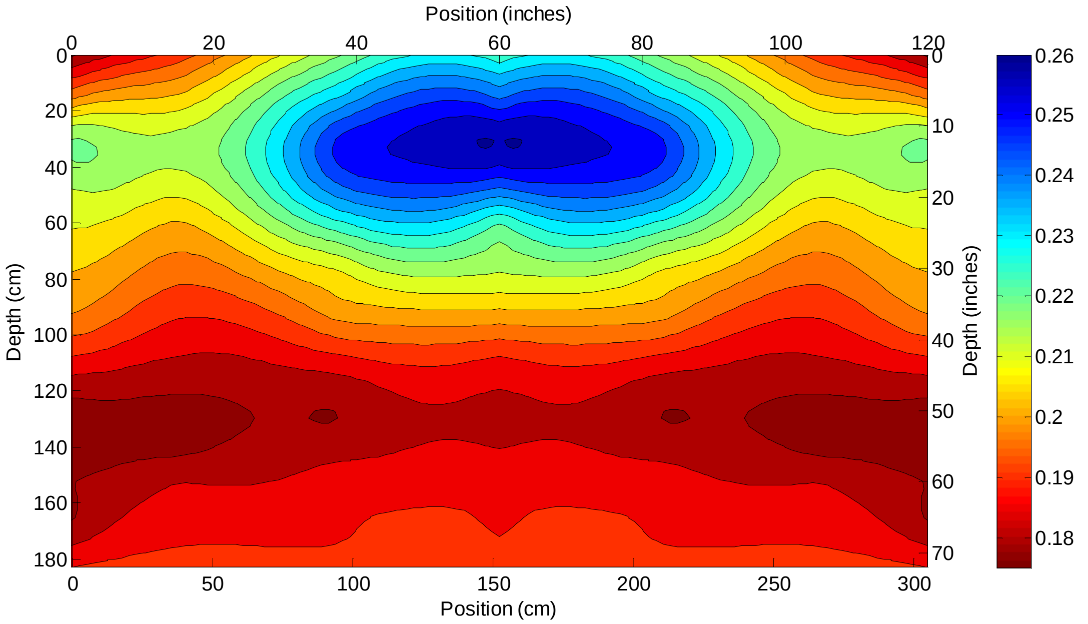

Figure A.10 - 2009 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

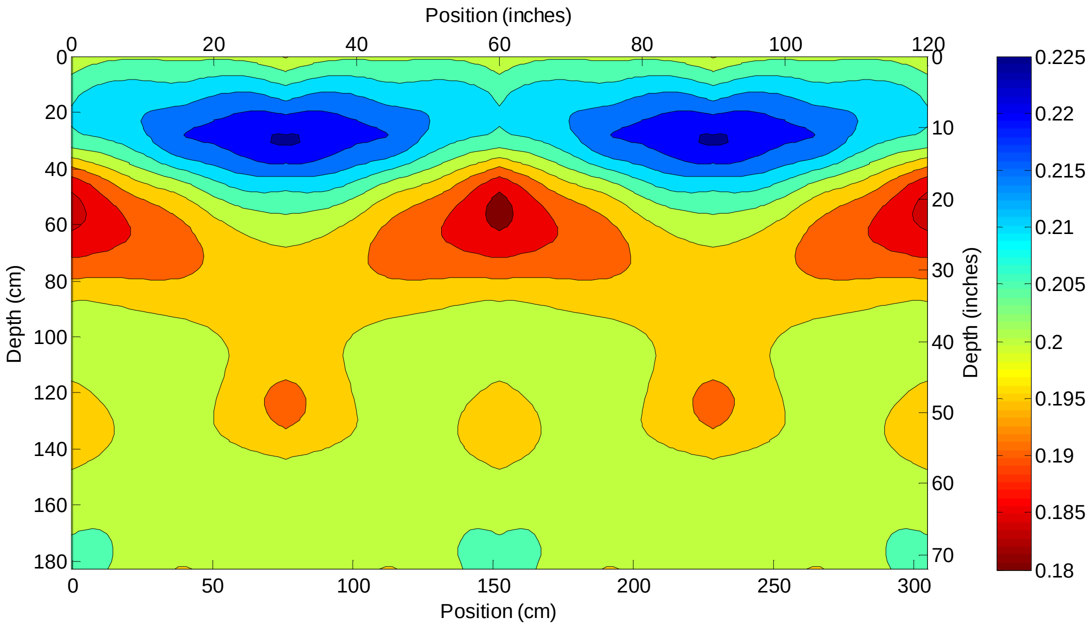

Figure A.11 - 2009 Corn mid vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

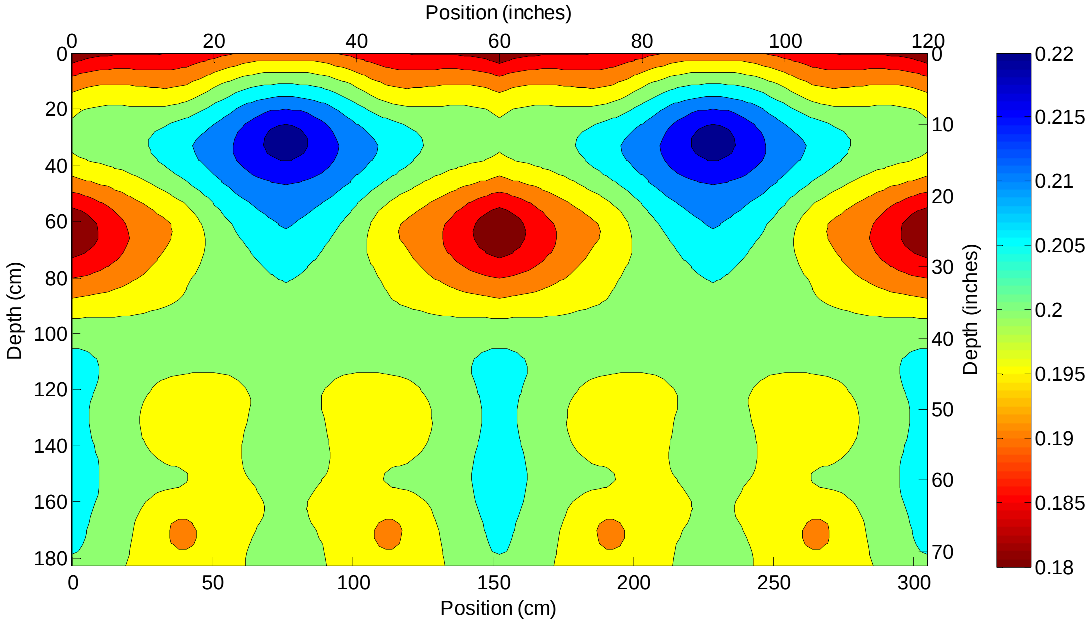

Figure A.12 - 2009 Corn mid vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

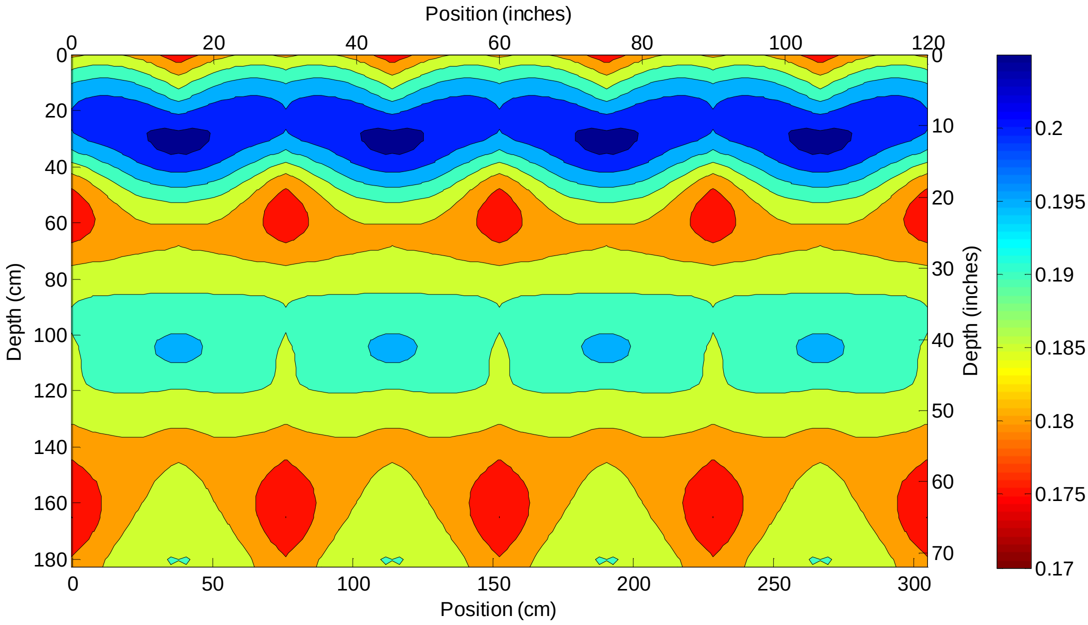

Figure A.13 - 2009 Corn mid vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

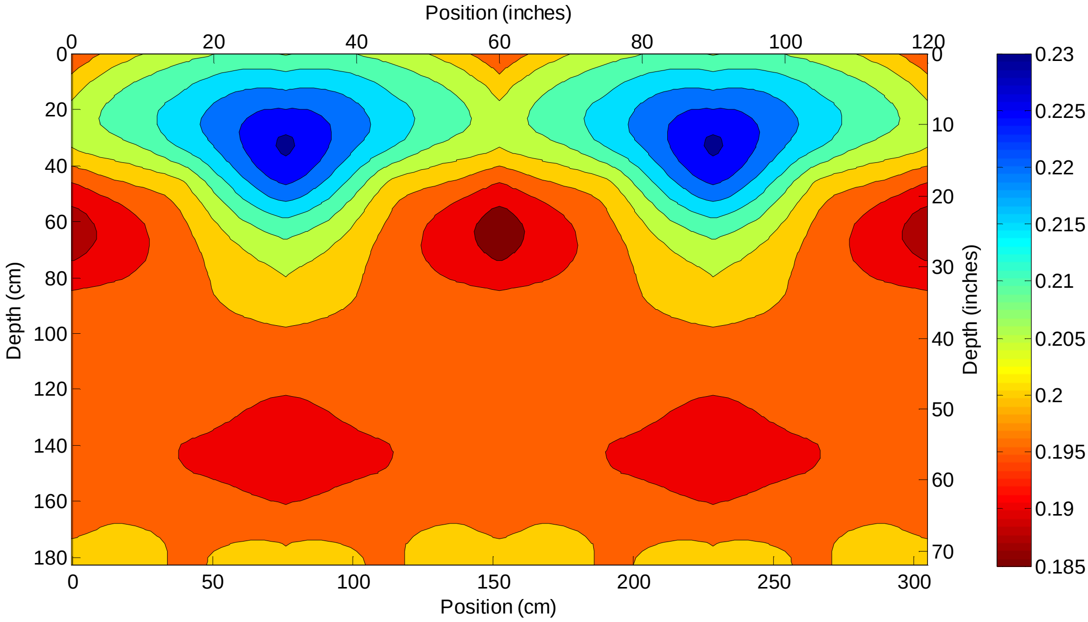

Figure A.14 - 2009 Corn mid vegetative soil water content, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, P1S1 geometry.

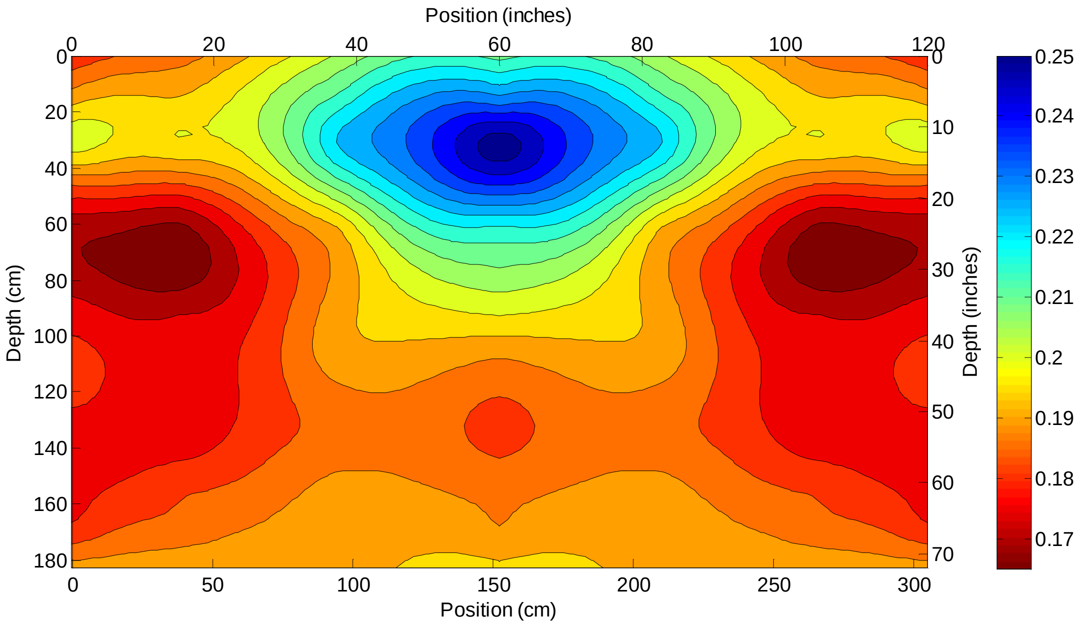

Figure A.15 - 2009 Corn mid vegetative soil water content, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, P2S2 geometry.

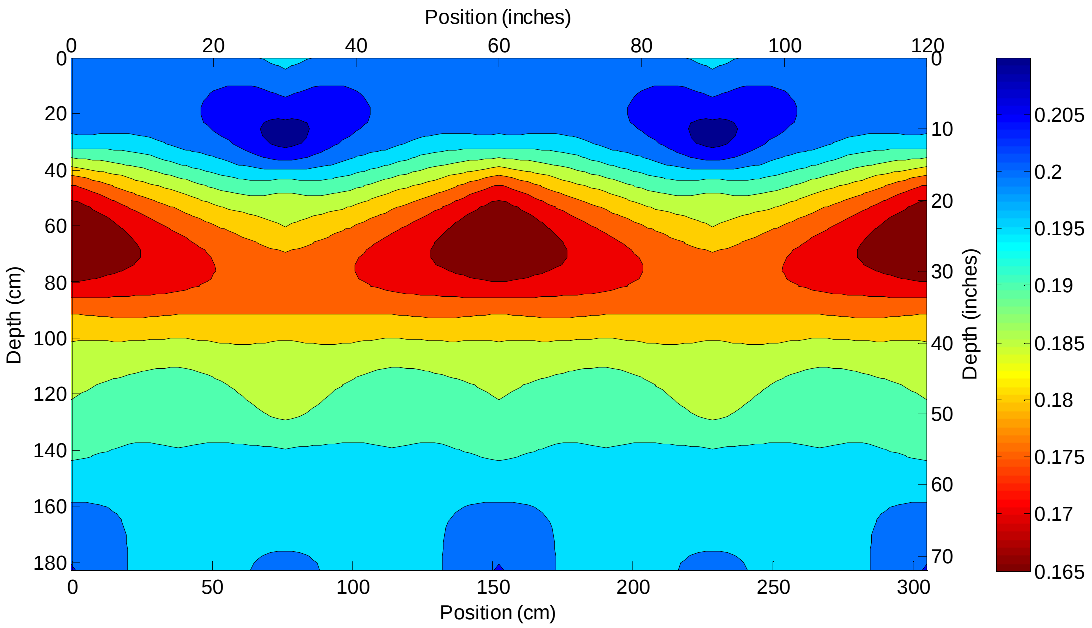

Figure A.16 - 2009 Corn late vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

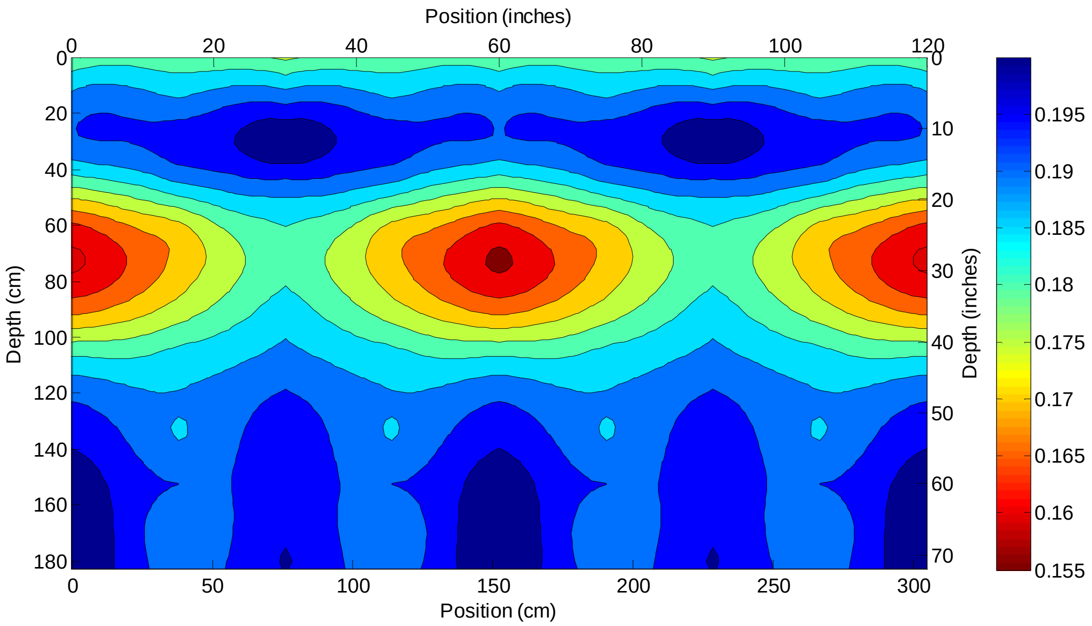

Figure A.17 - 2009 Corn late vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

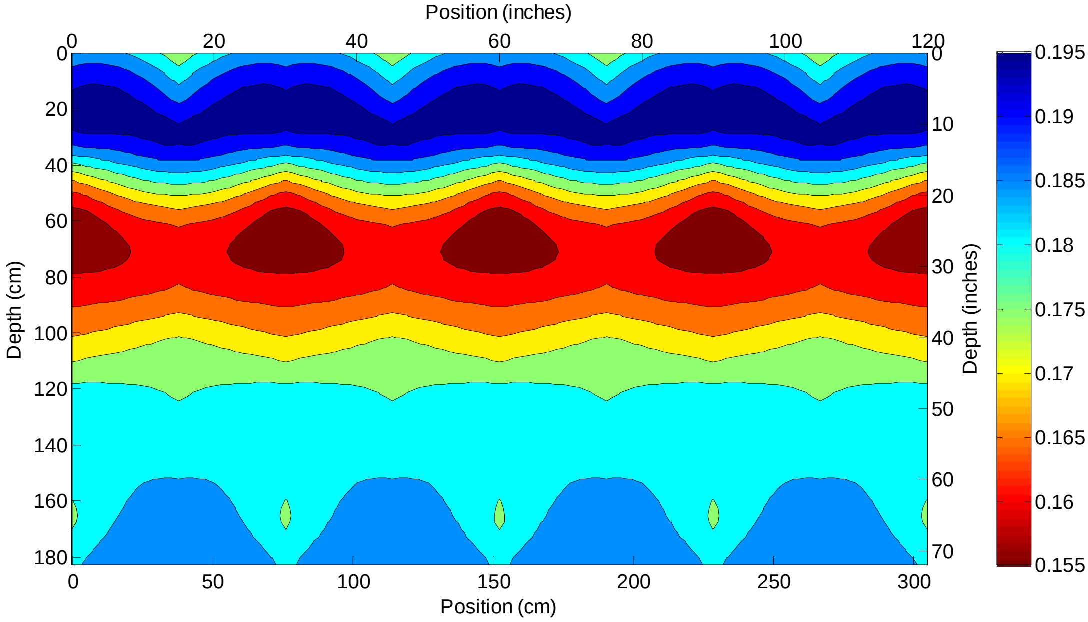

Figure A.18 - 2009 Corn late vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

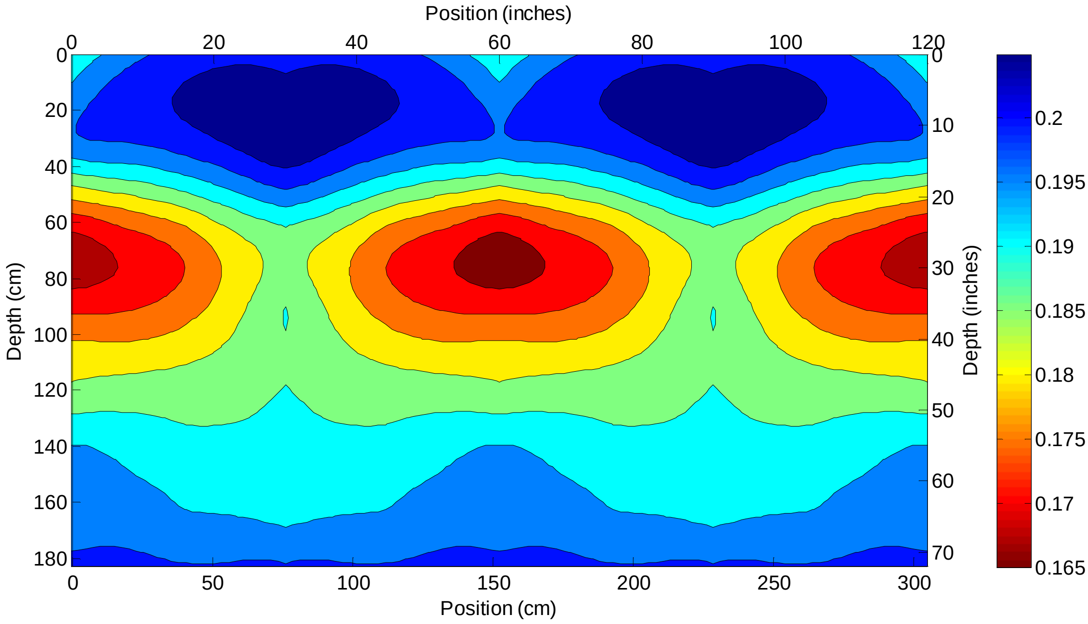

Figure A.19 - 2009 Corn late vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

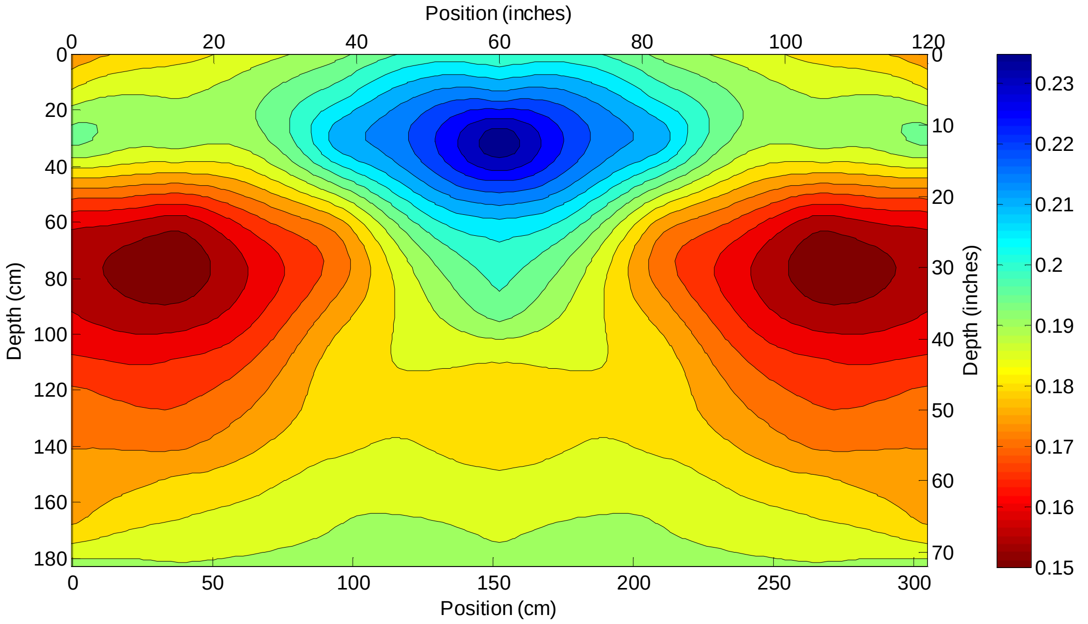

Figure A.20 - 2009 Corn late vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

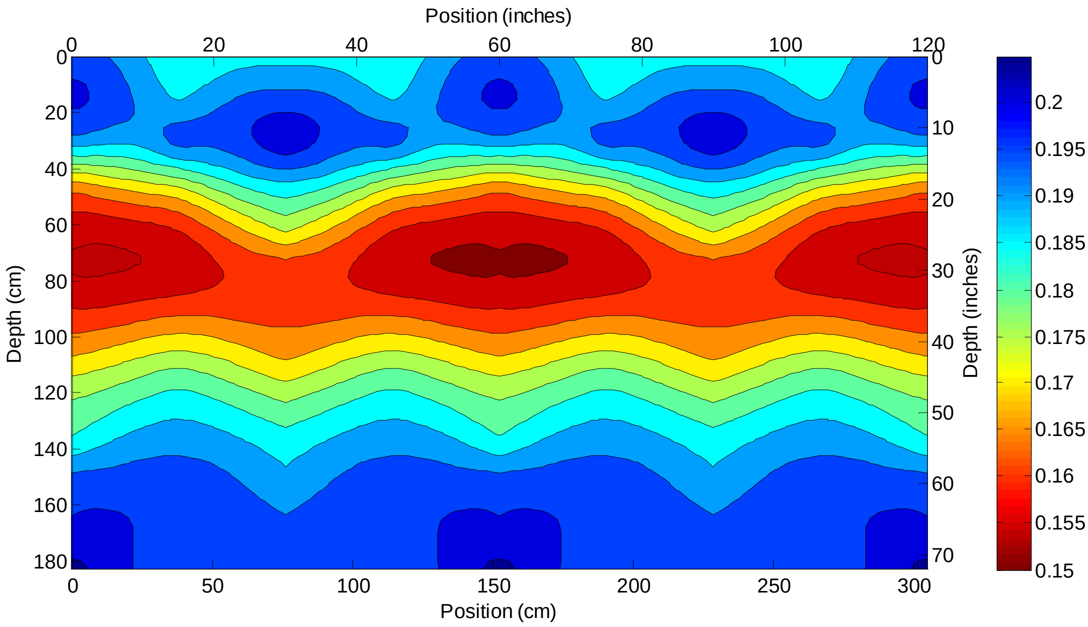

Figure A.21 - 2009 Corn tassel-silk soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

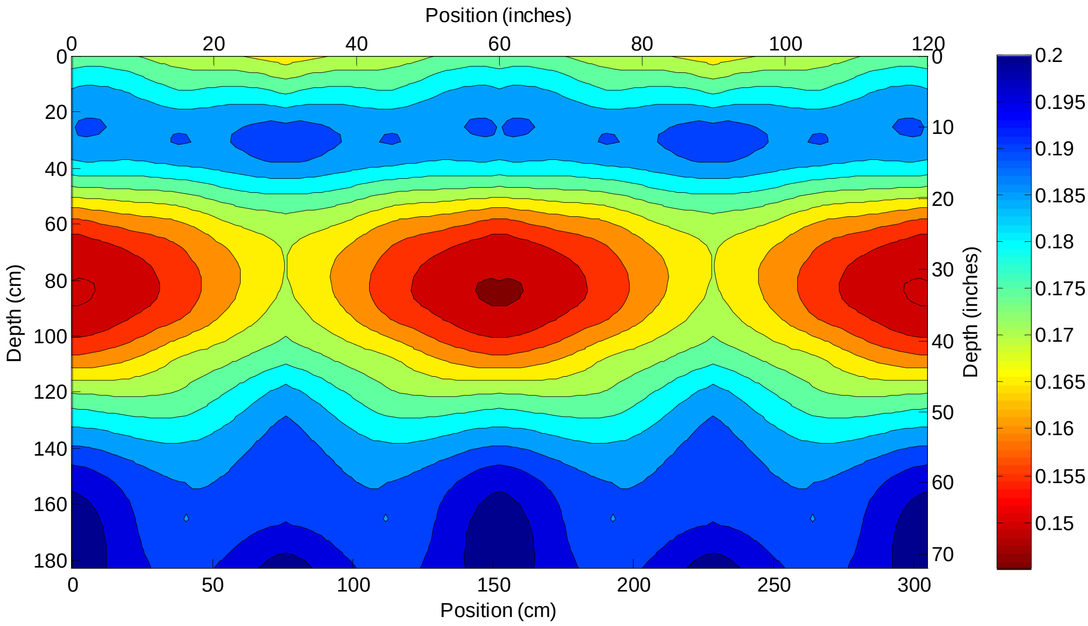

Figure A.22 - 2009 Corn tassel-silk soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

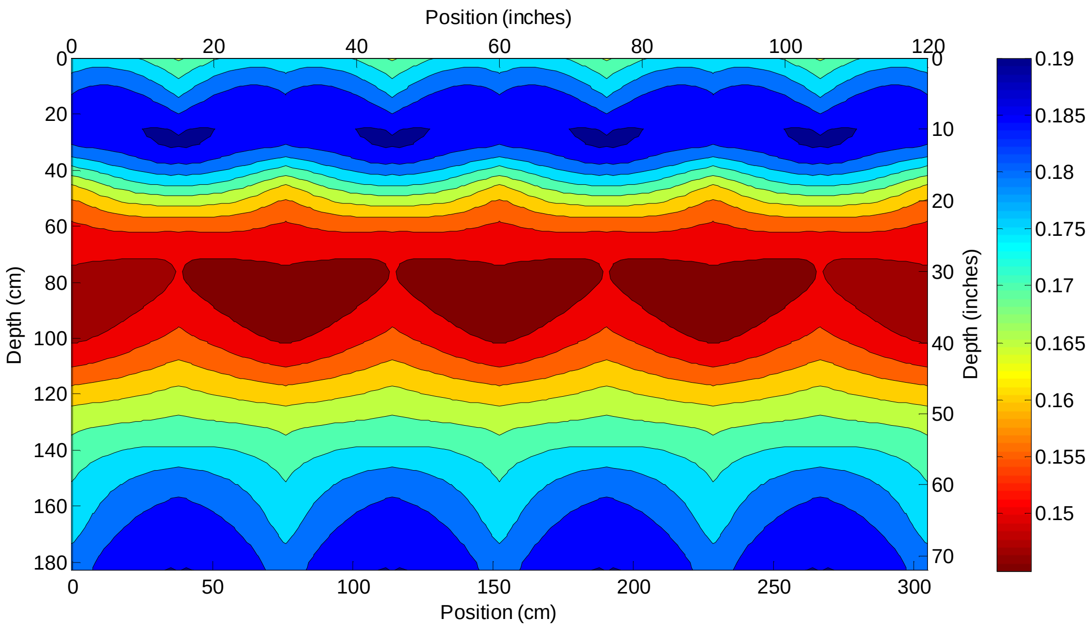

Figure A.23 - 2009 Corn tassel-silk soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

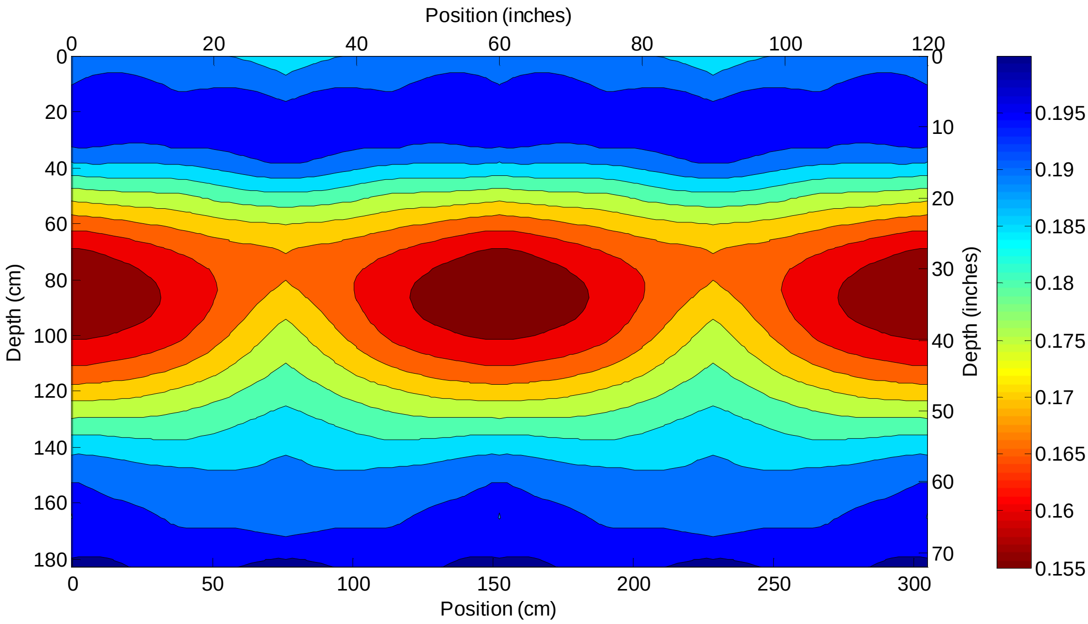

Figure A.24 - 2009 Corn tassel-silk soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

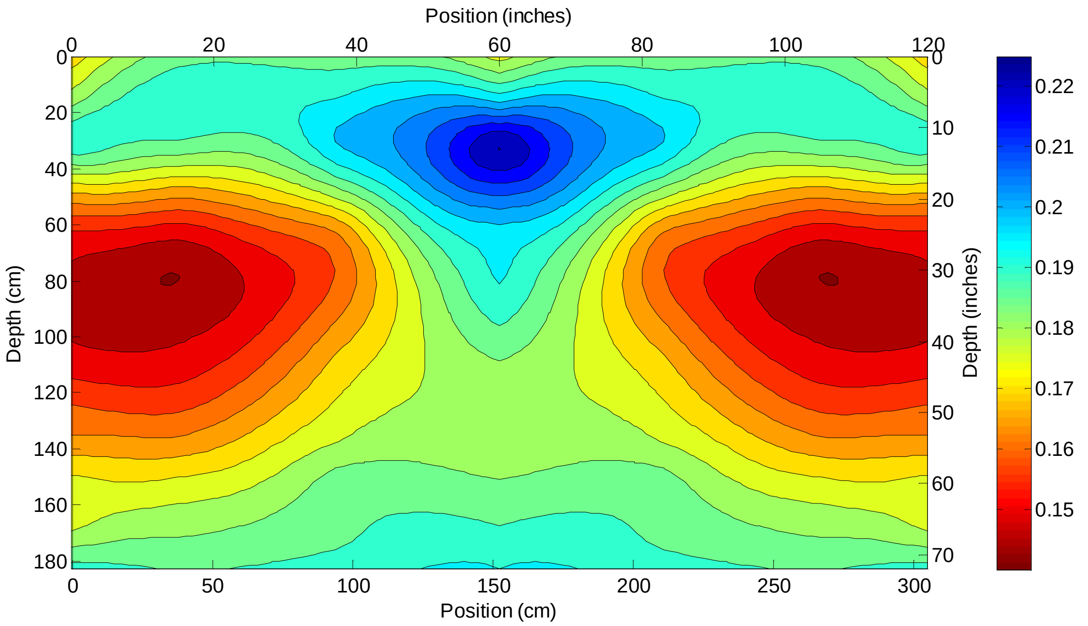

Figure A.25 - 2009 Corn tassel-silk soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

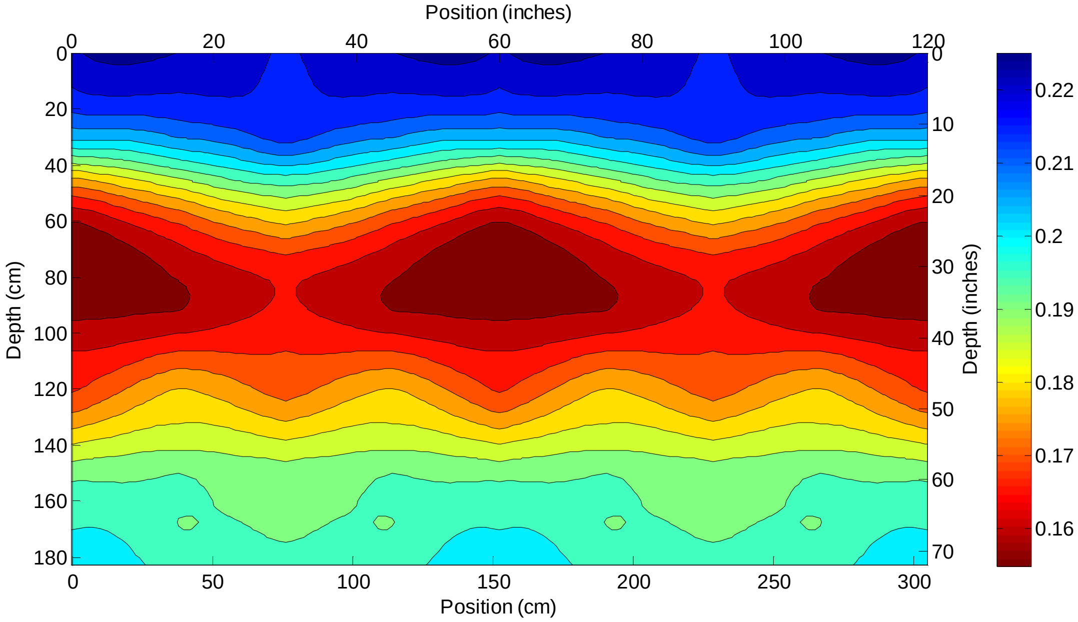

Figure A.26 - 2009 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

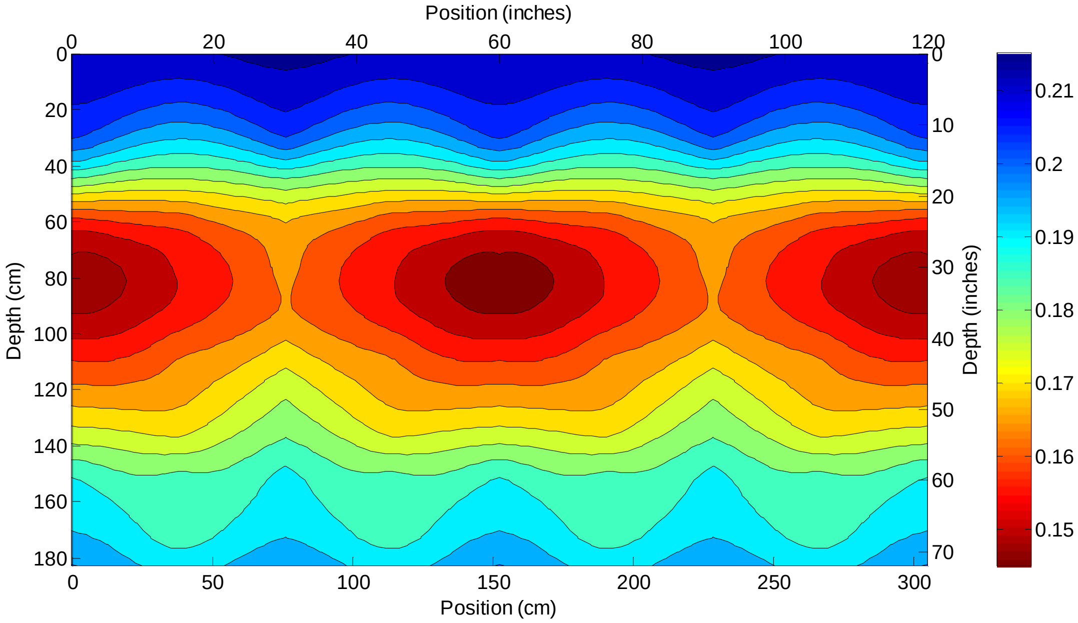

Figure A.27 - 2009 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

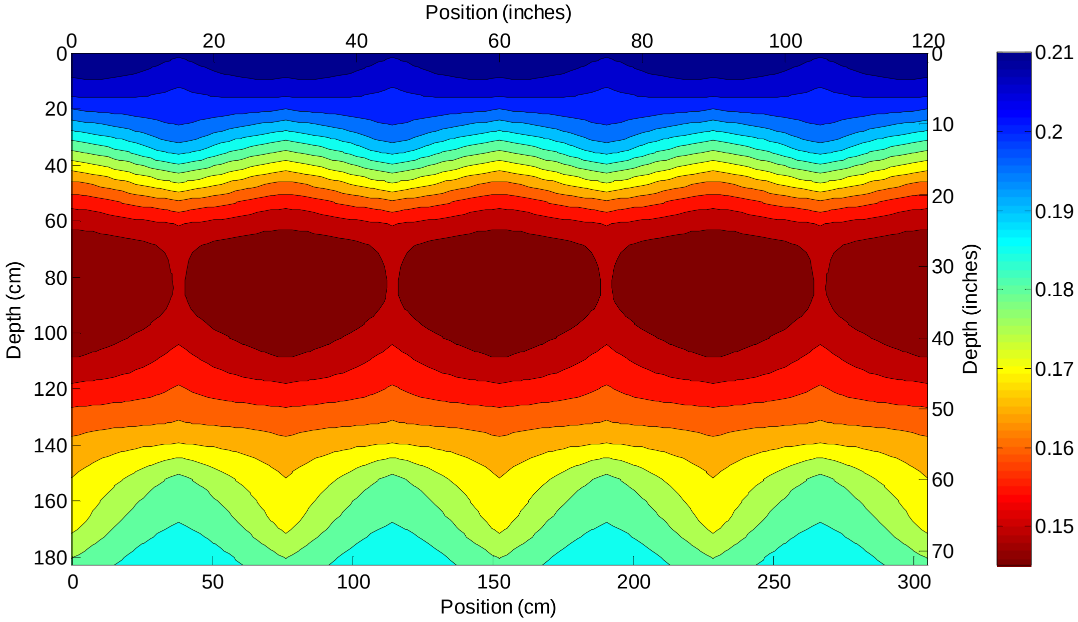

Figure A.28 - 2009 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

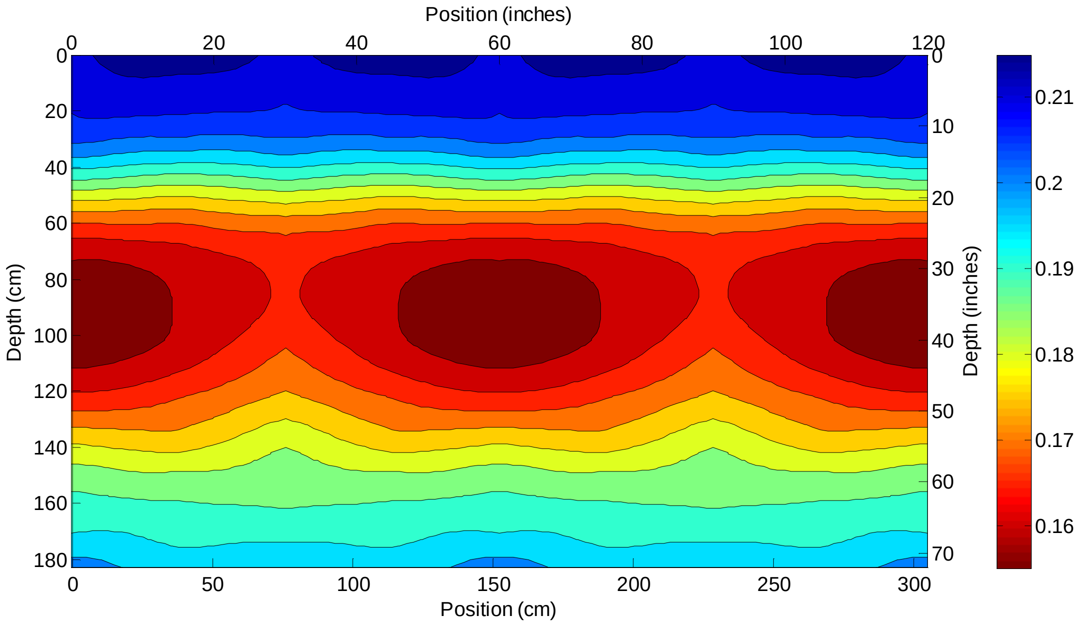

Figure A.29 - 2009 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

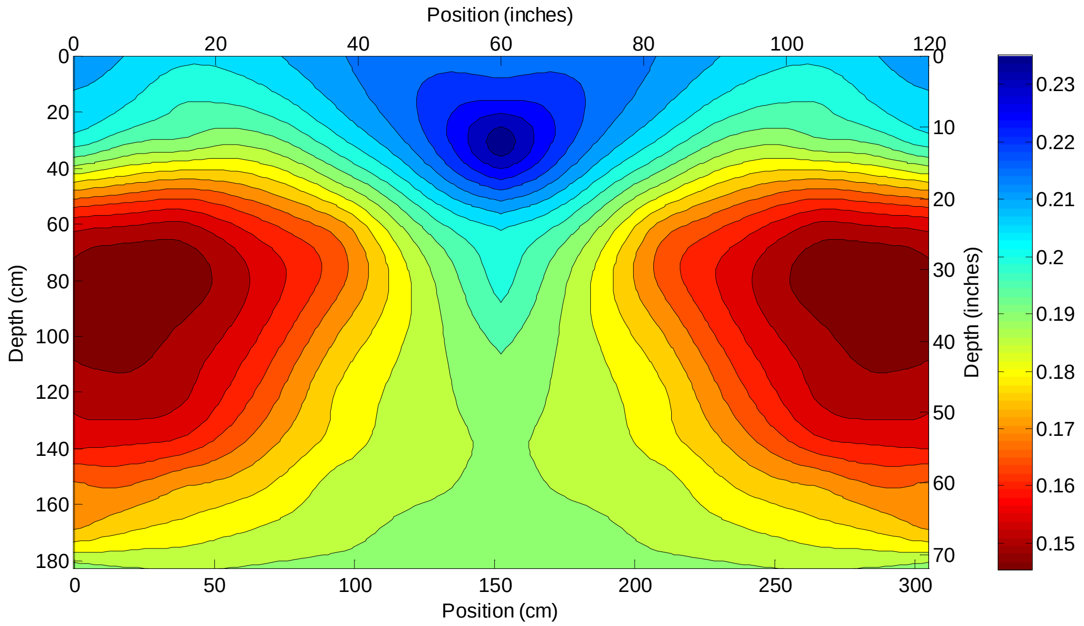

Figure A.30 - 2009 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

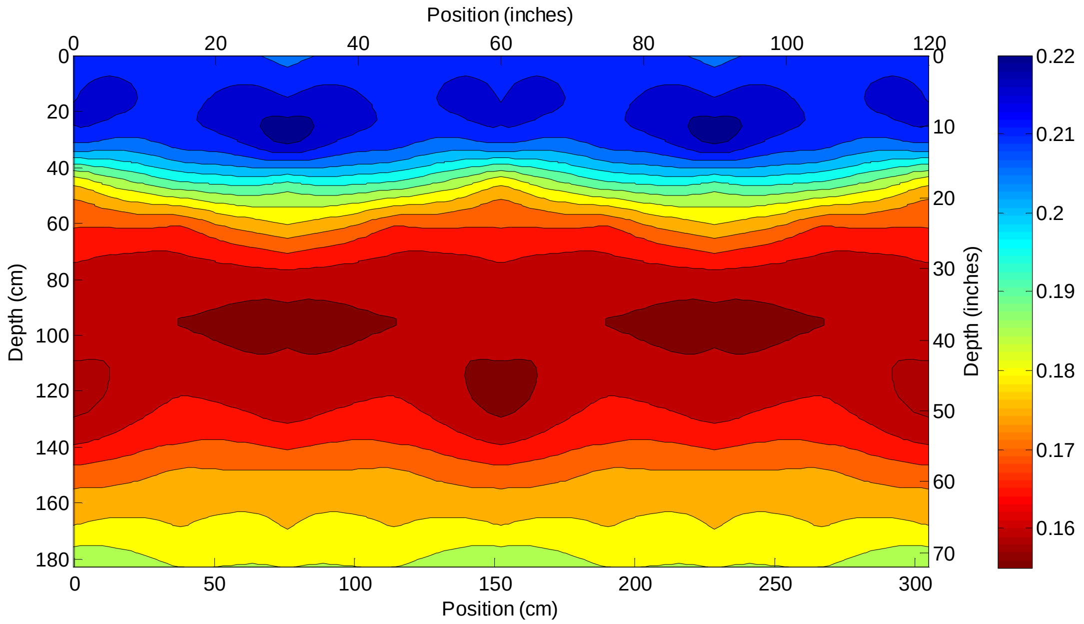

Figure A.31 - 2009 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

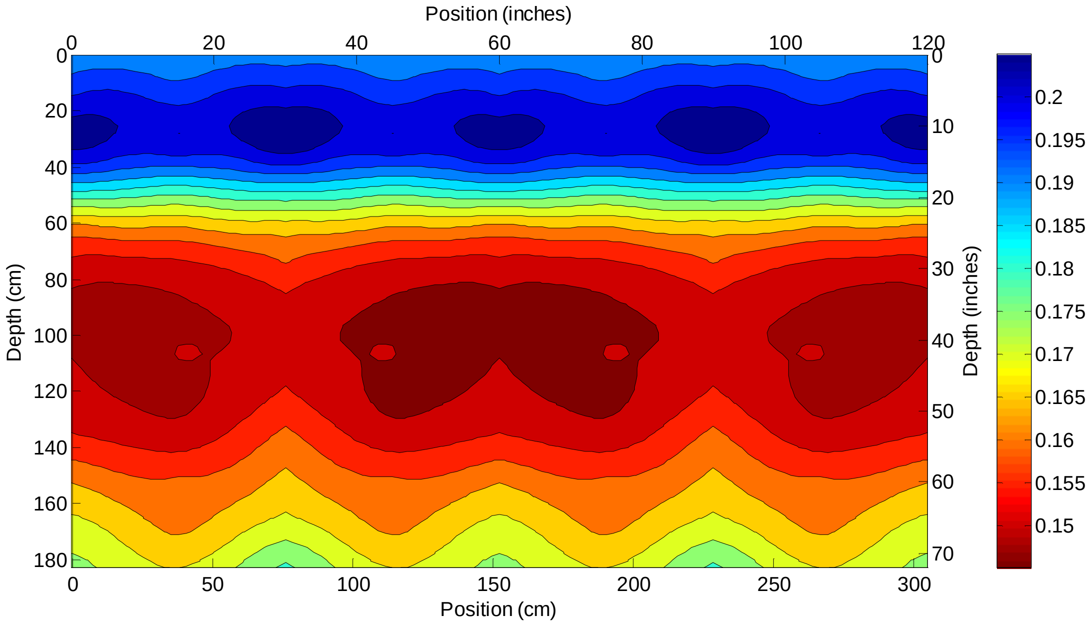

Figure A.32 - 2009 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

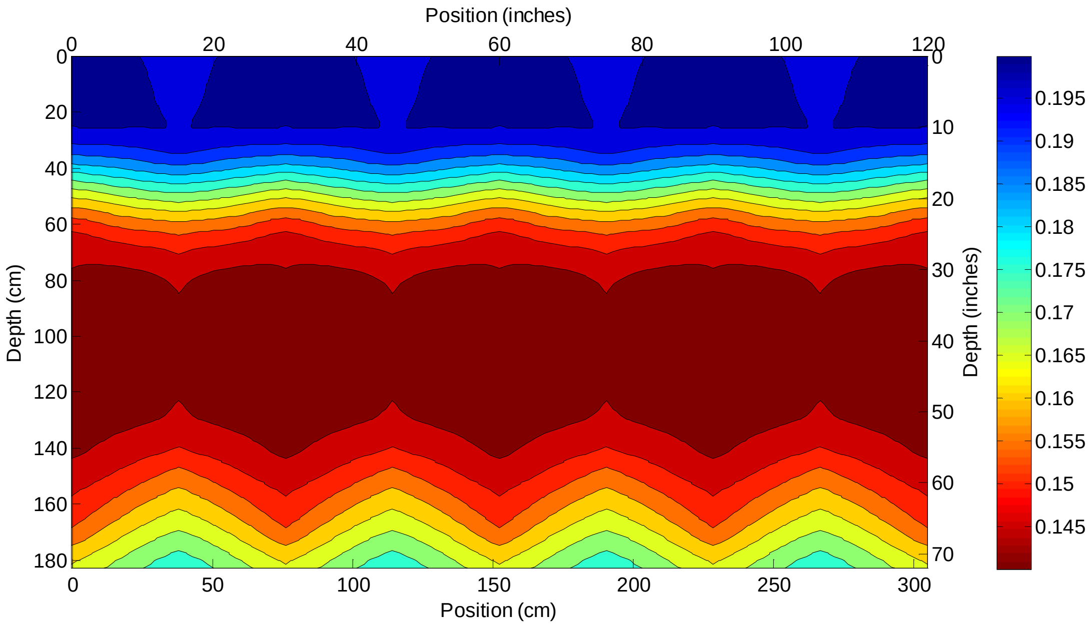

Figure A.33 - 2009 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

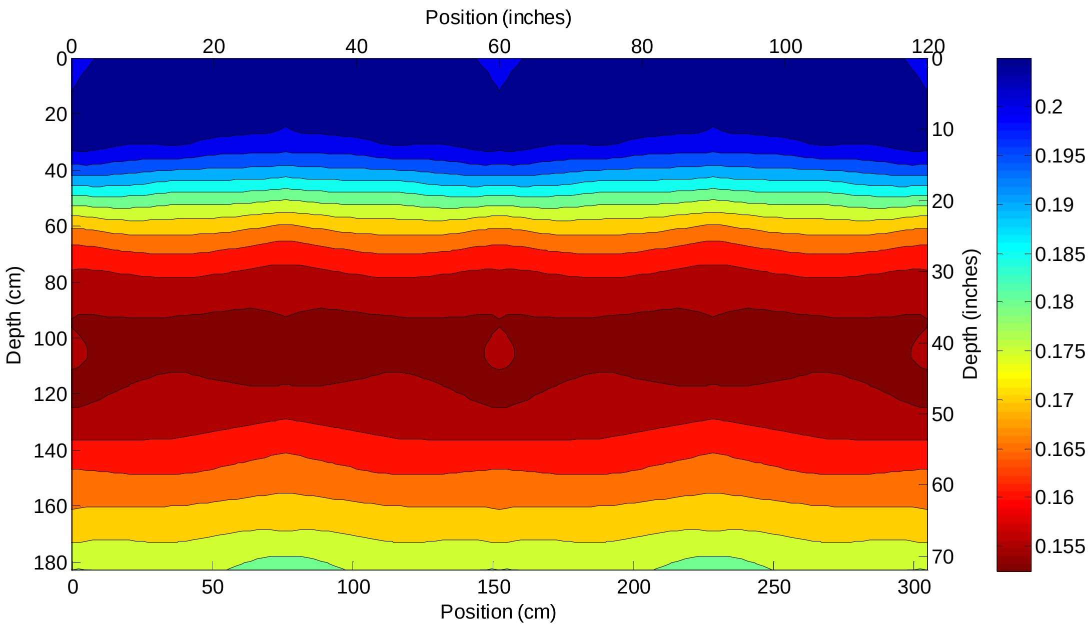

Figure A.34 - 2009 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

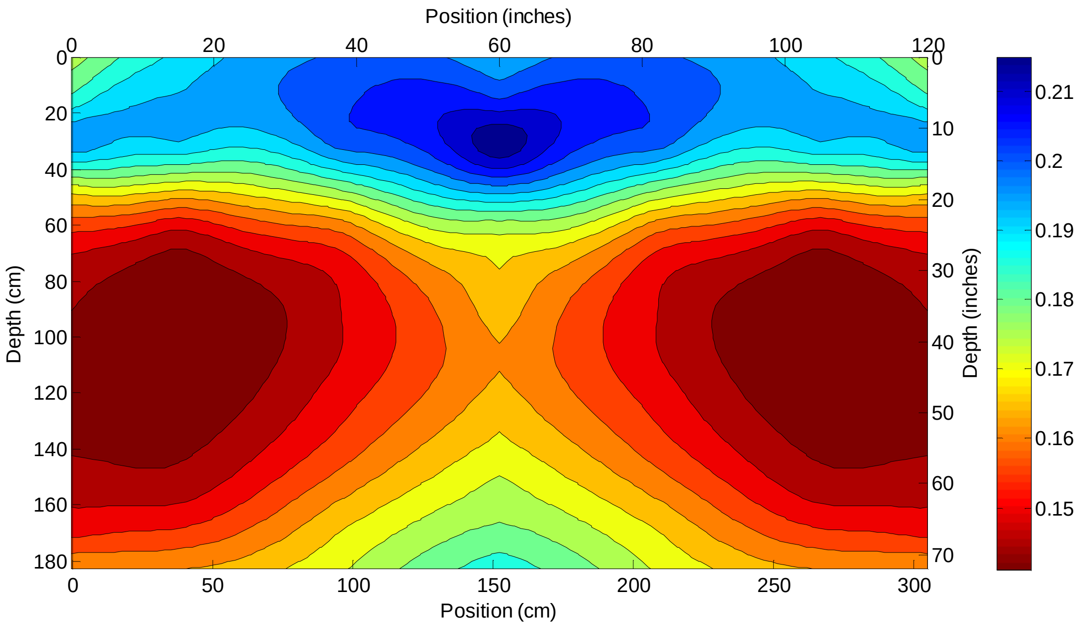

Figure A.35 - 2009 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

2009 Changes in soil water content

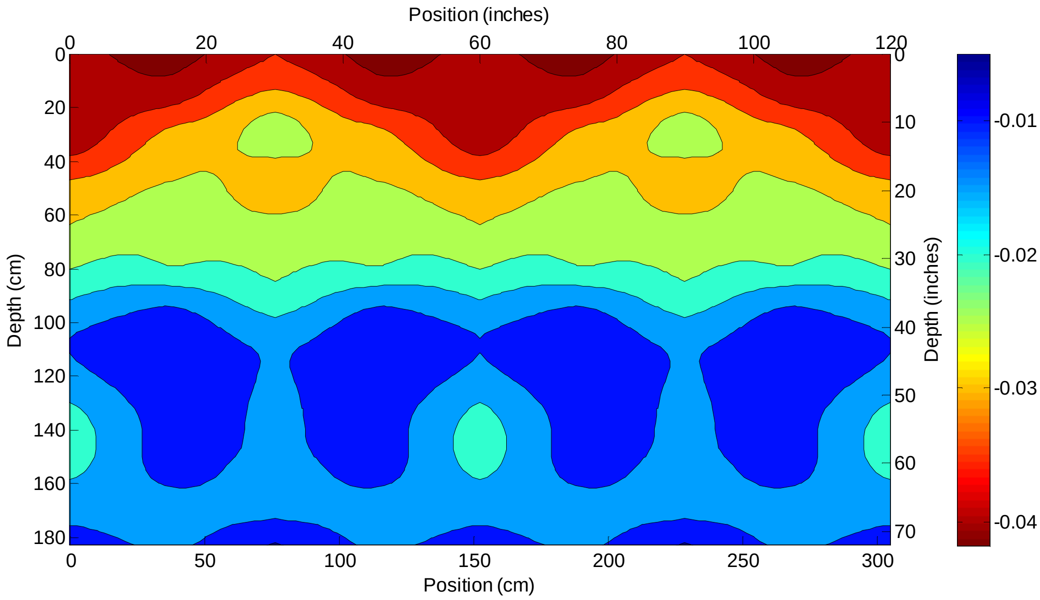

Figure A.36 - 2009 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

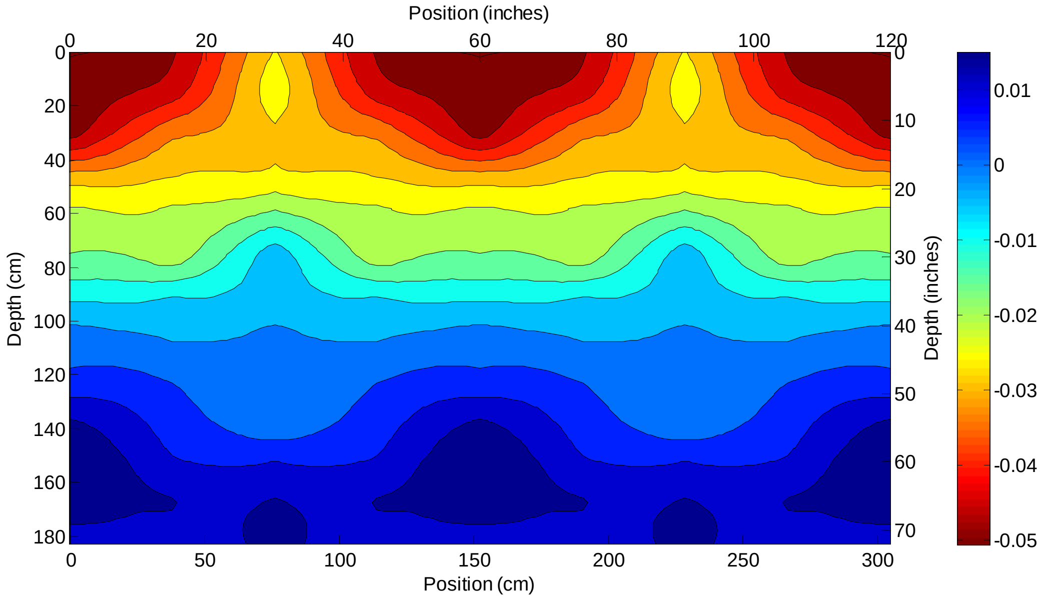

Figure A.37 - 2009 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

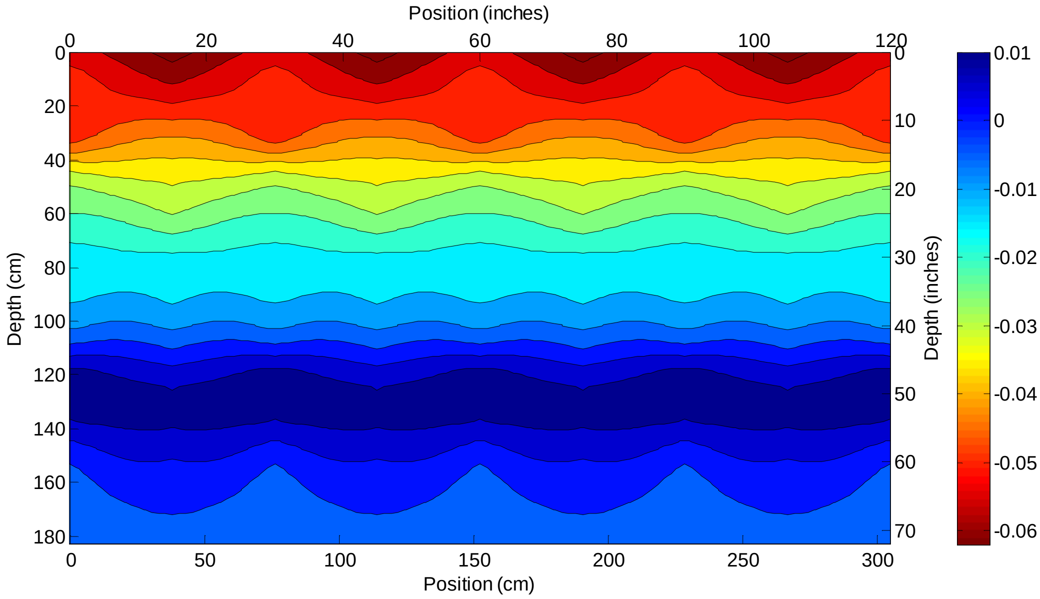

Figure A.38 - 2009 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

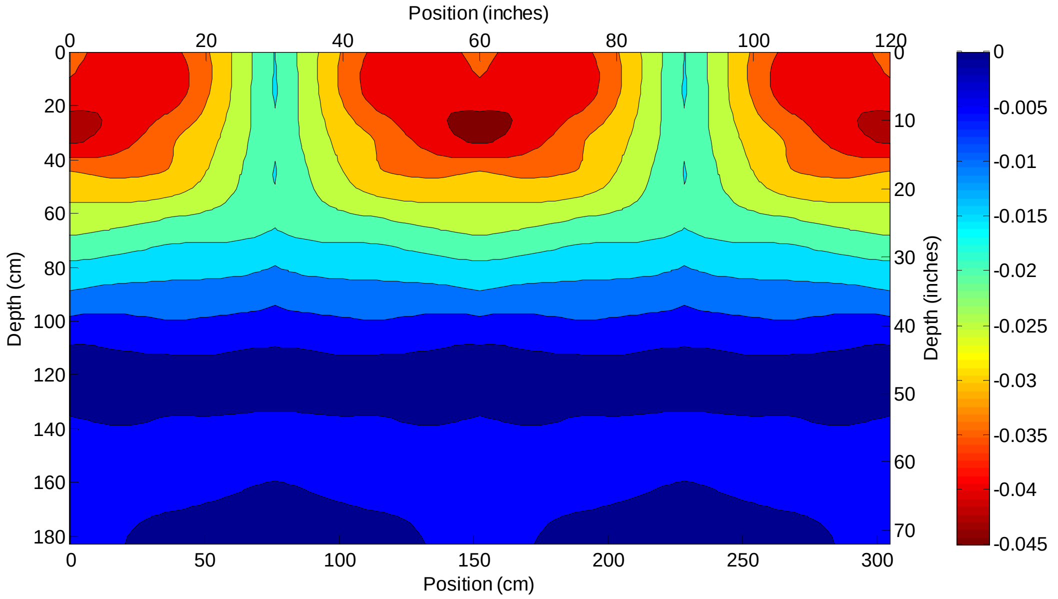

Figure A.39 - 2009 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

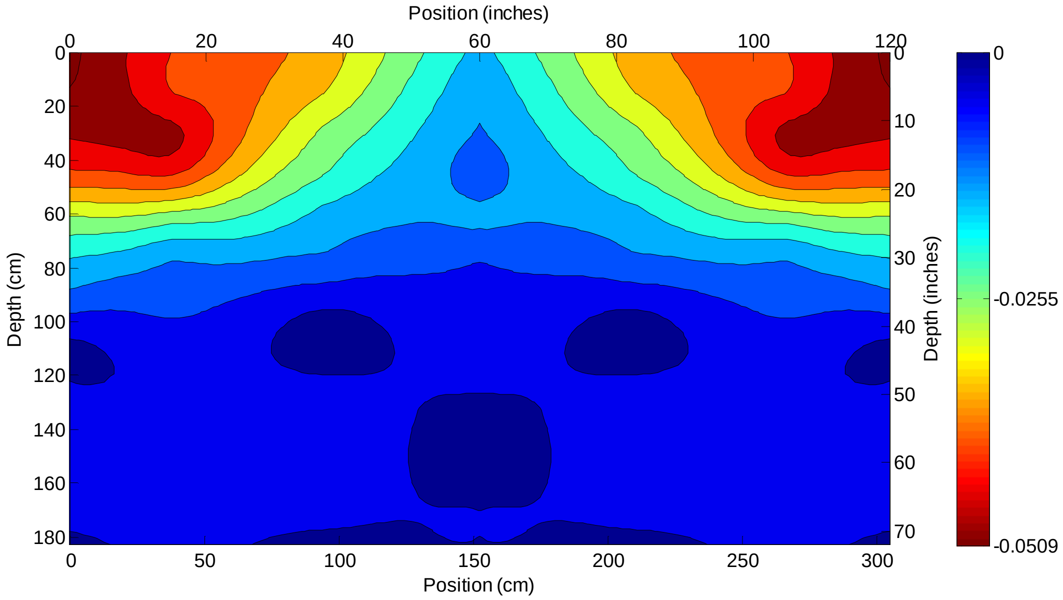

Figure A.40 - 2009 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

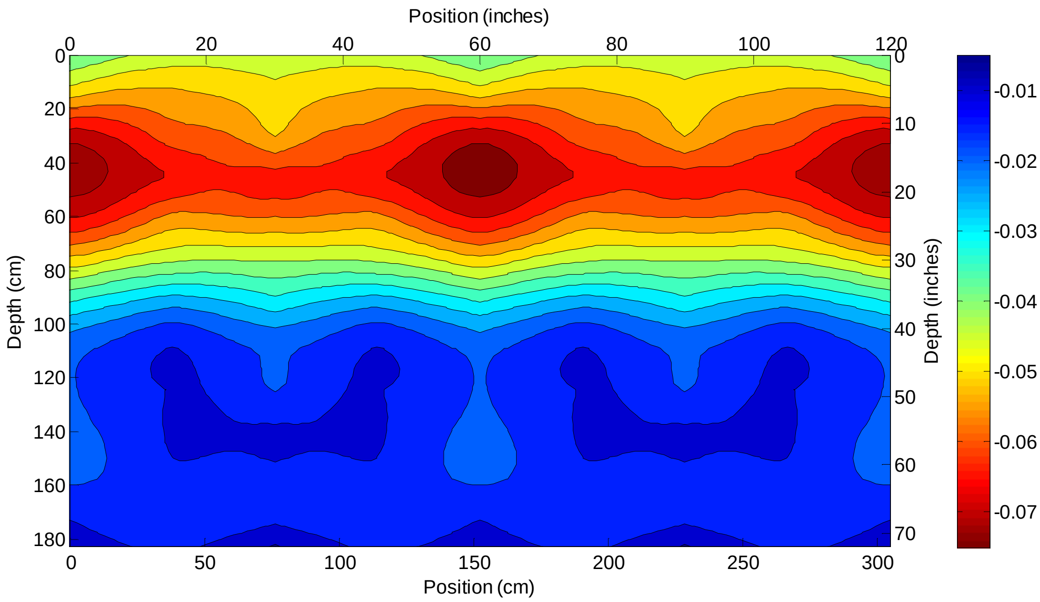

Figure A.41 - 2009 Corn planting to mid vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

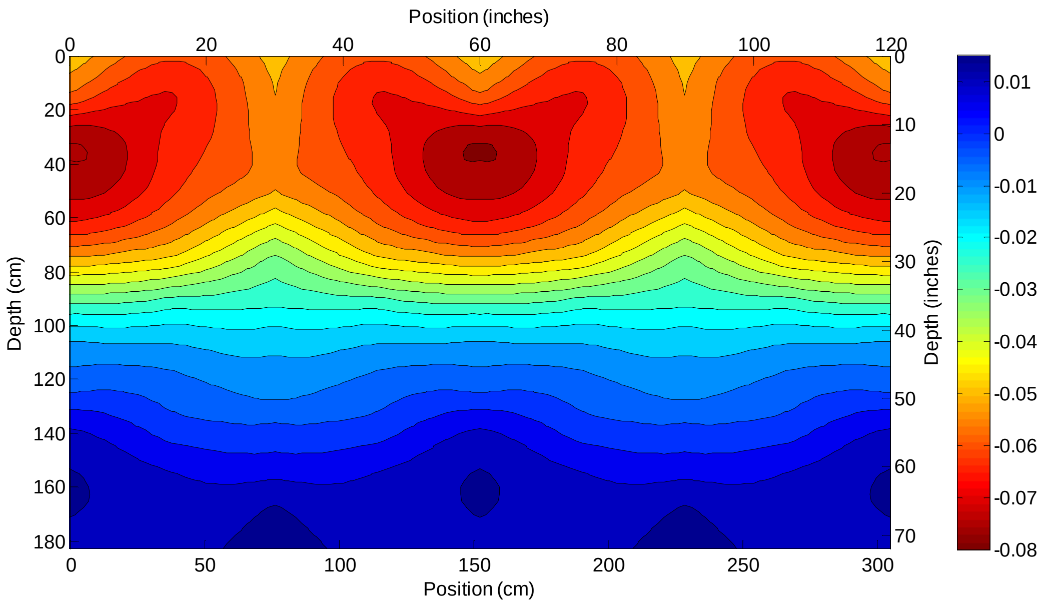

Figure A.42 - 2009 Corn planting to mid vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

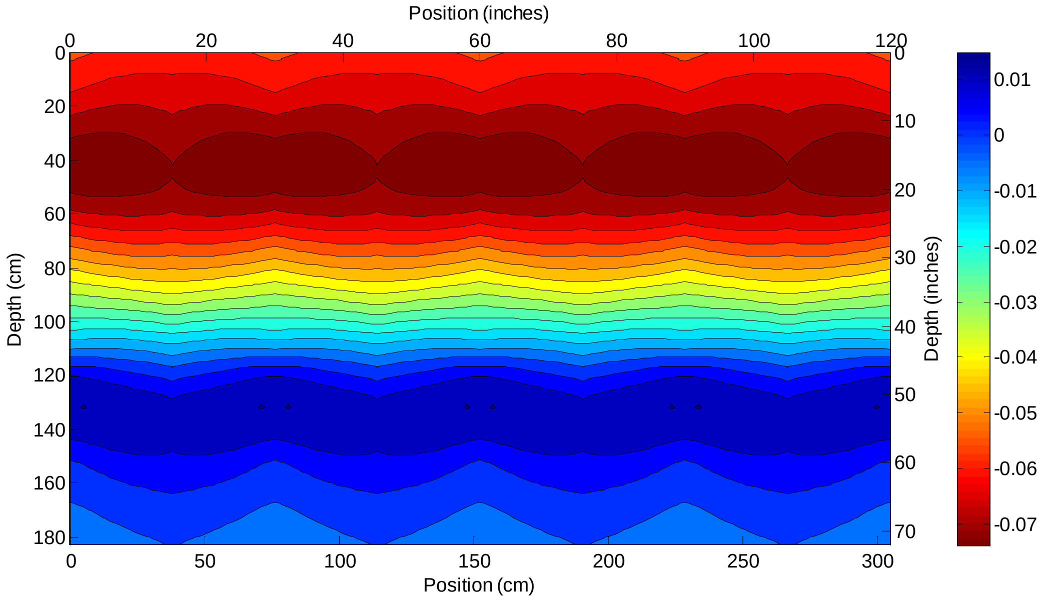

Figure A.43 - 2009 Corn planting to mid vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

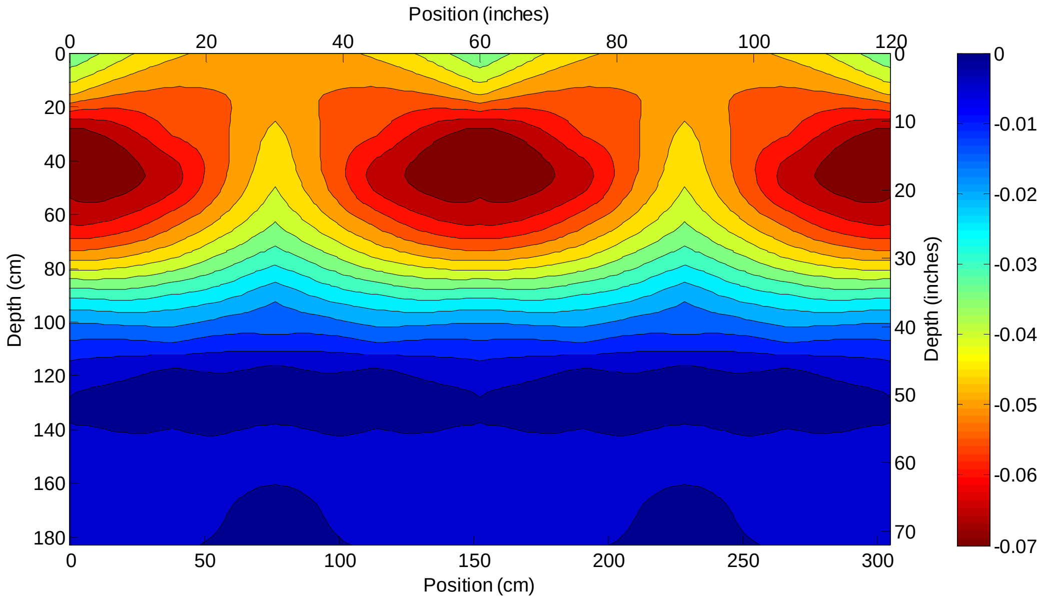

Figure A.44 - 2009 Corn planting to mid vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

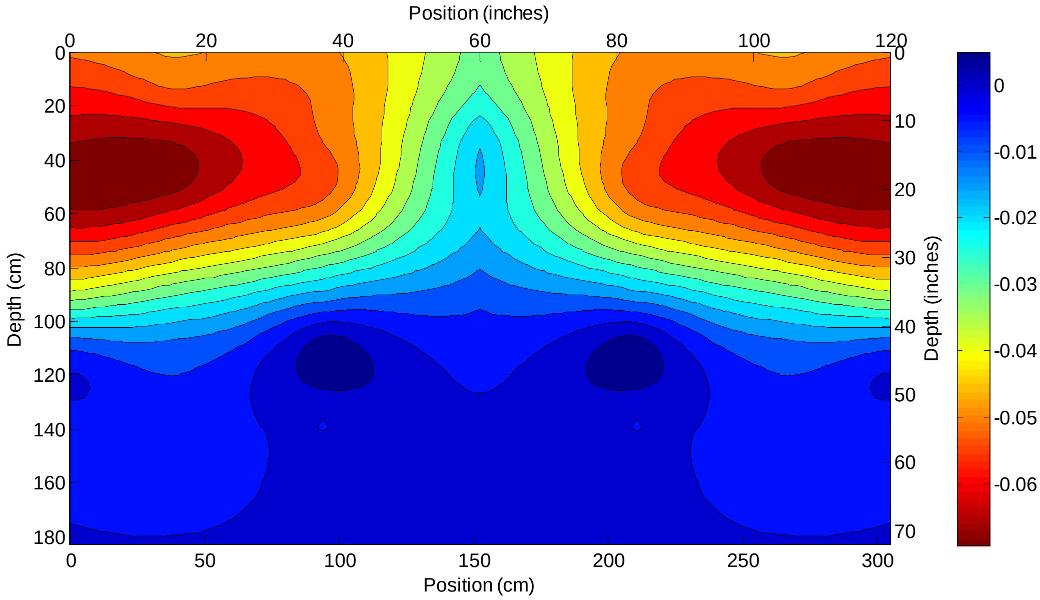

Figure A.45 - 2009 Corn planting to mid vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

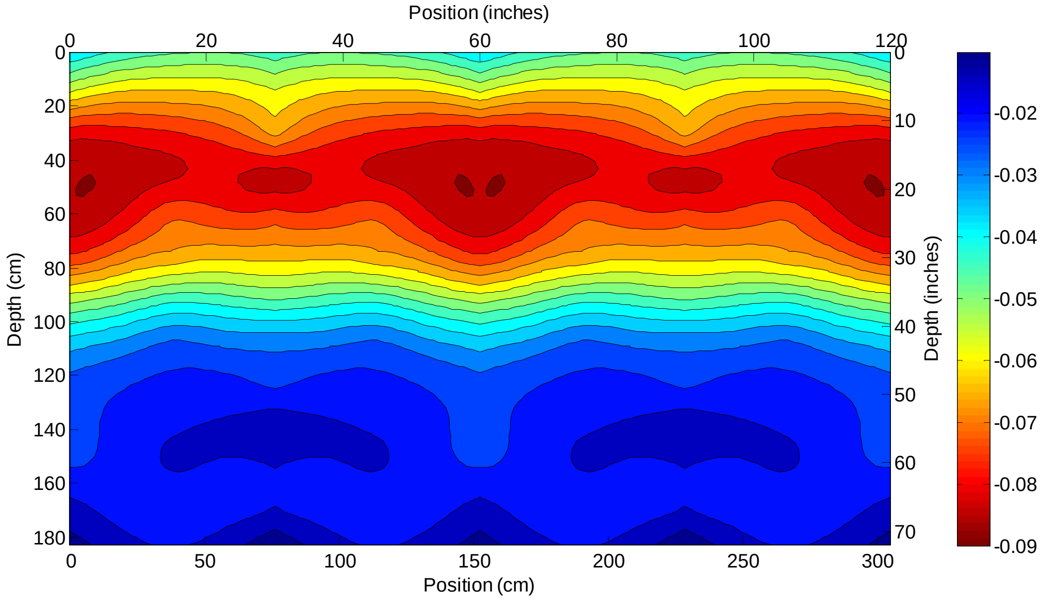

Figure A.46 - 2009 Corn planting to late vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

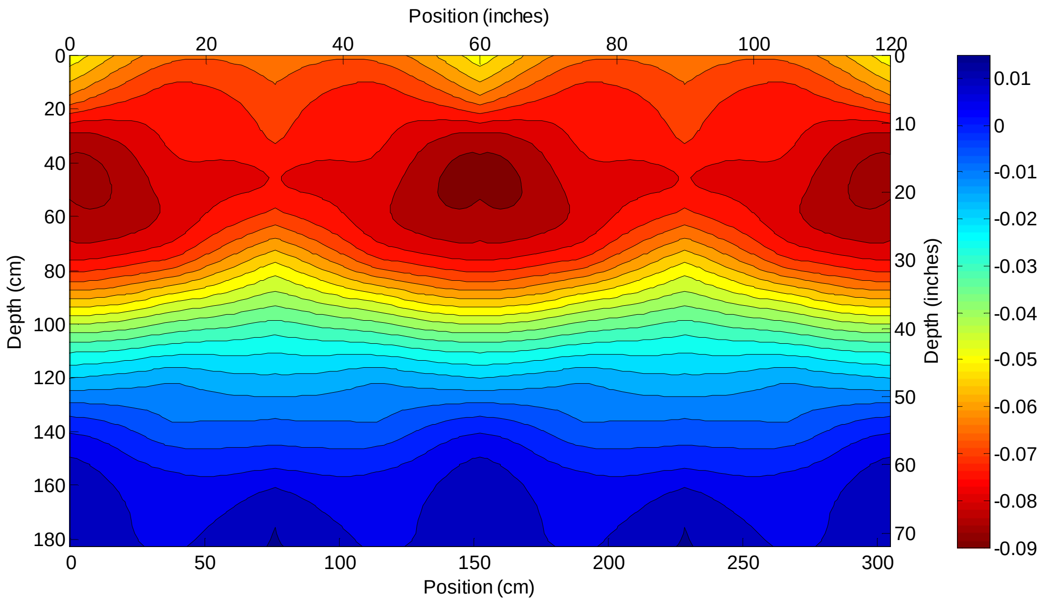

Figure A.47 - 2009 Corn planting to late vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

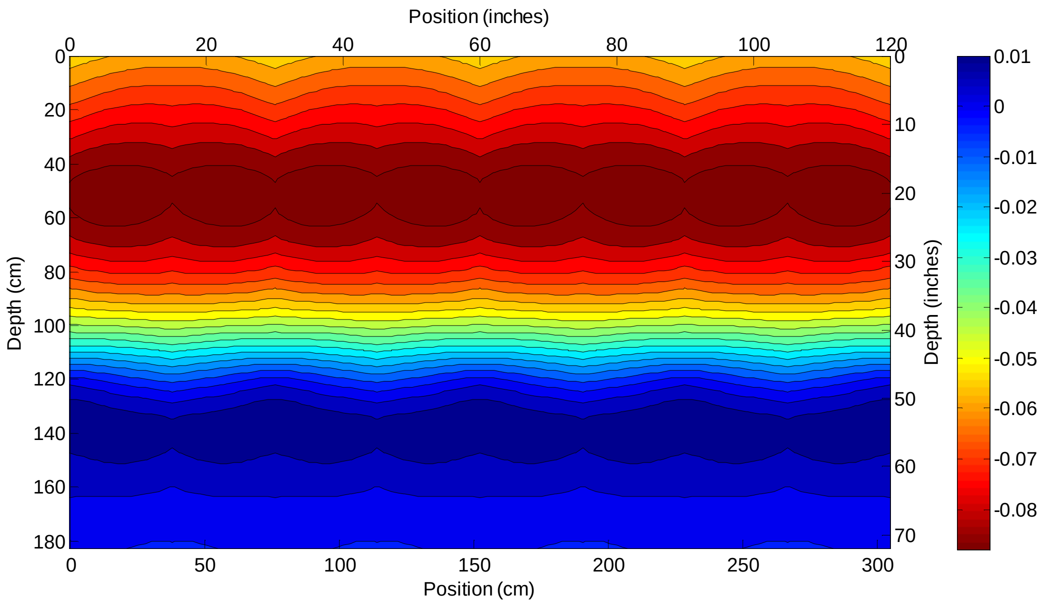

Figure A.48 - 2009 Corn planting to late vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

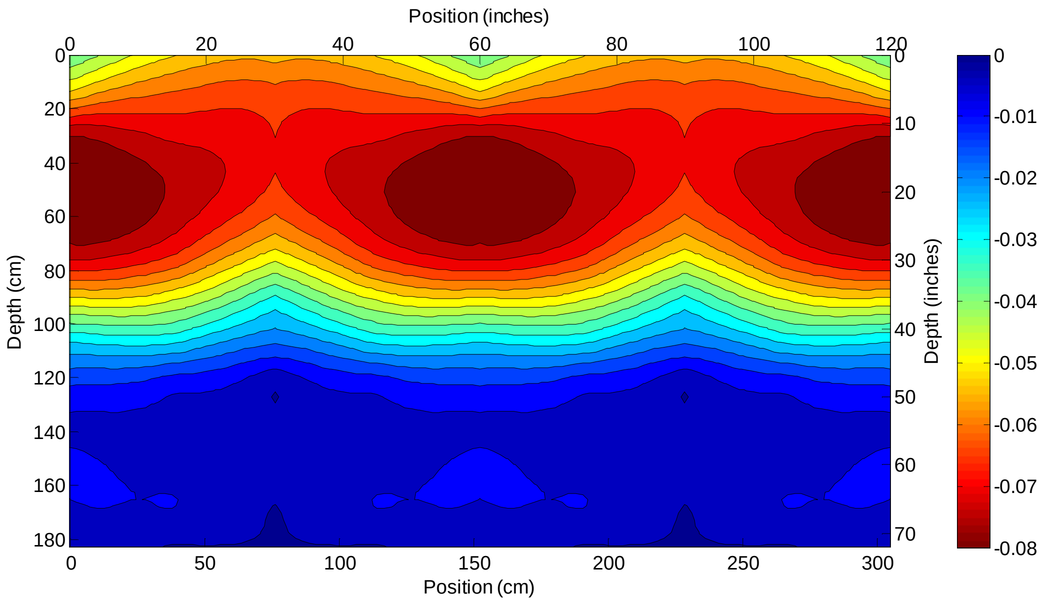

Figure A.49 - 2009 Corn planting to late vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

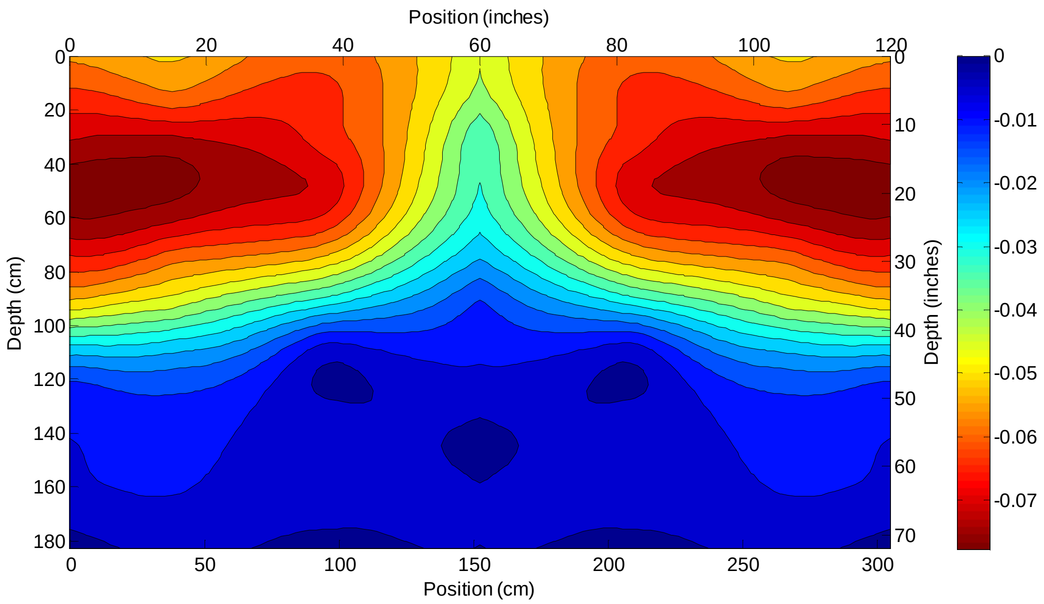

Figure A.50 - 2009 Corn planting to late vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

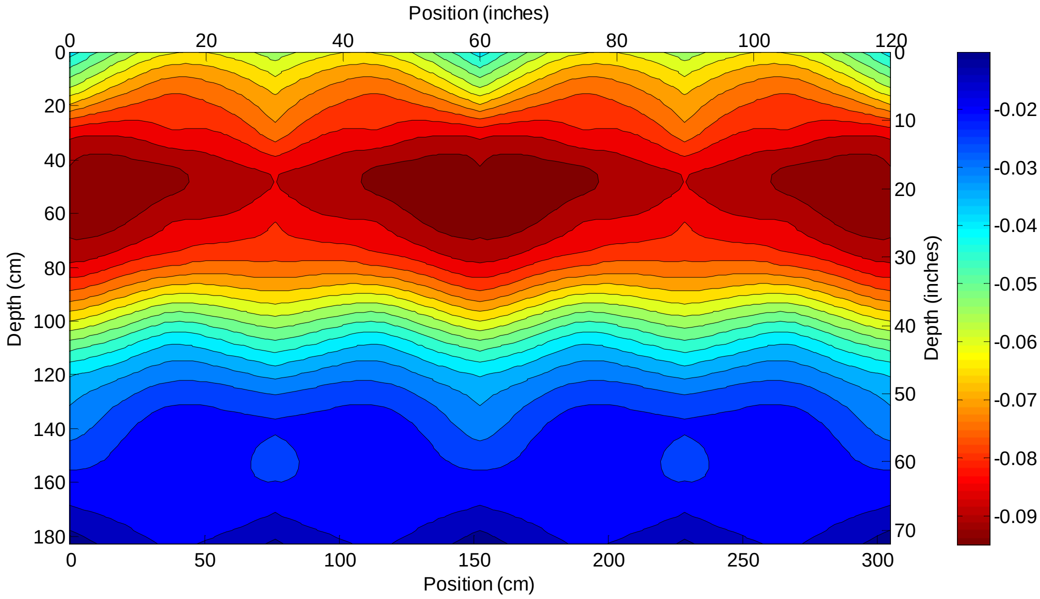

Figure A.51 - 2009 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

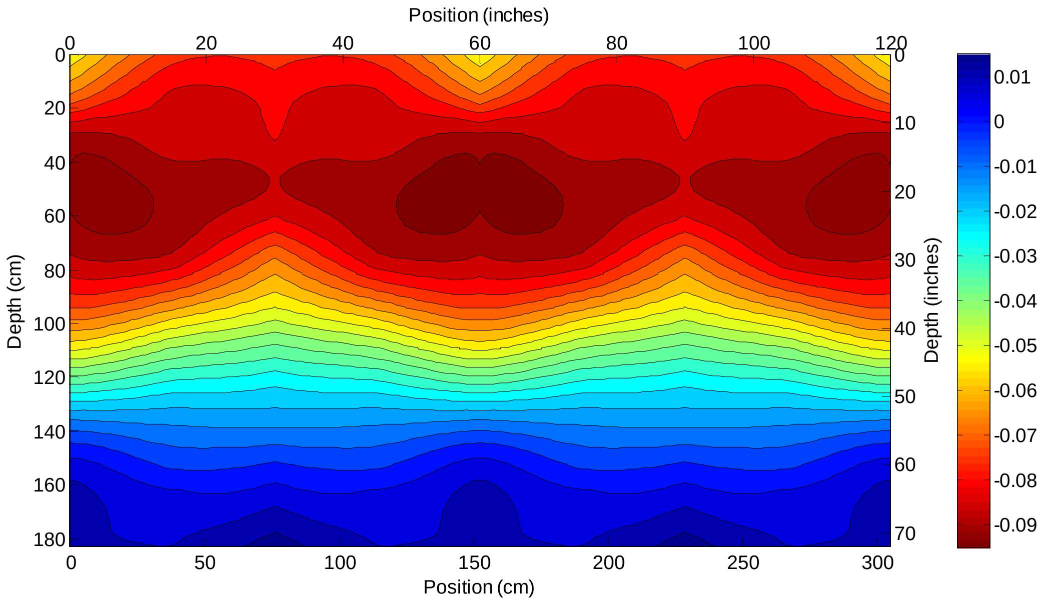

Figure A.52 - 2009 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

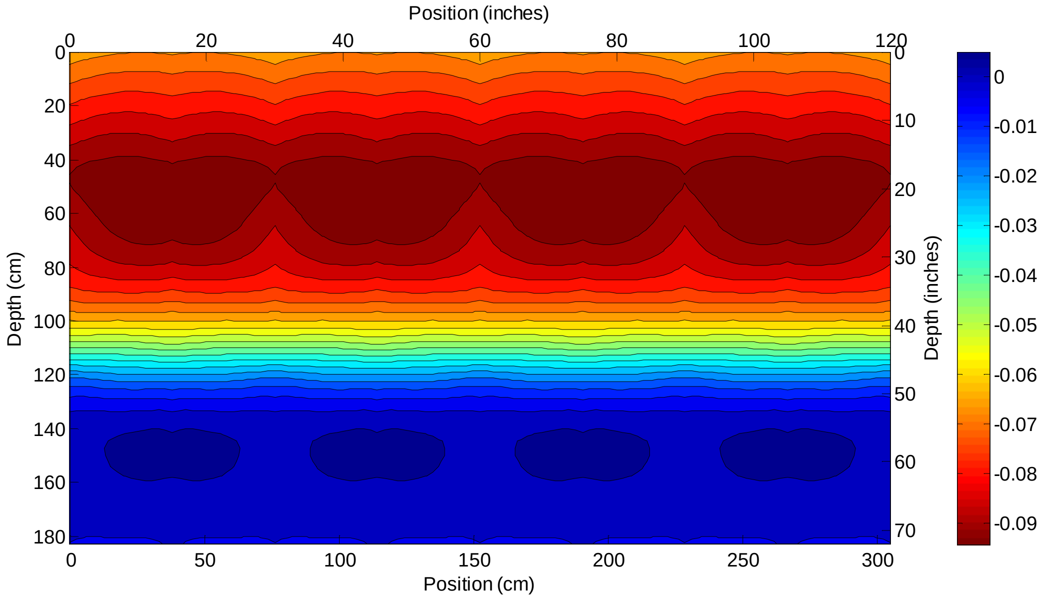

Figure A.53 - 2009 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3 \, cm^{-3}$, conventional geometry.

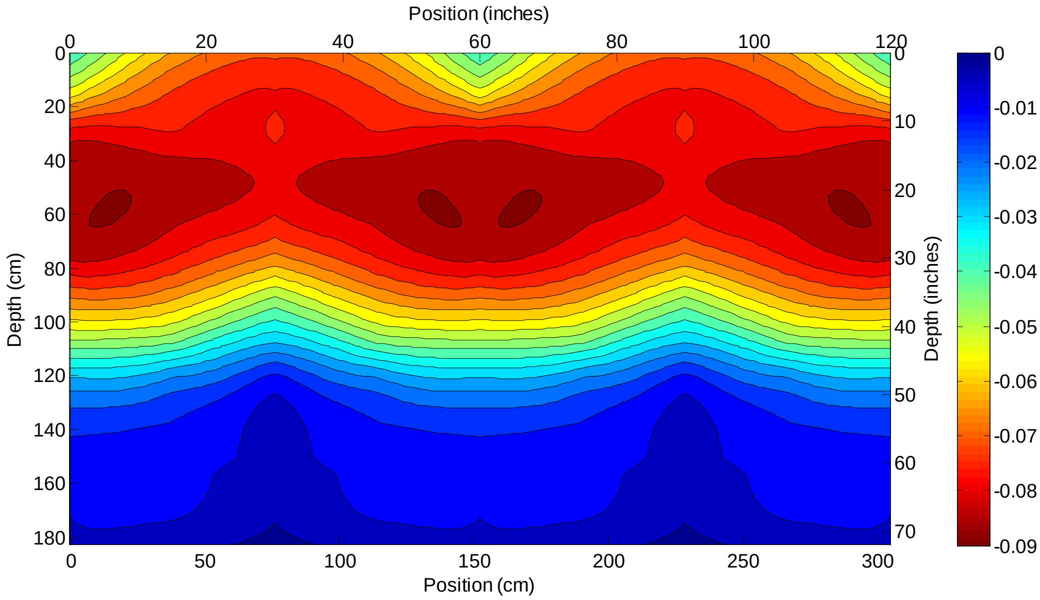

Figure A.54 - 2009 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3 \, cm^{-3}$, P1S1 geometry.

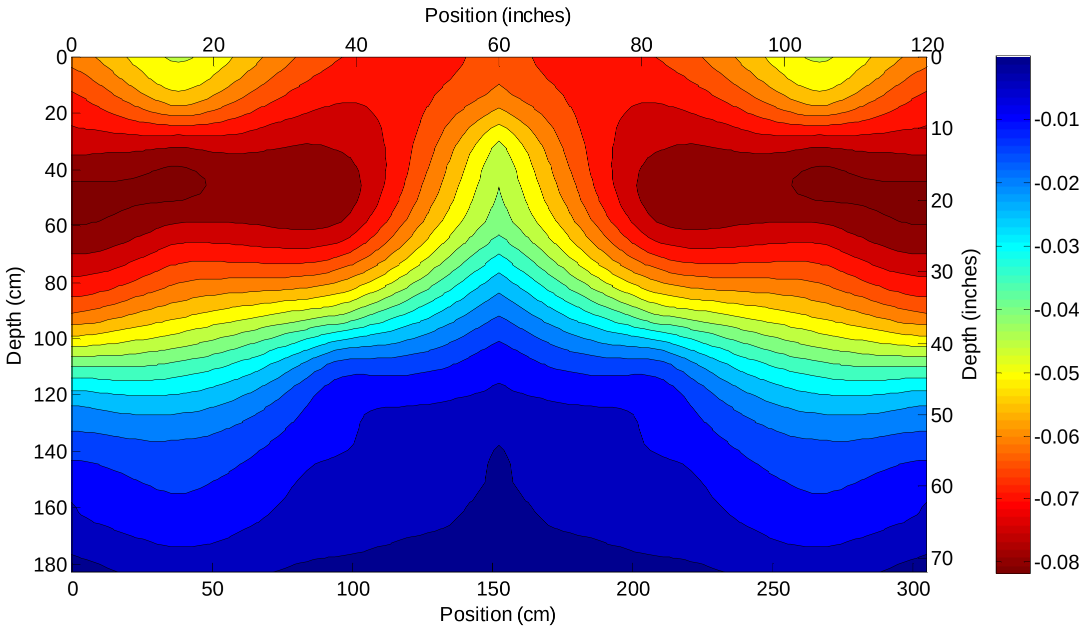

Figure A.55 - 2009 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, P2S2 geometry.

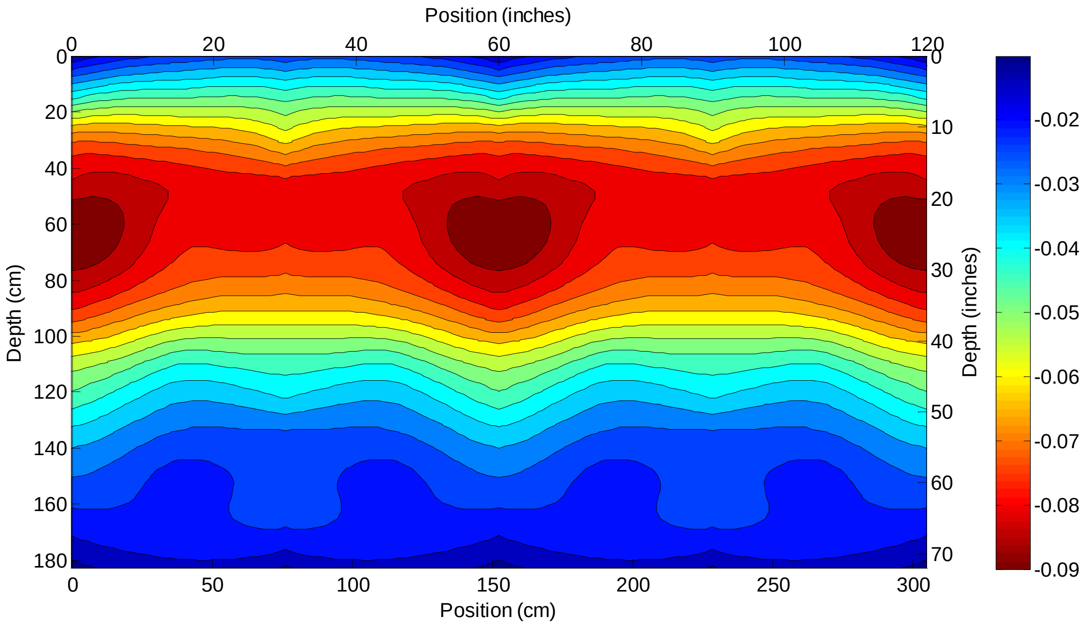

Figure A.56 - 2009 Corn planting to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, clump geometry.

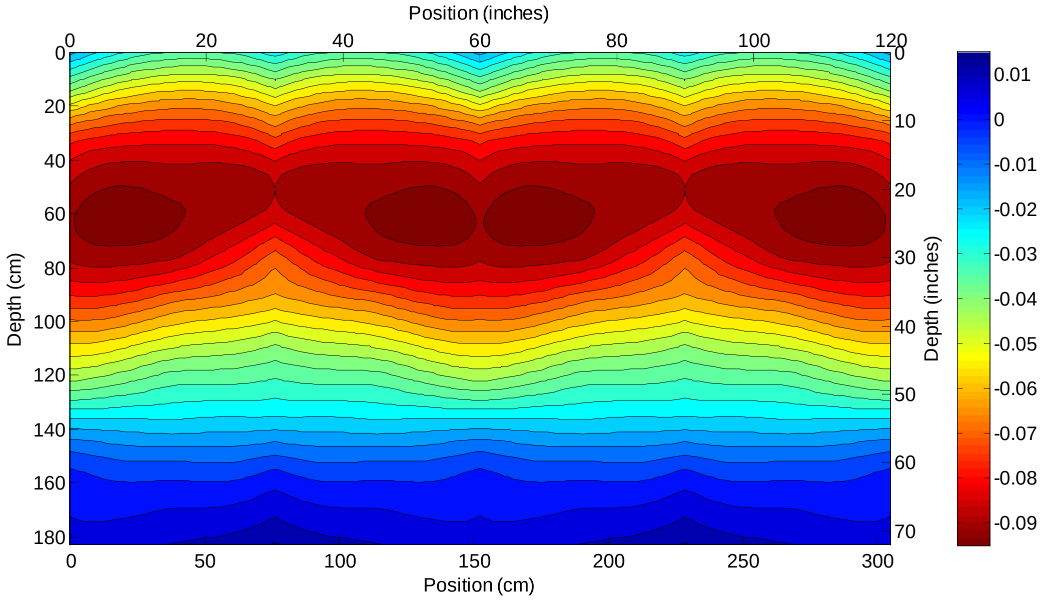

Figure A.57 - 2009 Corn planting to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

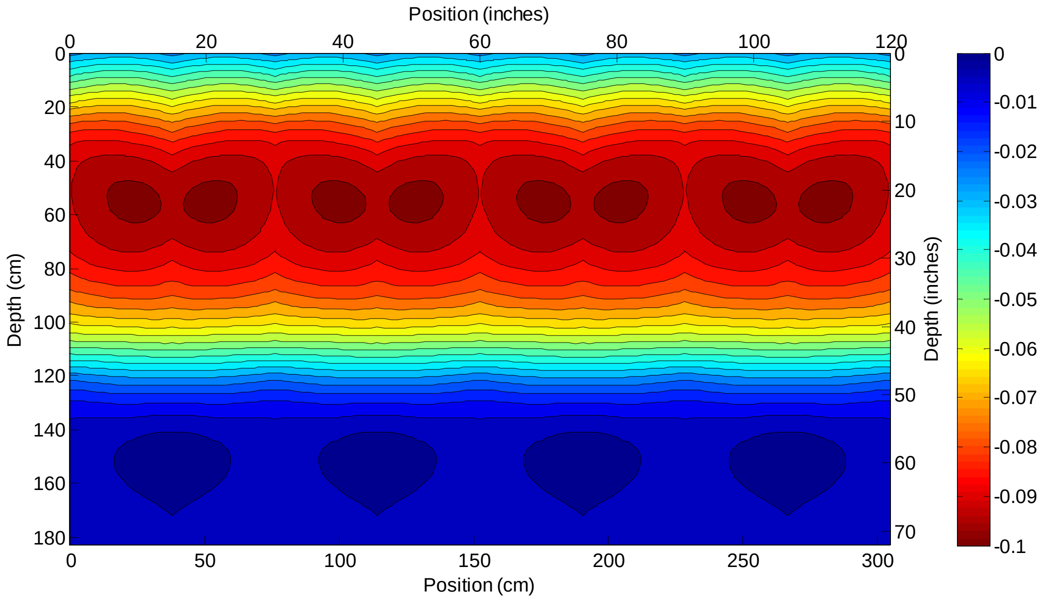

Figure A.58 - 2009 Corn planting to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

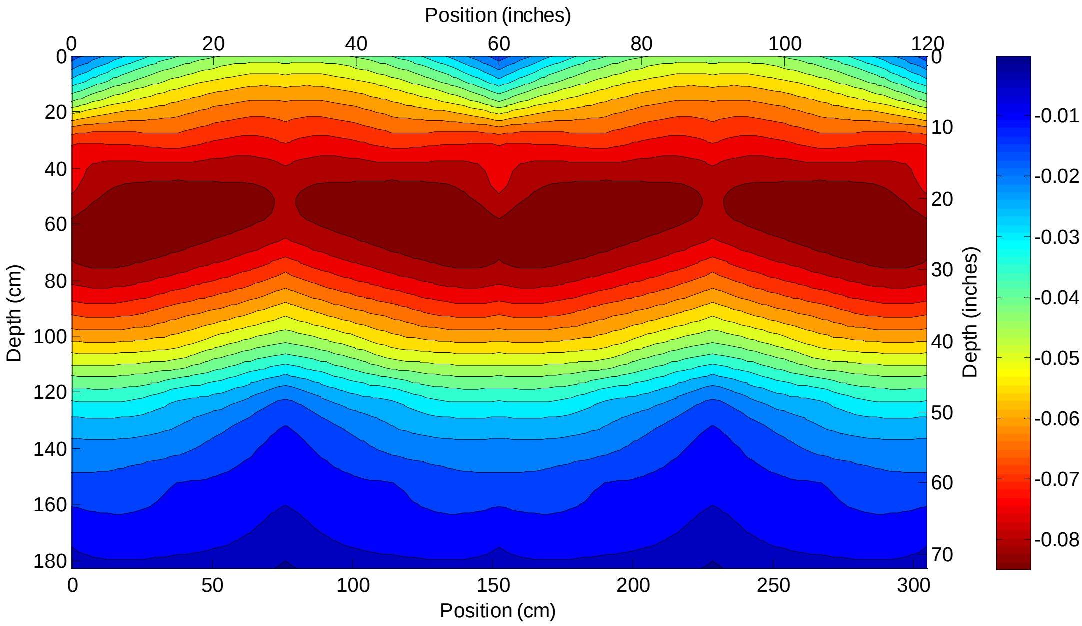

Figure A.59 - 2009 Corn planting to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, P1S1 geometry.

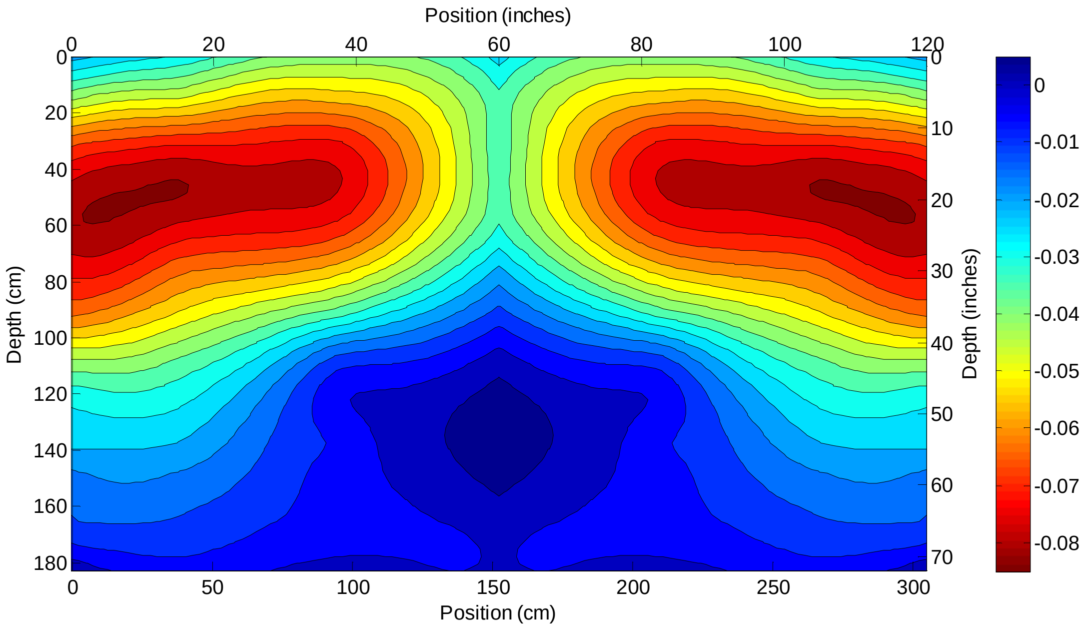

Figure A.60 - 2009 Corn planting to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, P2S2 geometry.

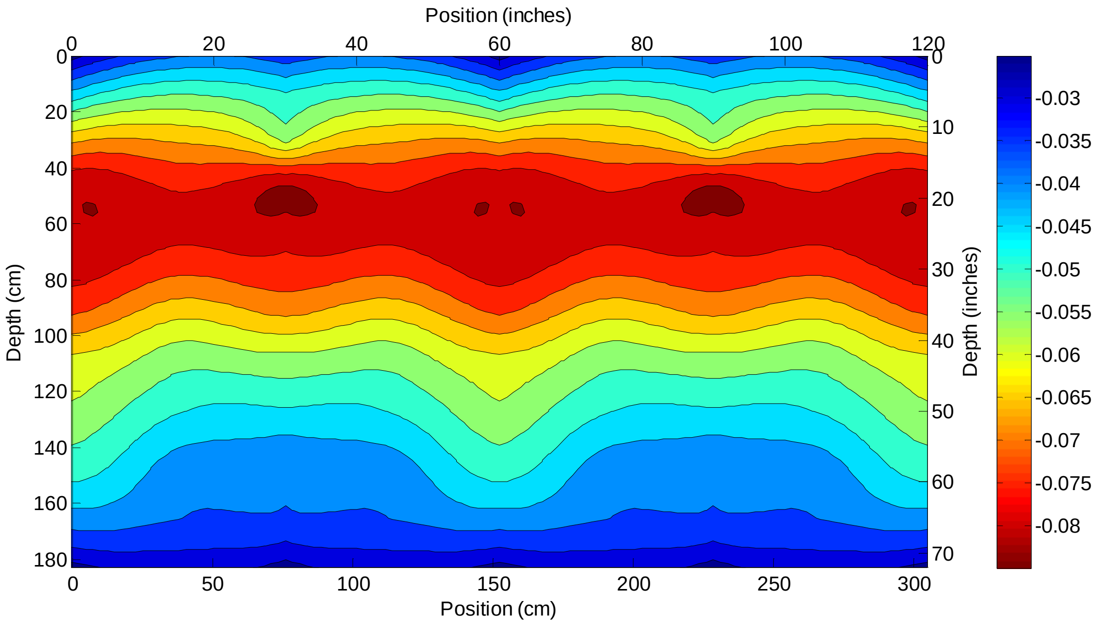

Figure A.61 - 2009 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

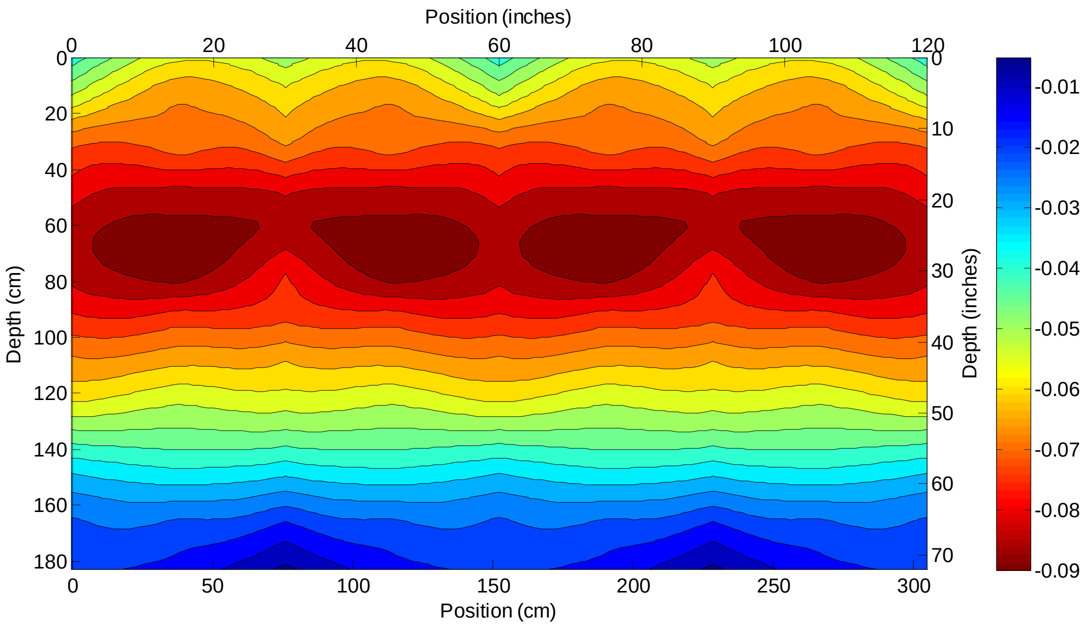

Figure A.62 - 2009 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

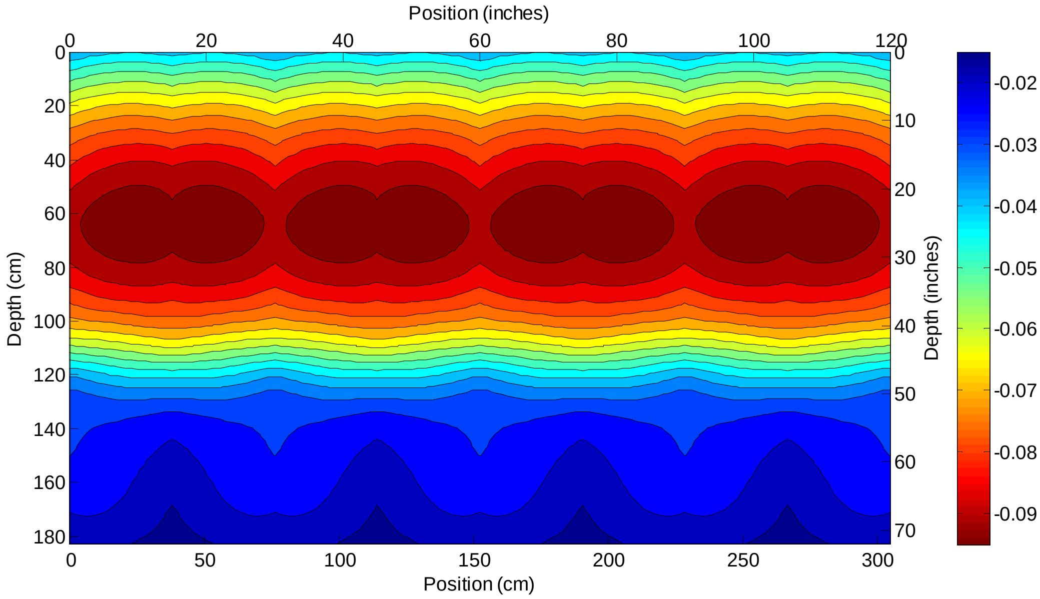

Figure A.63 - 2009 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

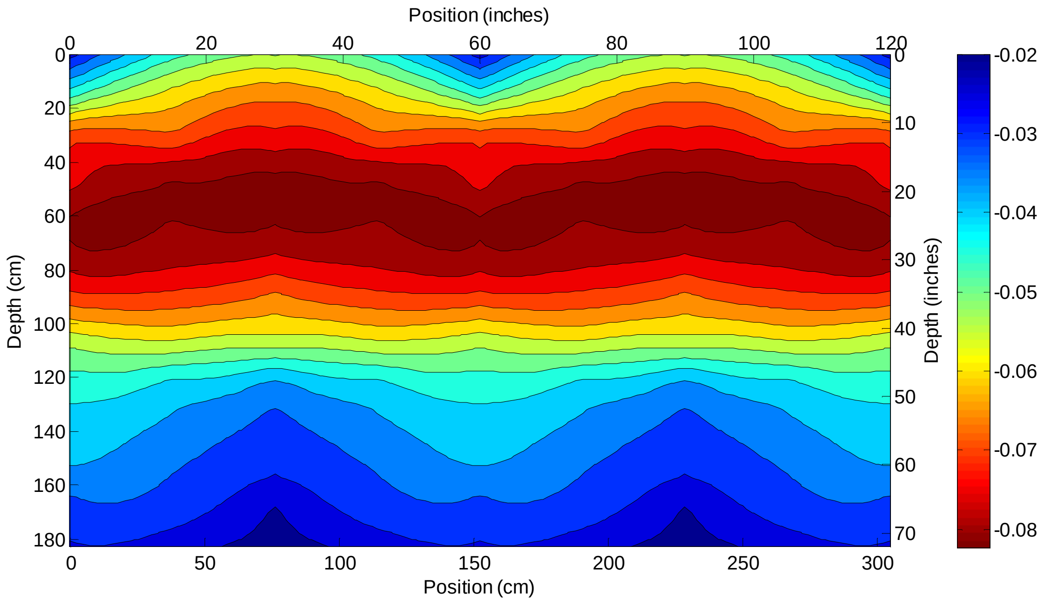

Figure A.64 - 2009 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

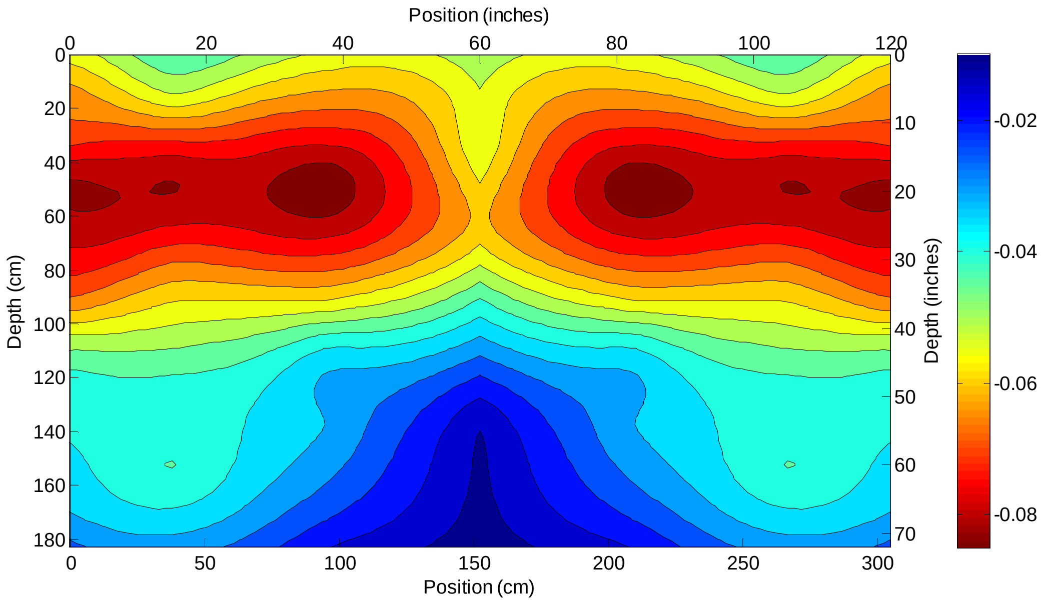

Figure A.65 - 2009 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

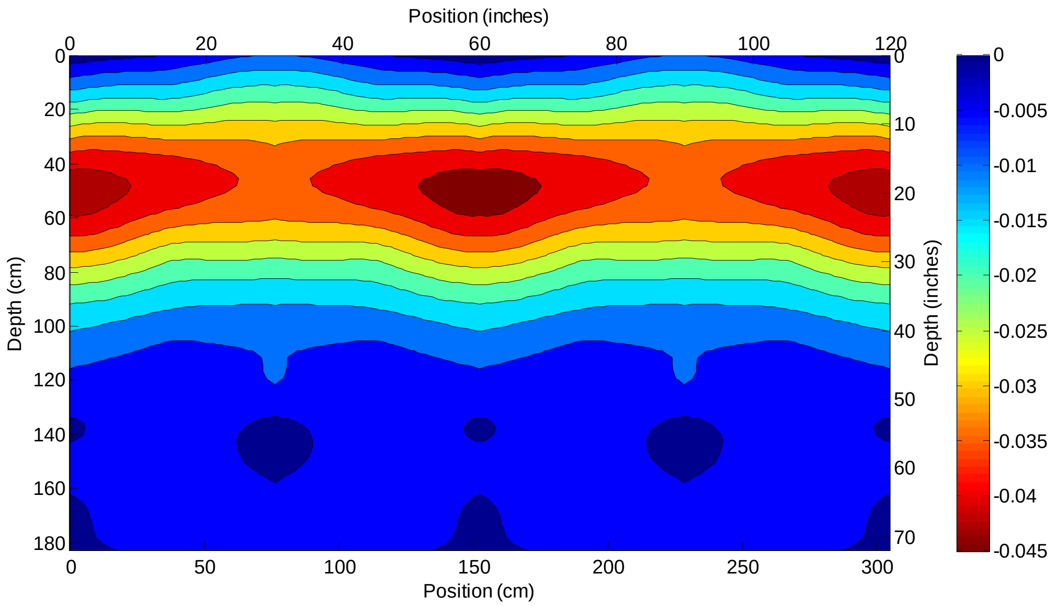

Figure A.66 - 2009 Corn early vegetative to mid vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

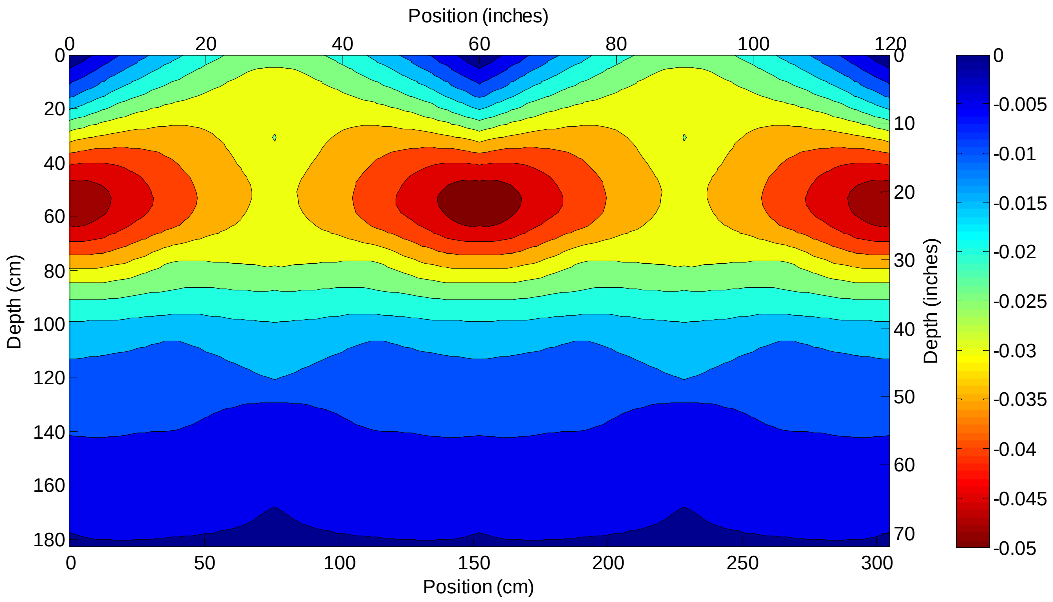

Figure A.67 - 2009 Corn early vegetative to mid vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

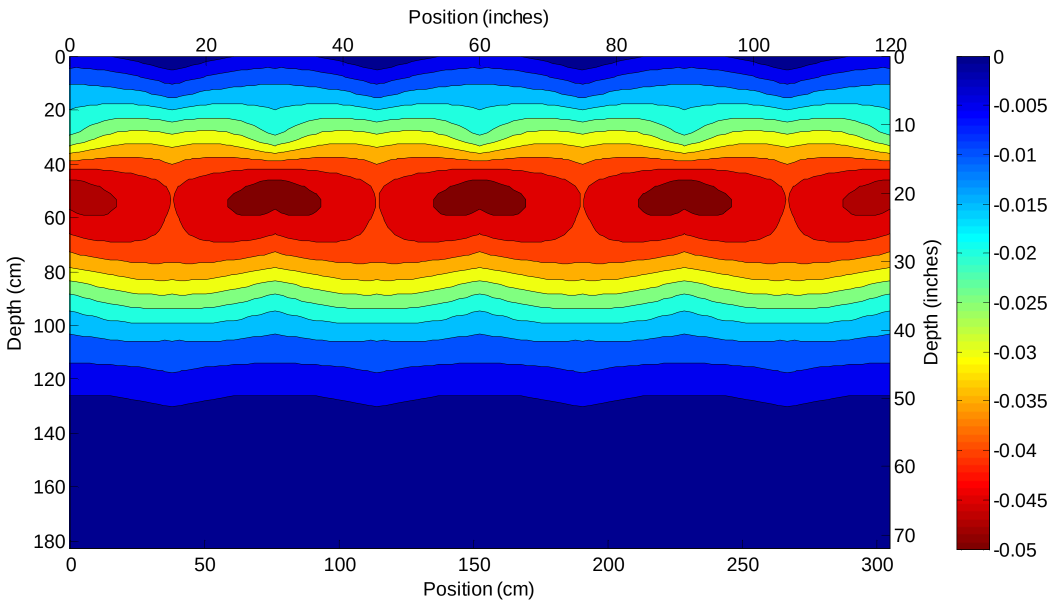

Figure A.68 - 2009 Corn early vegetative to mid vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

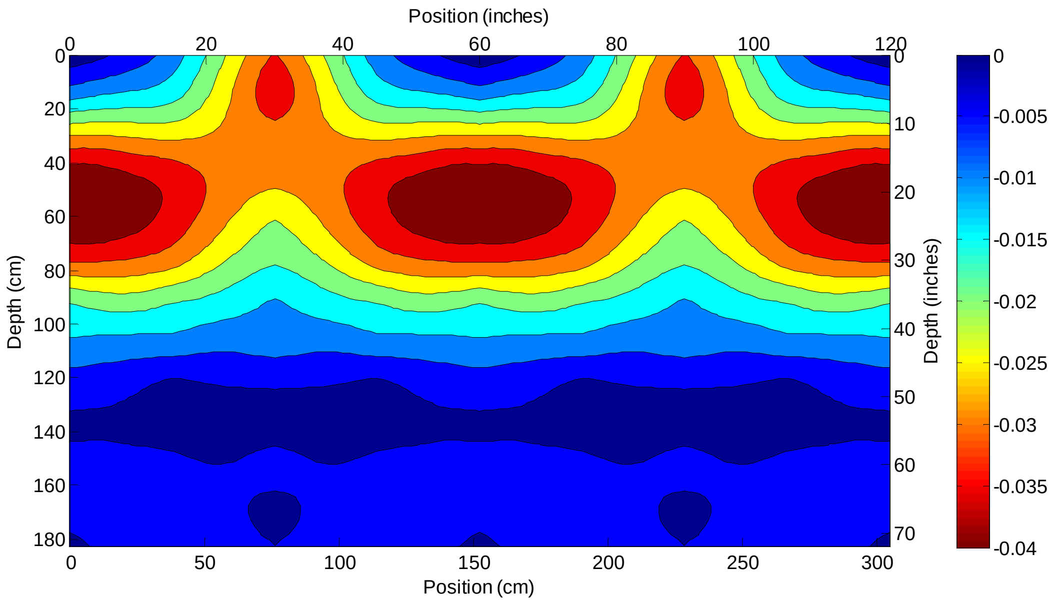

Figure A.69 - 2009 Corn early vegetative to mid vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

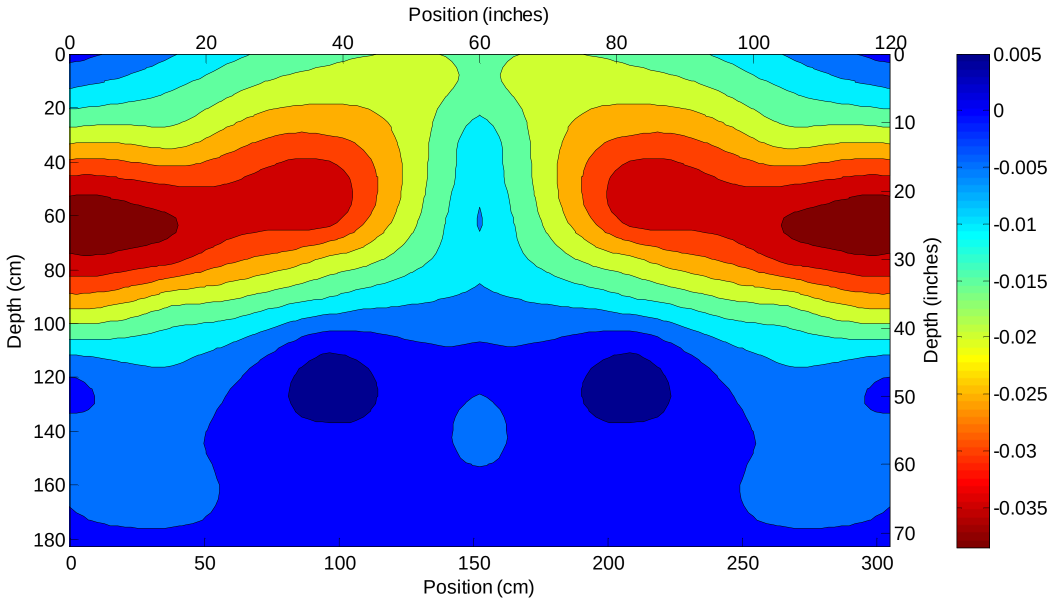

Figure A.70 - 2009 Corn early vegetative to mid vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

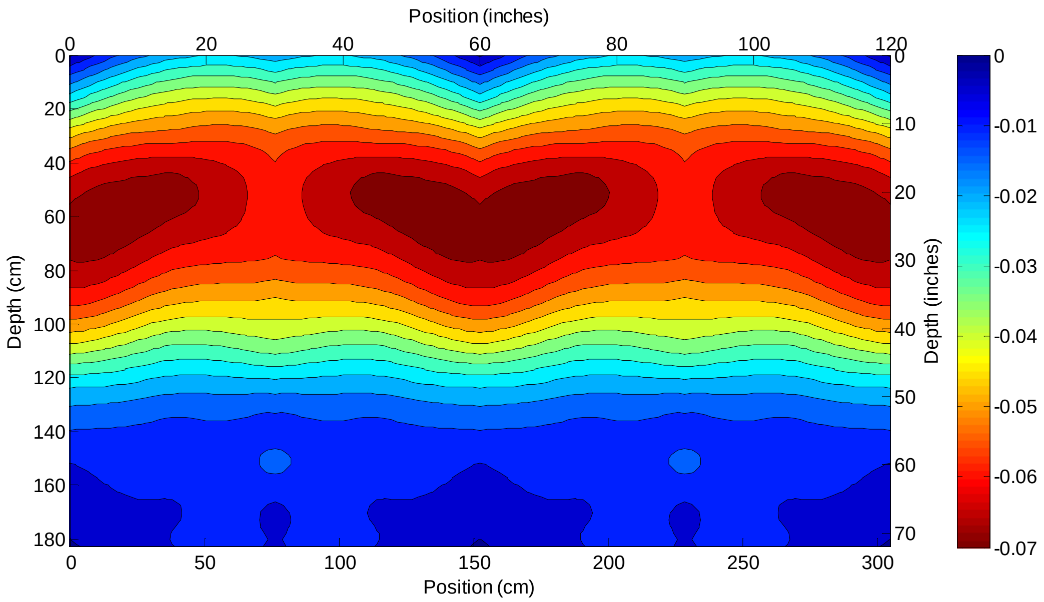

Figure A.71 - 2009 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

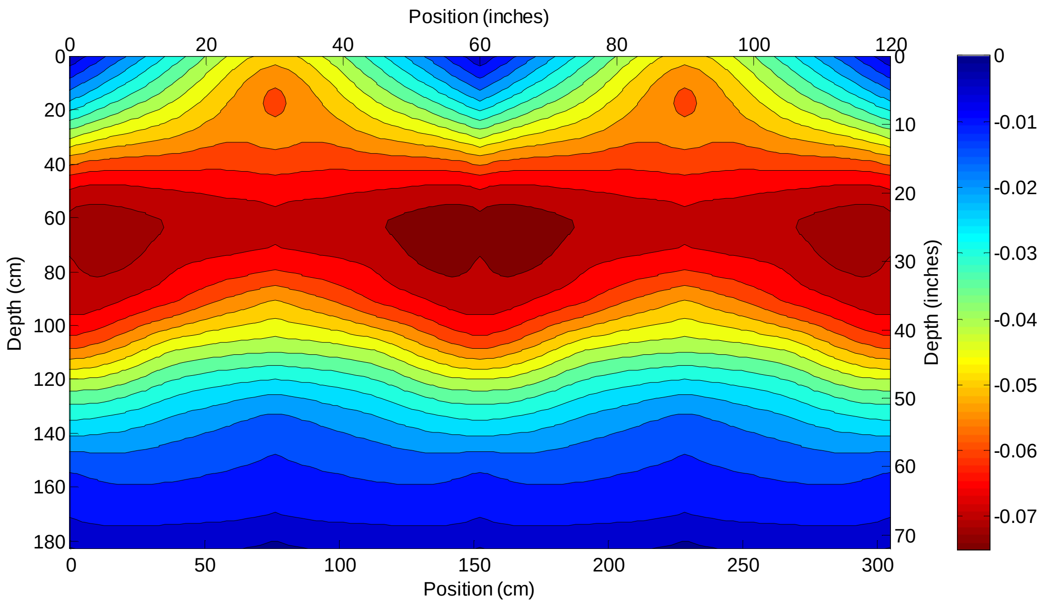

Figure A.72 - 2009 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

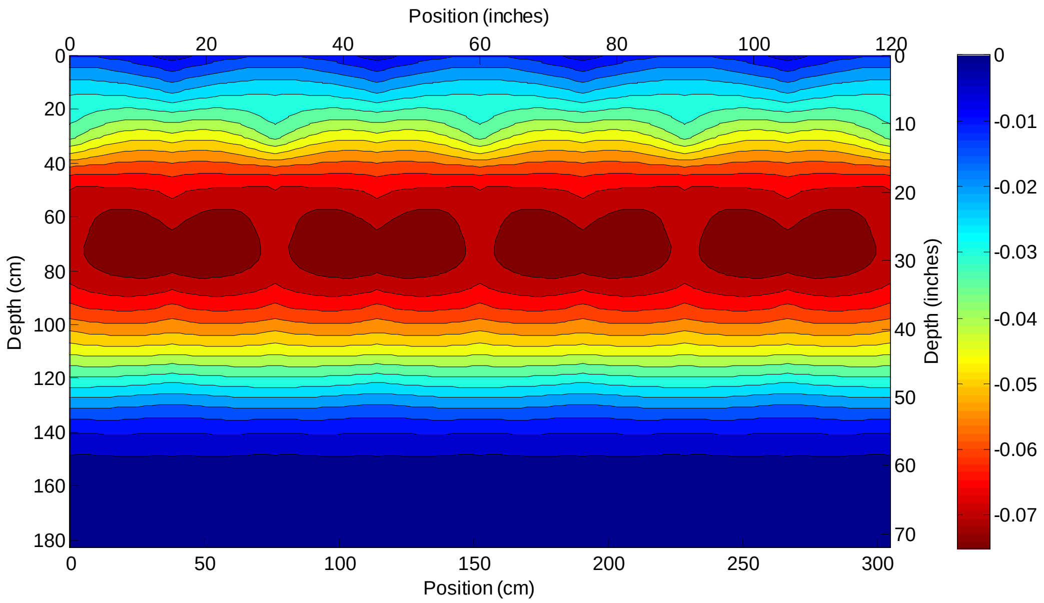

Figure A.73 - 2009 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

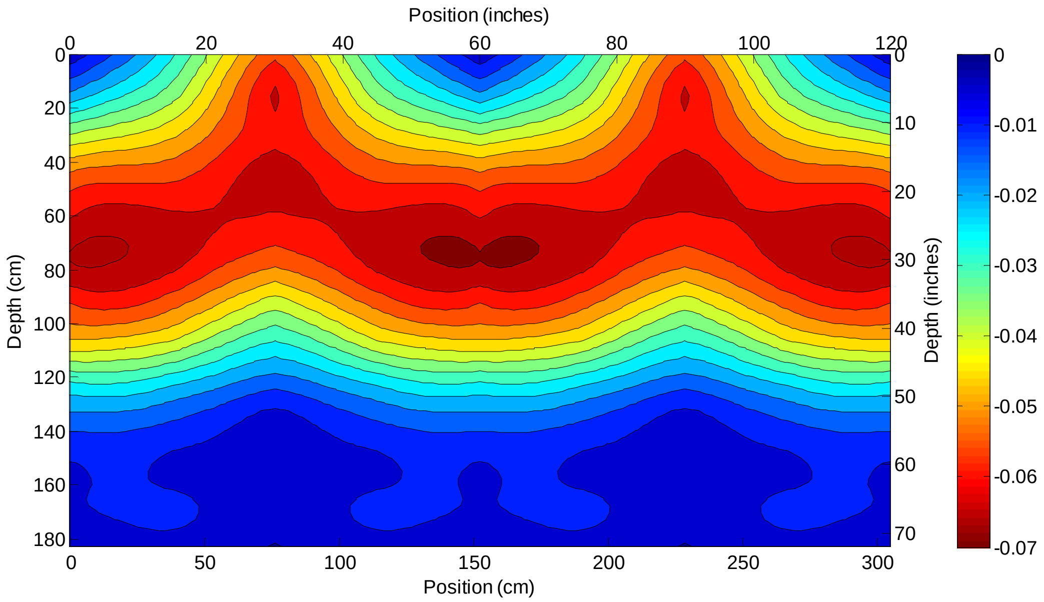

Figure A.74 - 2009 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

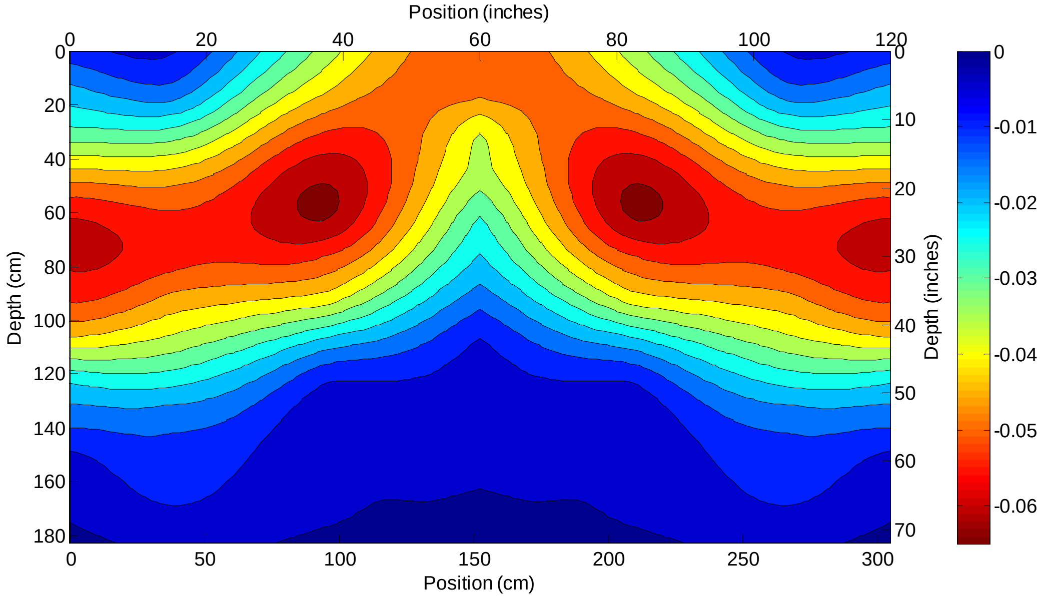

Figure A.75 - 2009 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

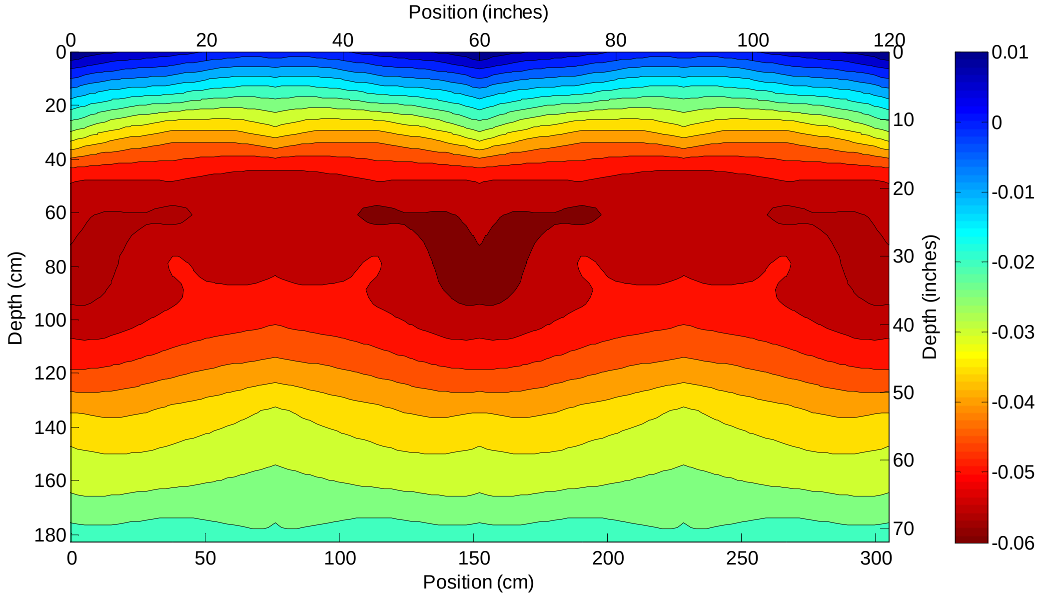

Figure A.76 - 2009 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

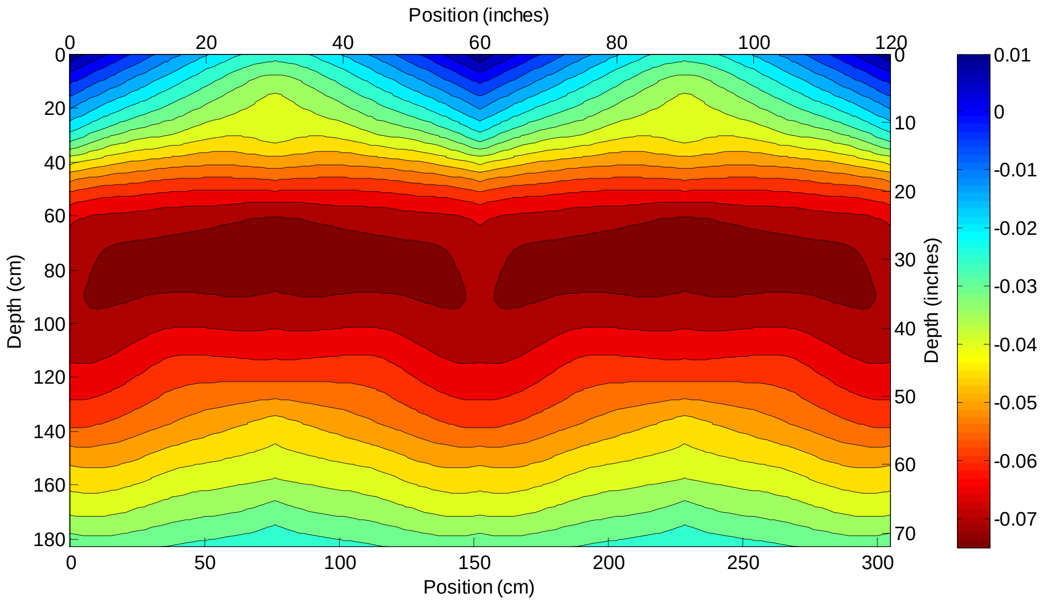

Figure A.77 - 2009 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

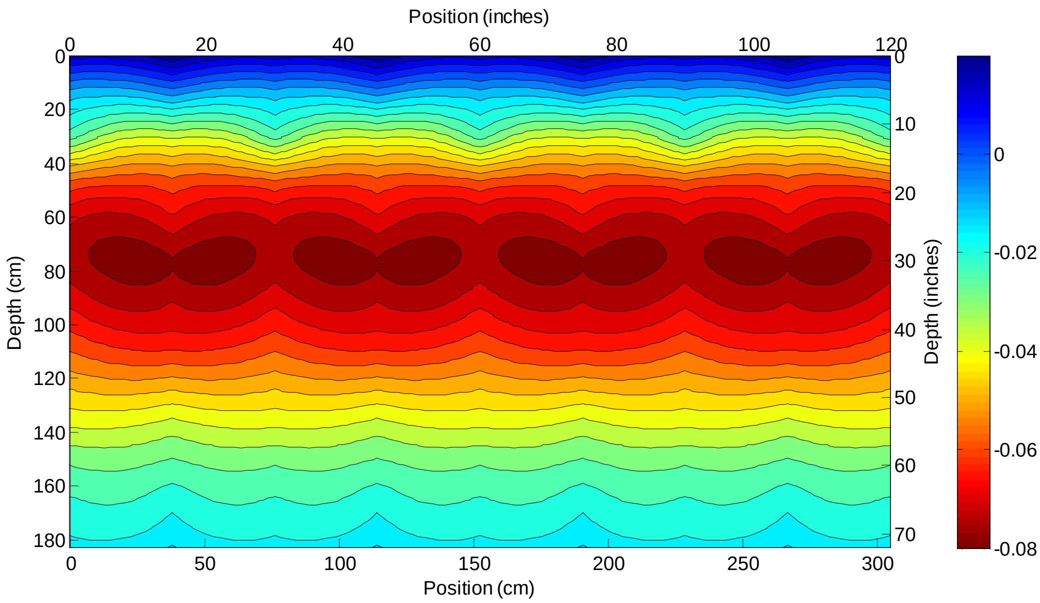

Figure A.78 - 2009 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

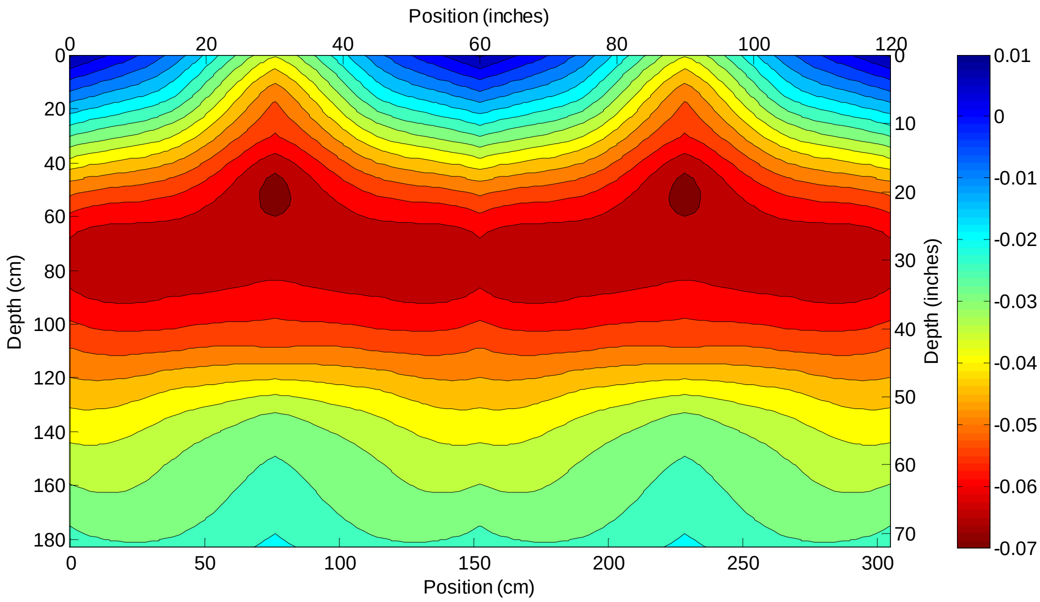

Figure A.79 - 2009 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

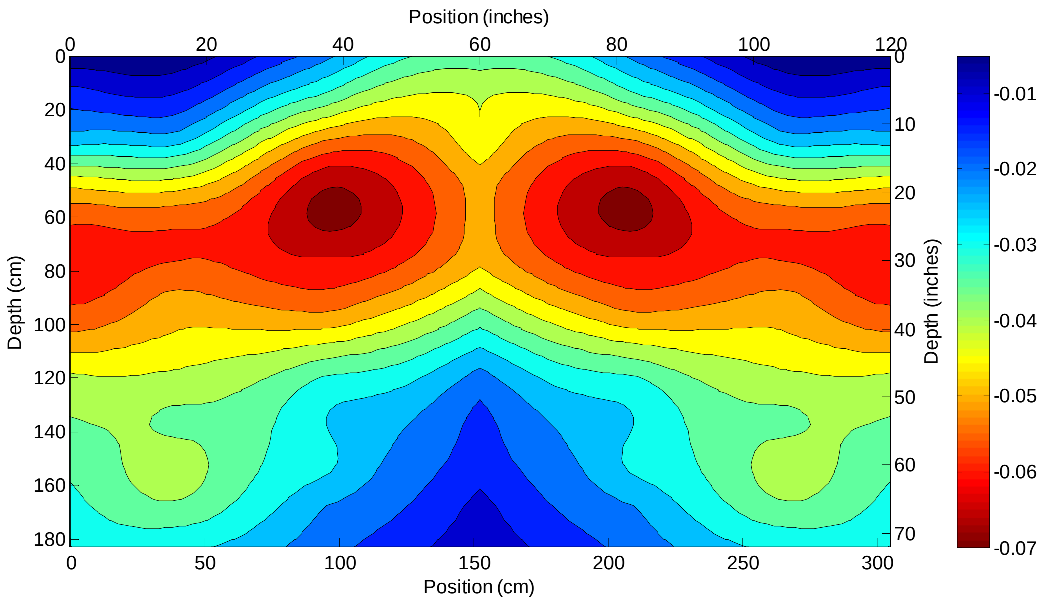

Figure A.80 - 2009 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

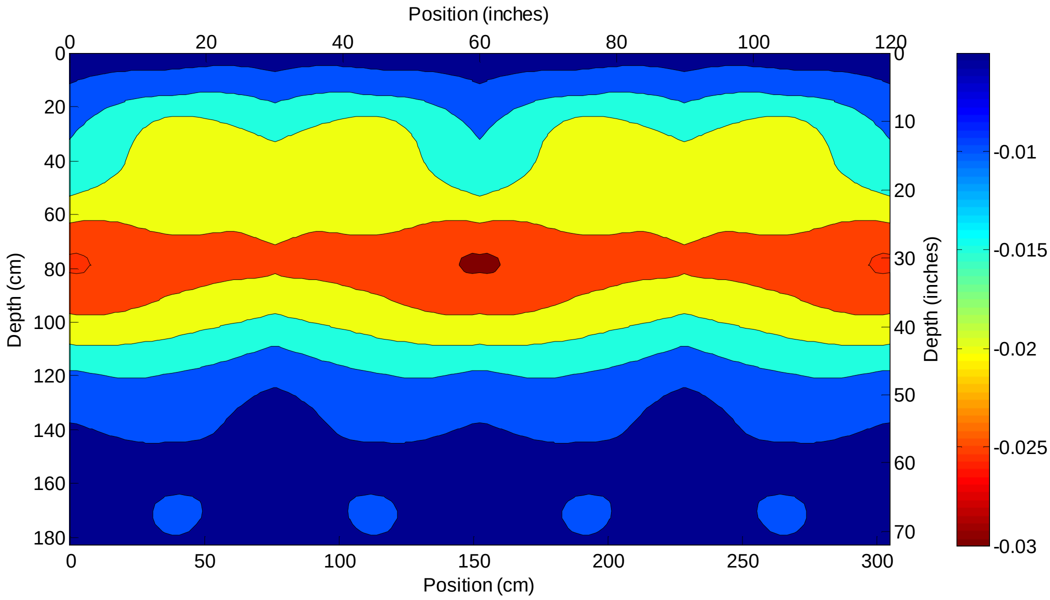

Figure A.81 - 2009 Corn mid vegetative to late vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

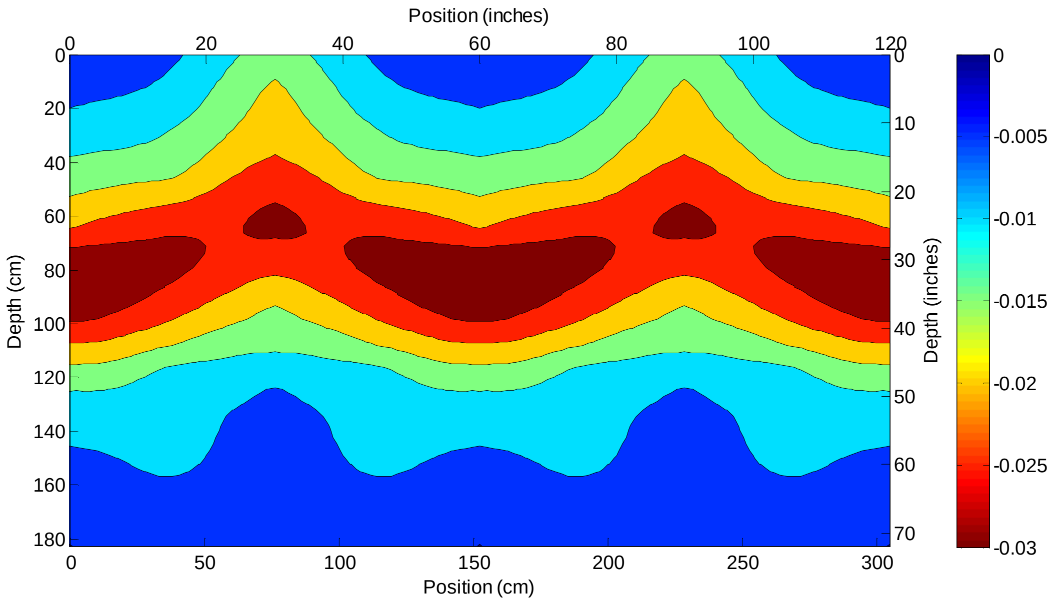

Figure A.82 - 2009 Corn mid vegetative to late vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

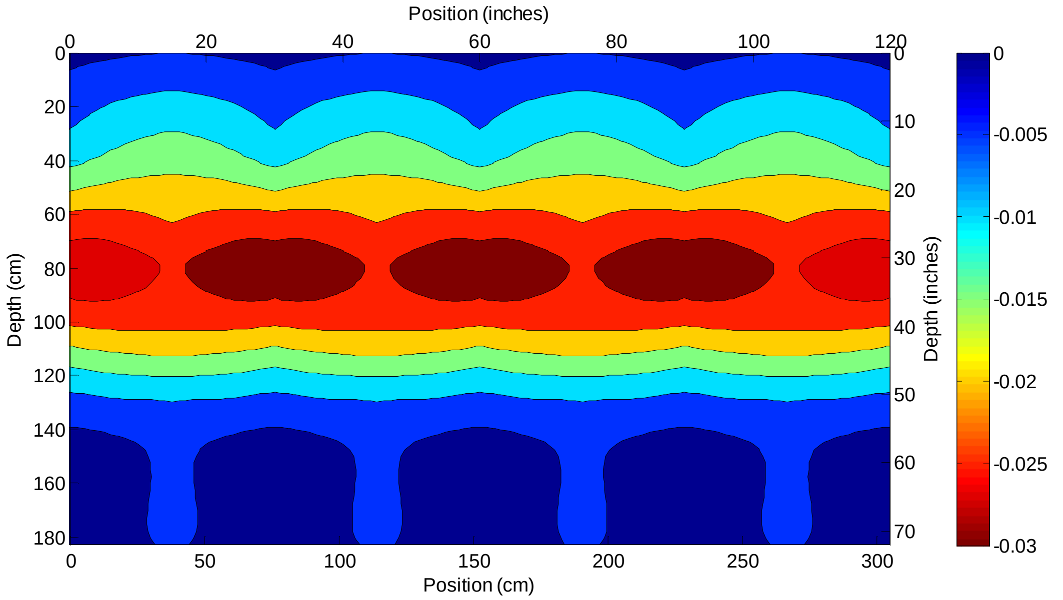

Figure A.83 - 2009 Corn mid vegetative to late vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

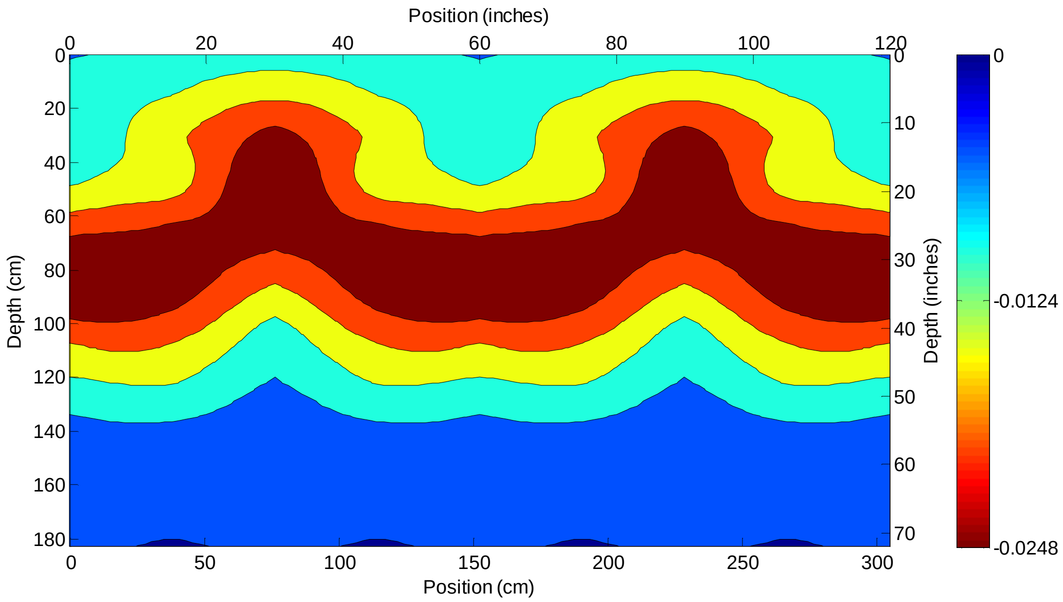

Figure A.84 - 2009 Corn mid vegetative to late vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

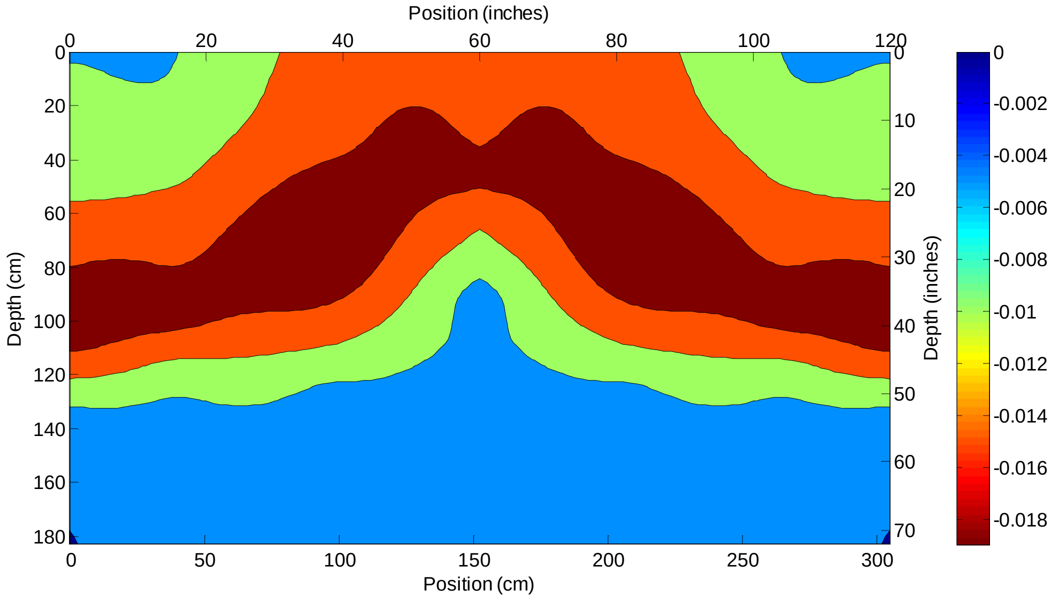

Figure A.85 - 2009 Corn mid vegetative to late vegetative change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

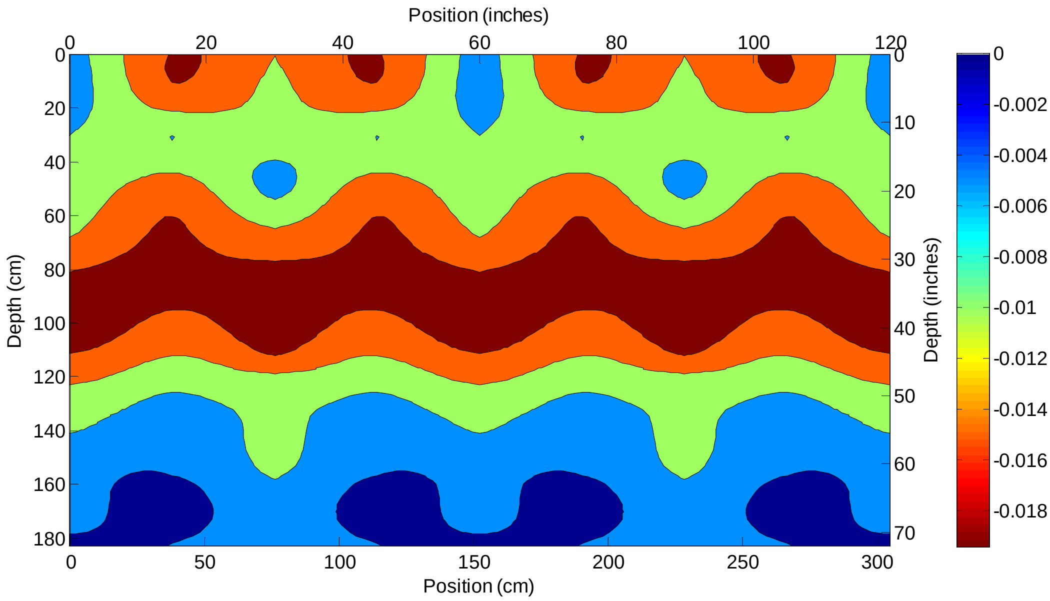

Figure A.86 - 2009 Corn late vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

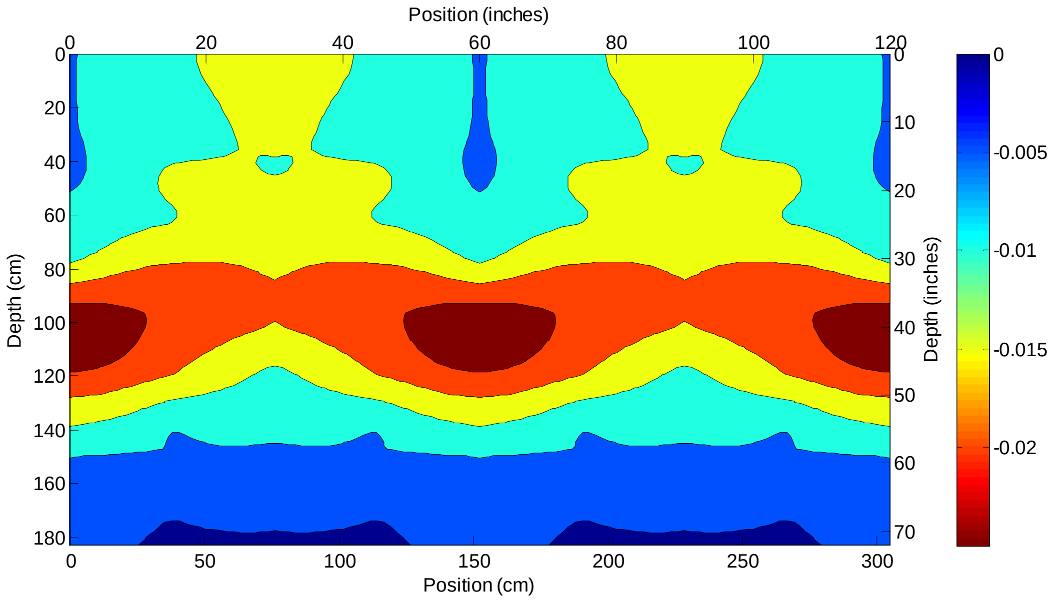

Figure A.87 - 2009 Corn late vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

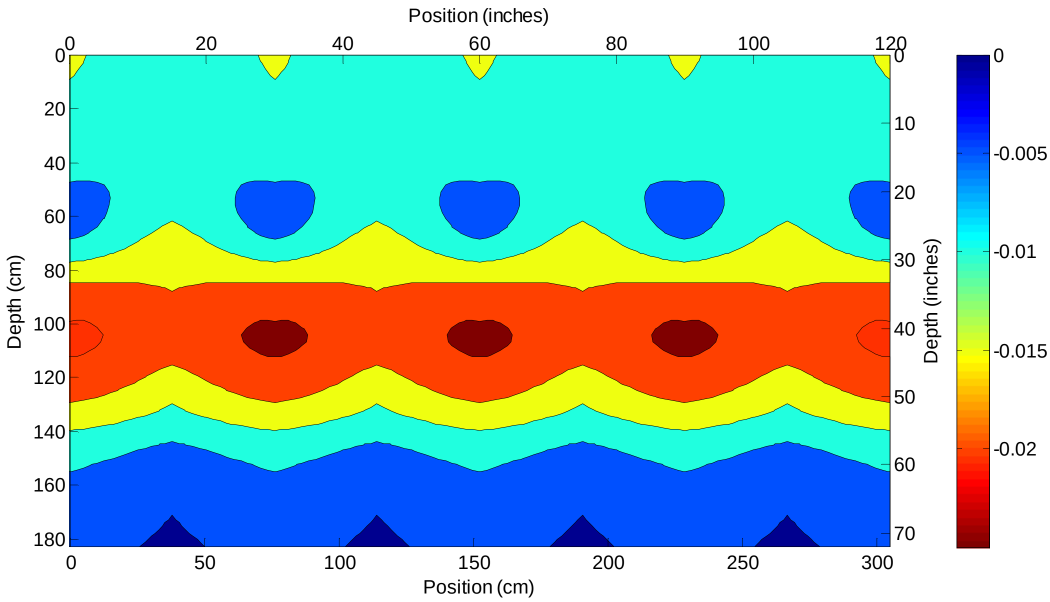

Figure A.88 - 2009 Corn late vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

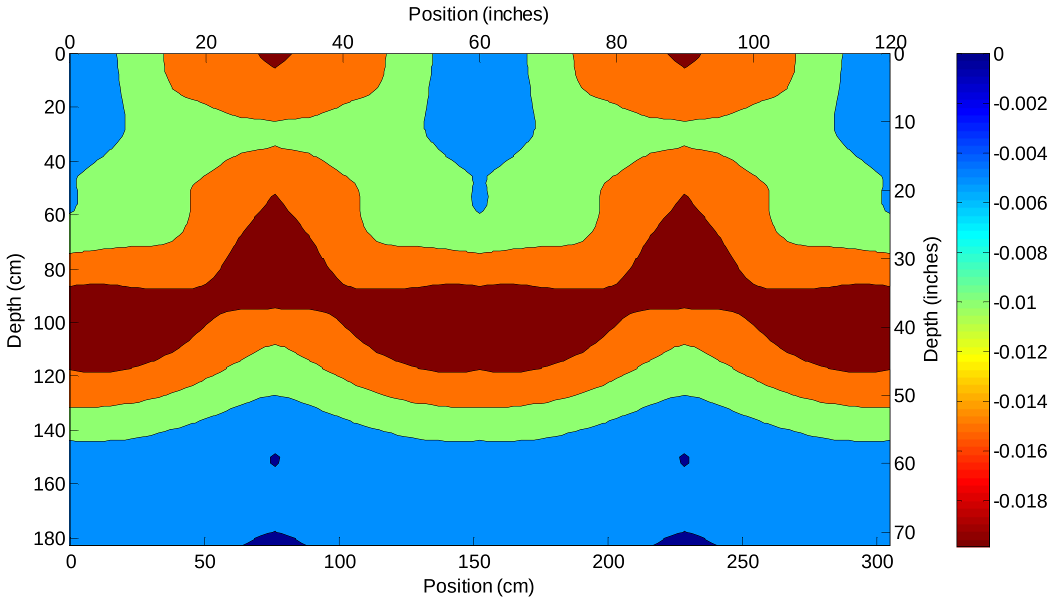

Figure A.89 - 2009 Corn late vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

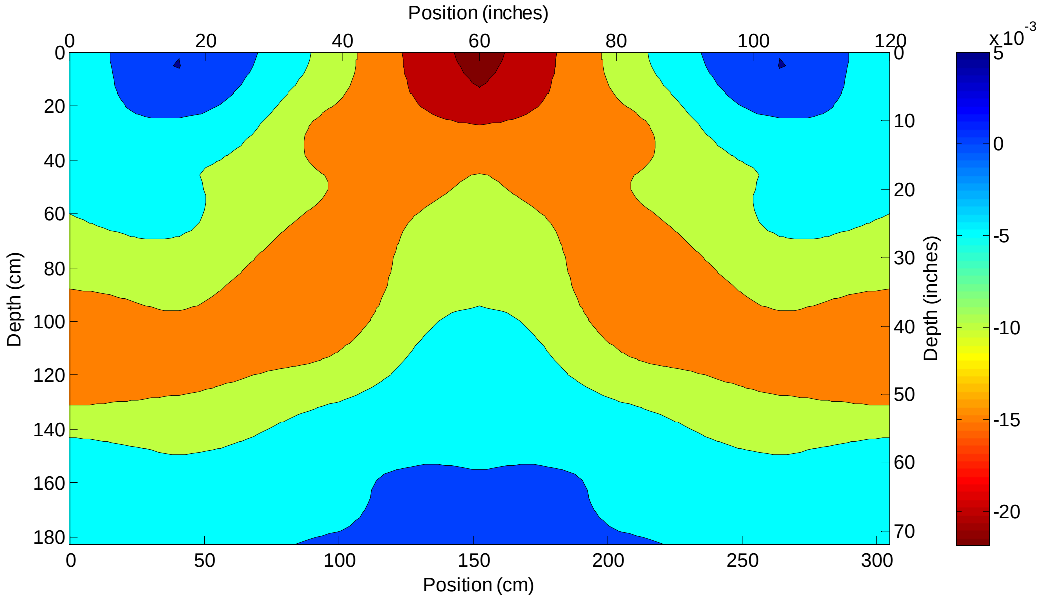

Figure A.90 - 2009 Corn late vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

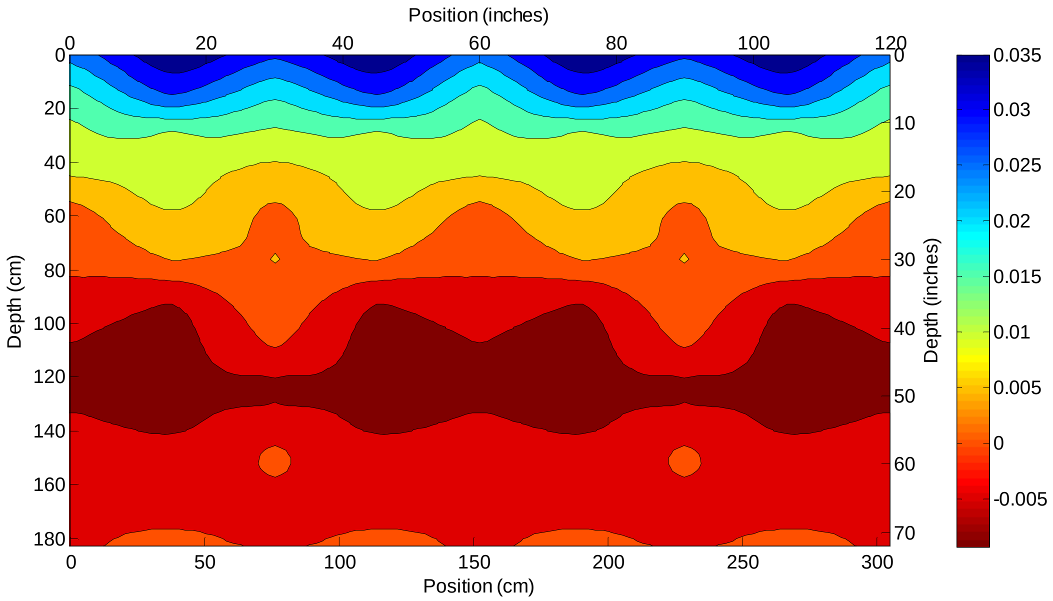

Figure A.91 - 2009 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

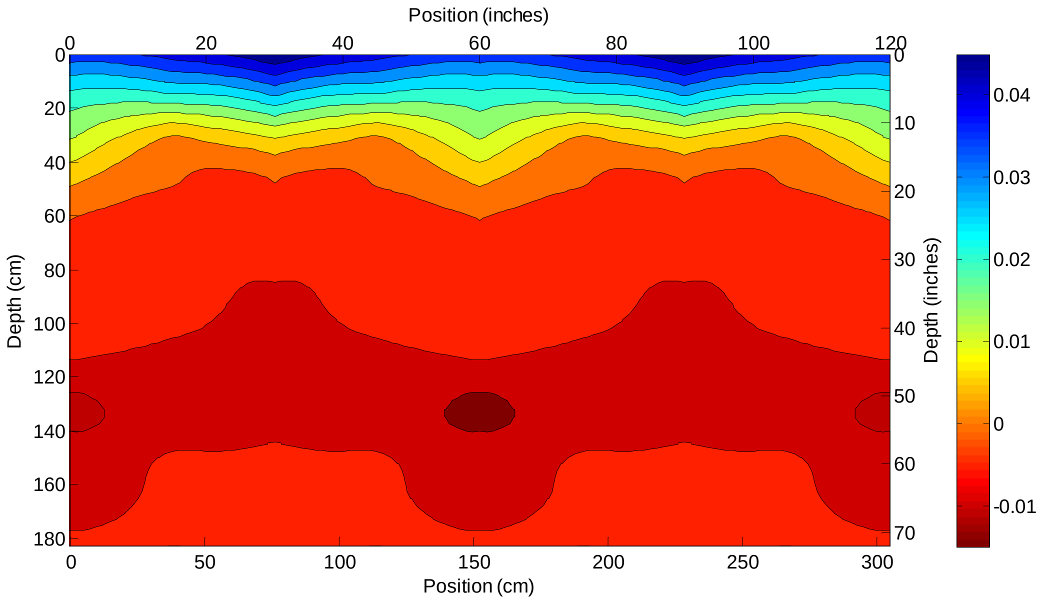

Figure A.92 - 2009 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

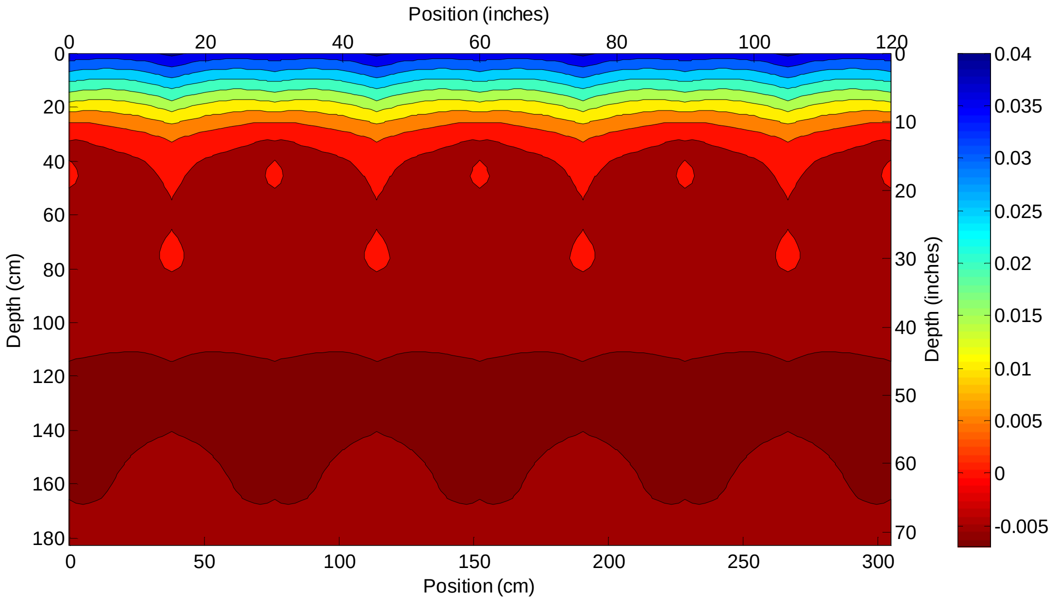

Figure A.93 - 2009 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

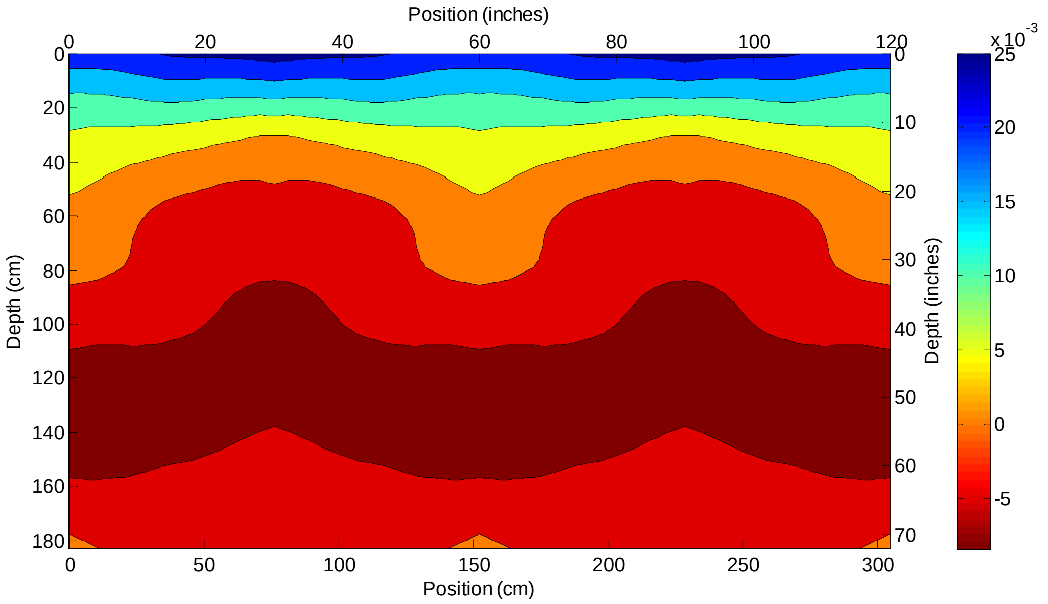

Figure A.94 - 2009 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

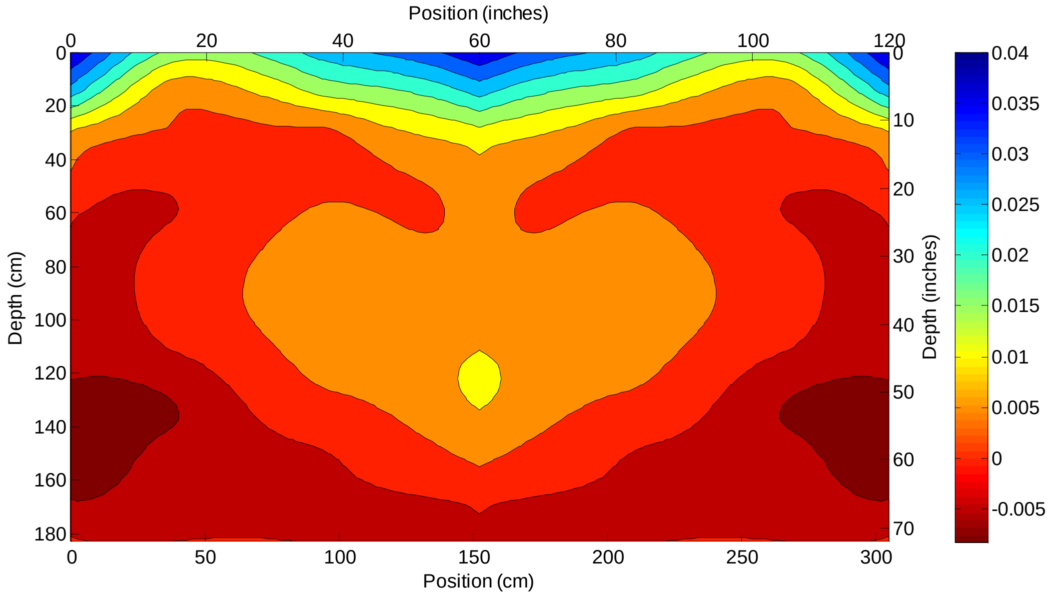

Figure A.95 - 2009 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

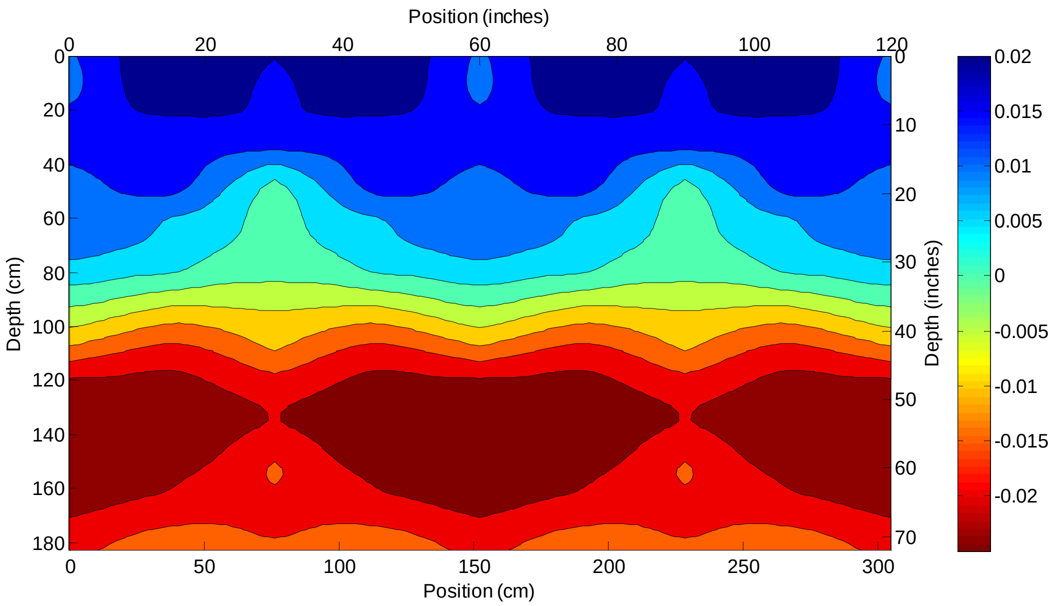

Figure A.96 - 2009 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

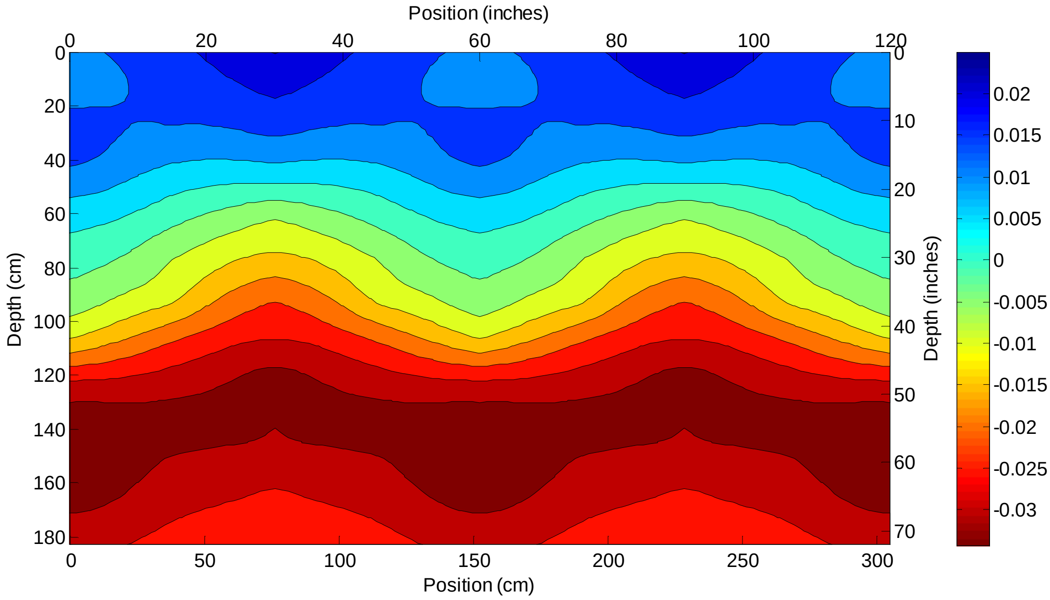

Figure A.97 - 2009 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

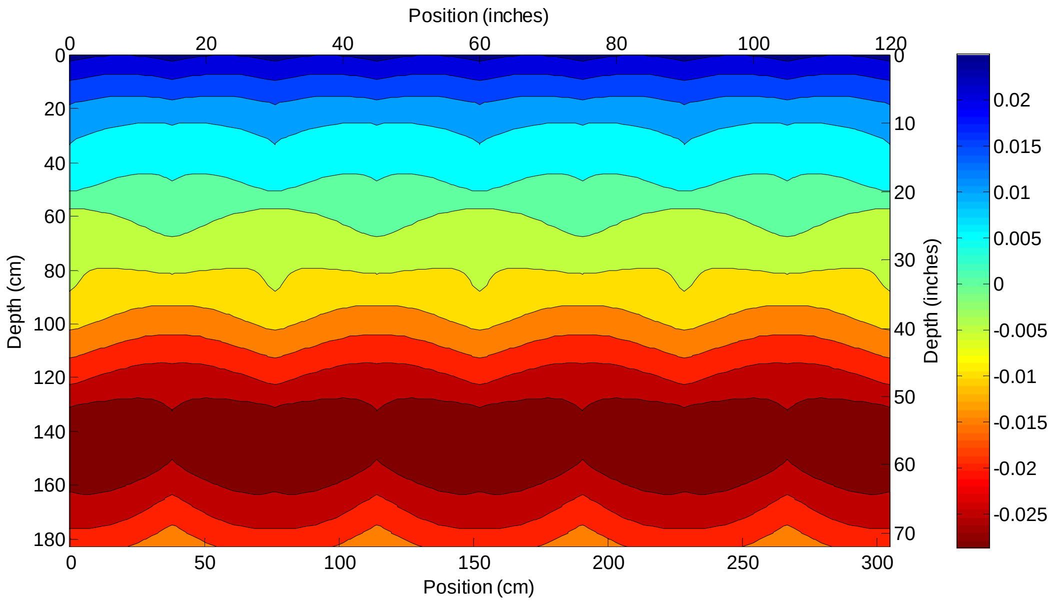

Figure A.98 - 2009 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

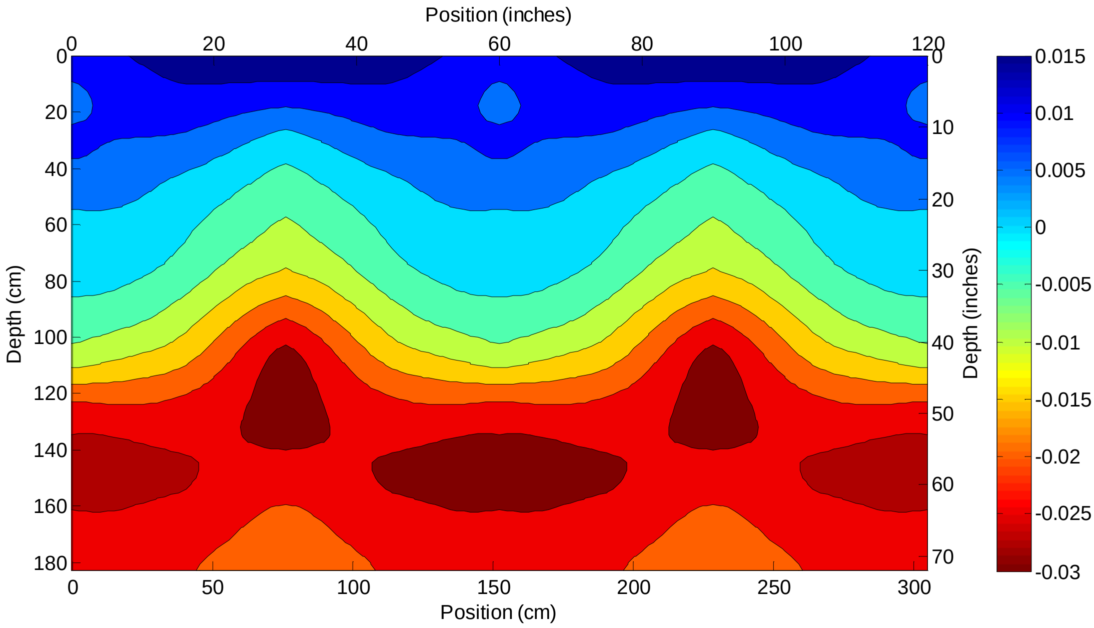

Figure A.99 - 2009 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

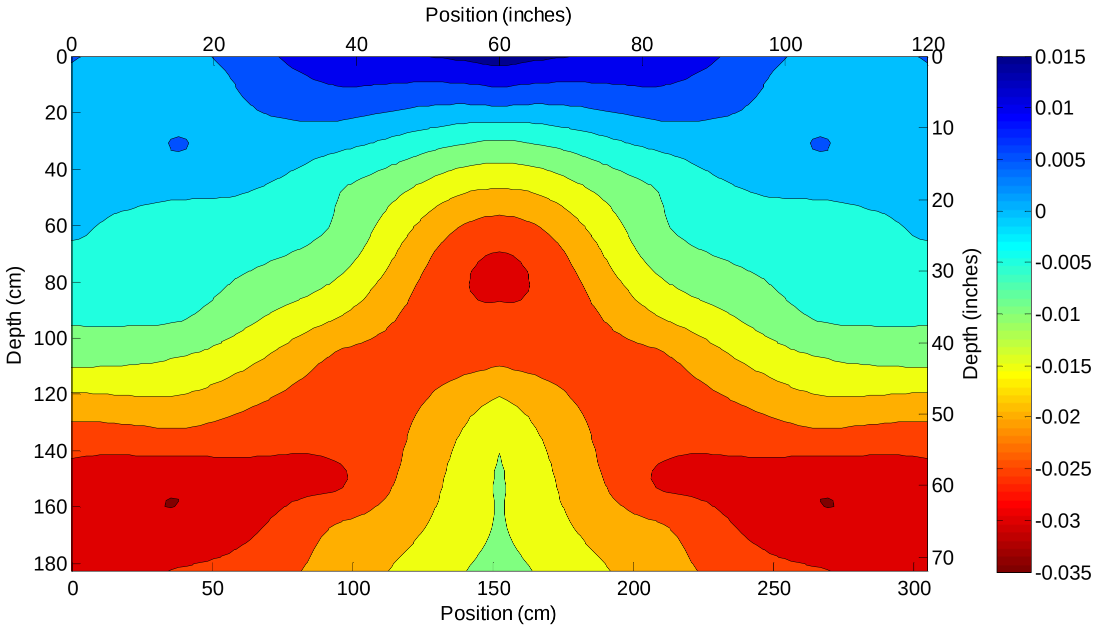

Figure A.100 - 2009 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

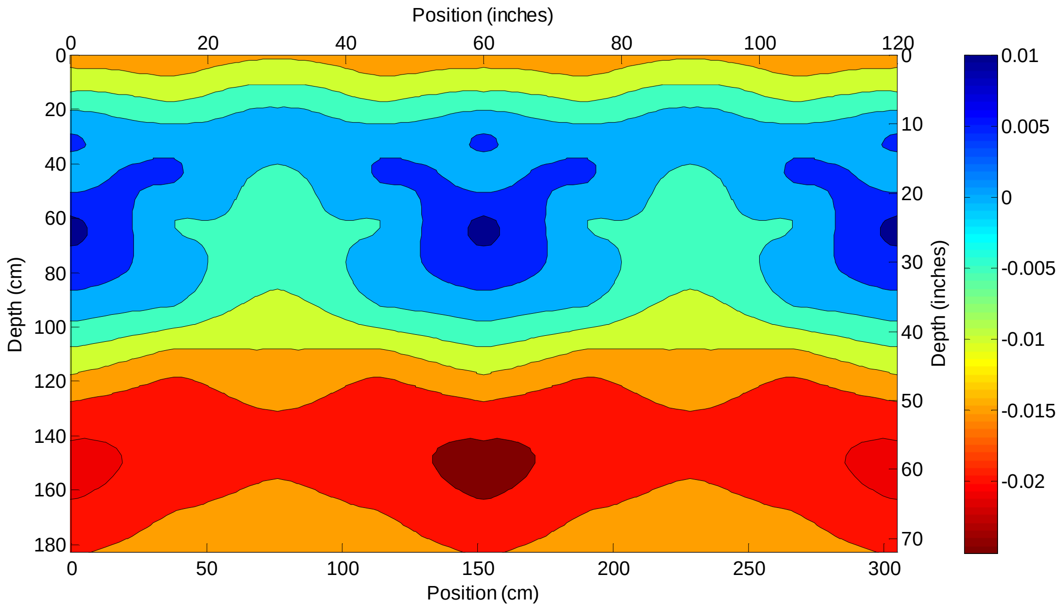

Figure A.101 - 2009 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

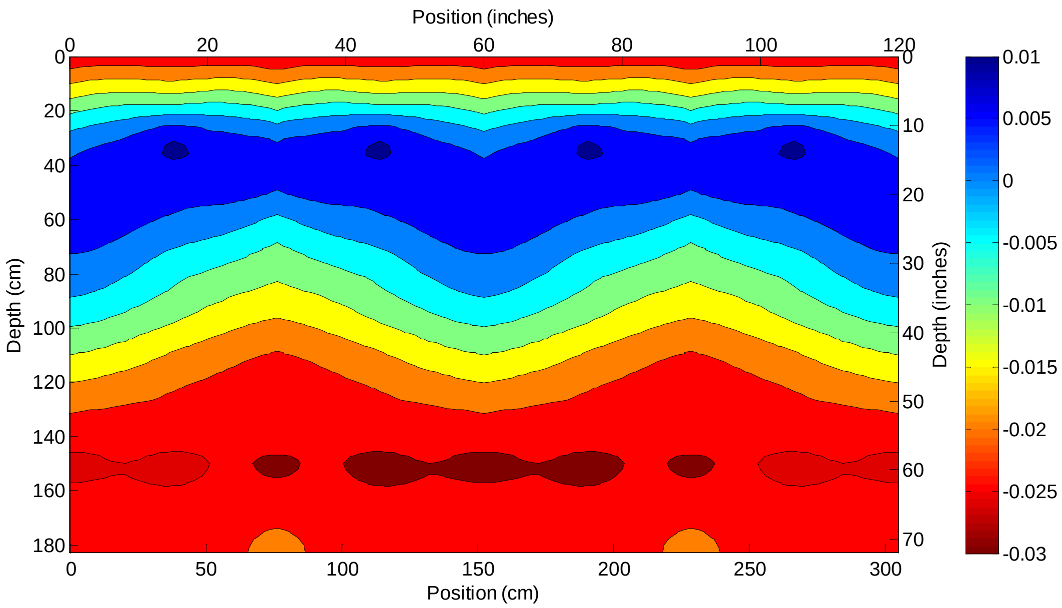

Figure A.102 - 2009 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

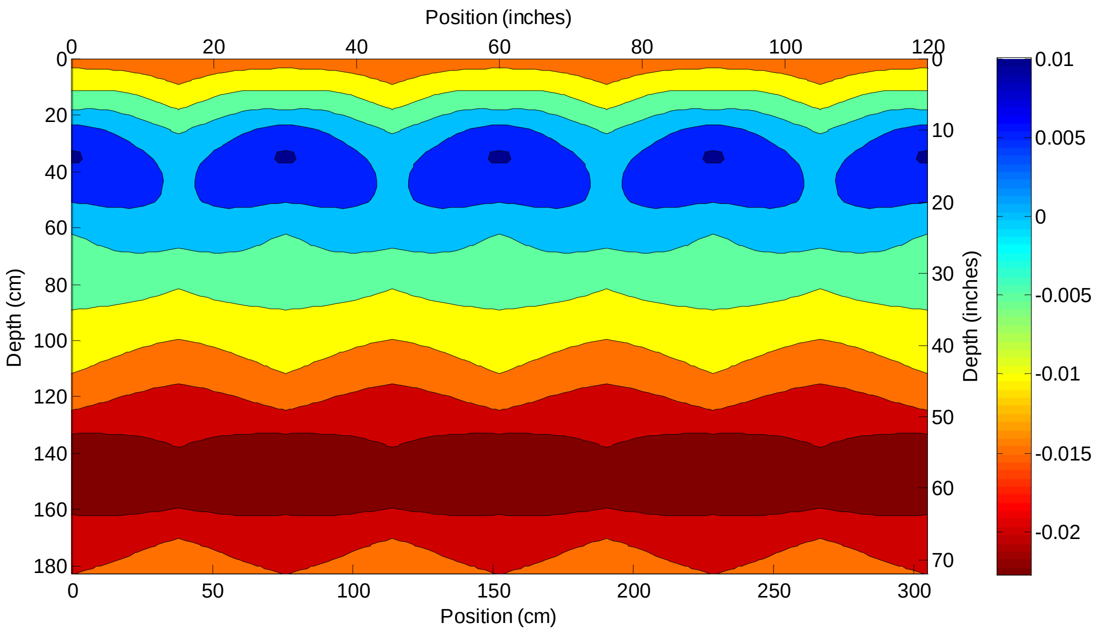

Figure A.103 - 2009 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

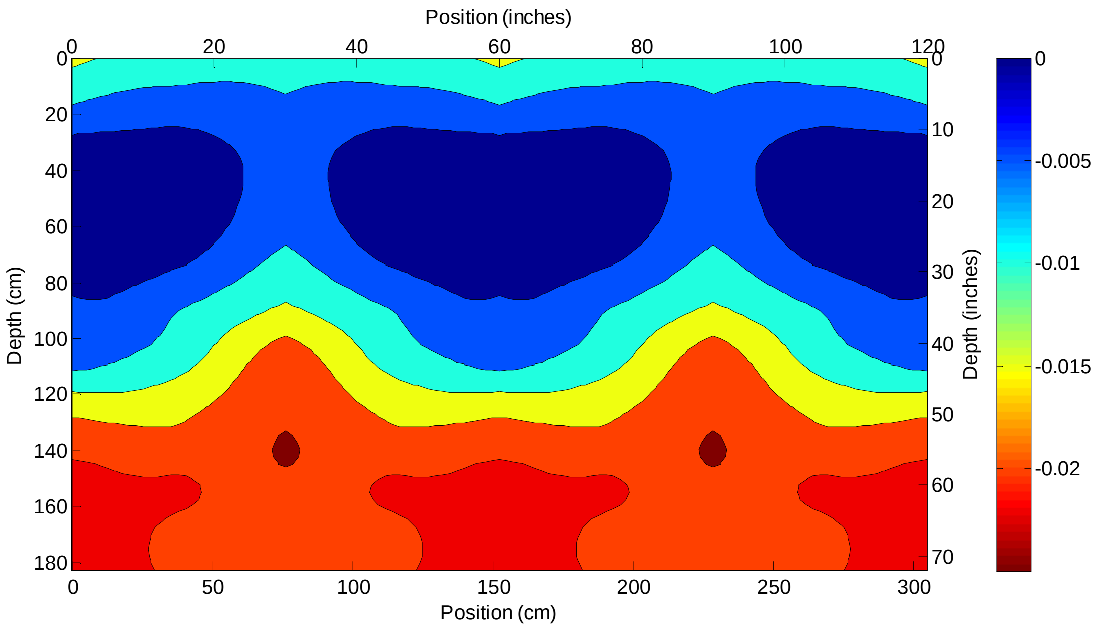

Figure A.104 - 2009 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

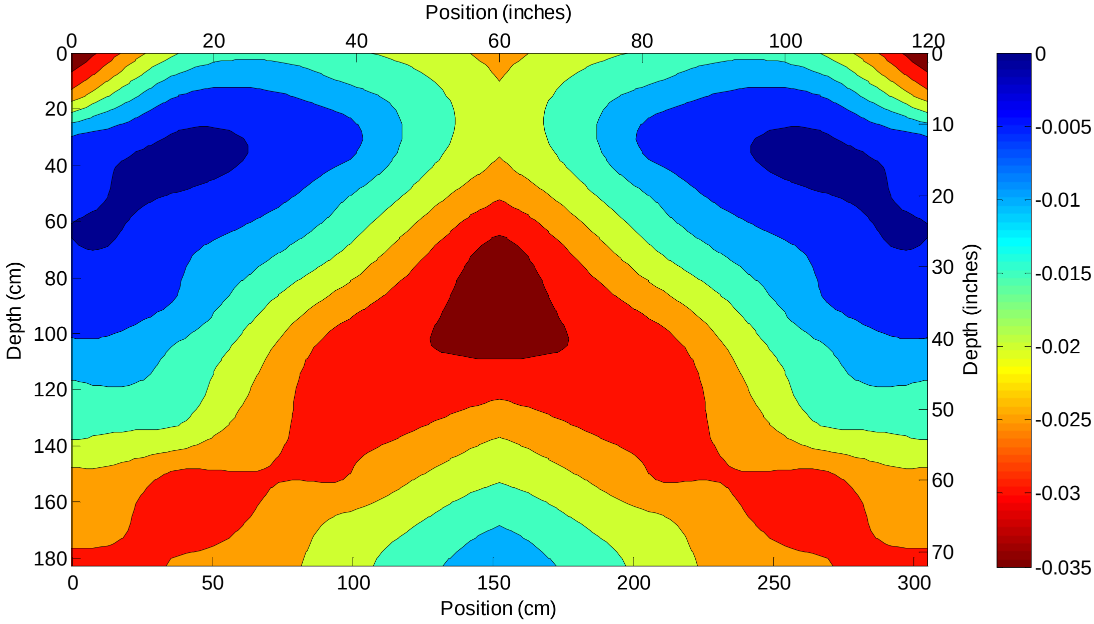

Figure A.105 - 2009 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

2010 Interpolated soil water content

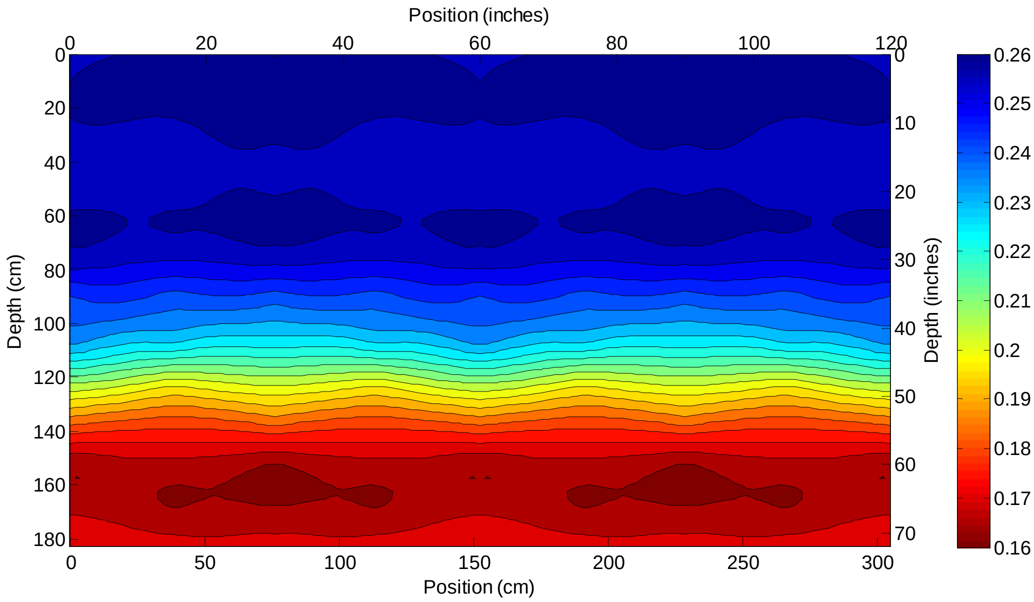

Figure A.106 - 2010 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

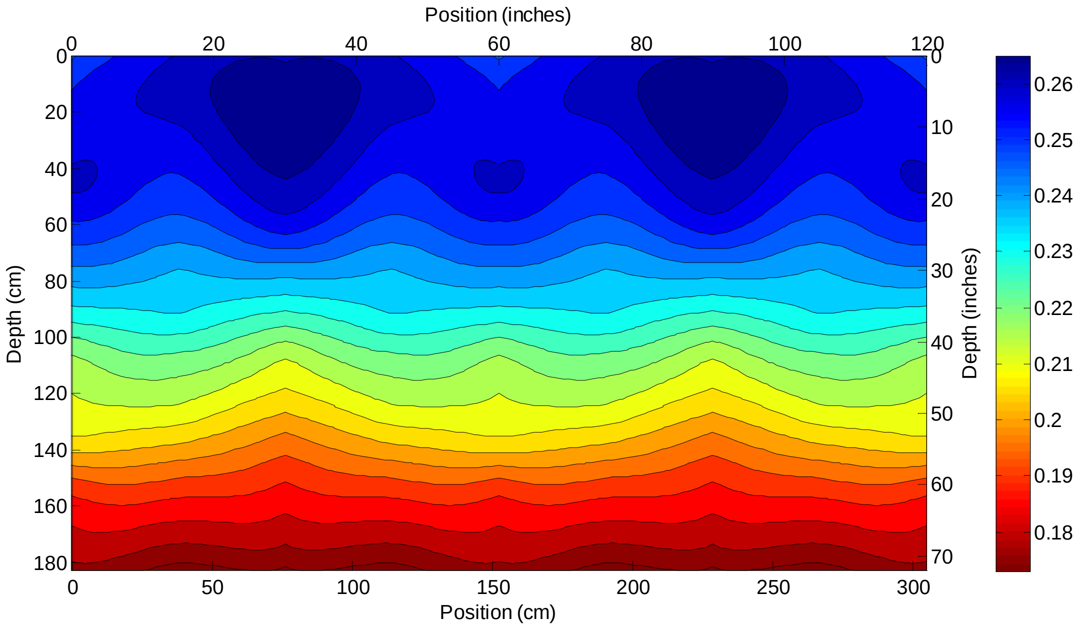

Figure A.107 - 2010 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

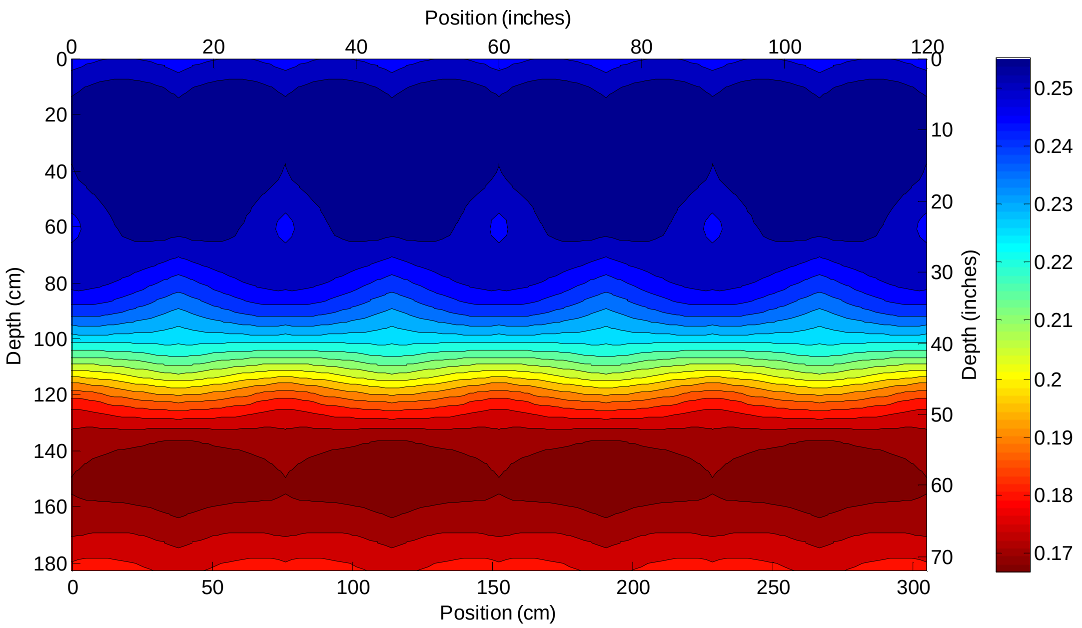

Figure A.108 - 2010 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

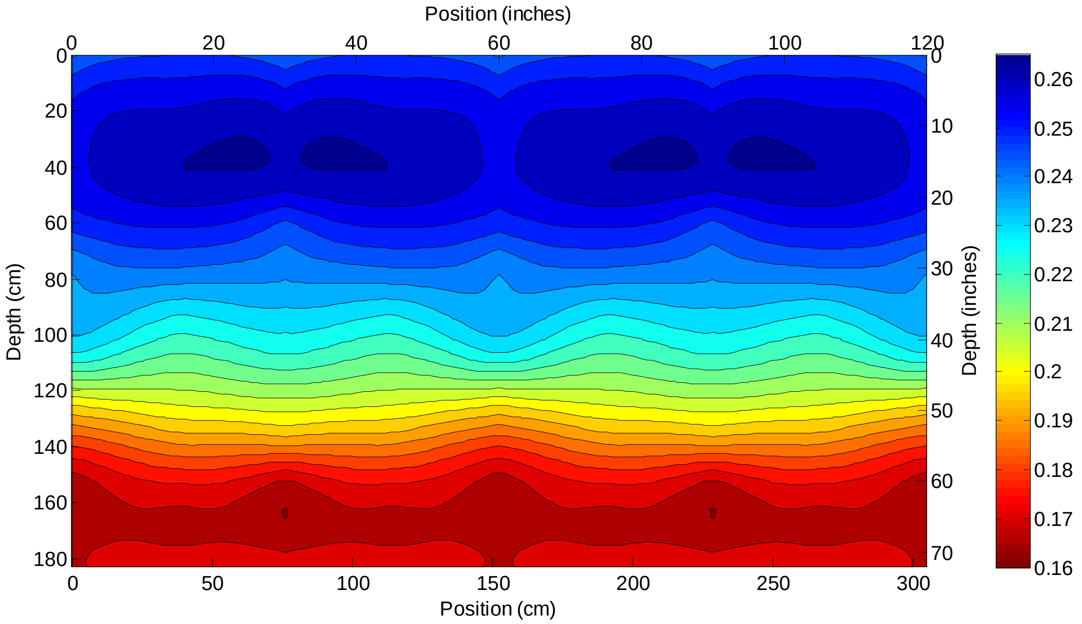

Figure A.109 - 2010 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

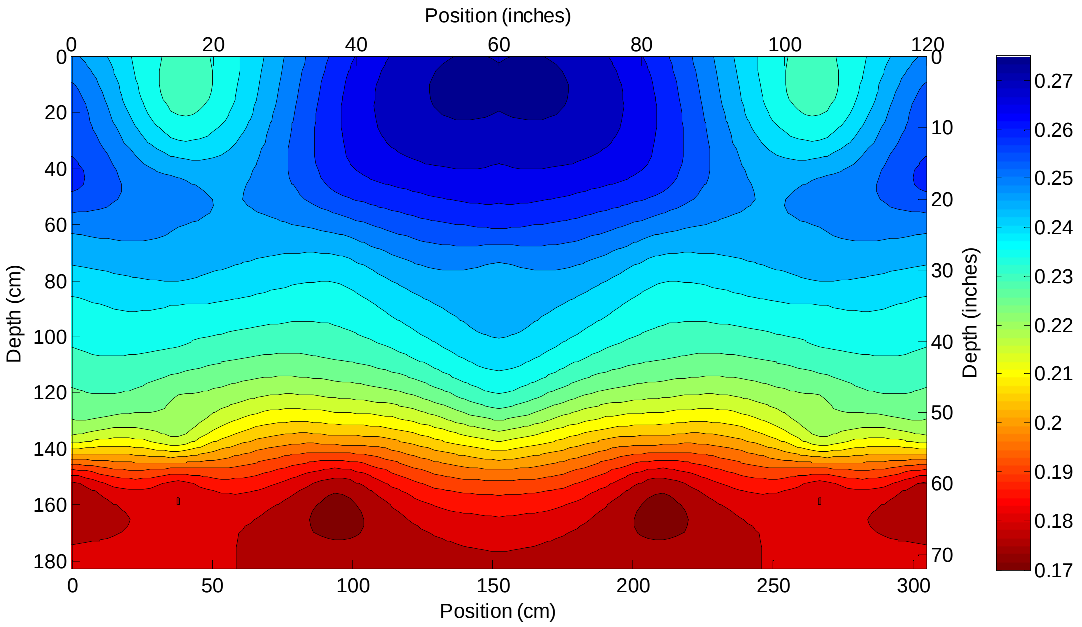

Figure A.110 - 2010 Corn planting soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

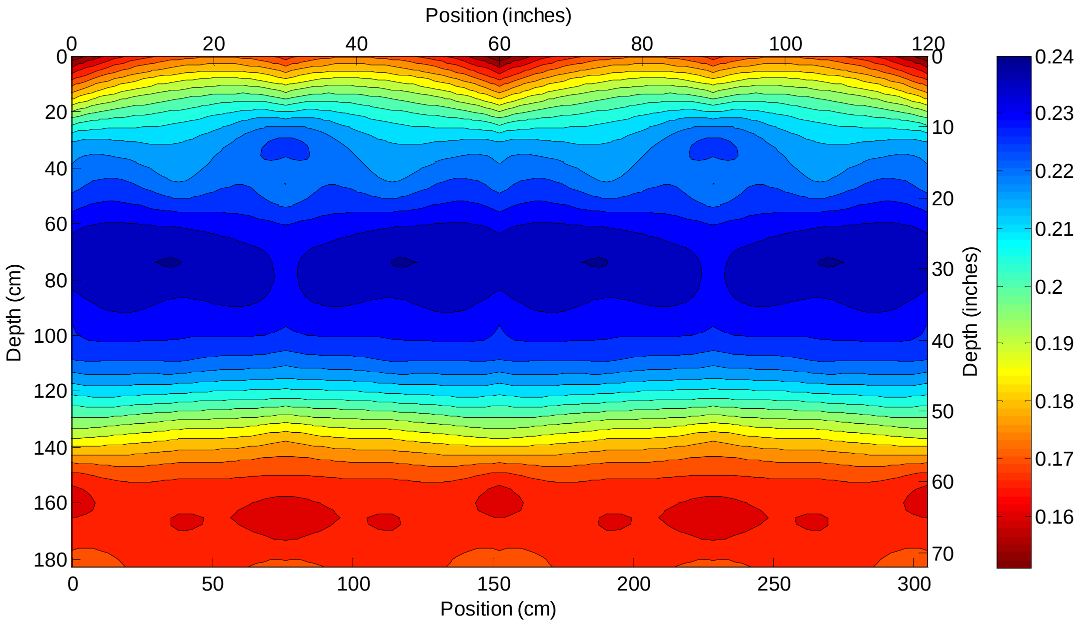

Figure A.111 - 2010 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, clump geometry.

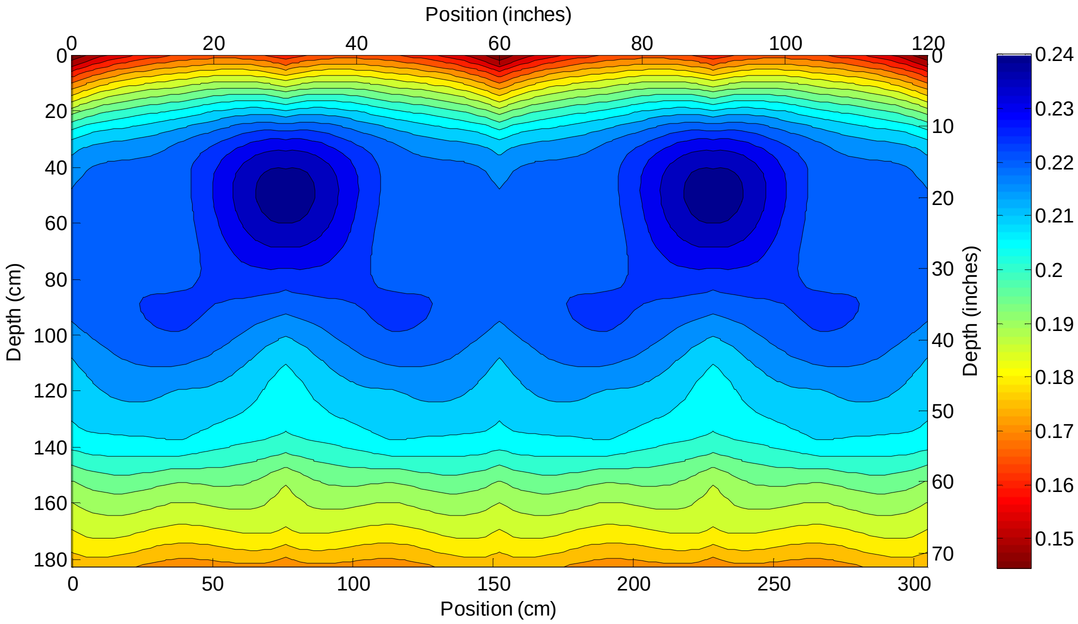

Figure A.112 - 2010 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, cluster geometry.

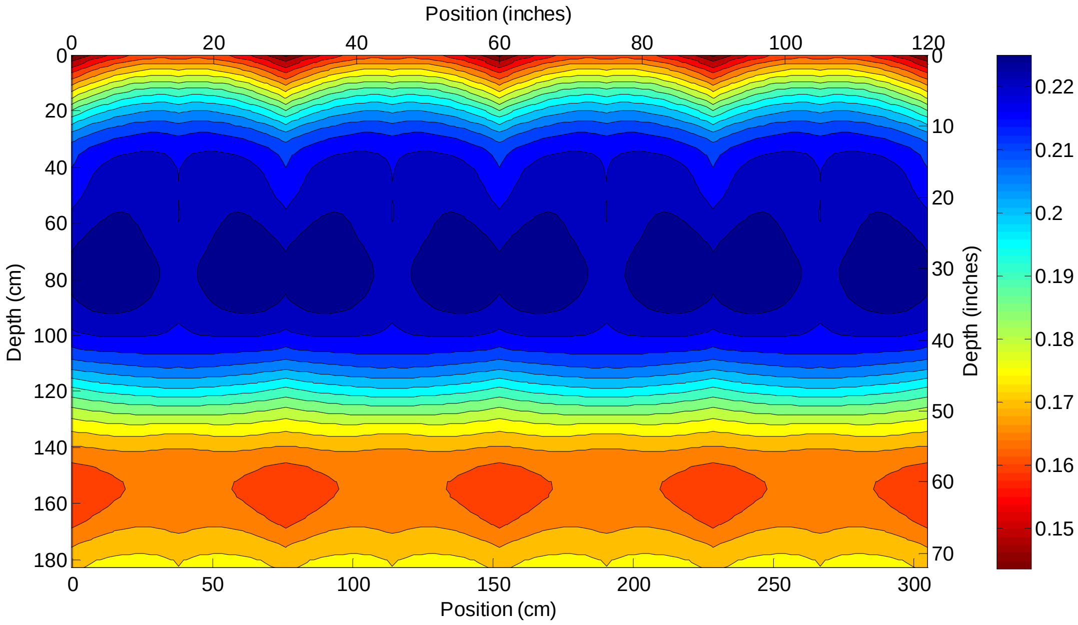

Figure A.113 - 2010 Corn early vegetative soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

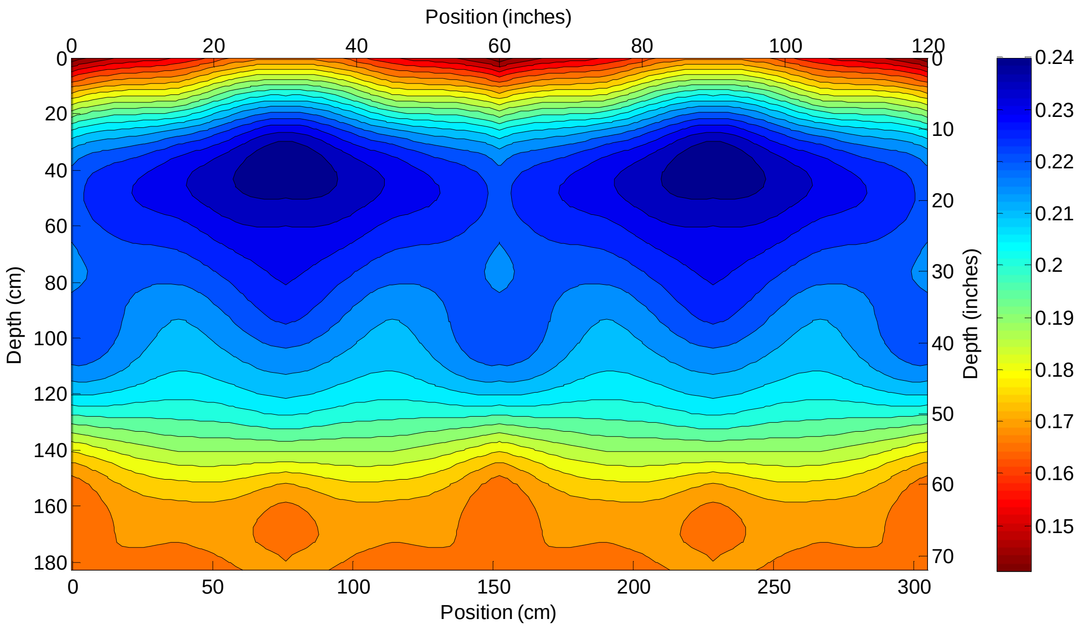

Figure A.114 - 2010 Corn early vegetative soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

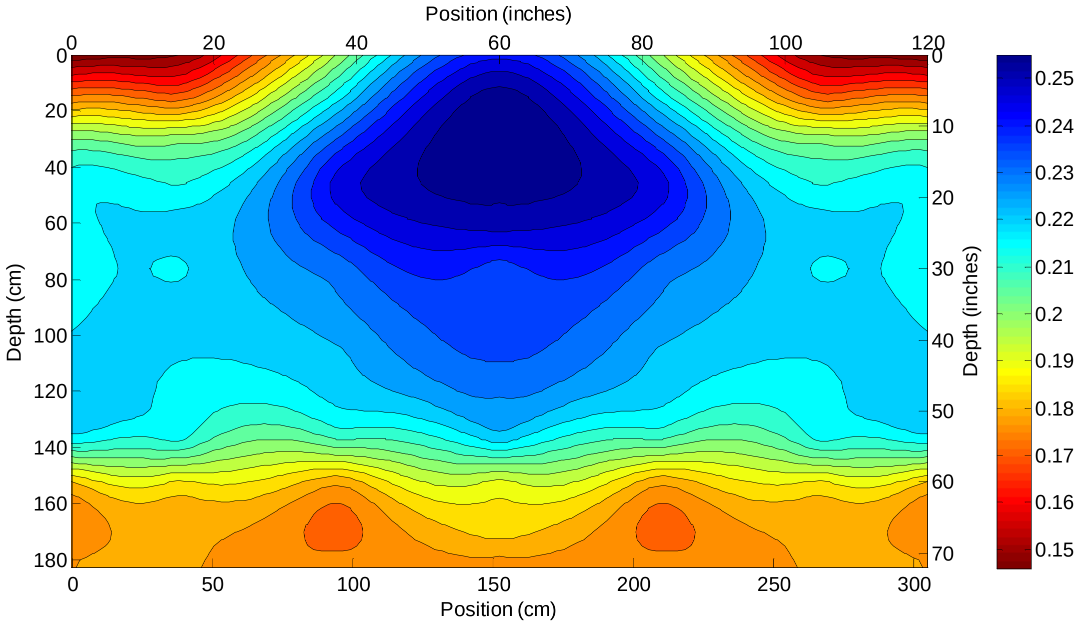

Figure A.115 - 2010 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

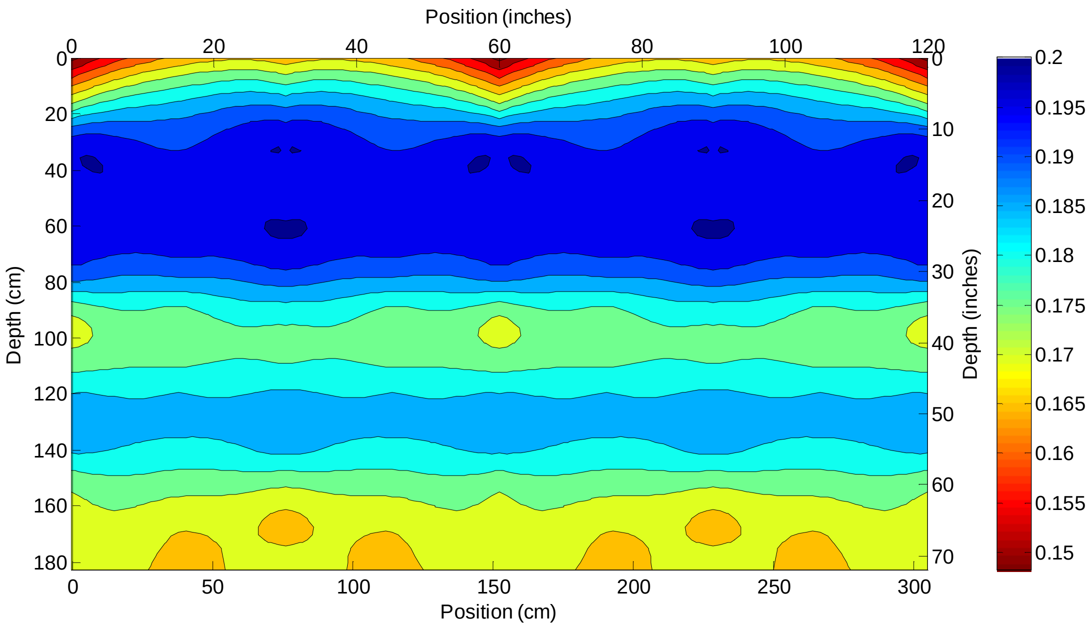

Figure A.116 - 2010 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

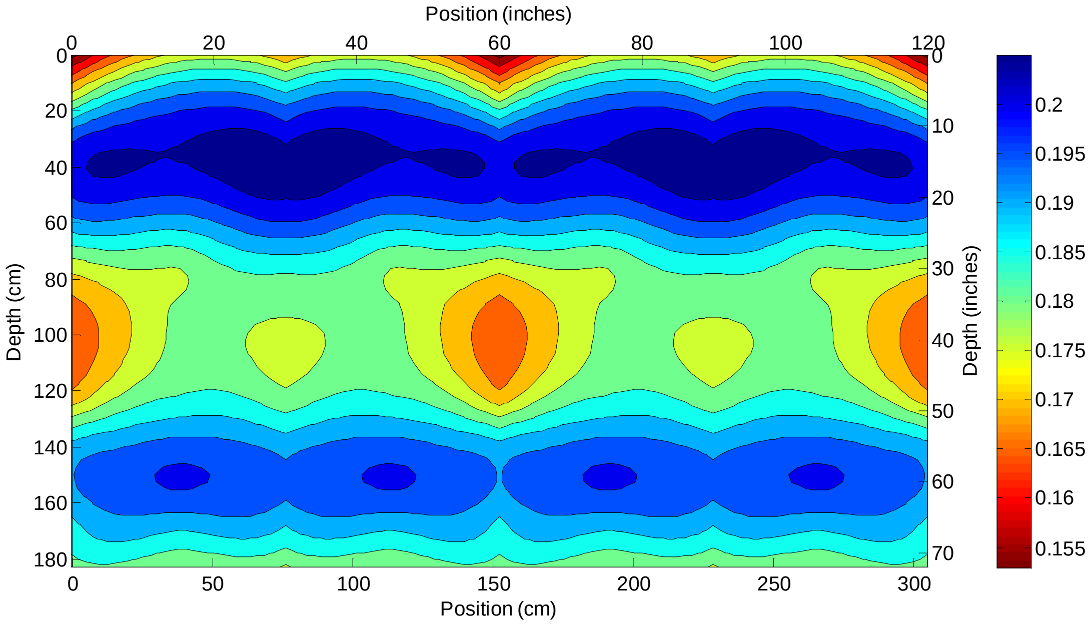

Figure A.117 - 2010 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

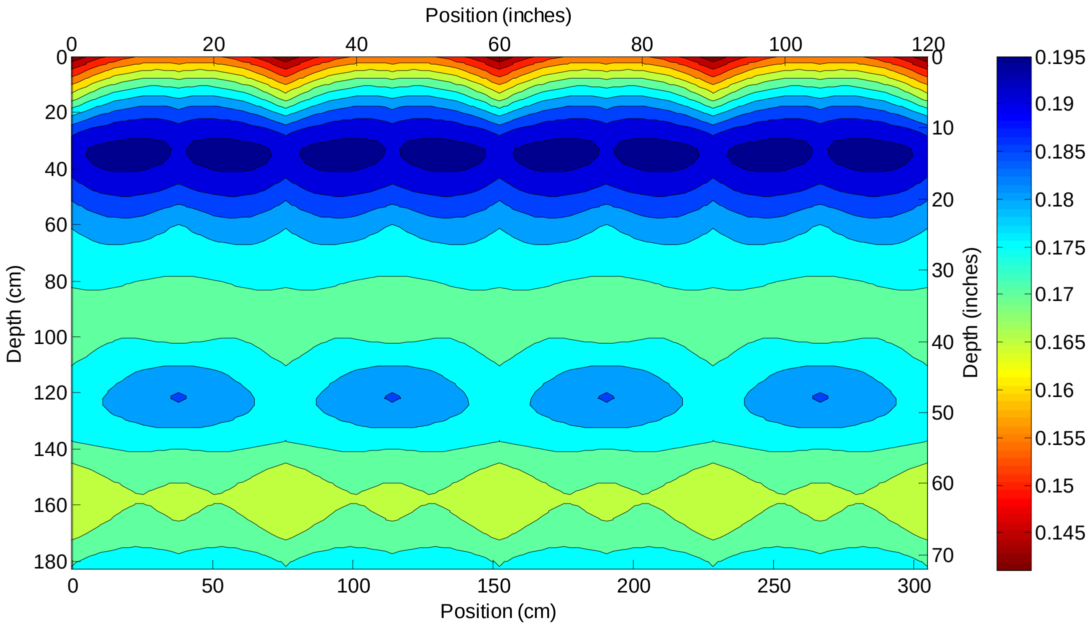

Figure A.118 - 2010 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

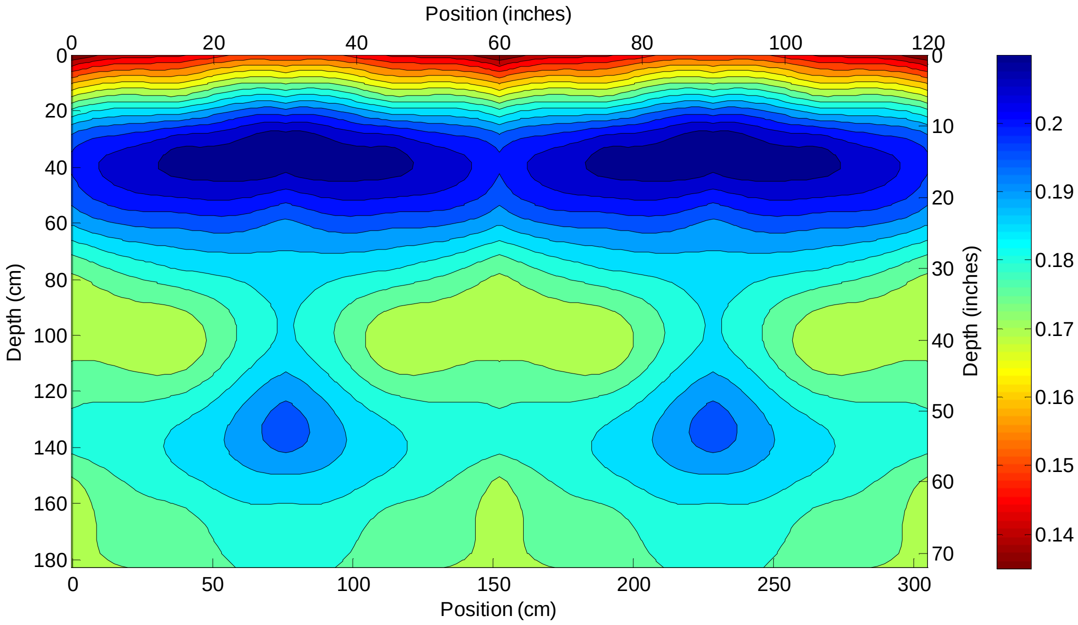

Figure A.119 - 2010 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

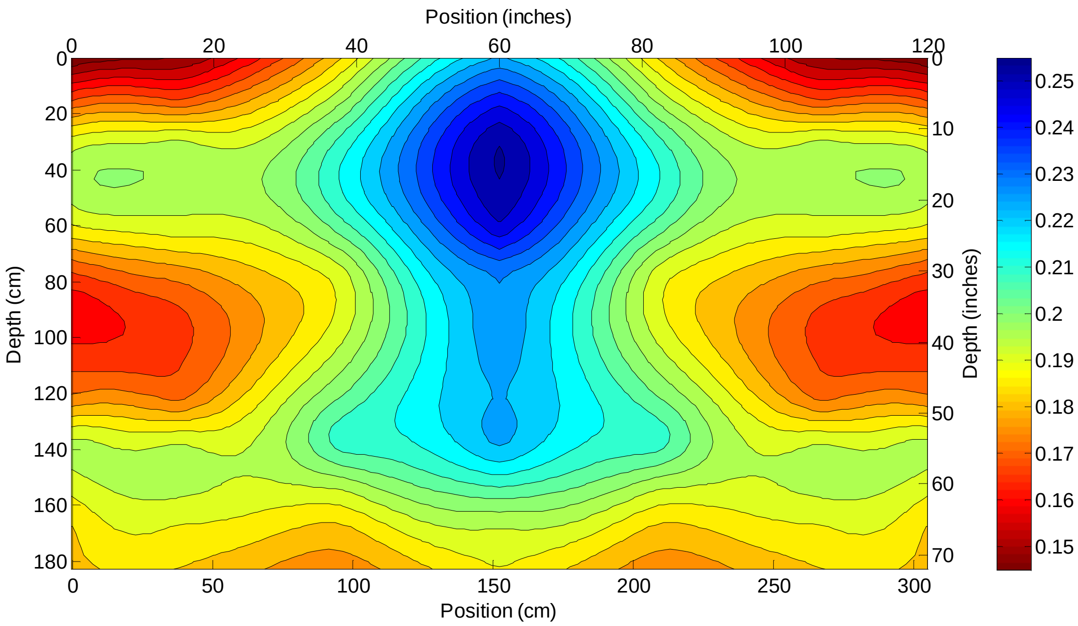

Figure A.120 - 2010 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

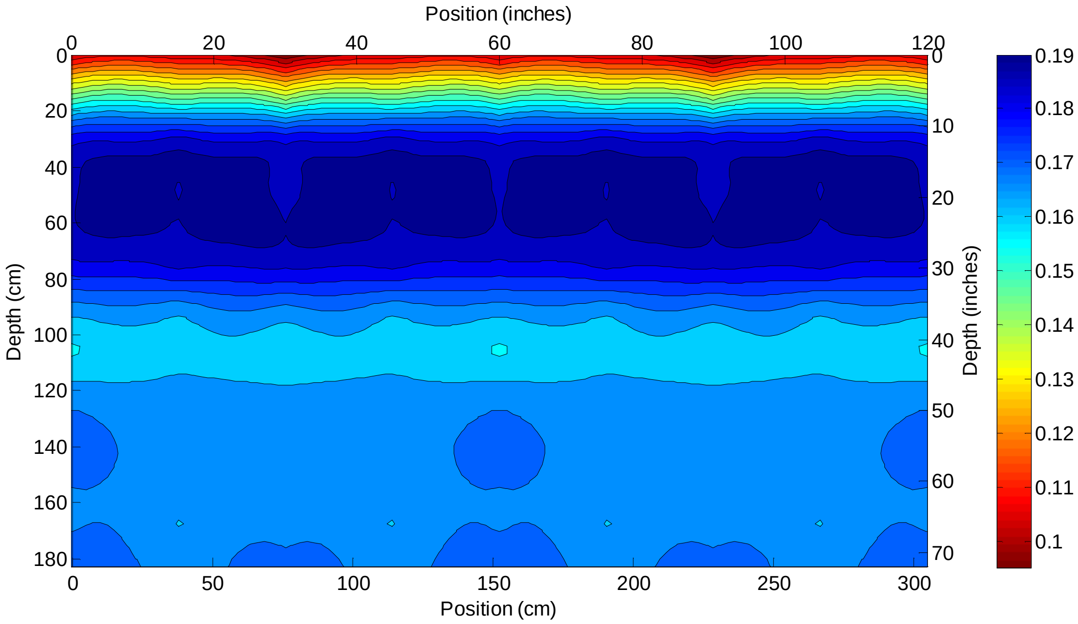

Figure A.121 - 2010 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

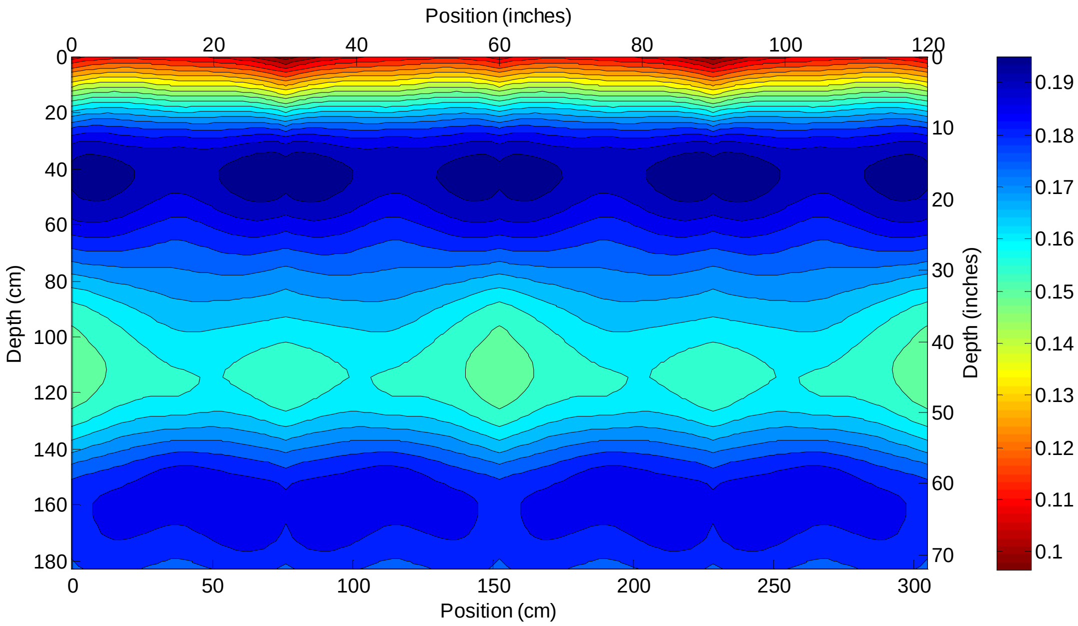

Figure A.122 - 2010 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

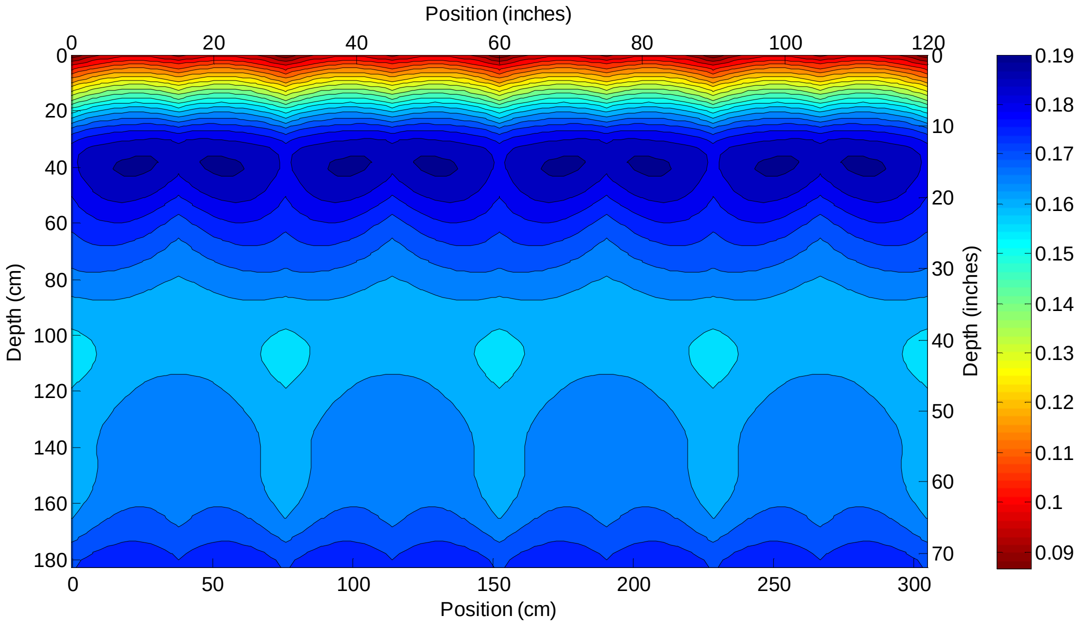

Figure A.123 - 2010 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

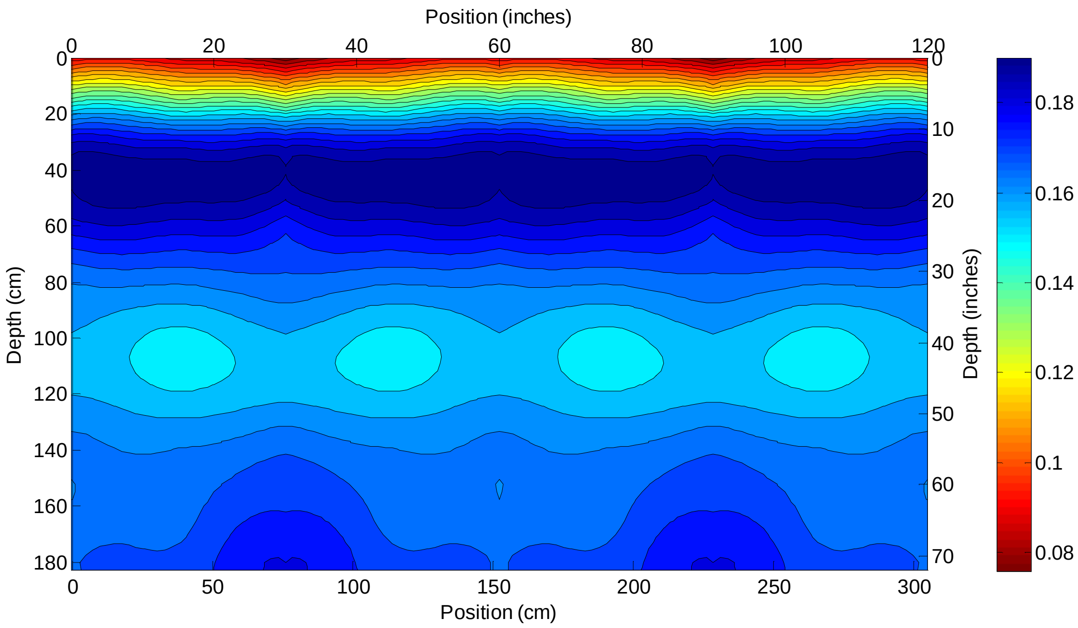

Figure A.124 - 2010 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

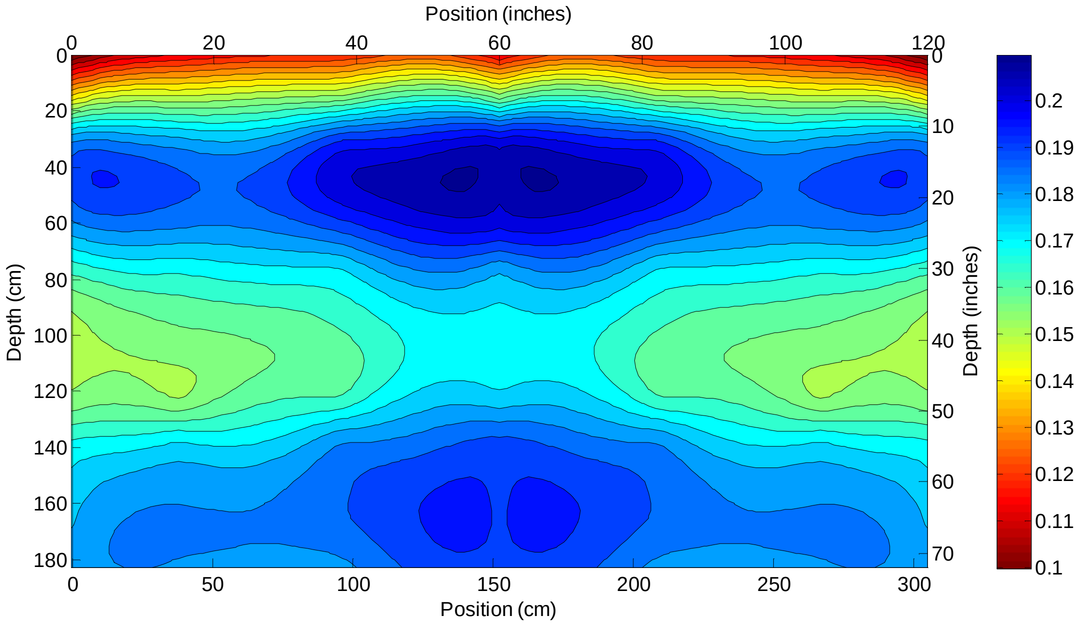

Figure A.125 - 2010 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

2010 Changes in soil water content

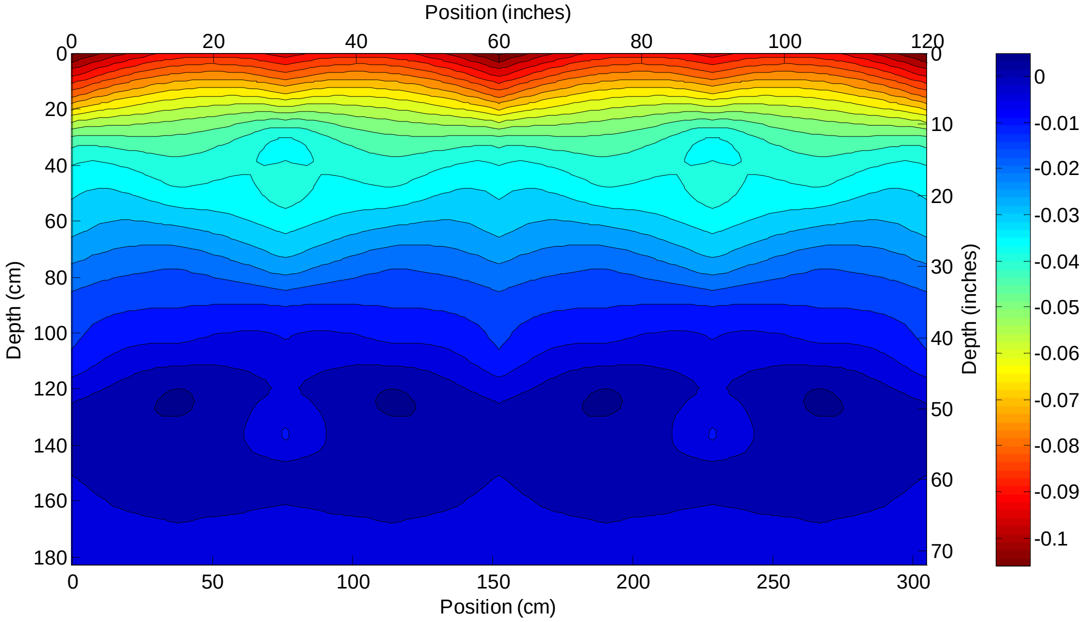

Figure A.126 - 2010 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

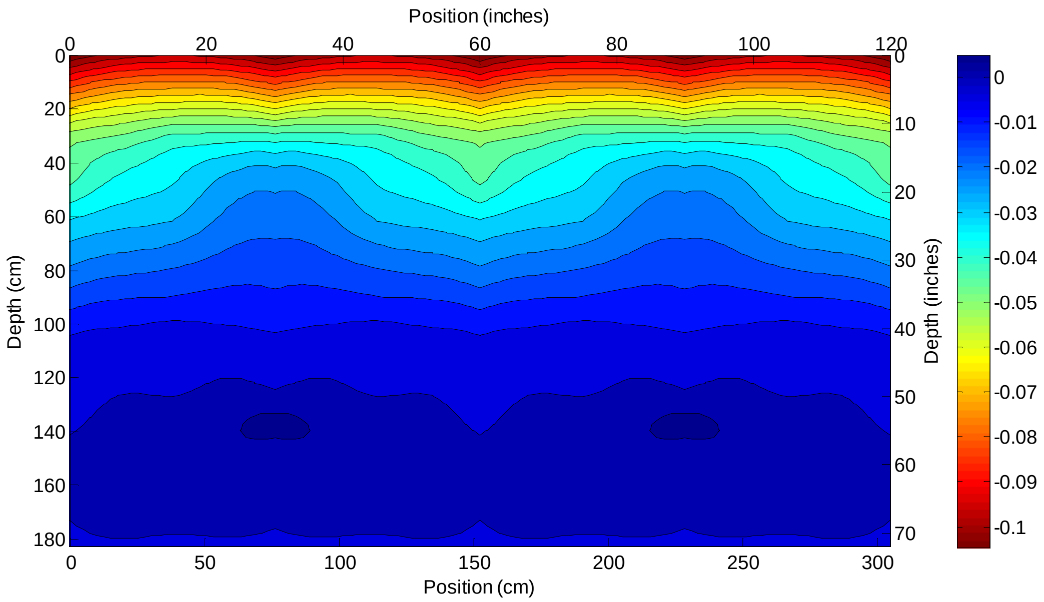

Figure A.127 - 2010 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

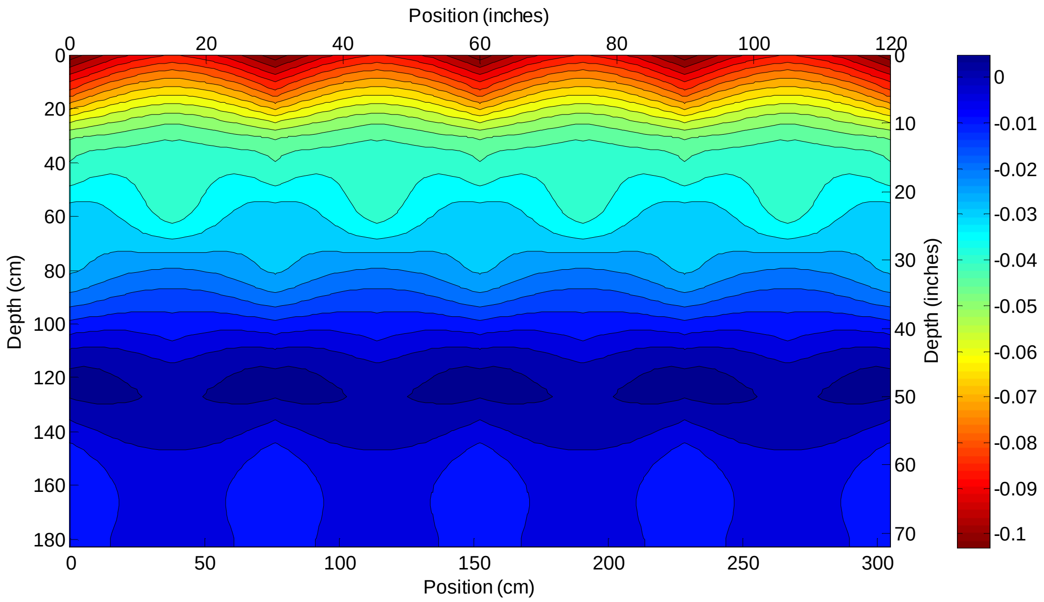

Figure A.128 - 2010 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

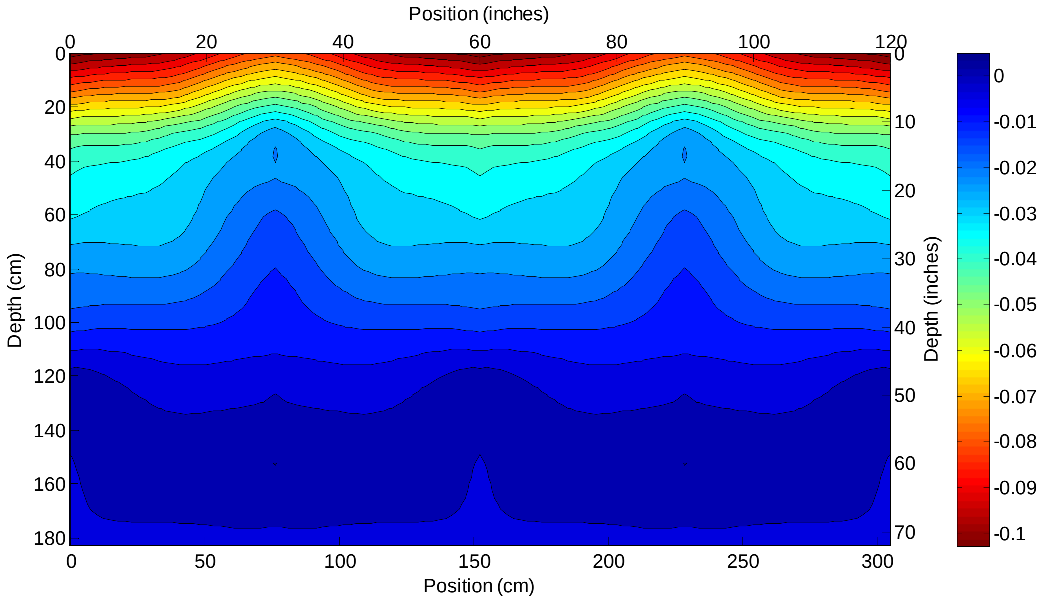

Figure A.129 - 2010 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

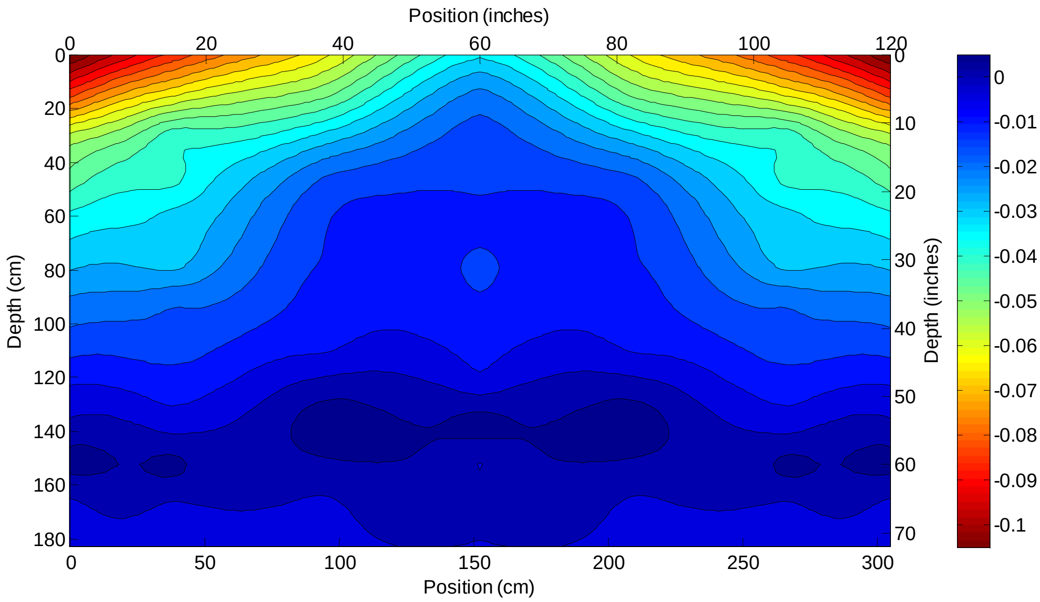

Figure A.130 - 2010 Corn planting to early vegetative change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

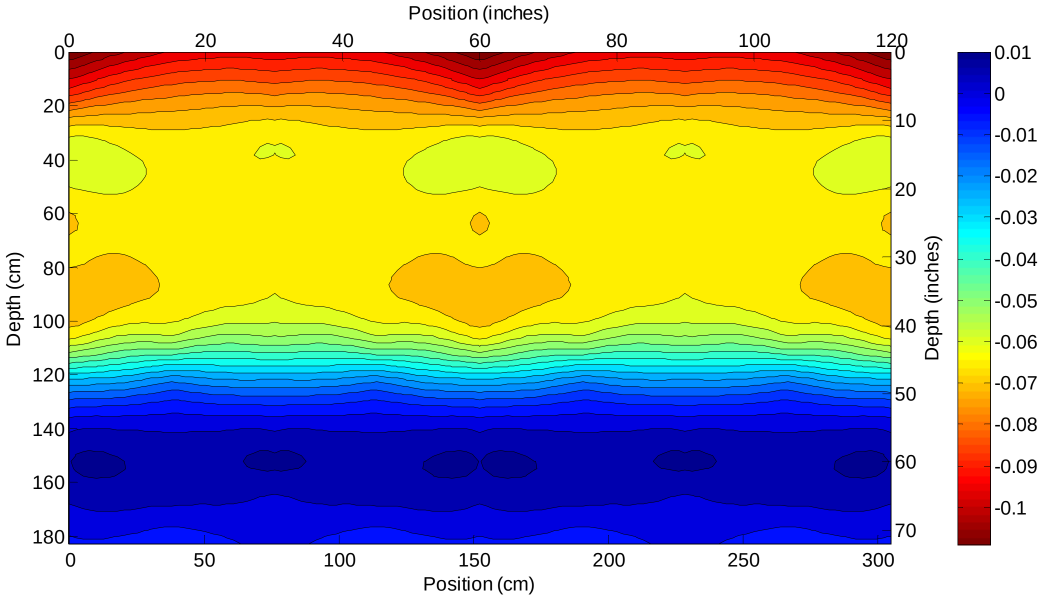

Figure A.131 - 2010 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

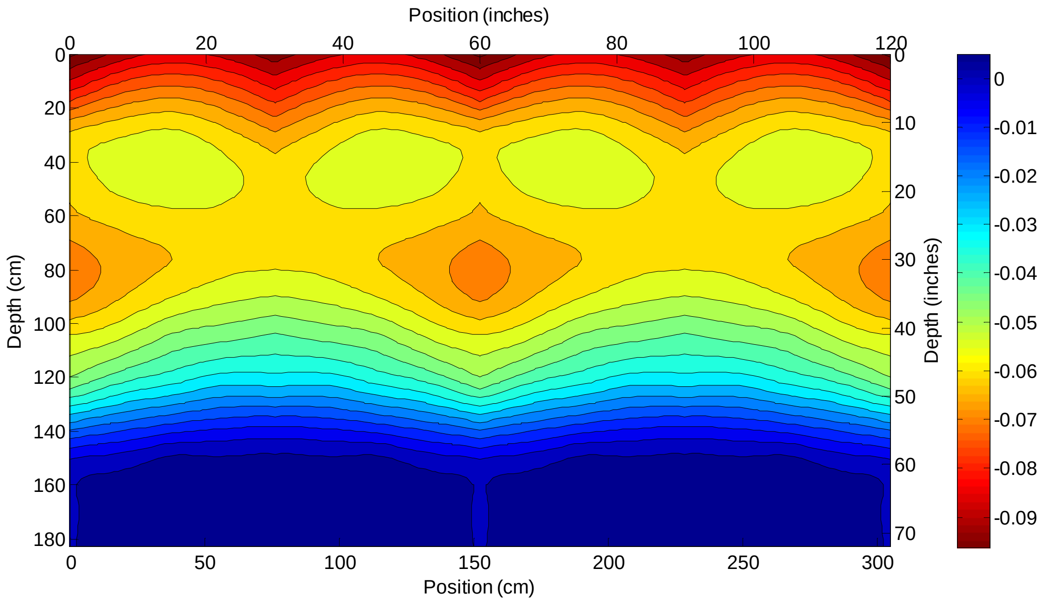

Figure A.132 - 2010 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

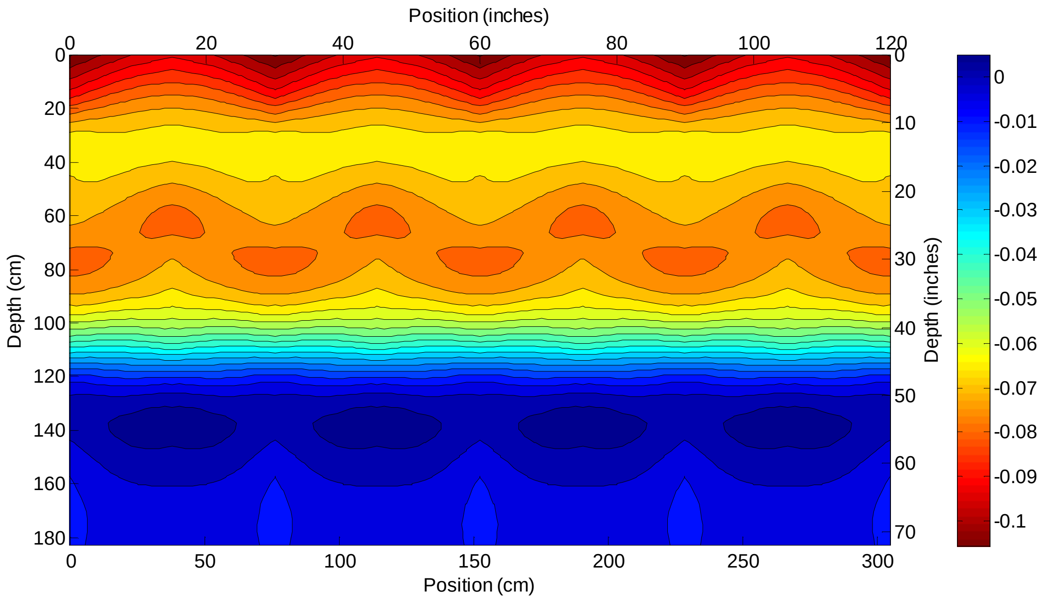

Figure A.133 - 2010 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

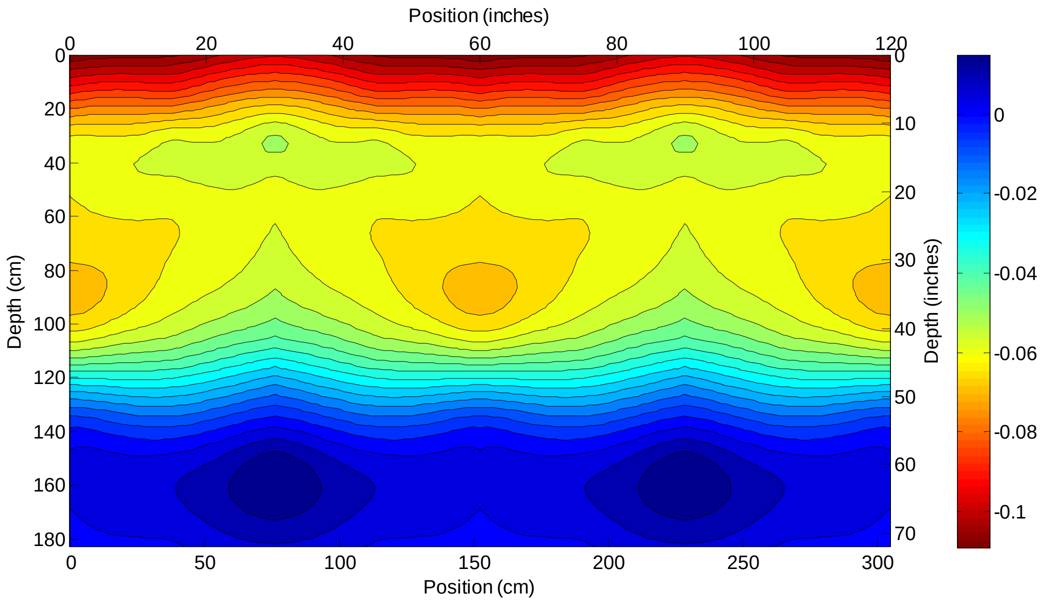

Figure A.134 - 2010 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

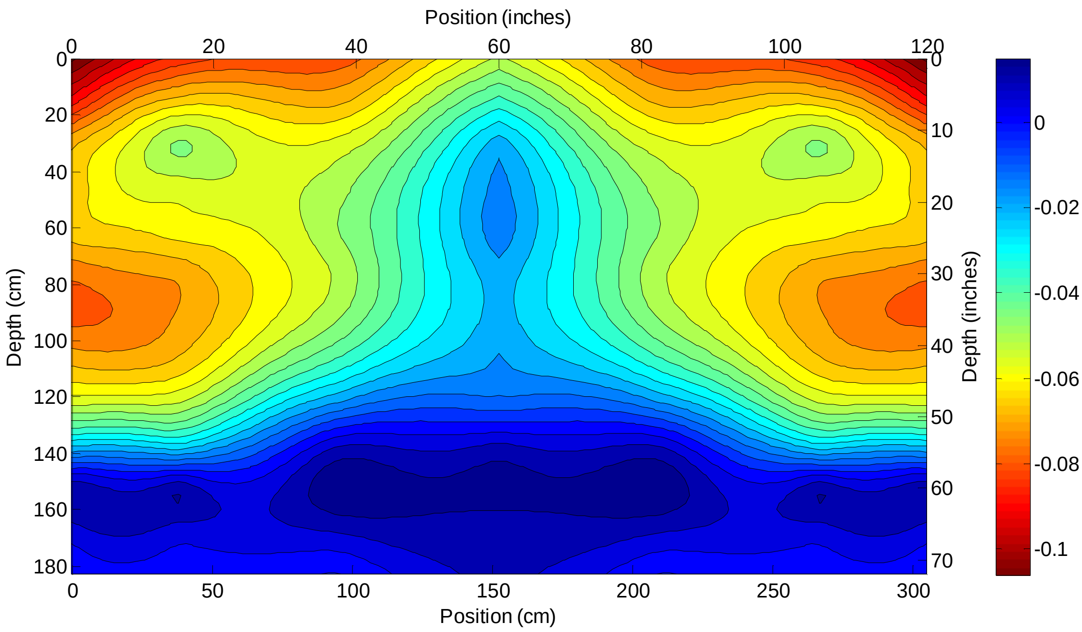

Figure A.135 - 2010 Corn planting to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

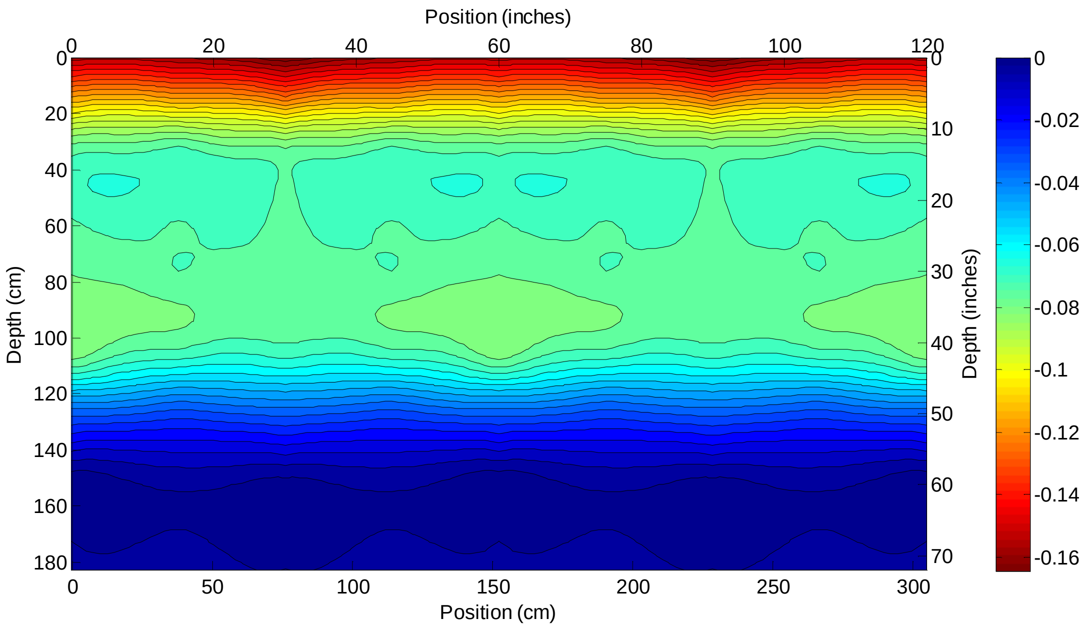

Figure A.136 - 2010 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

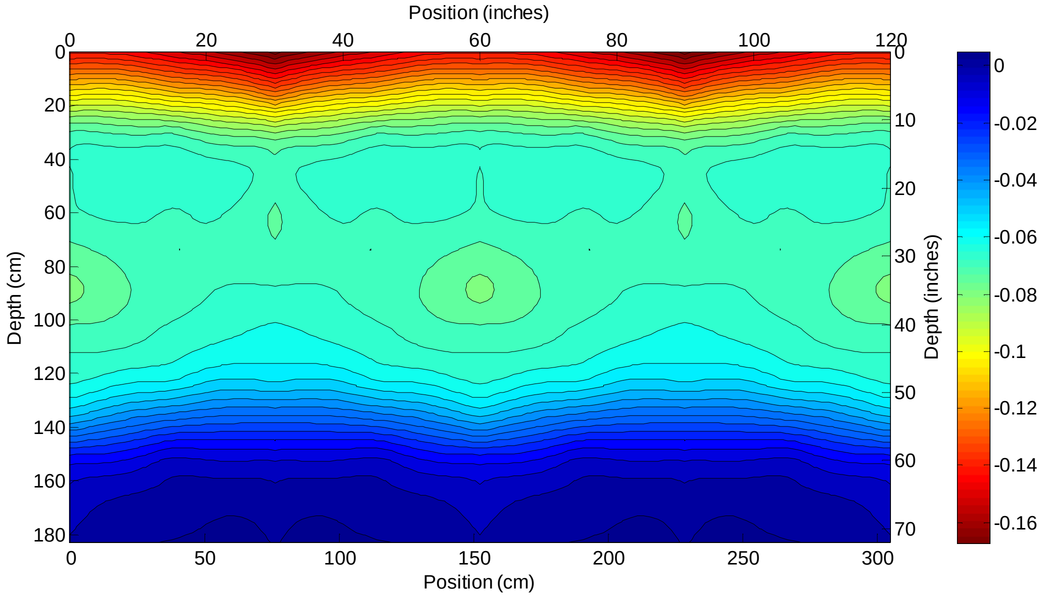

Figure A.137 - 2010 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

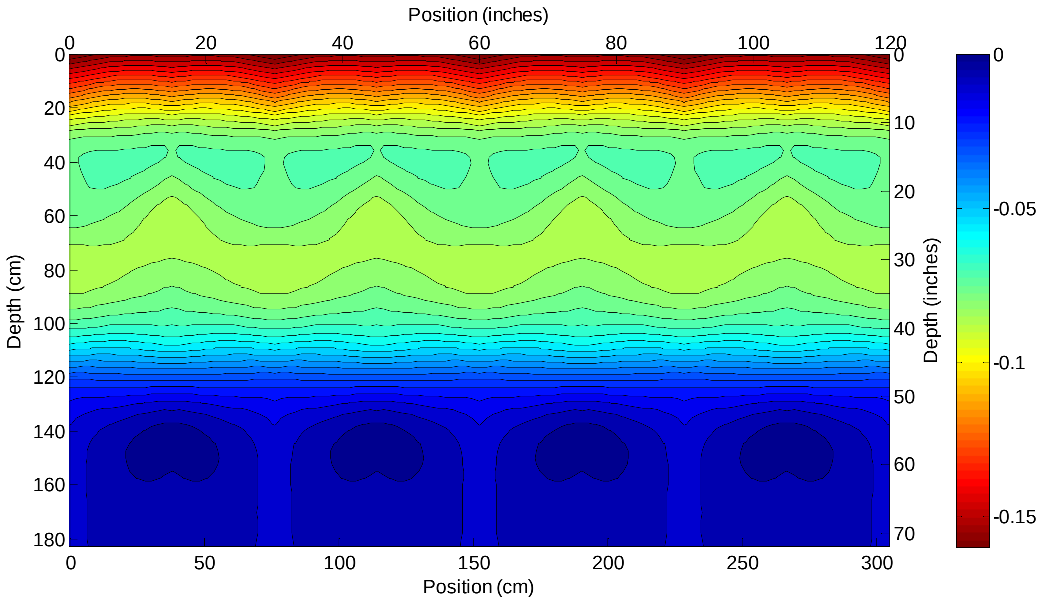

Figure A.138 - 2010 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

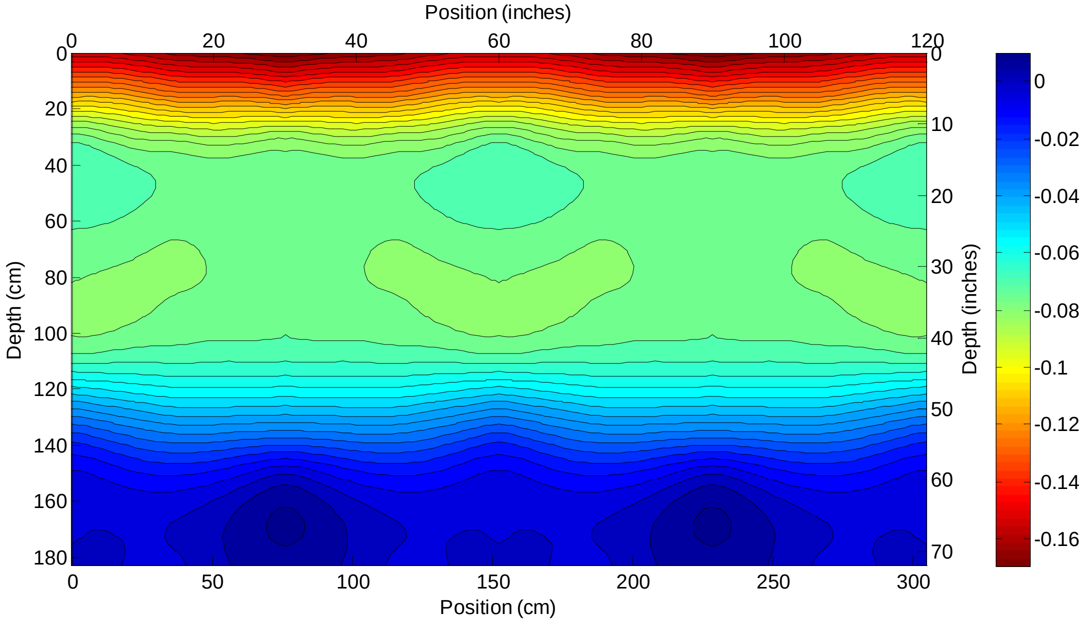

Figure A.139 - 2010 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

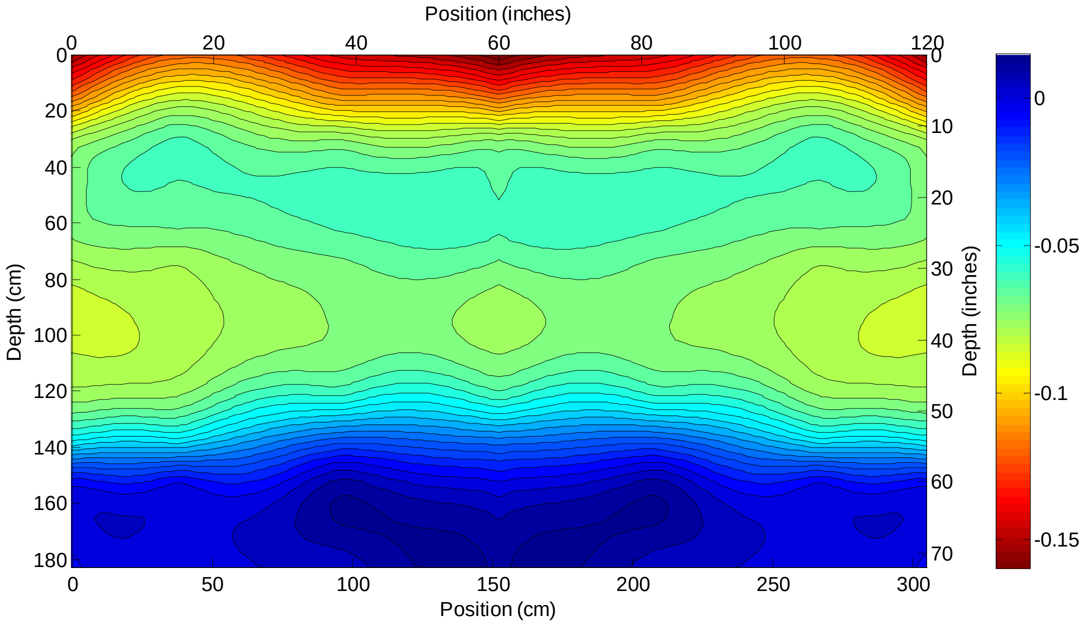

Figure A.140 - 2010 Corn planting to harvest change in soil water content, drawn with contour step = 0.005 cm3 cm-3, P2S2 geometry.

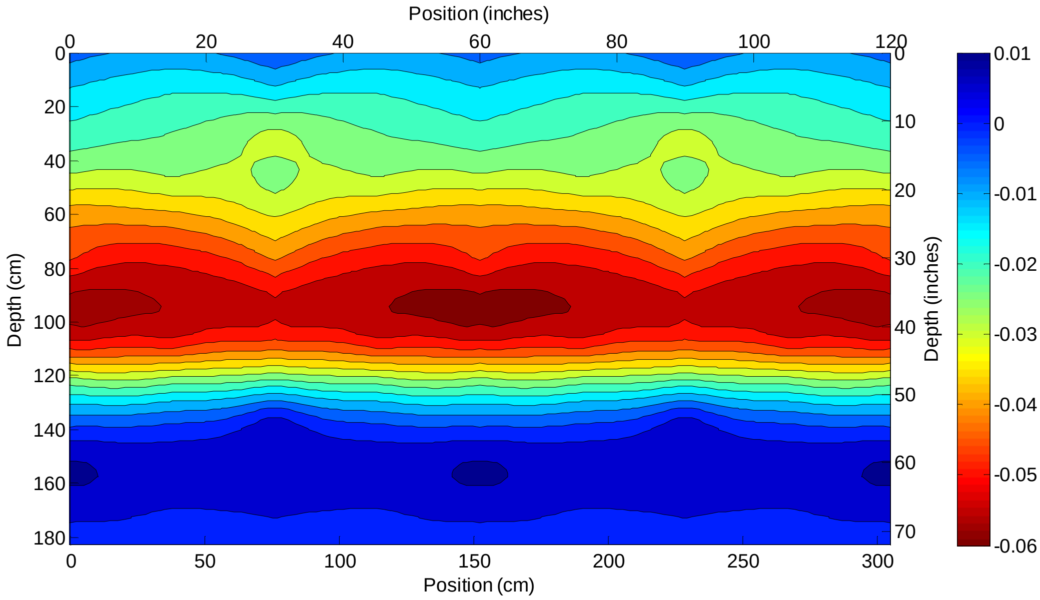

Figure A.141 - 2010 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm3 cm-3, clump geometry

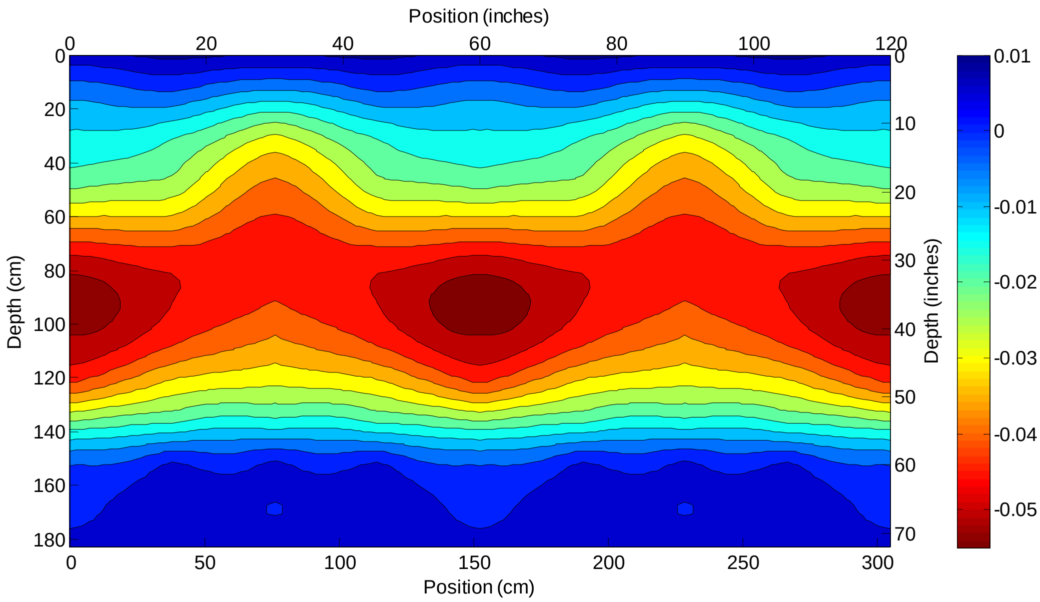

Figure A.142 - 2010 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm3 cm-3, cluster geometry.

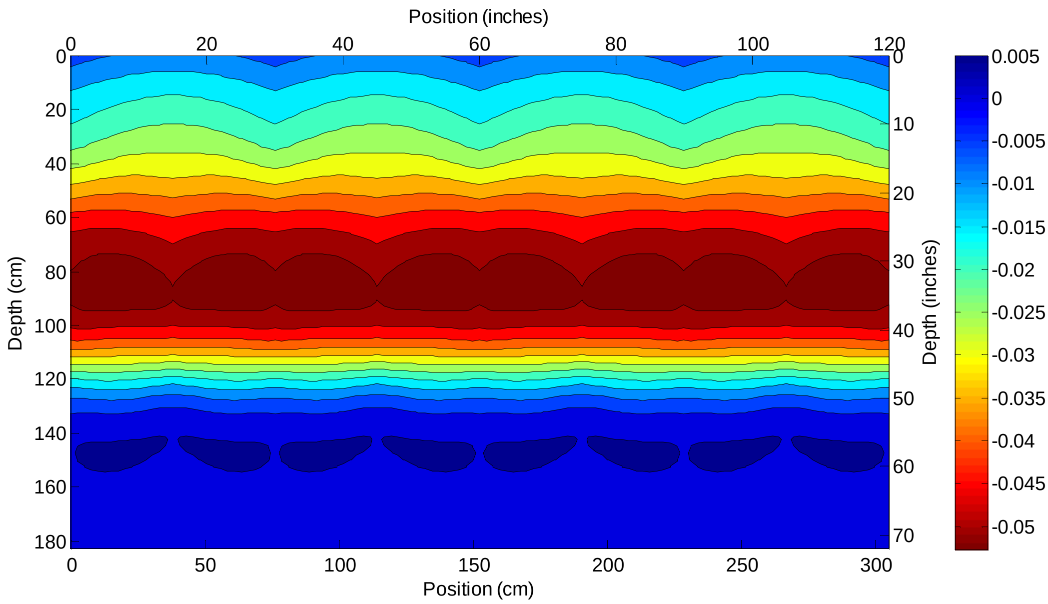

Figure A.143 - 2010 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm3 cm-3, conventional geometry.

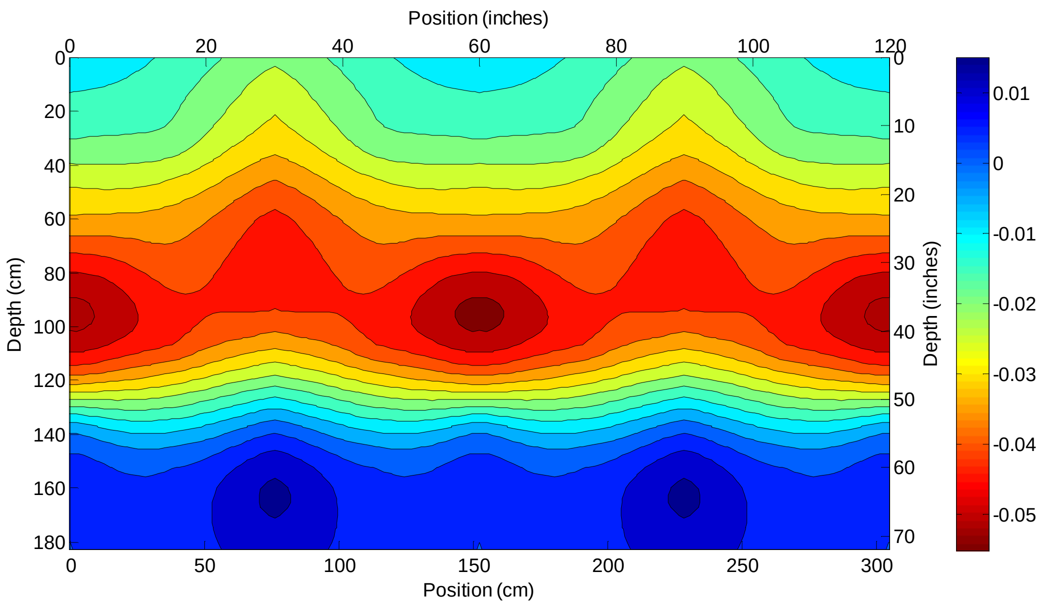

Figure A.144 - 2010 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm3 cm-3, P1S1 geometry.

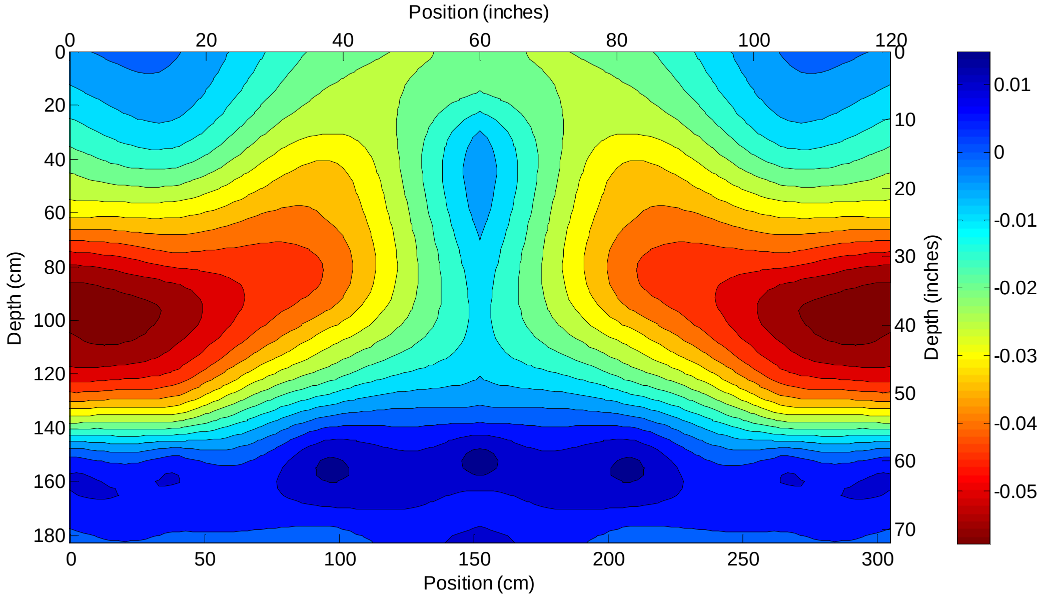

Figure A.145 - 2010 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm3 cm-3, P2S2 geometry.

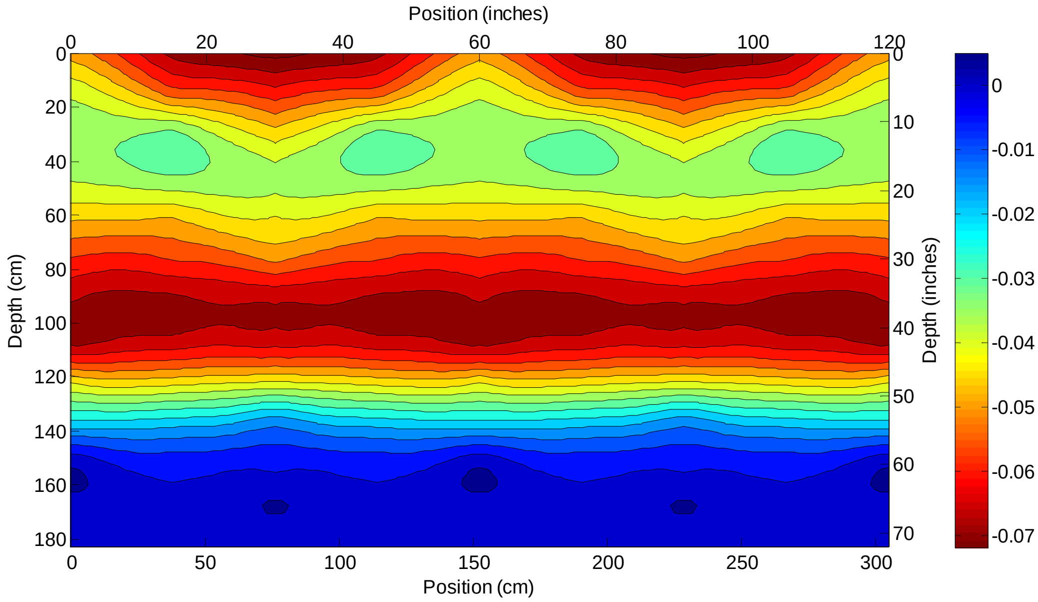

Figure A.146 - 2010 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm3 cm-3, clump geometry.

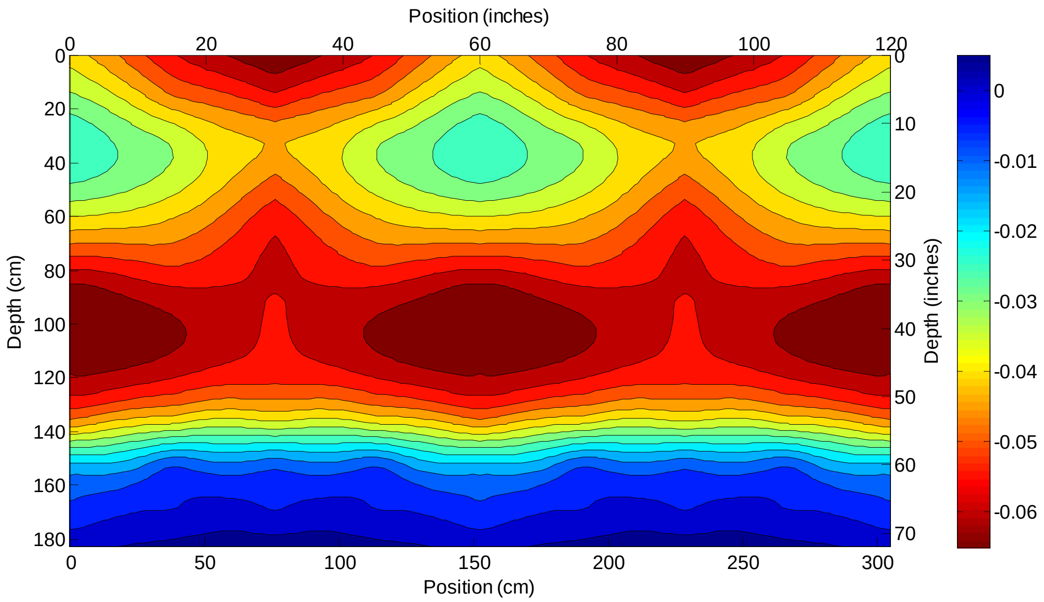

Figure A.147 - 2010 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm3 cm-3, cluster geometry.

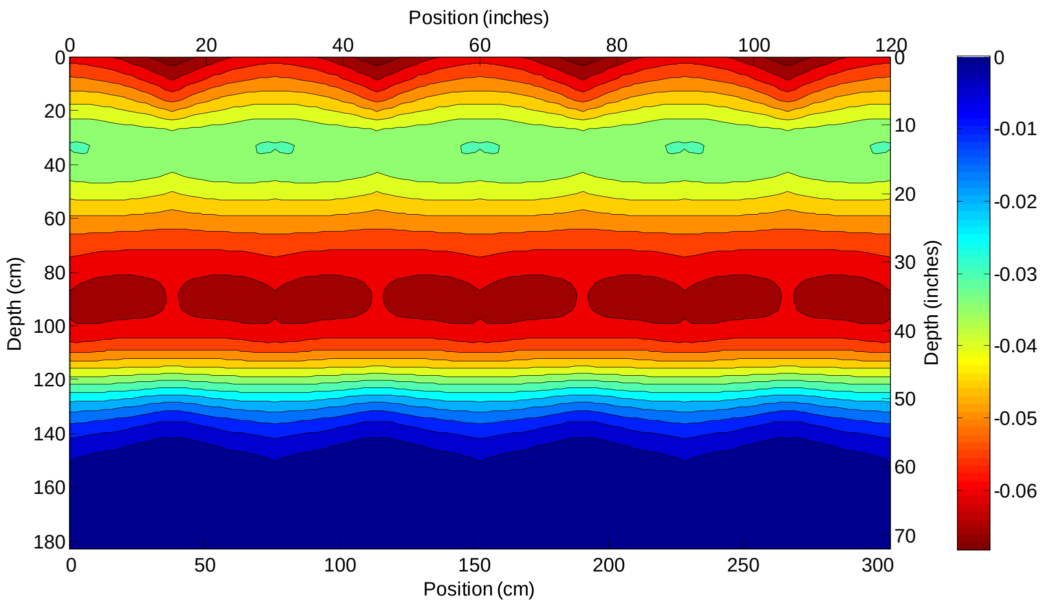

Figure A.148 - 2010 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm3 cm-3, conventional geometry.

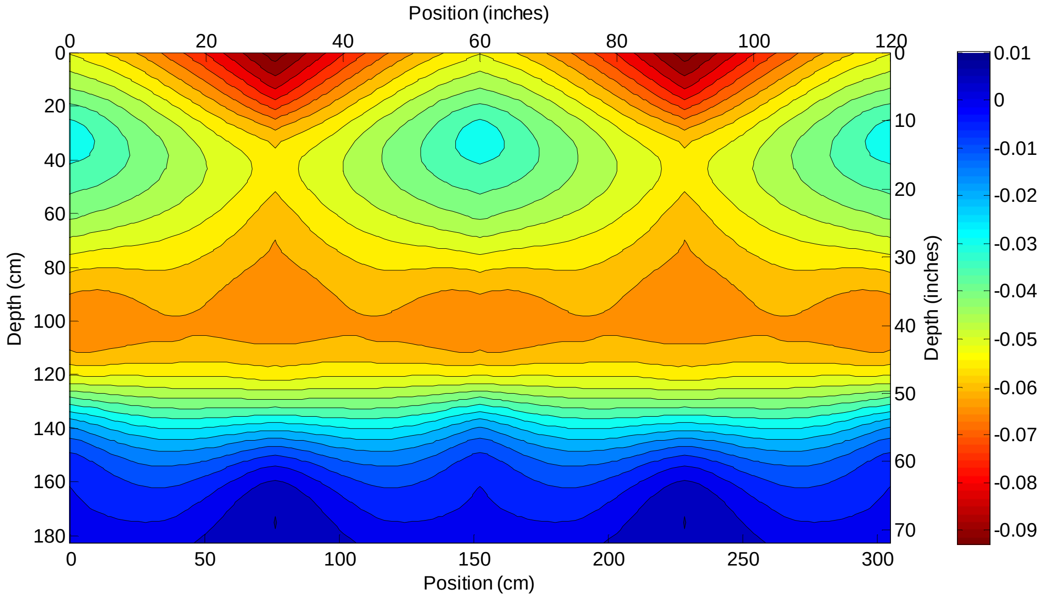

Figure A.149 - 2010 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm3 cm-3, P1S1 geometry.

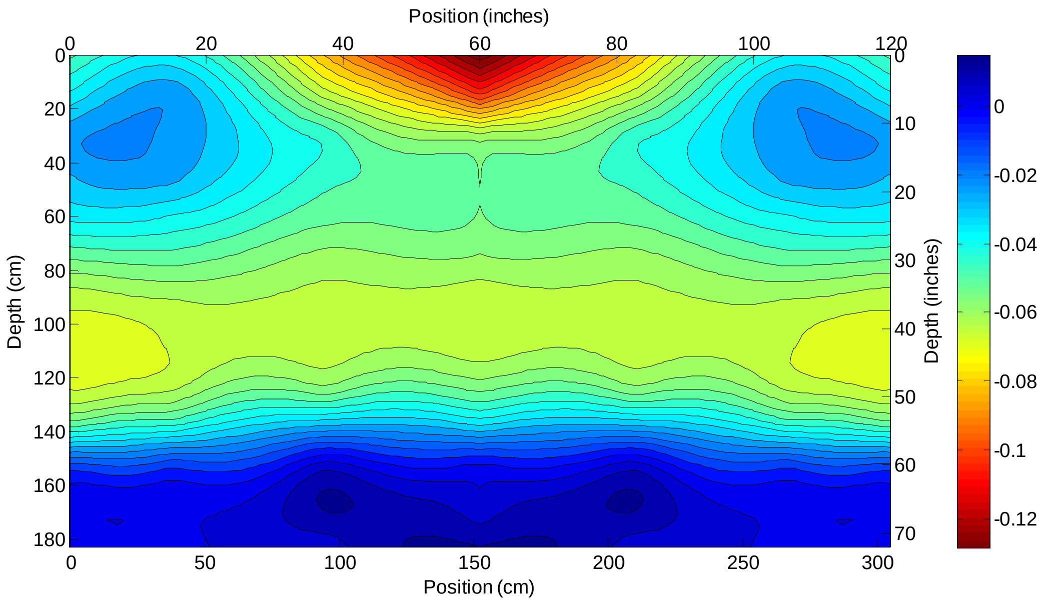

Figure A.150 - 2010 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm3 cm-3, P2S2 geometry.

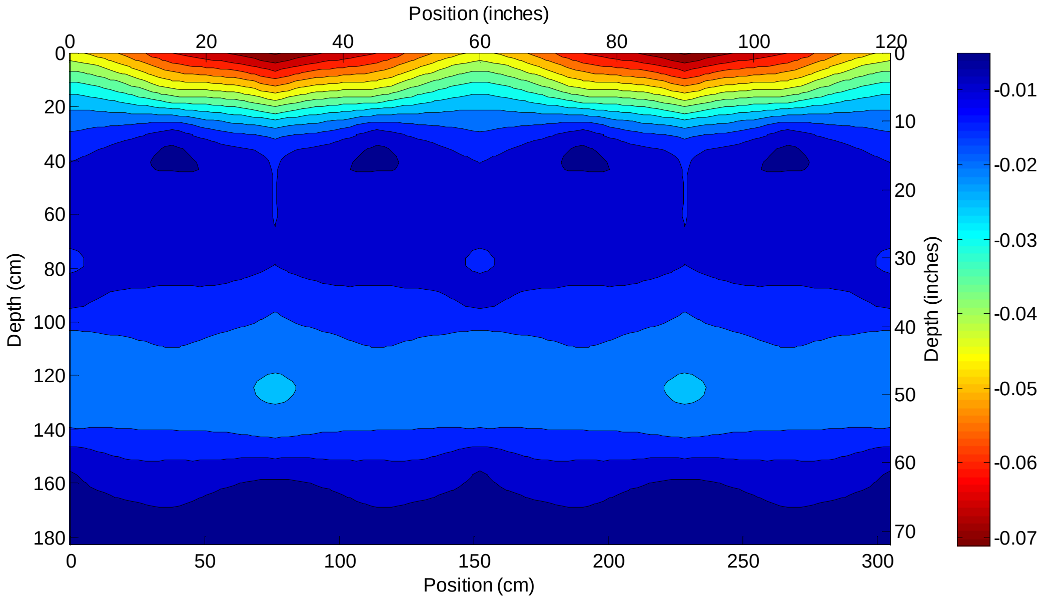

Figure A.151 - 2010 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

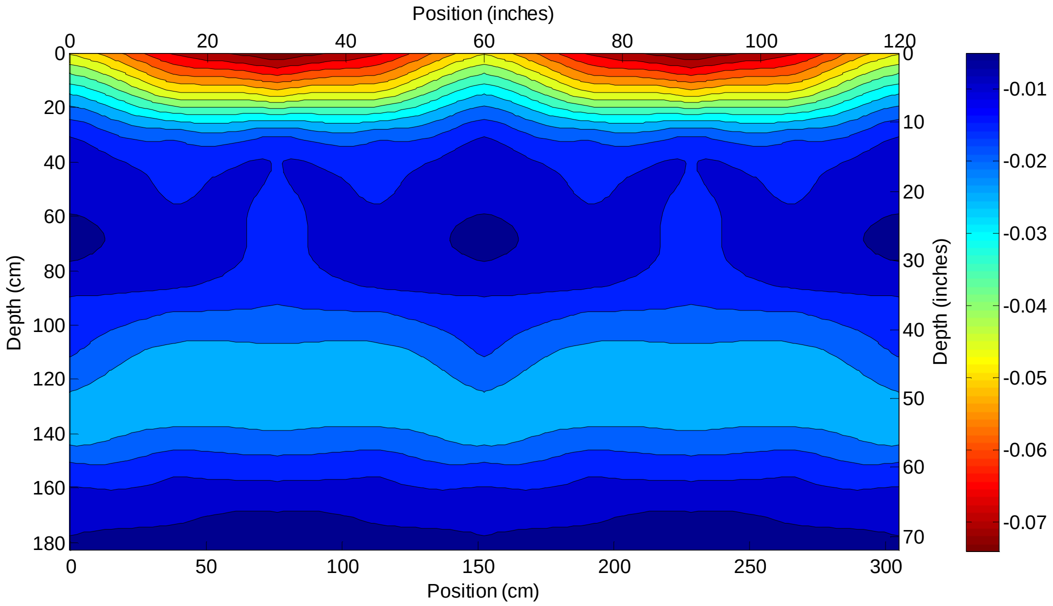

Figure A.152 - 2010 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

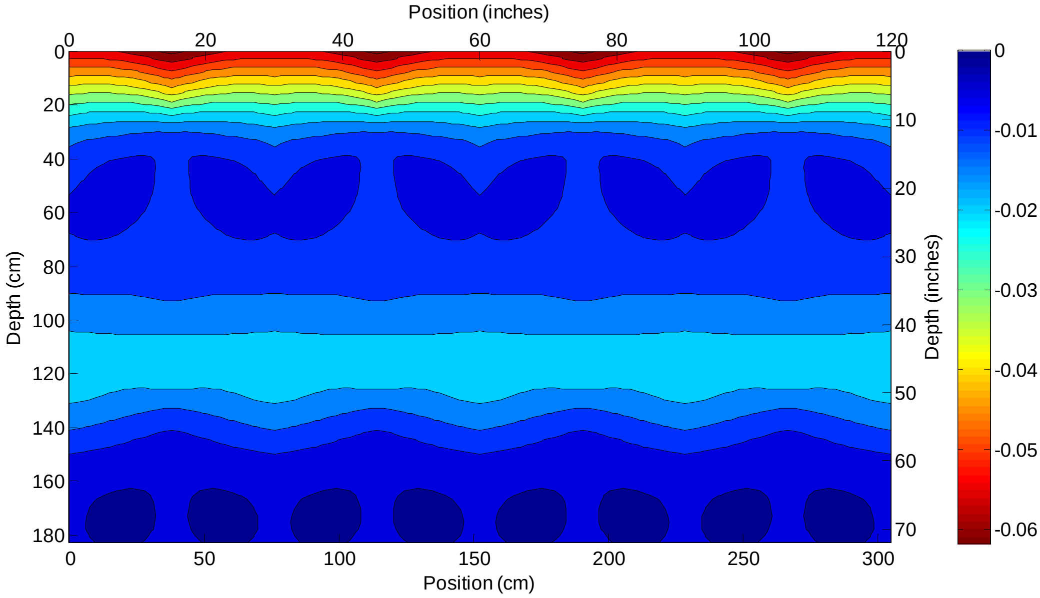

Figure A.153 - 2010 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

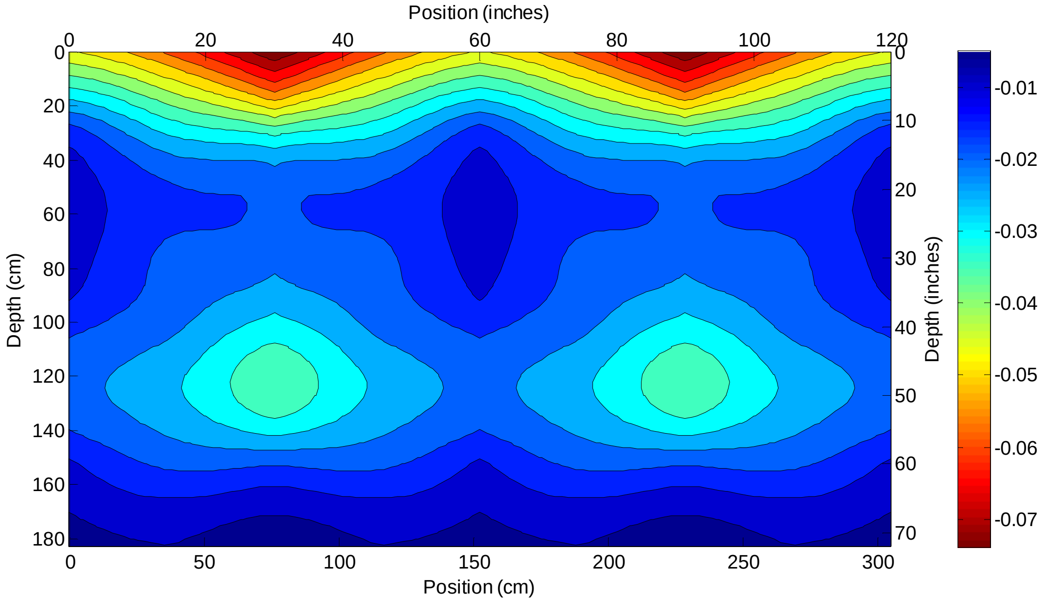

Figure A.154 - 2010 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

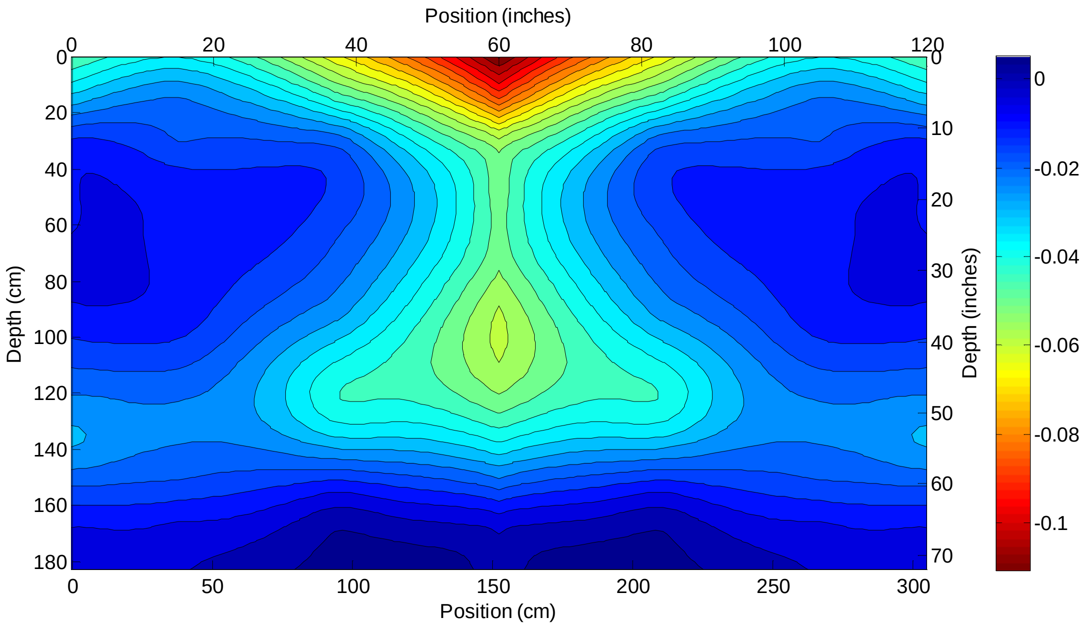

Figure A.155 - 2010 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, P2S2 geometry.

2011 Interpolated soil water content

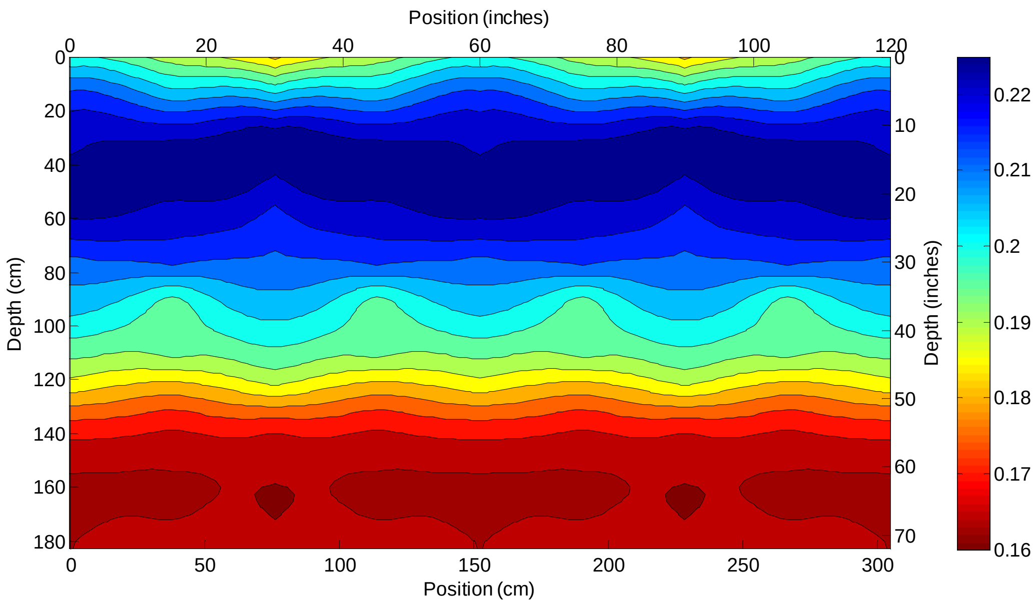

Figure A.156 - 2011 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, clump geometry.

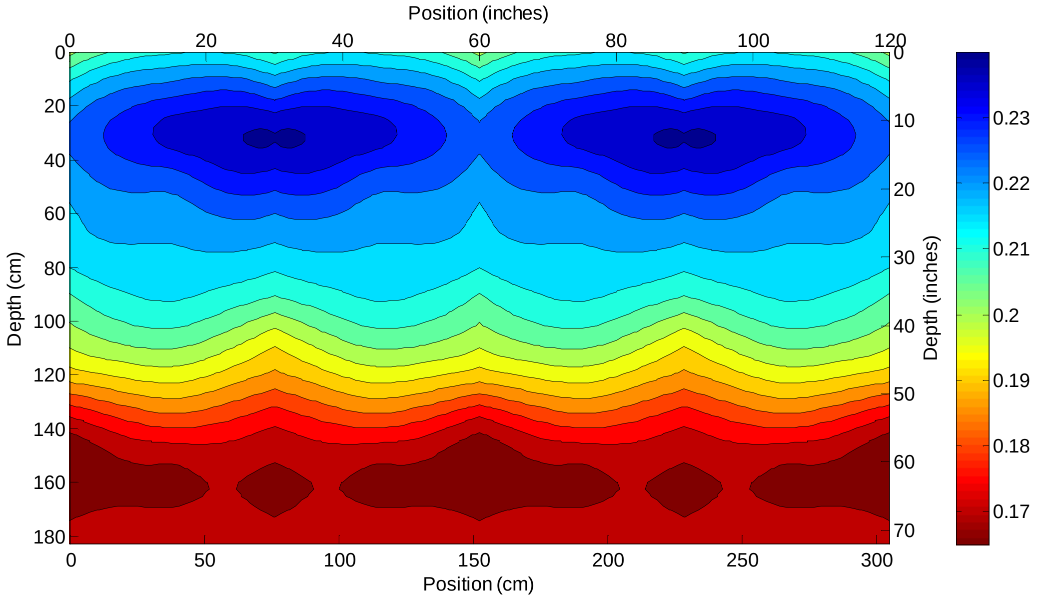

Figure A.157 - 2011 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

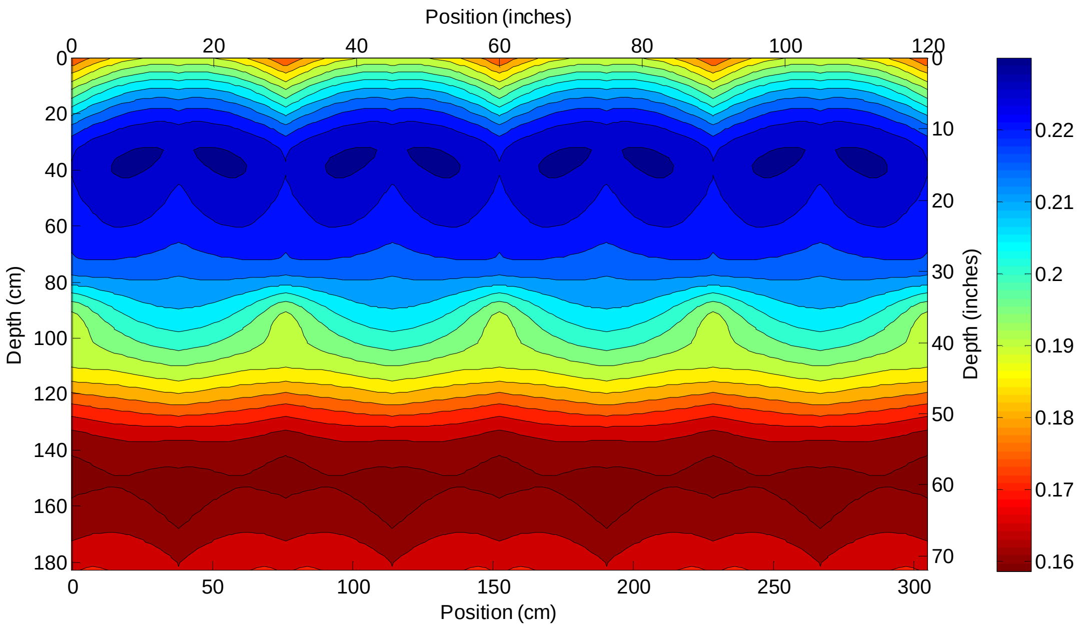

Figure A.158 - 2011 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

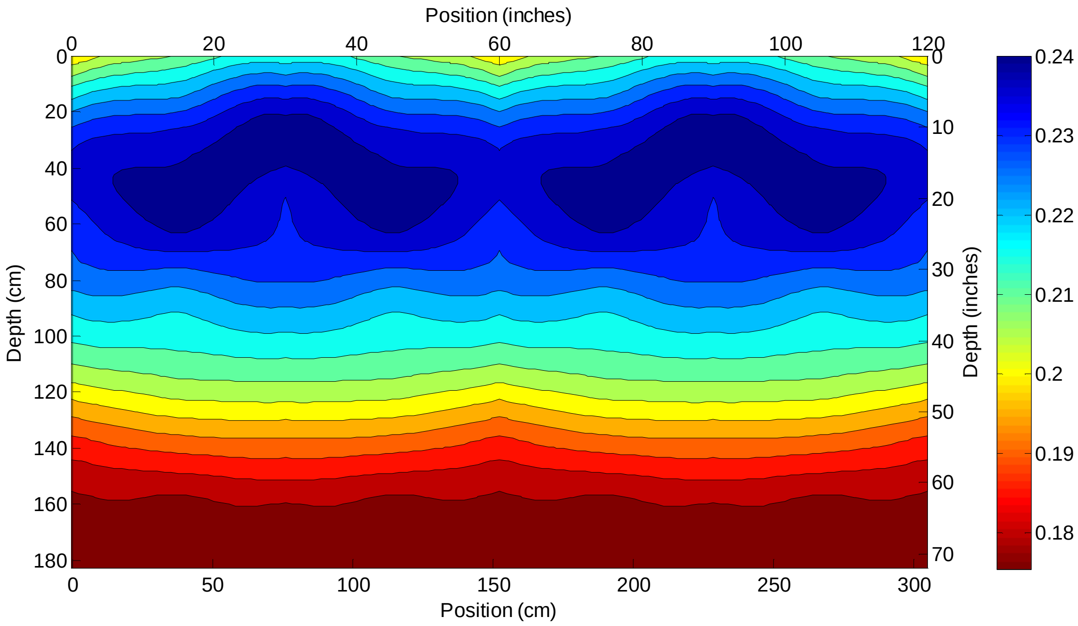

Figure A.159 - 2011 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

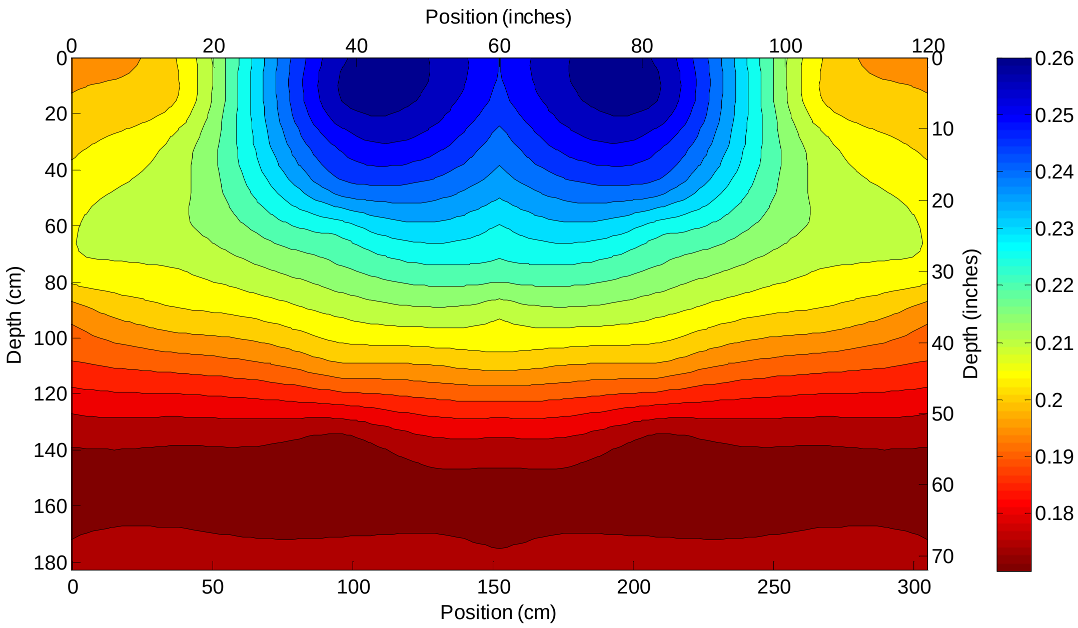

Figure A.160 - 2011 Corn early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

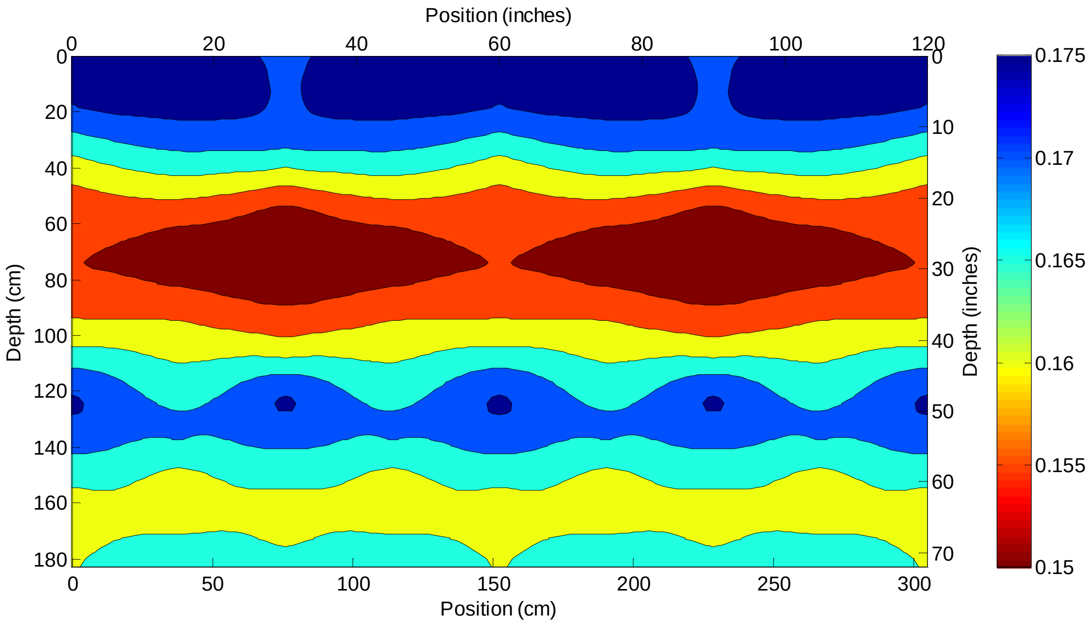

Figure A.161 - 2011 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

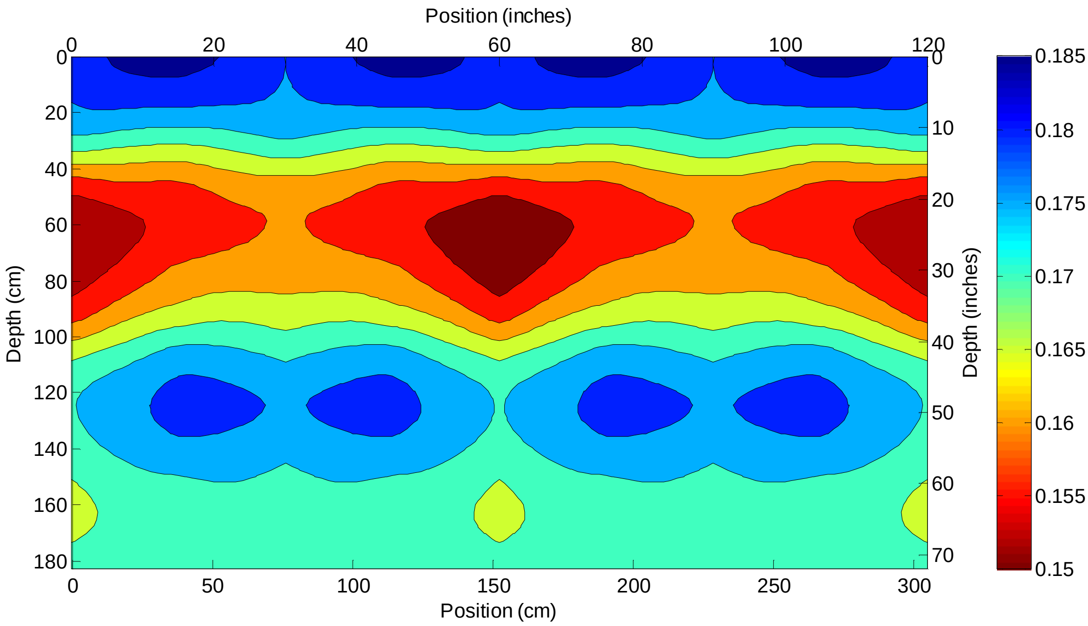

Figure A.162 - 2011 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

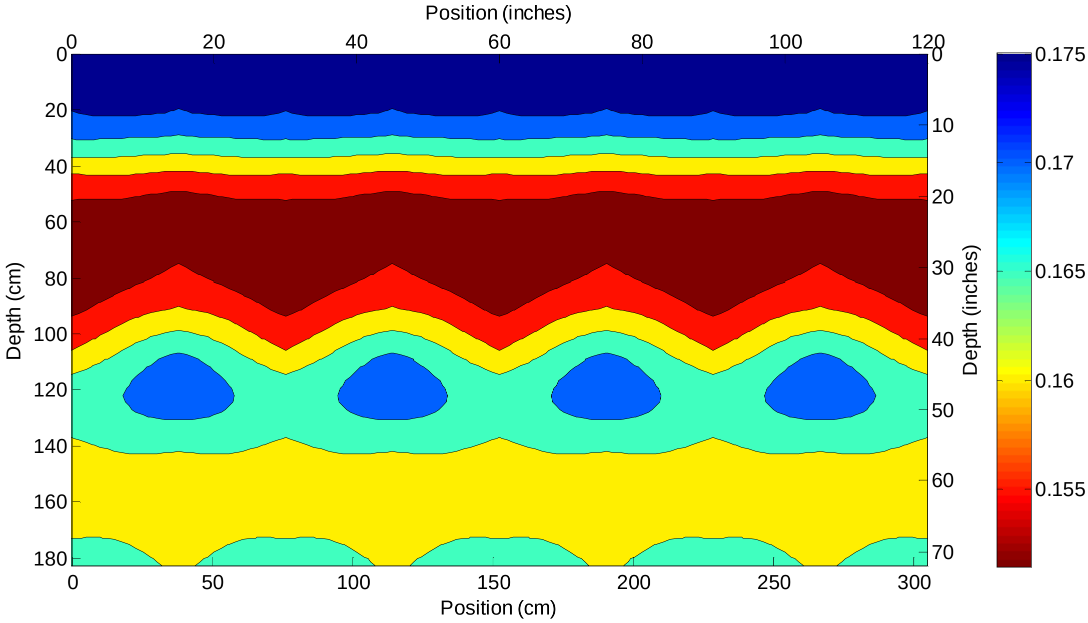

Figure A.163 - 2011 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

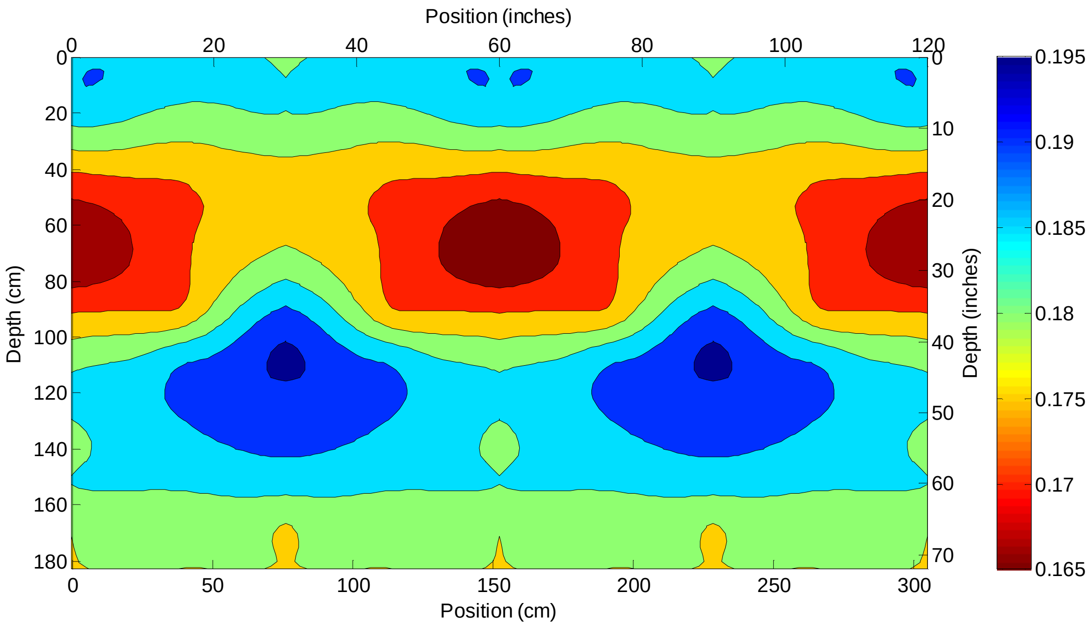

Figure A.164 - 2011 Corn tassel-silk soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

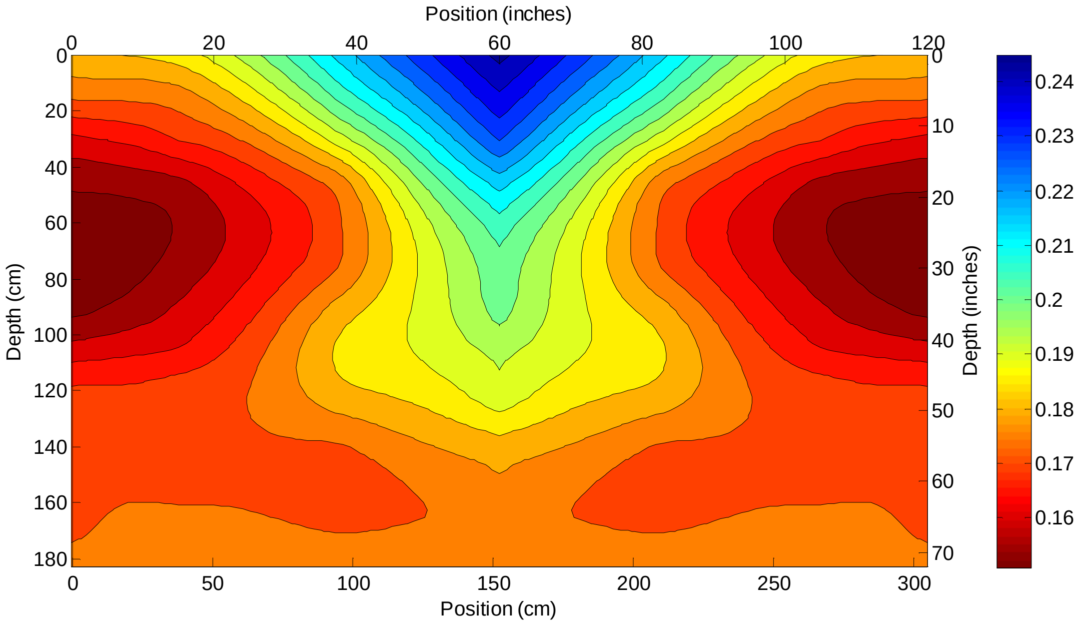

Figure A.165 - 2011 Corn tassel-silk soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

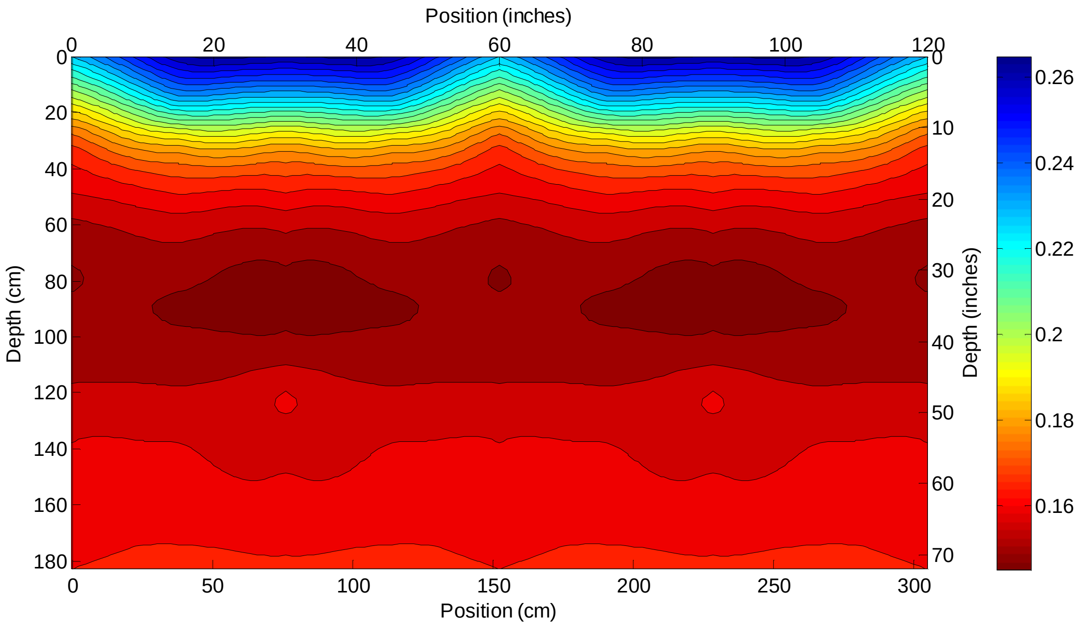

Figure A.166 - 2011 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

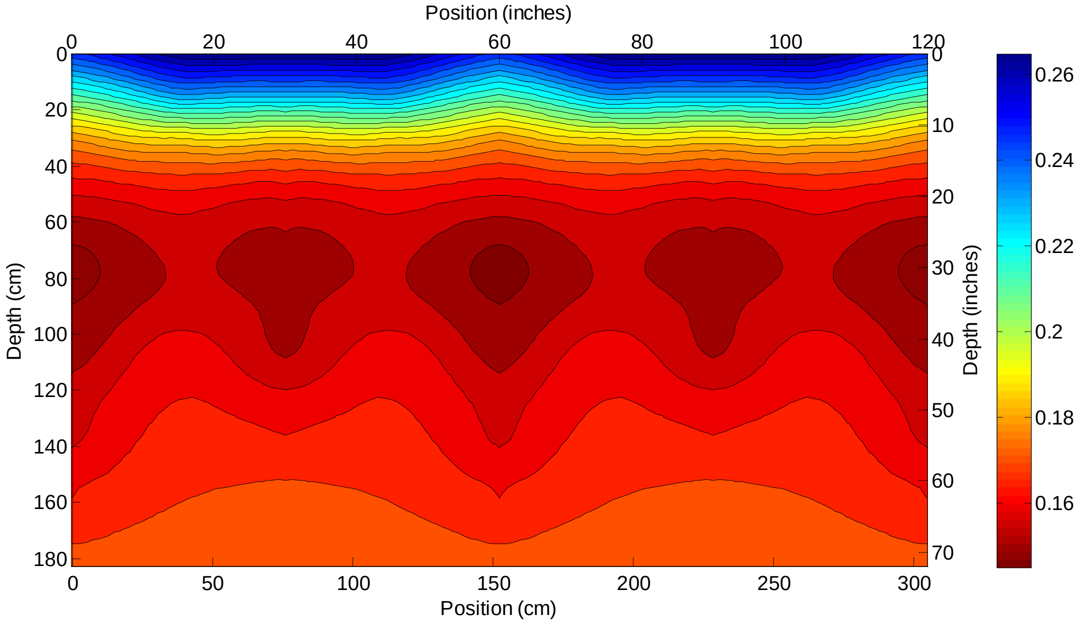

Figure A.167 - 2011 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

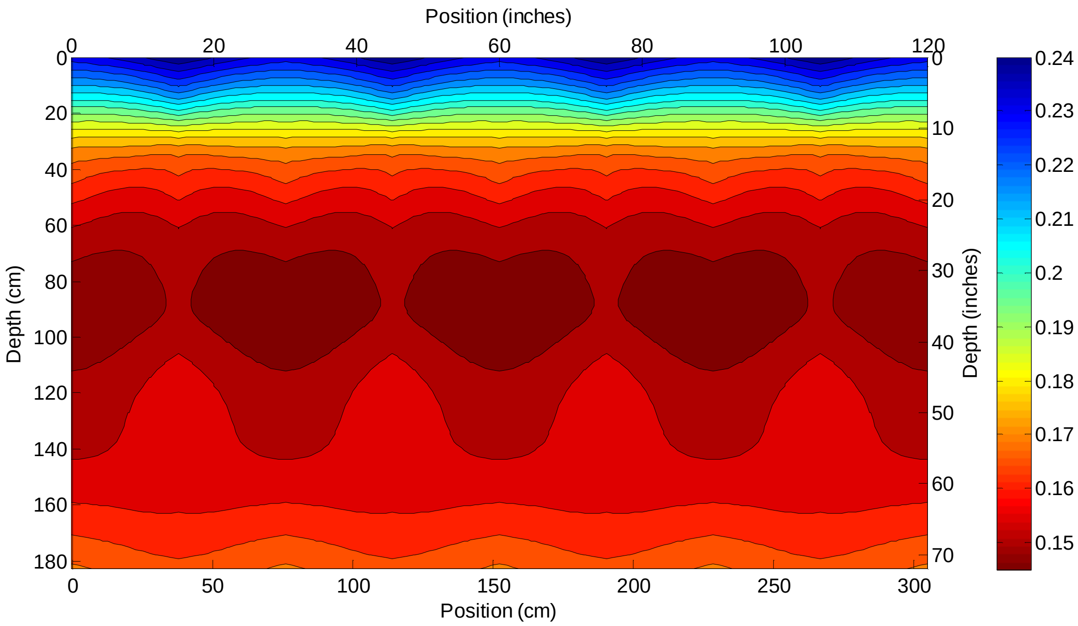

Figure A.168 - 2011 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

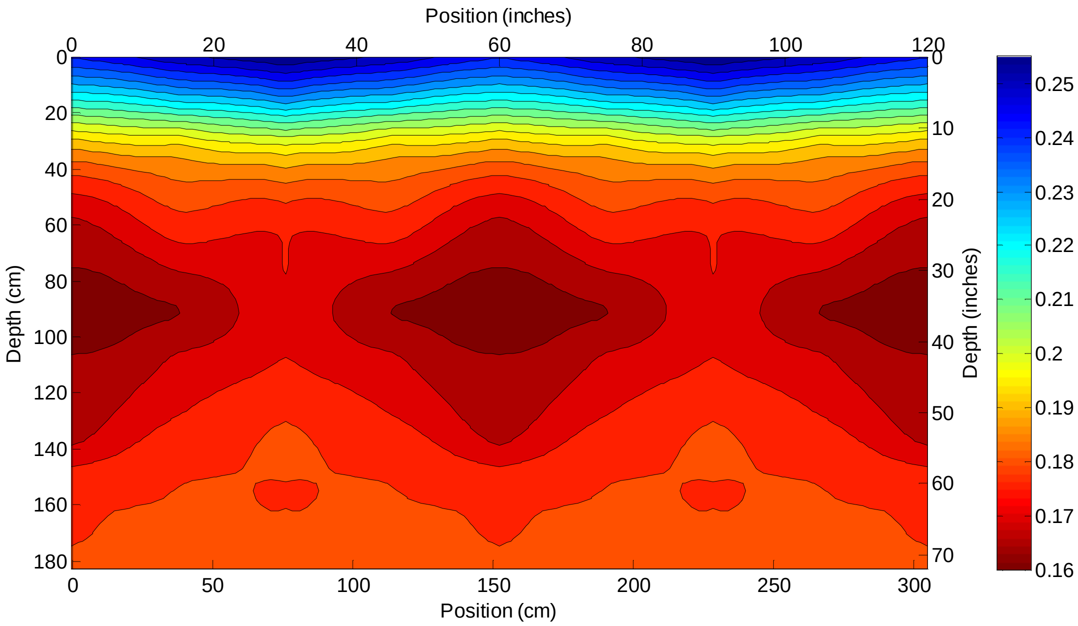

Figure A.169 - 2011 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

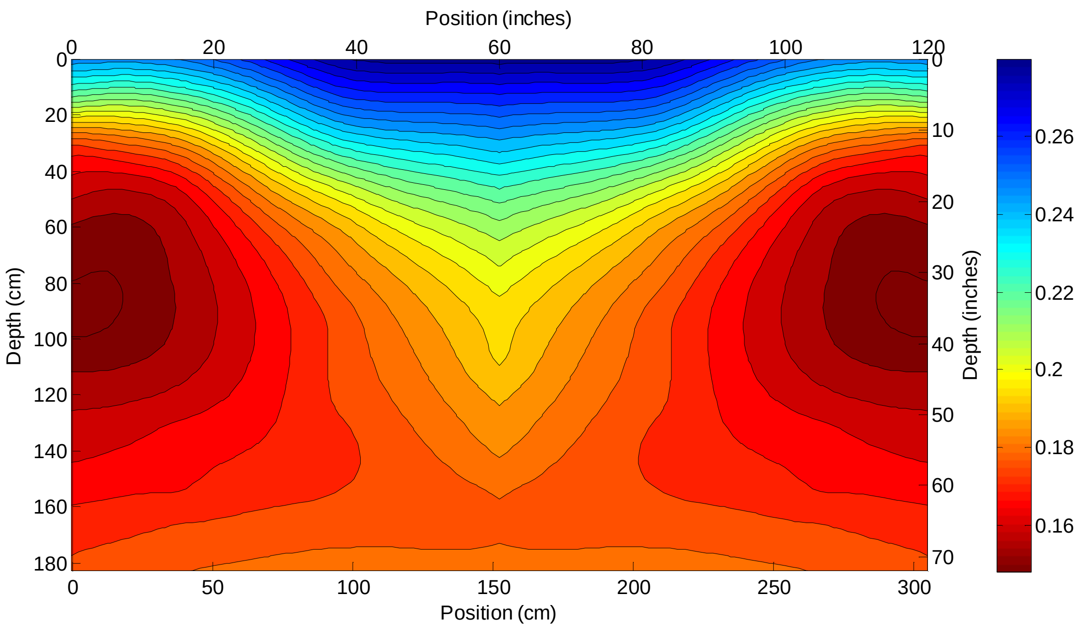

Figure A.170 - 2011 Corn grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

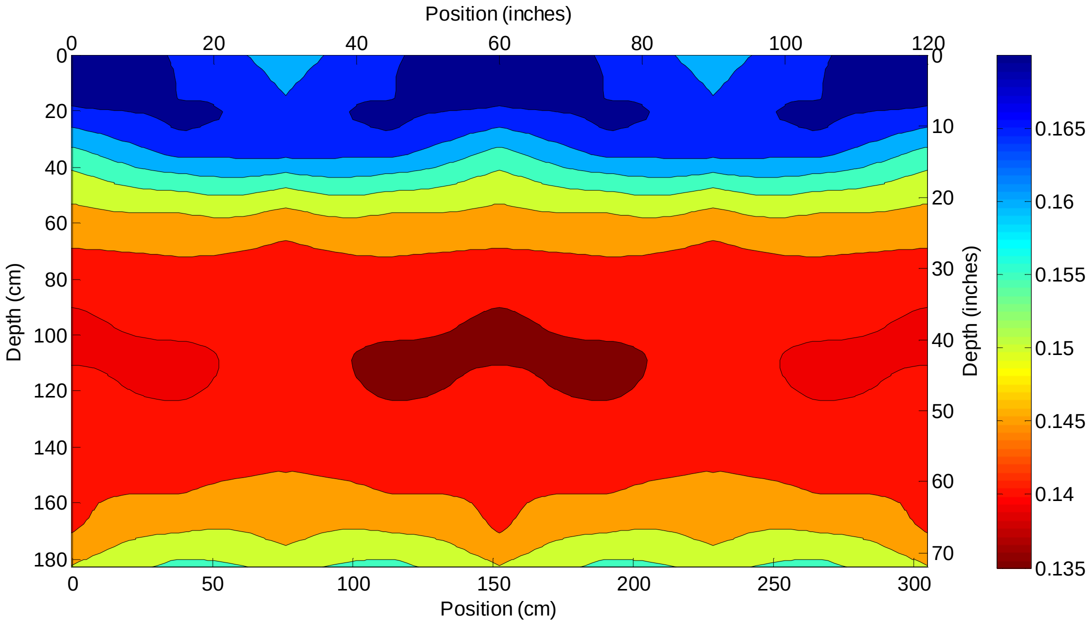

Figure A.171 - 2011 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

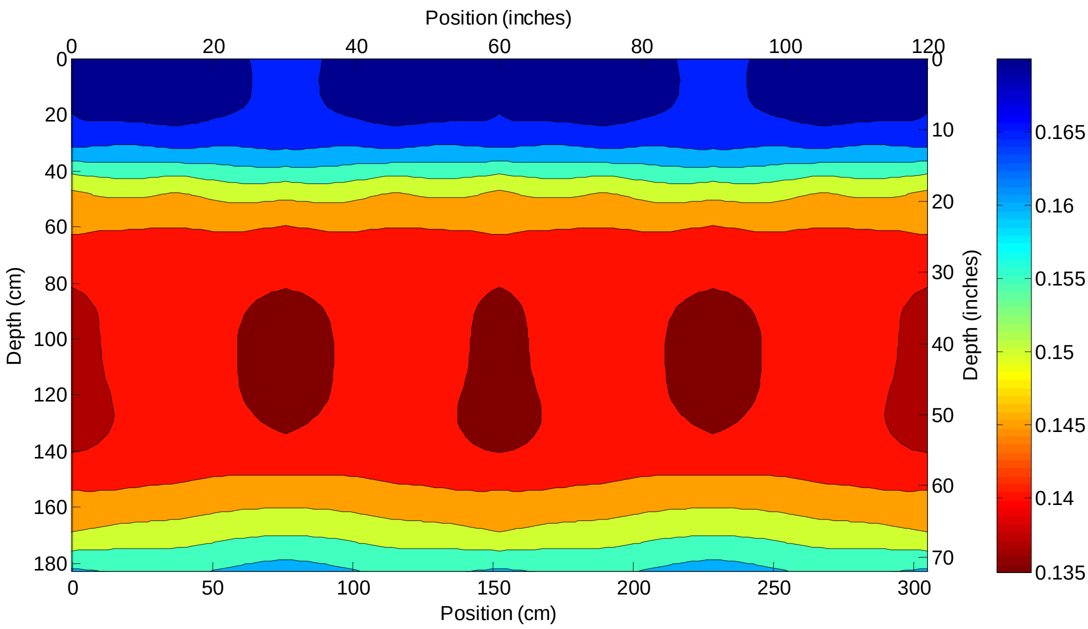

Figure A.172 - 2011 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

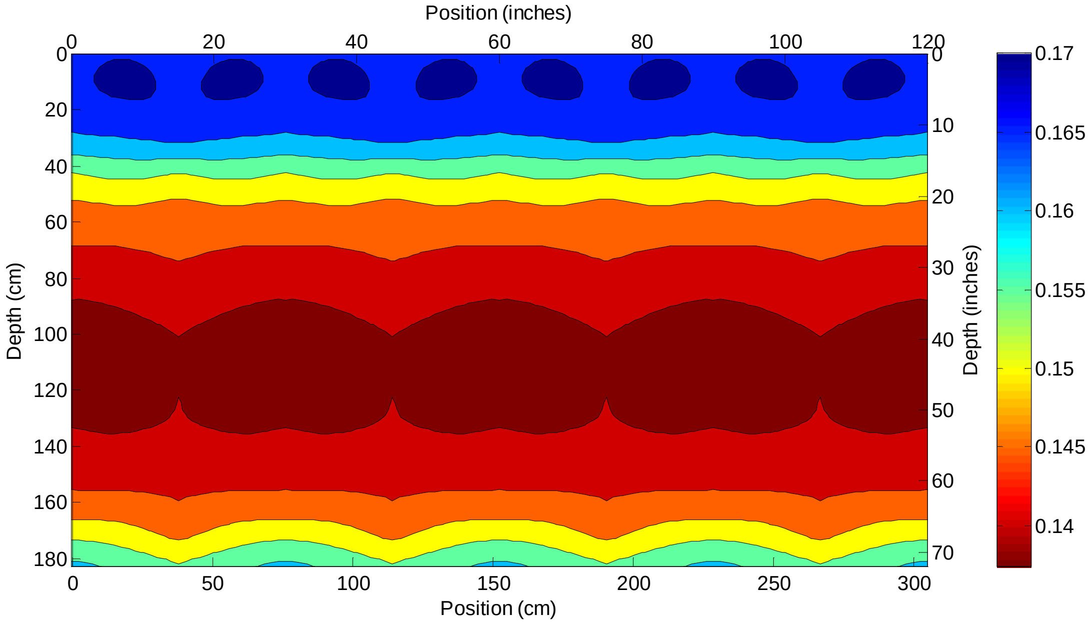

Figure A.173 - 2011 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

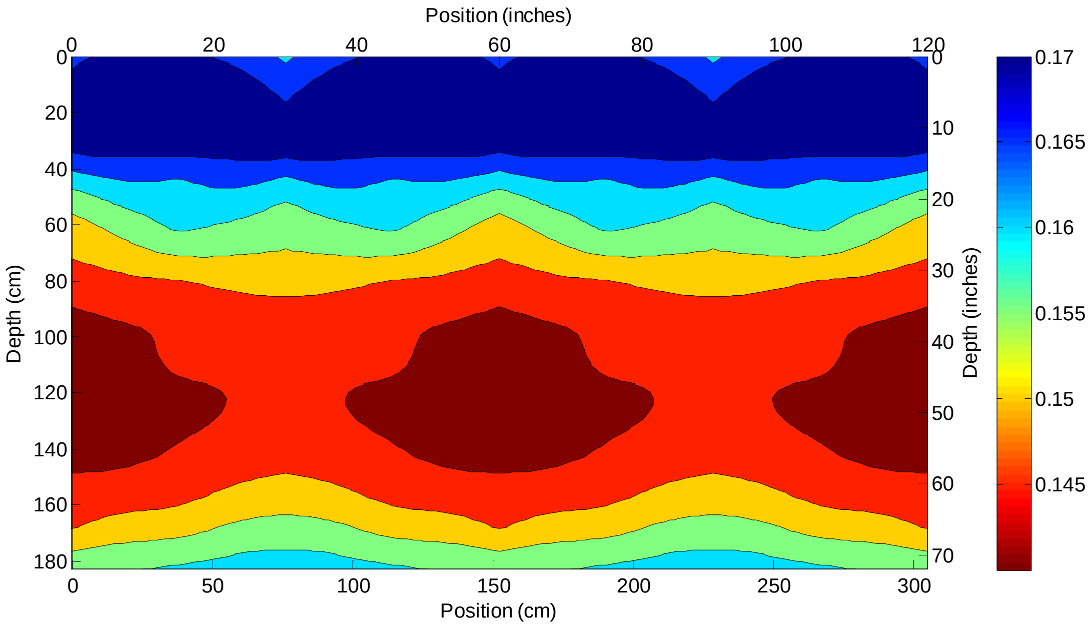

Figure A.174 - 2011 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

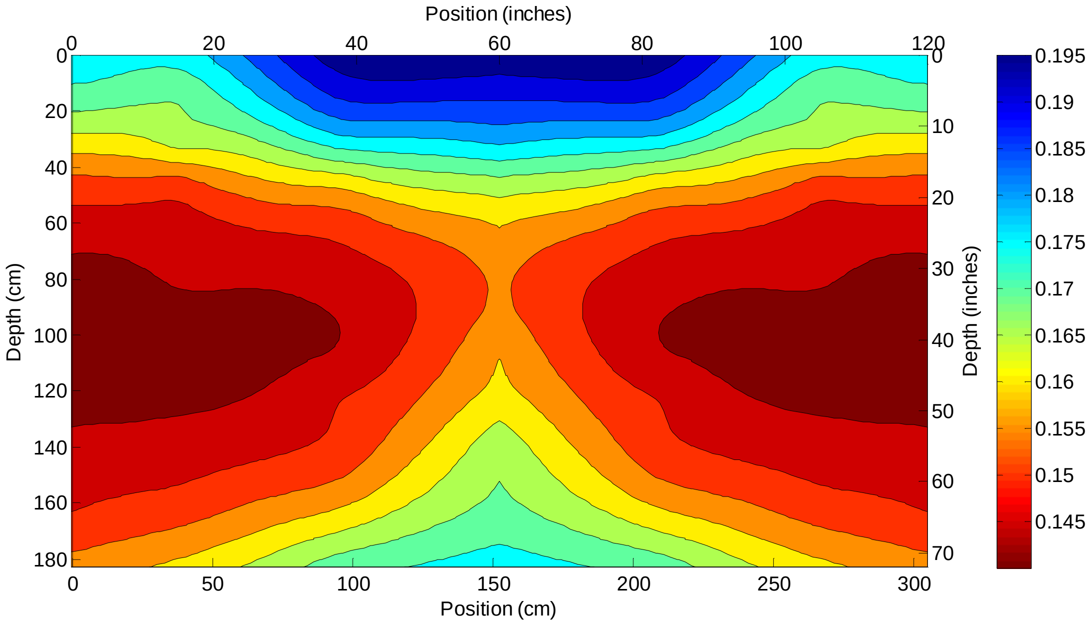

Figure A.175 - 2011 Corn harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

2011 Changes in soil water content

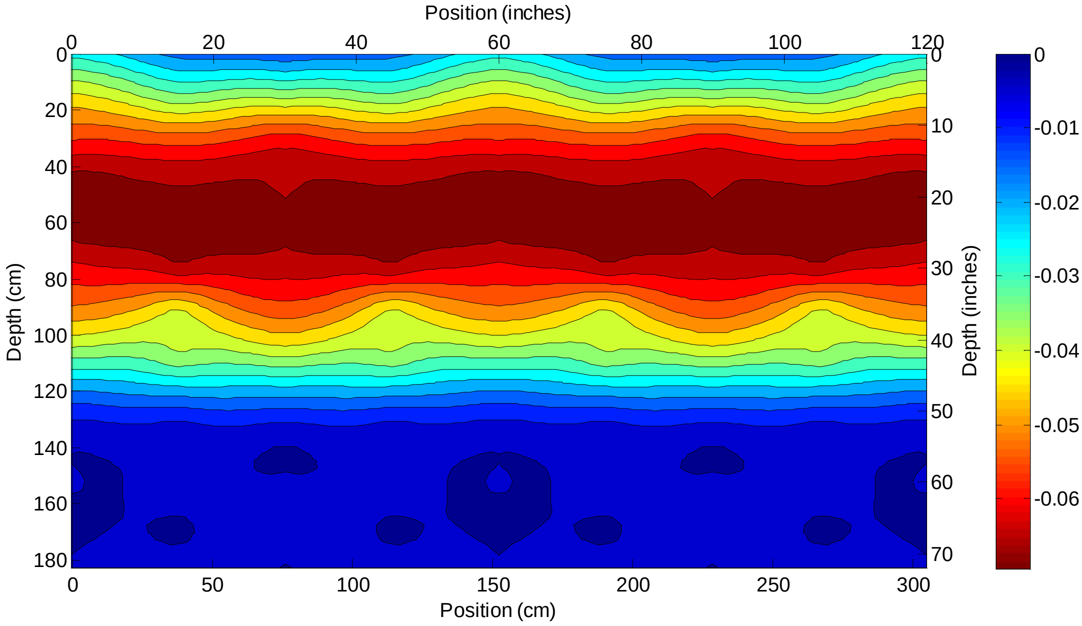

Figure A.176 - 2011 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

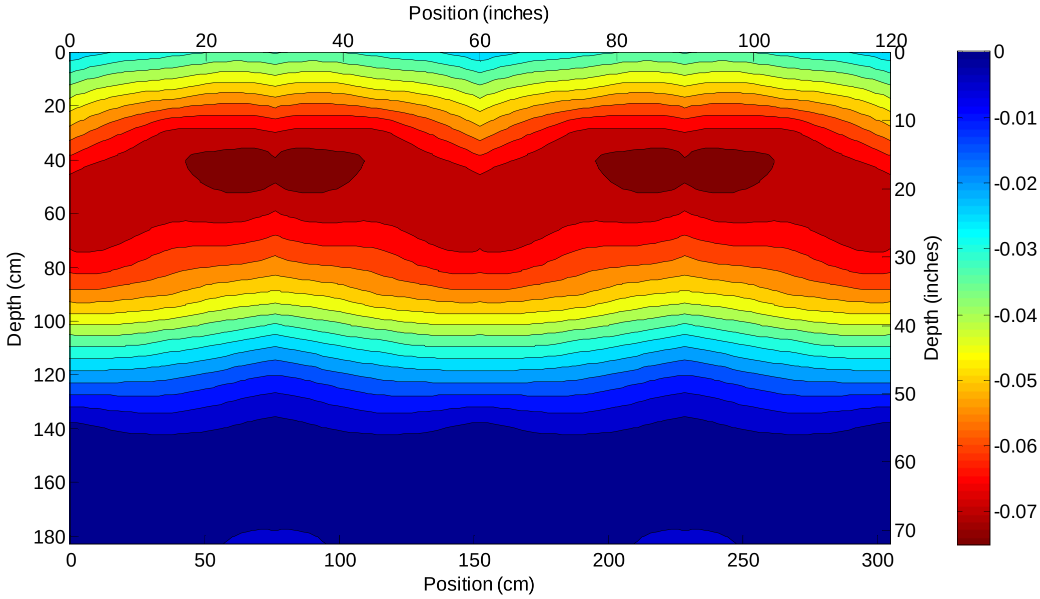

Figure A.177 - 2011 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

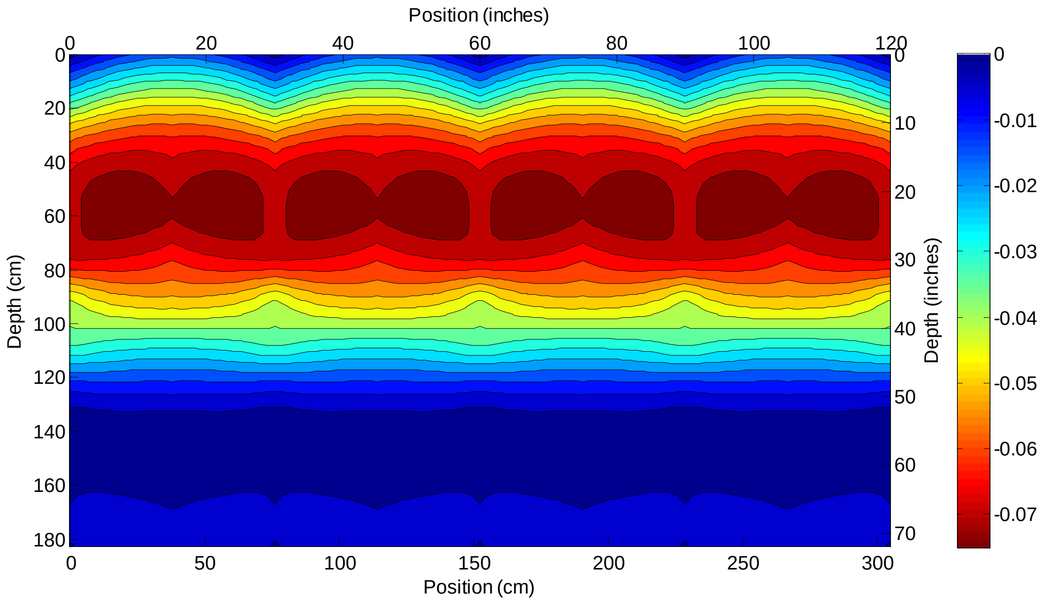

Figure A.178 - 2011 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

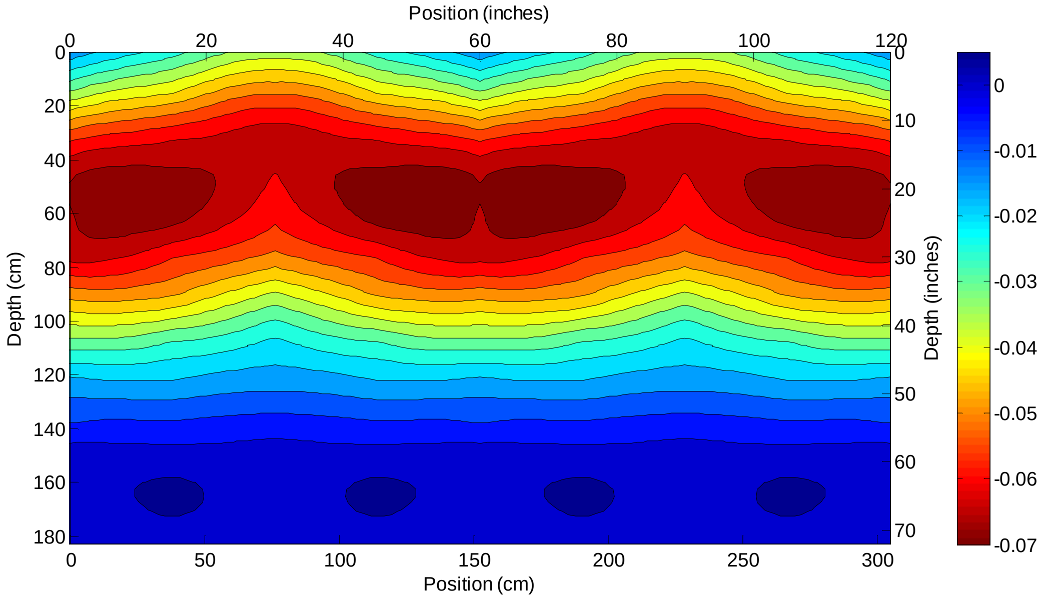

Figure A.179 - 2011 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

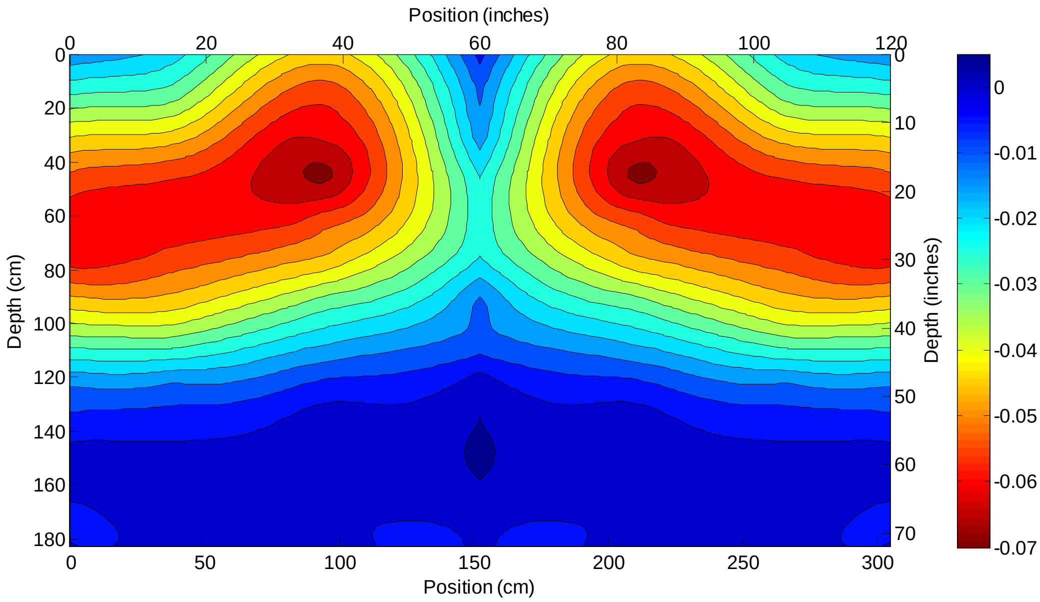

Figure A.180 - 2011 Corn early vegetative to tassel-silk change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

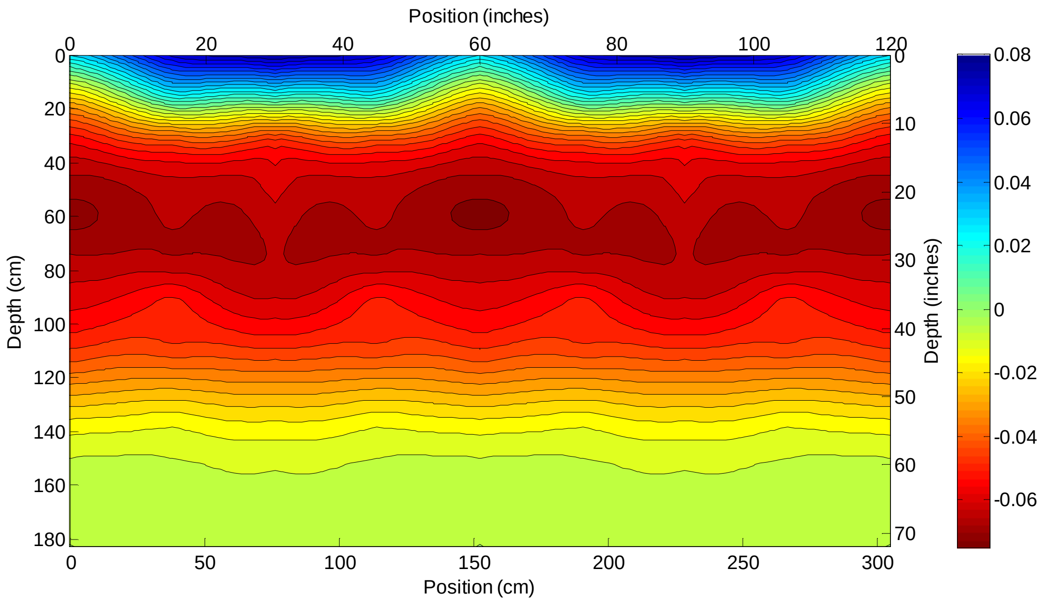

Figure A.181 - 2011 Corn early vegetative to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

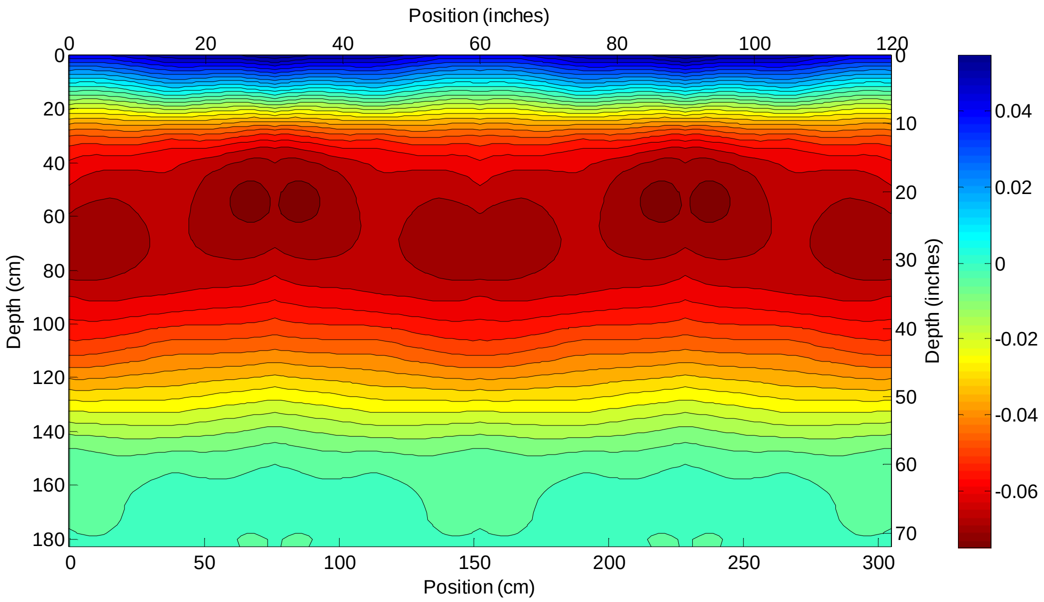

Figure A.182 - 2011 Corn early vegetative to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

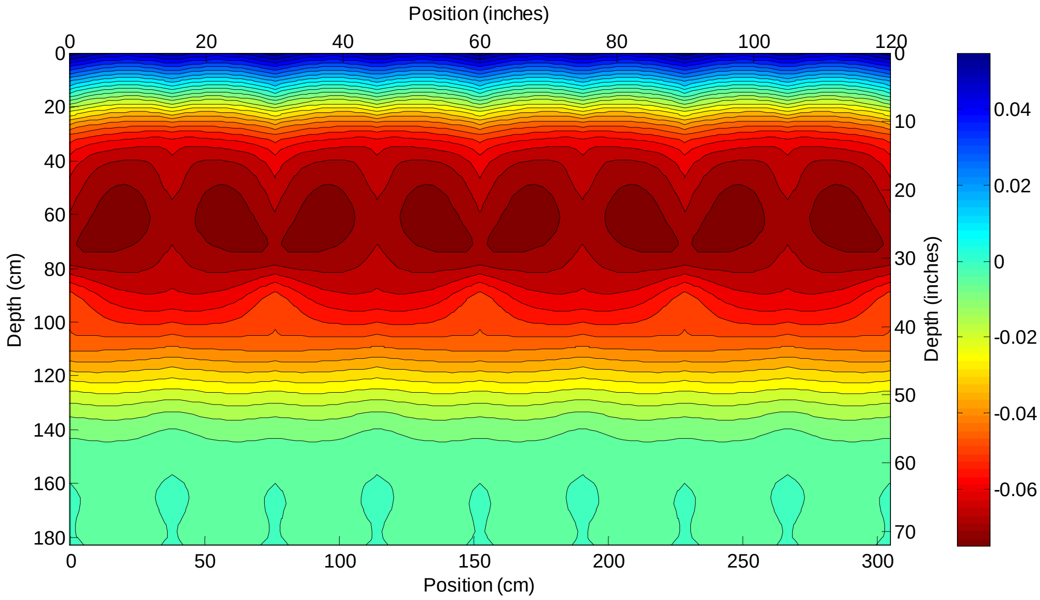

Figure A.183 - 2011 Corn early vegetative to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

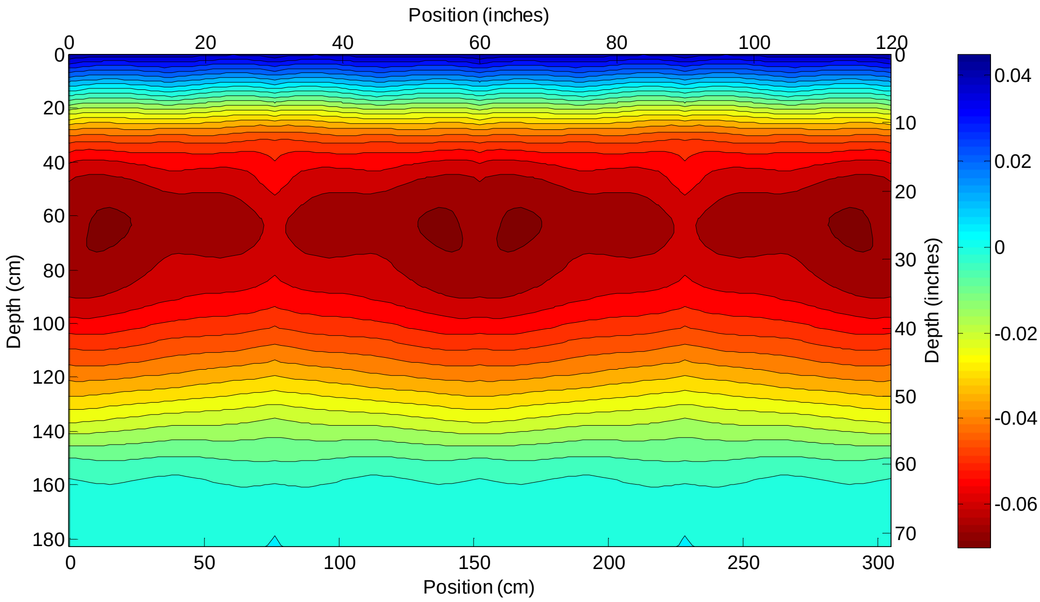

Figure A.184 - 2011 Corn early vegetative to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

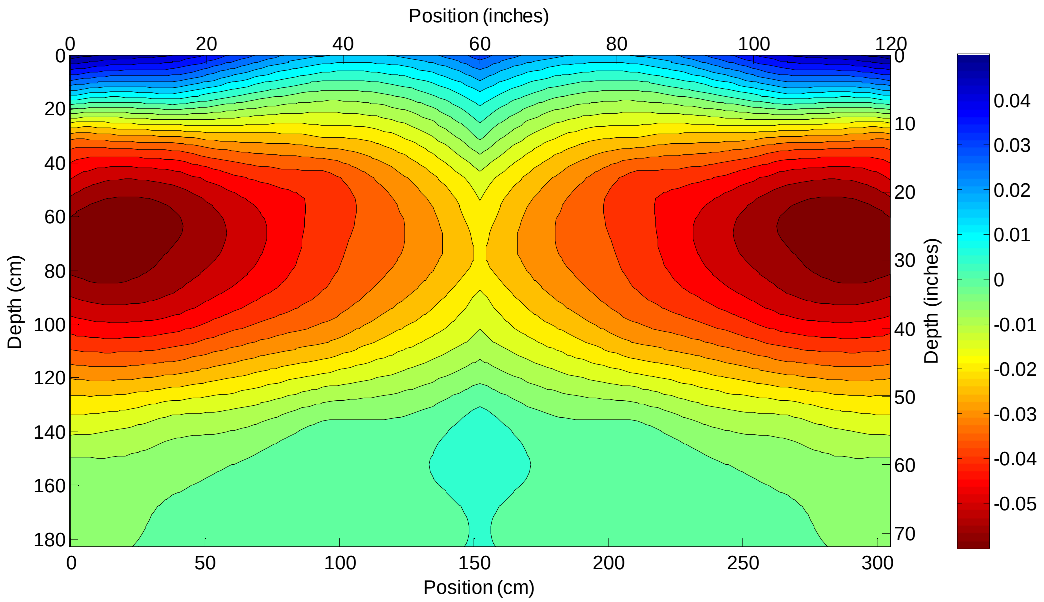

Figure A.185 - 2011 Corn early vegetative to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

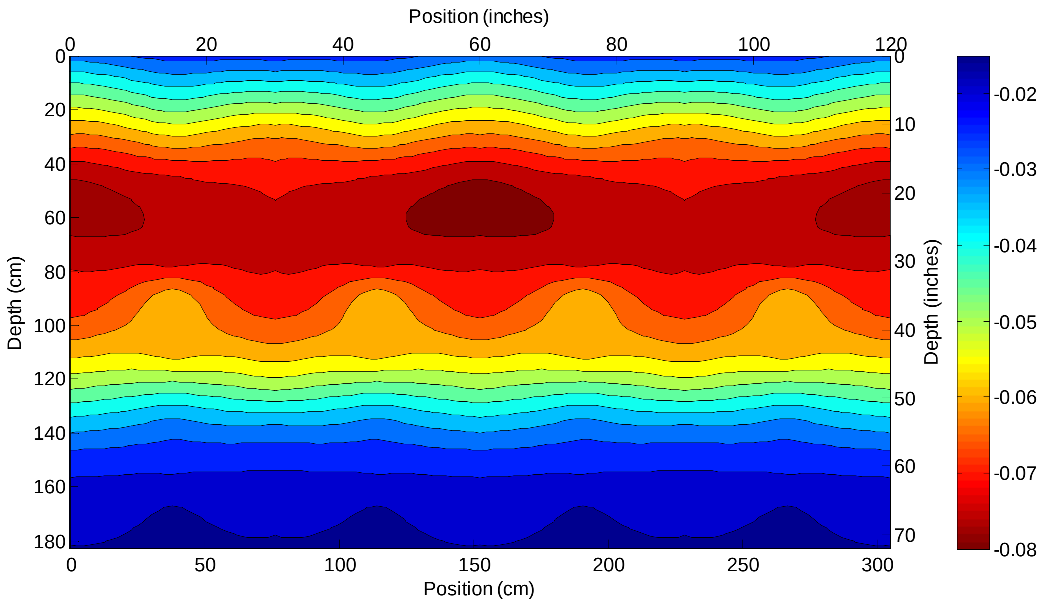

Figure A.186 - 2011 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

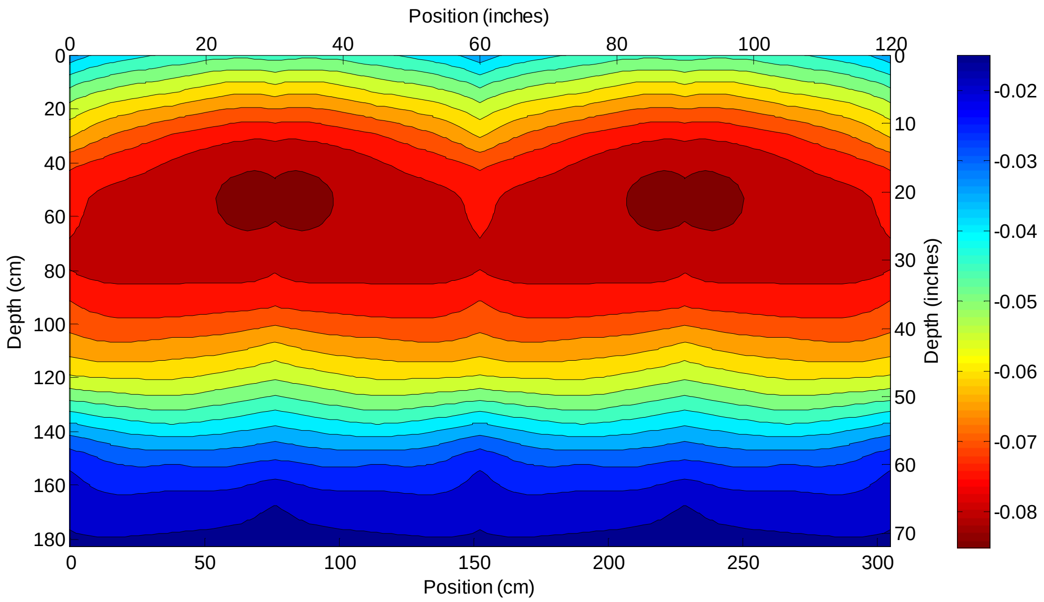

Figure A.187 - 2011 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, cluster geometry.

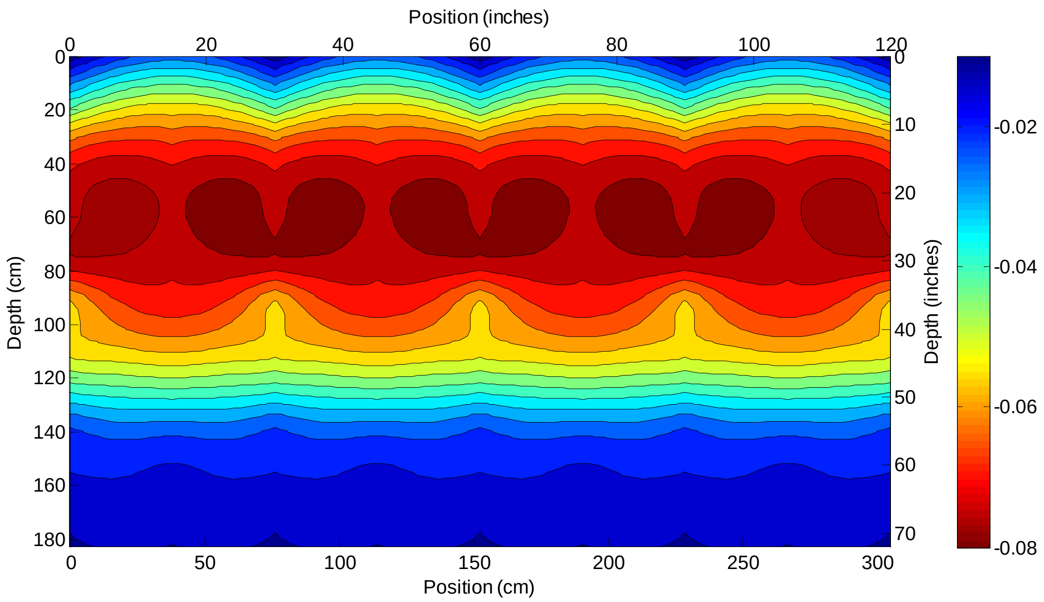

Figure A.188 - 2011 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, conventional geometry.

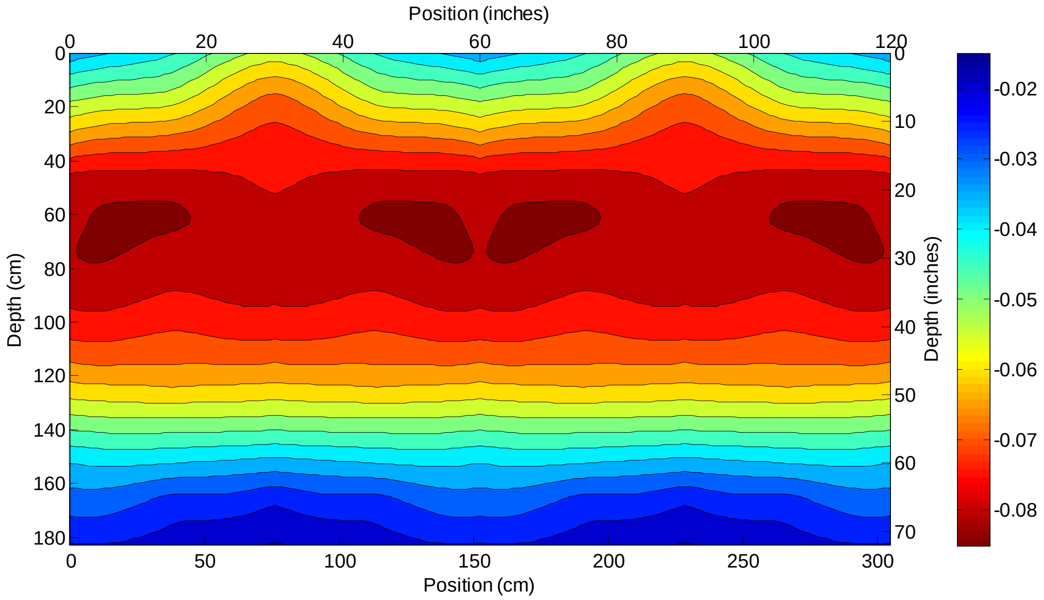

Figure A.189 - 2011 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

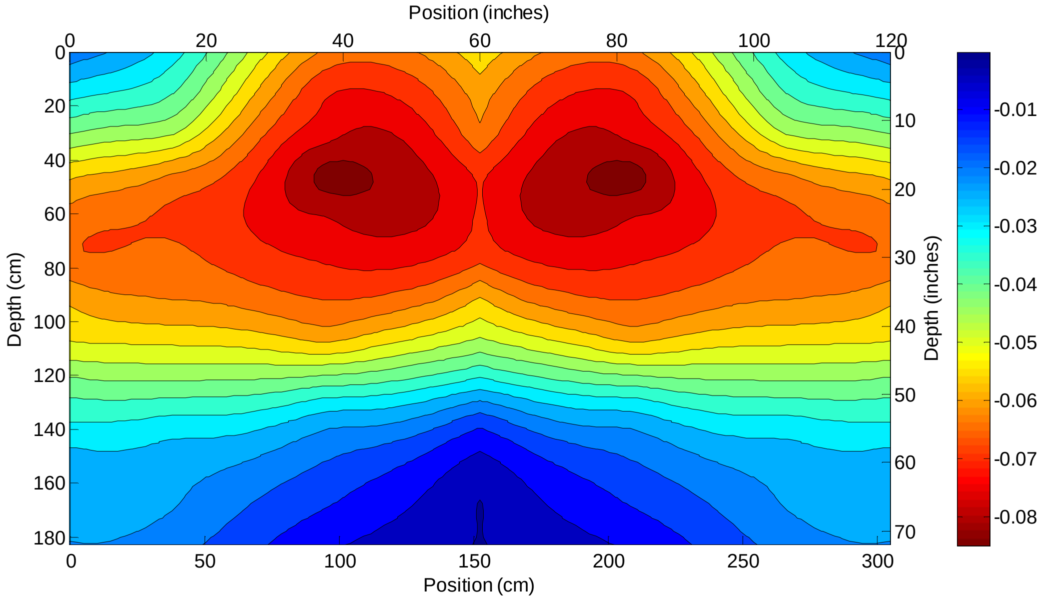

Figure A.190 - 2011 Corn early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

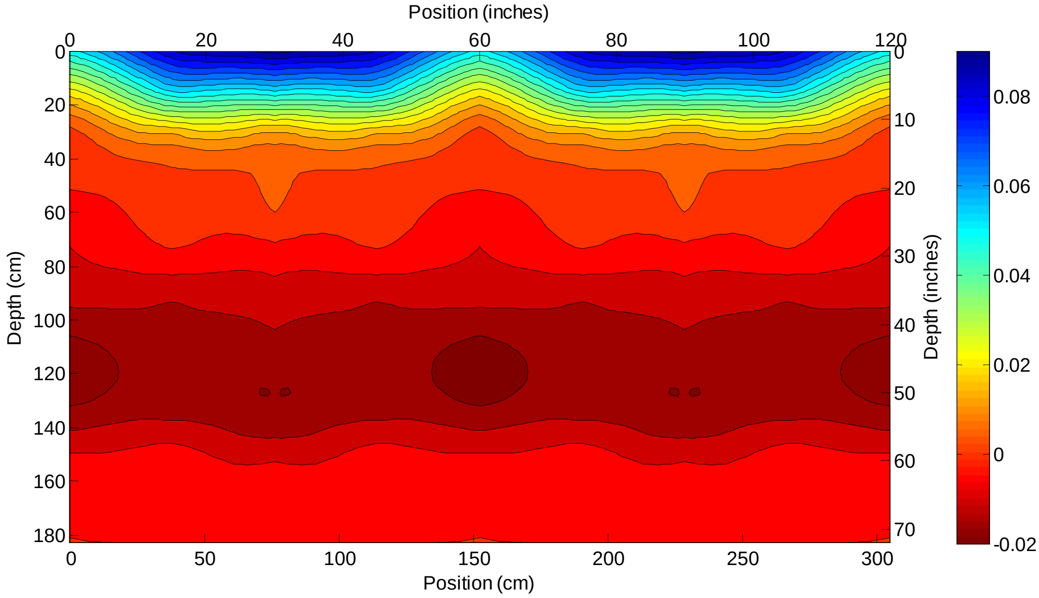

Figure A.191 - 2011 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

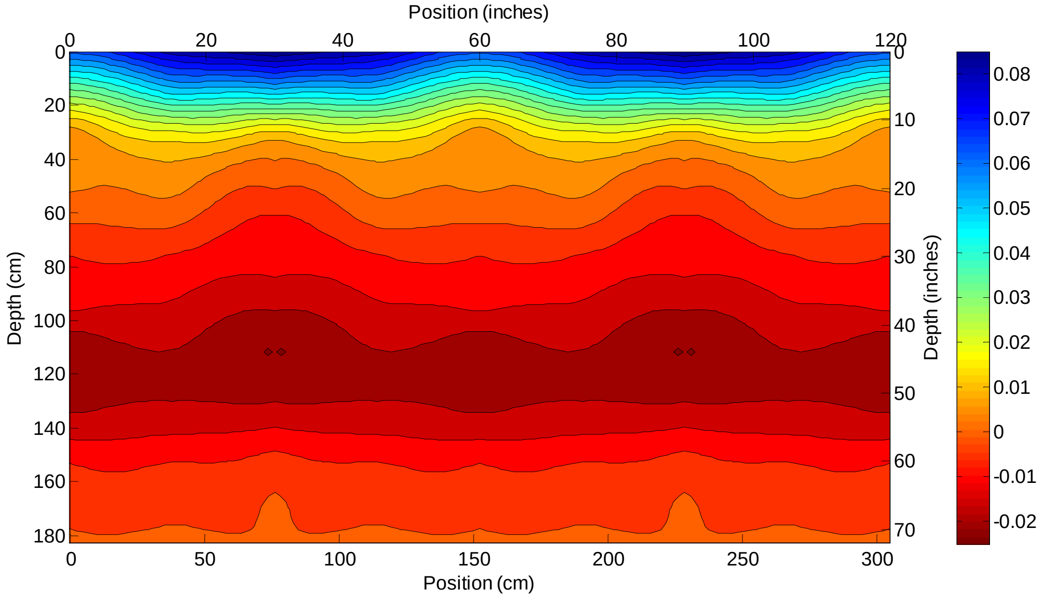

Figure A.192 - 2011 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

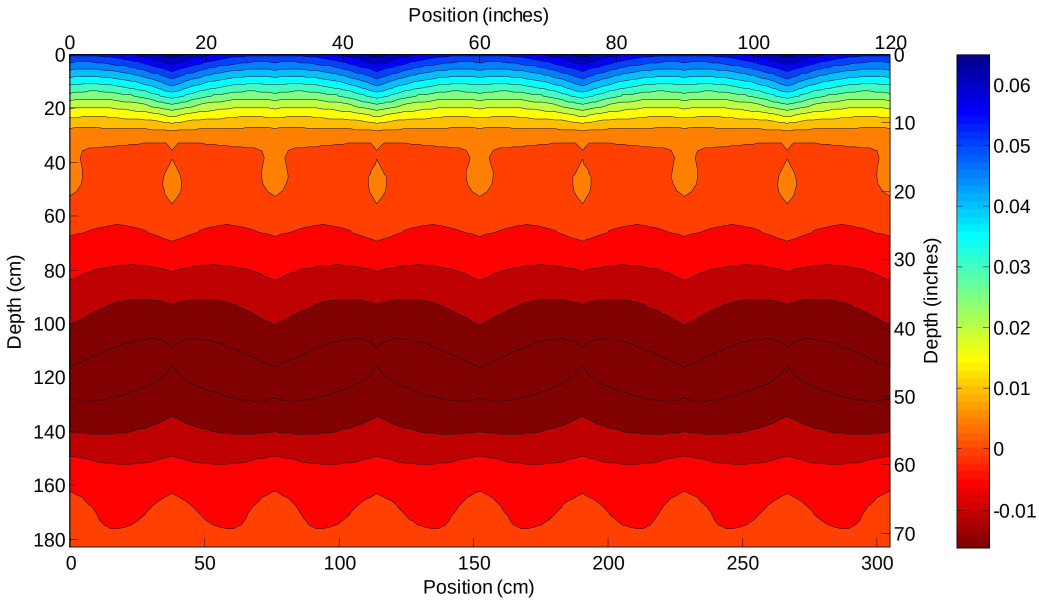

Figure A.193 - 2011 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

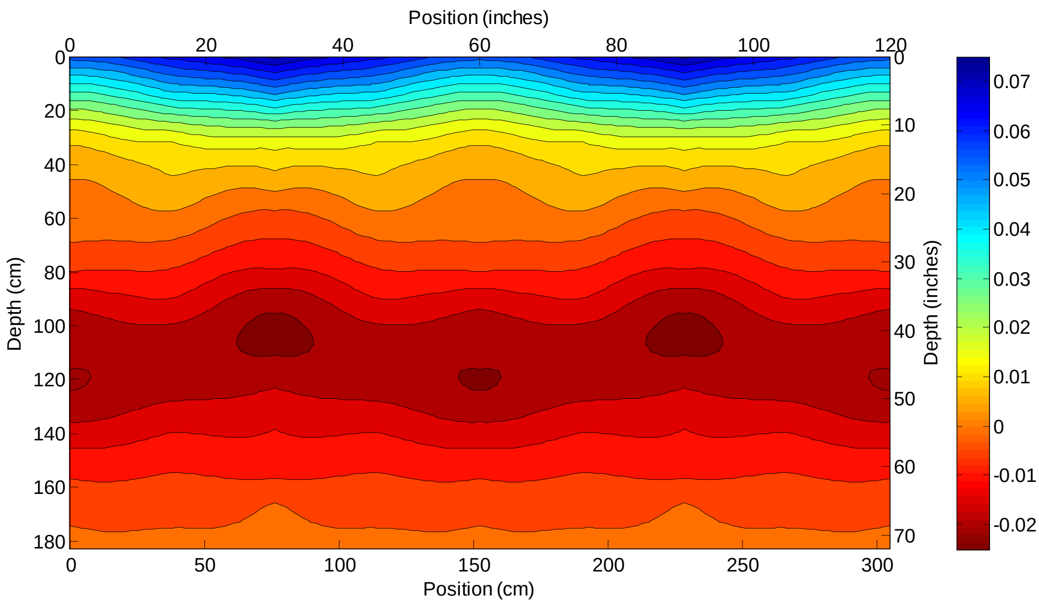

Figure A.194 - 2011 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

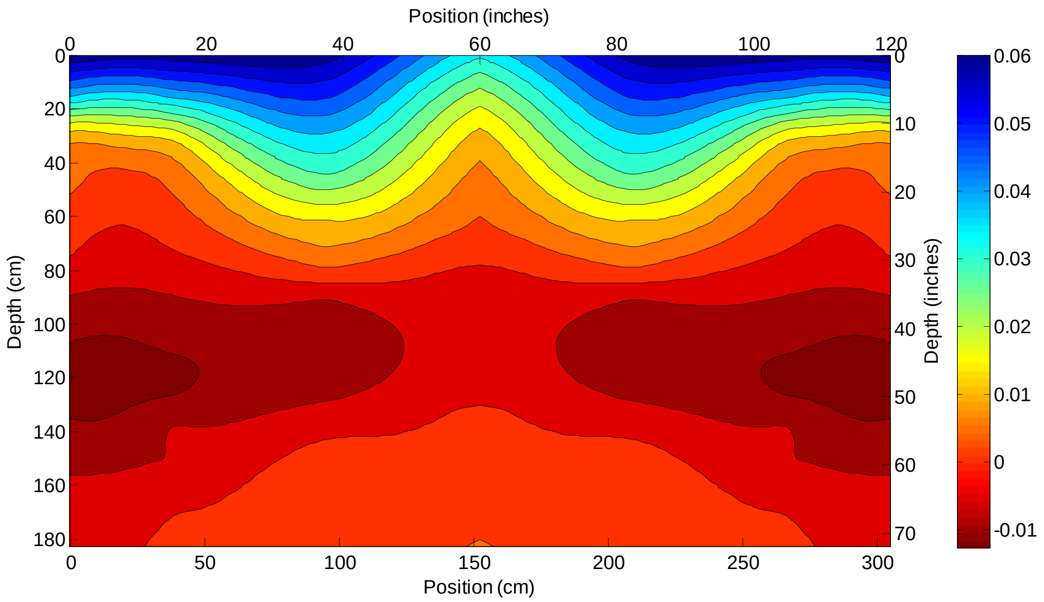

Figure A.195 - 2011 Corn tassel-silk to grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

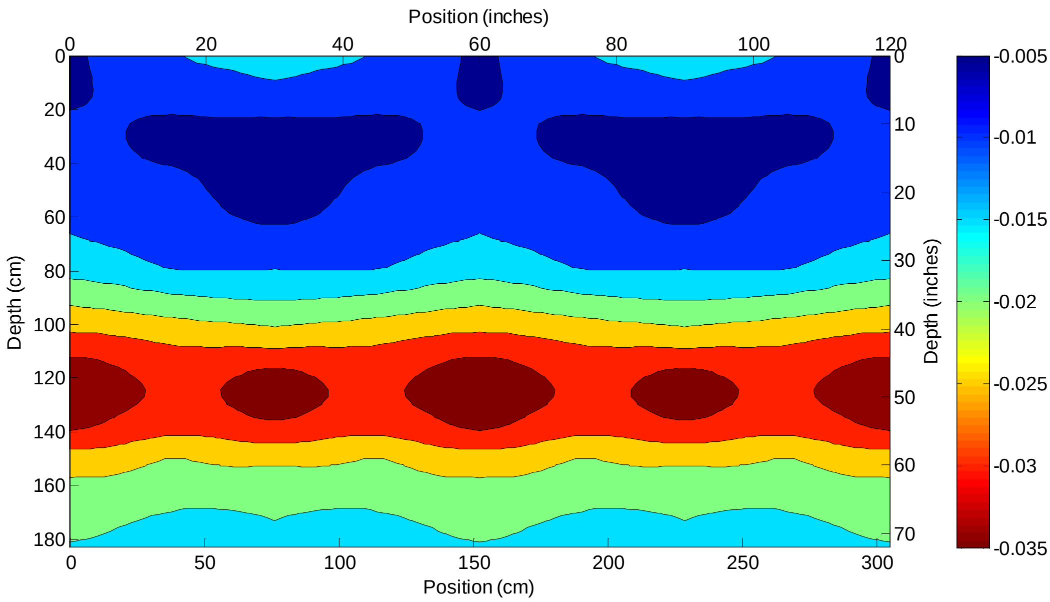

Figure A.196 - 2011 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

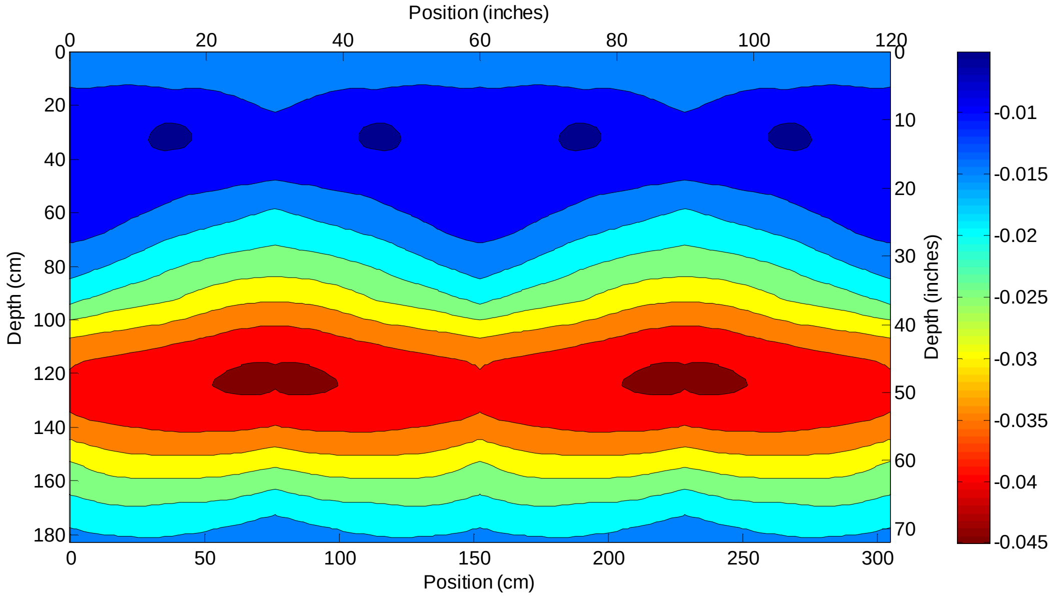

Figure A.197 - 2011 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, cluster geometry.

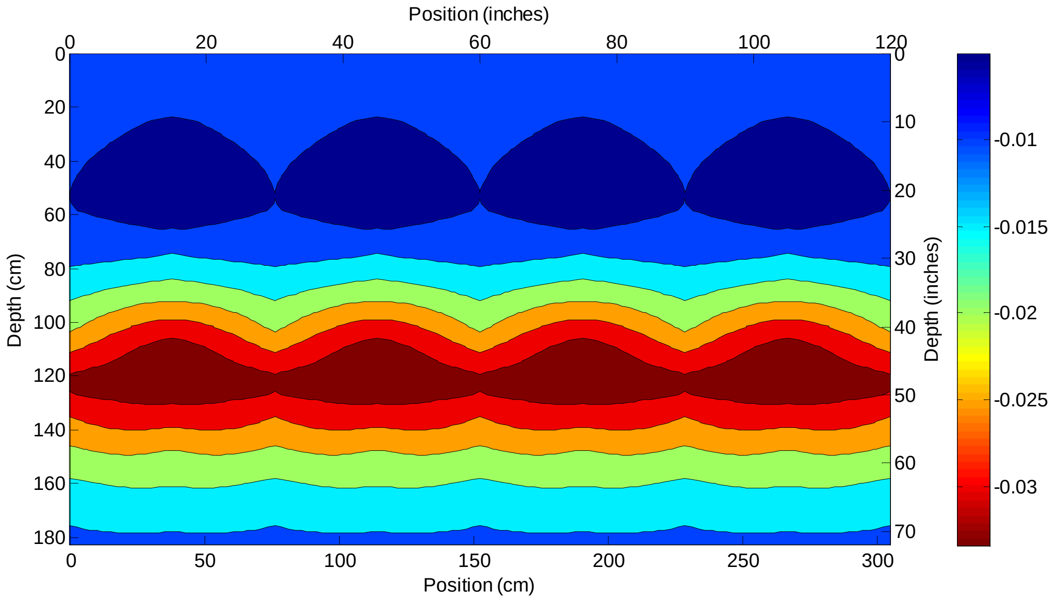

Figure A.198 - 2011 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, conventional geometry.

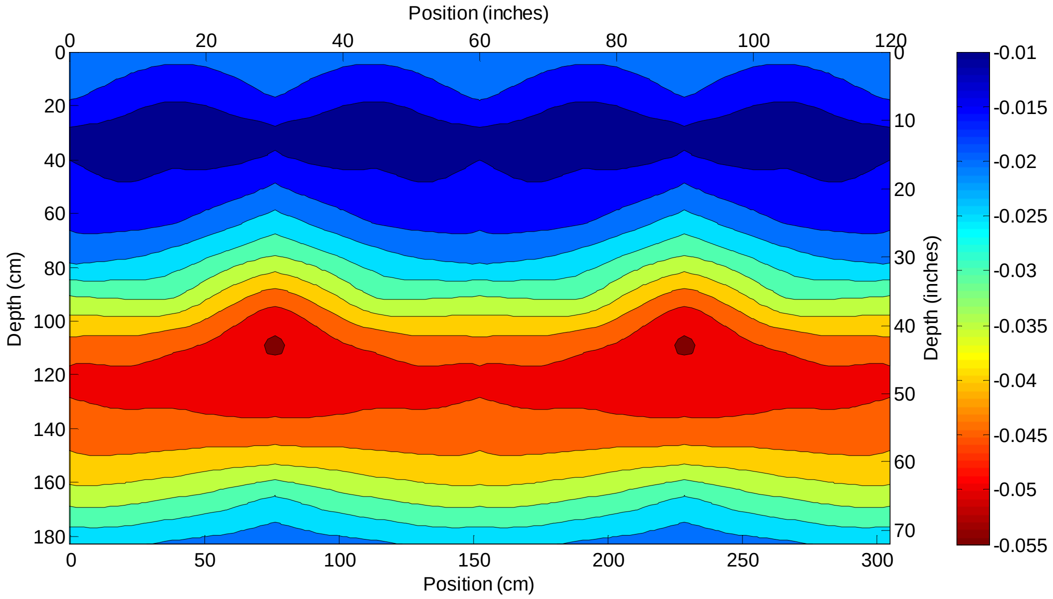

Figure A.199 - 2011 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

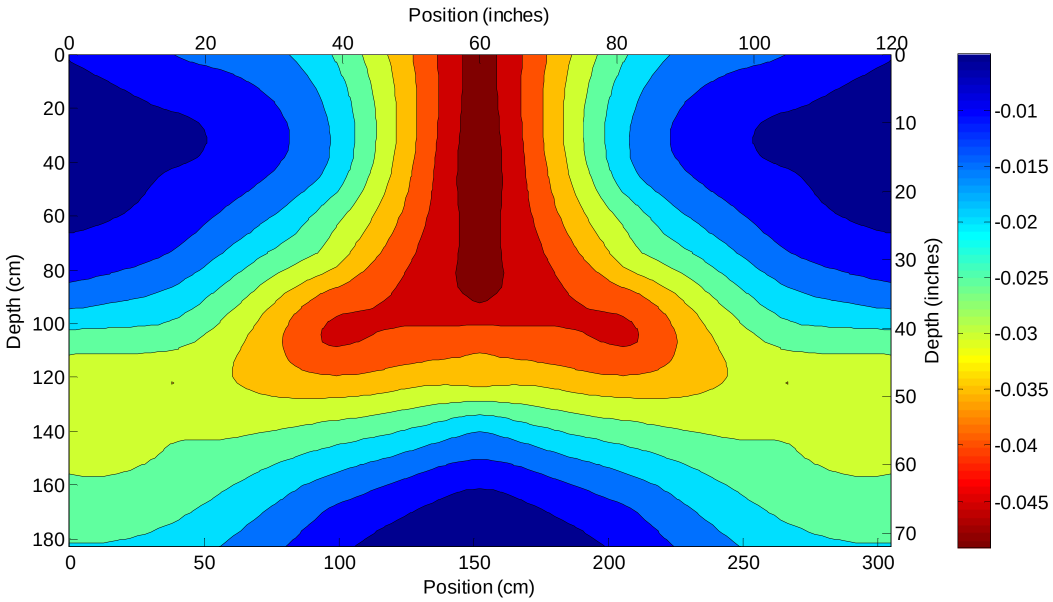

Figure A.200 - 2011 Corn tassel-silk to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

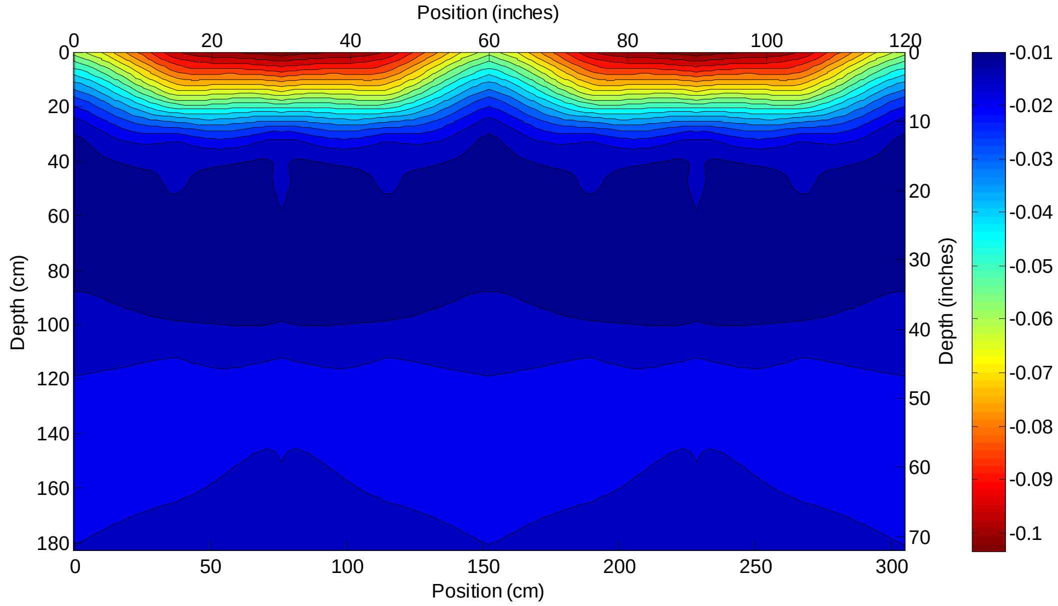

Figure A.201 - 2011 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

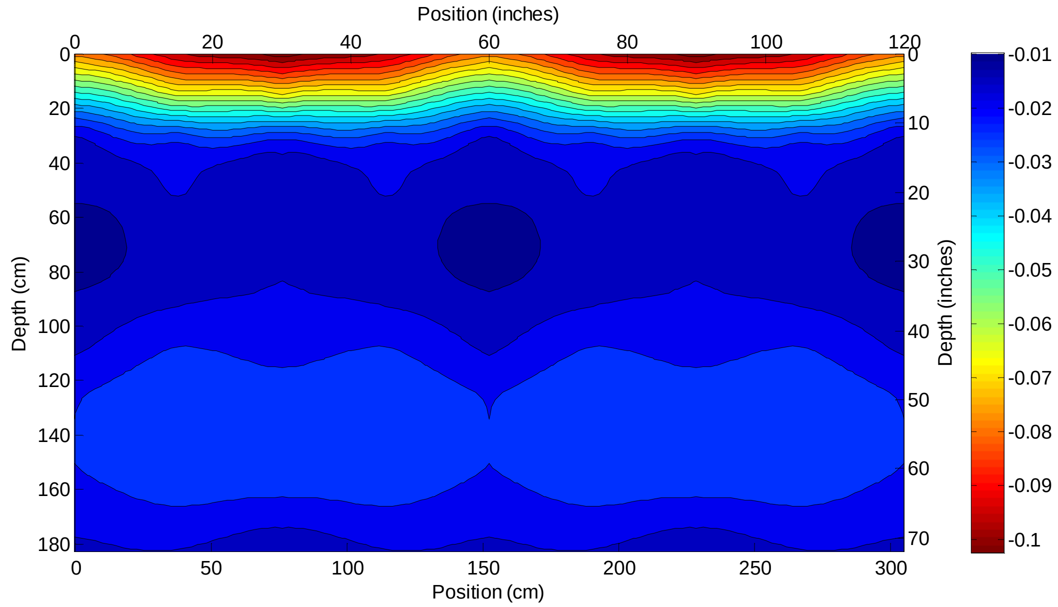

Figure A.202 - 2011 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

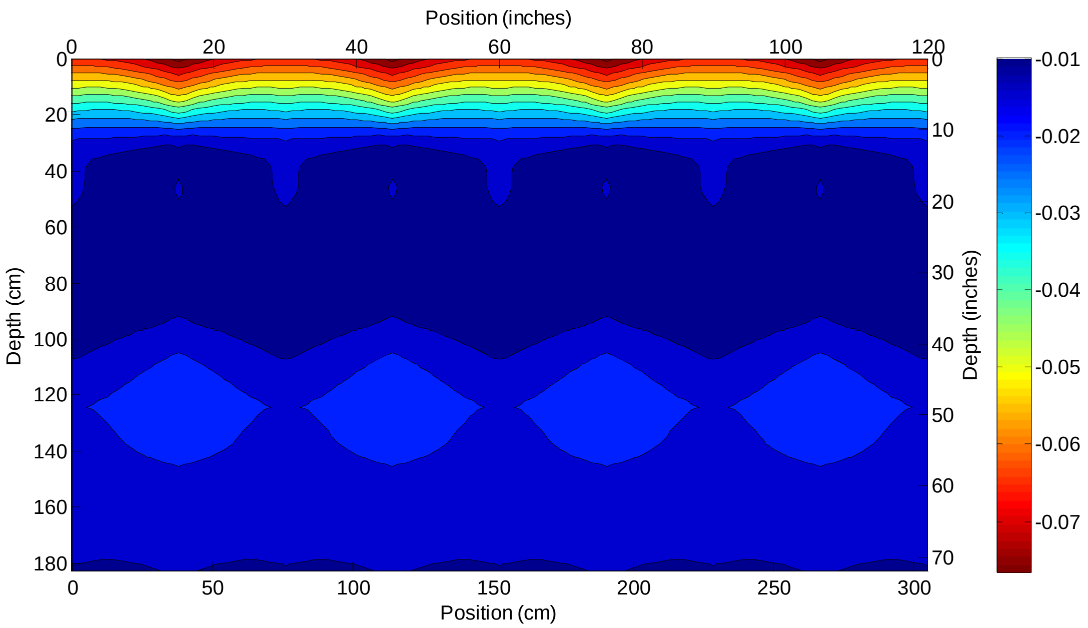

Figure A.203 - 2011 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

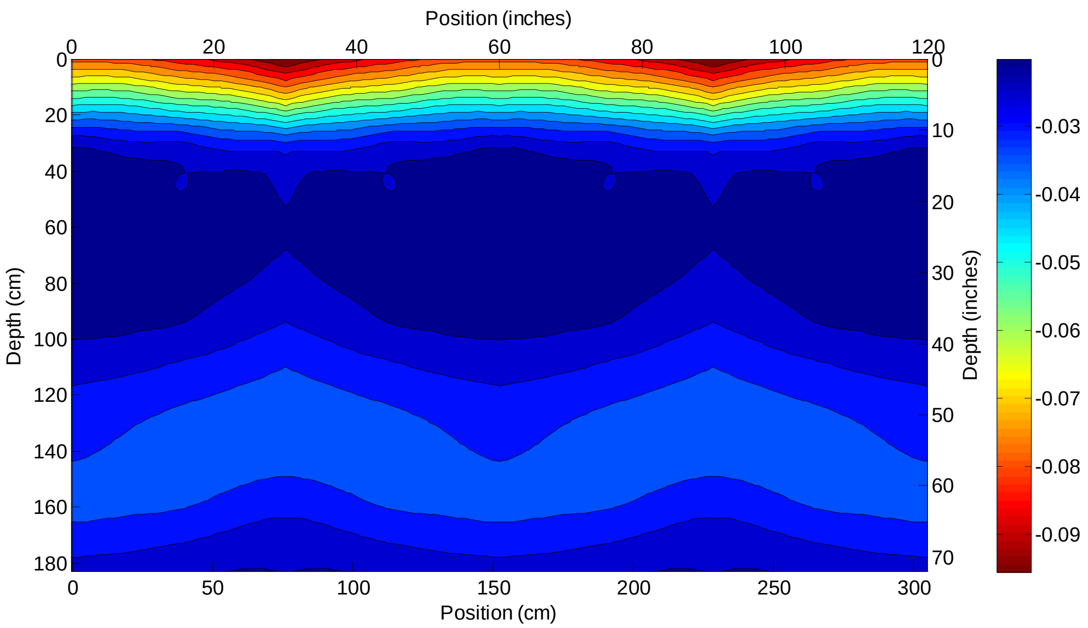

Figure A.204 - 2011 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

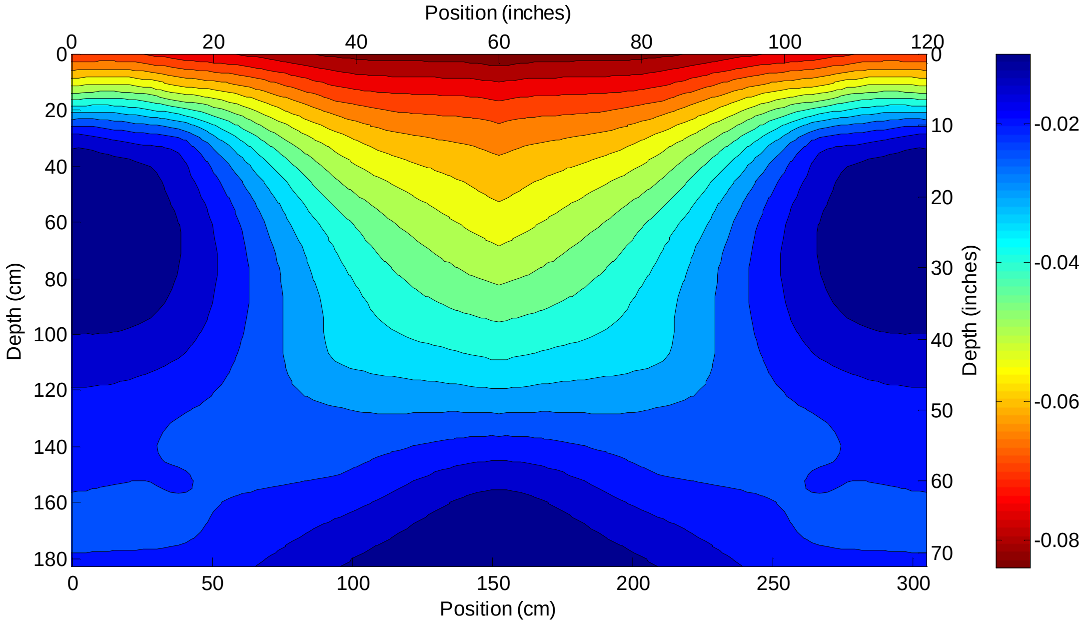

Figure A.205 - 2011 Corn grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

Across-years interpolated soil water content

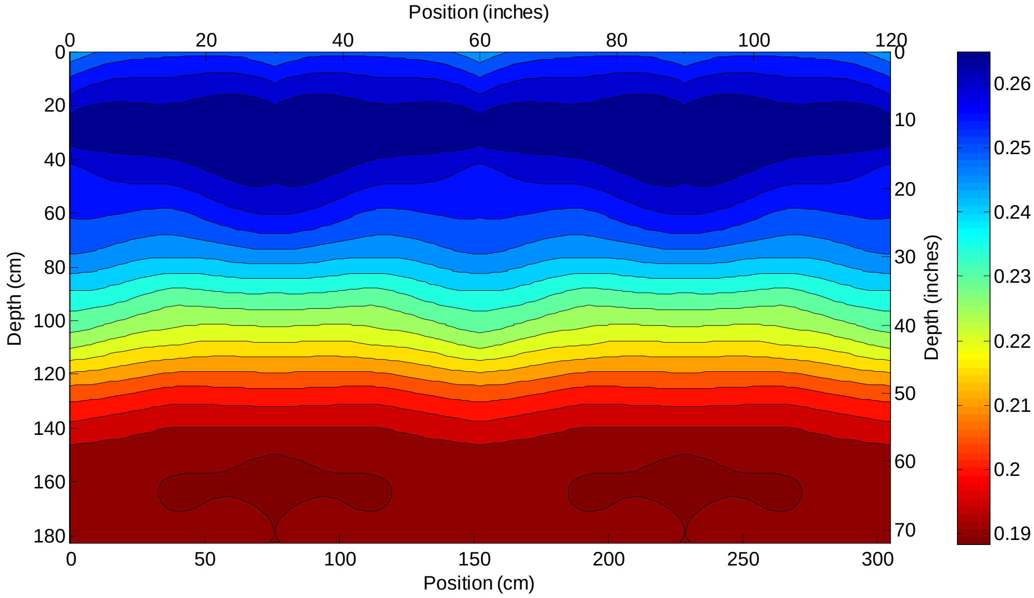

Figure A.206 - Corn planting soil water content across years, contour step = 0.005 cm^3 cm^{-3}, clump geometry.

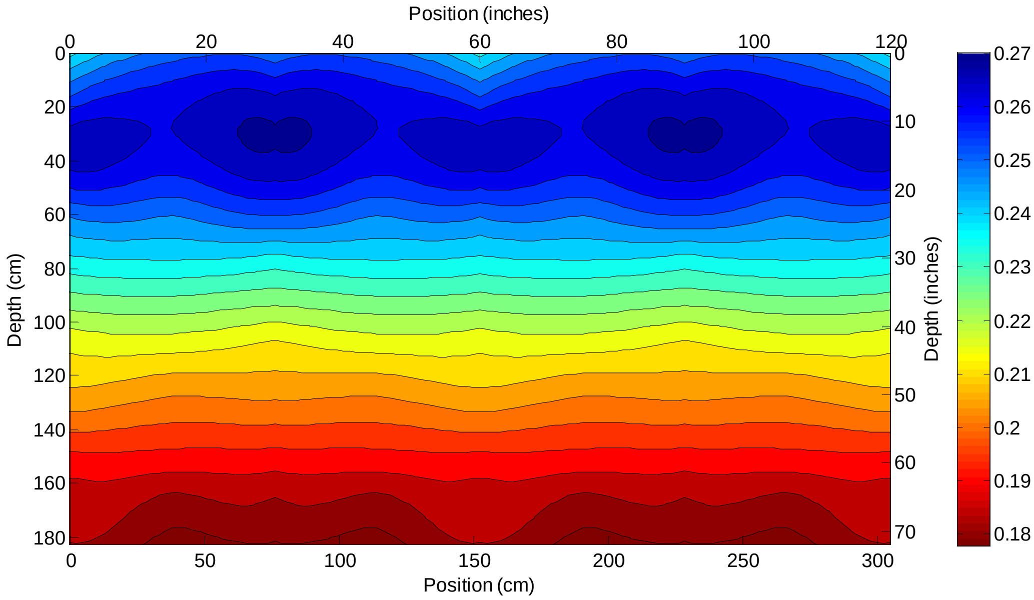

Figure A.207 - Corn planting soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

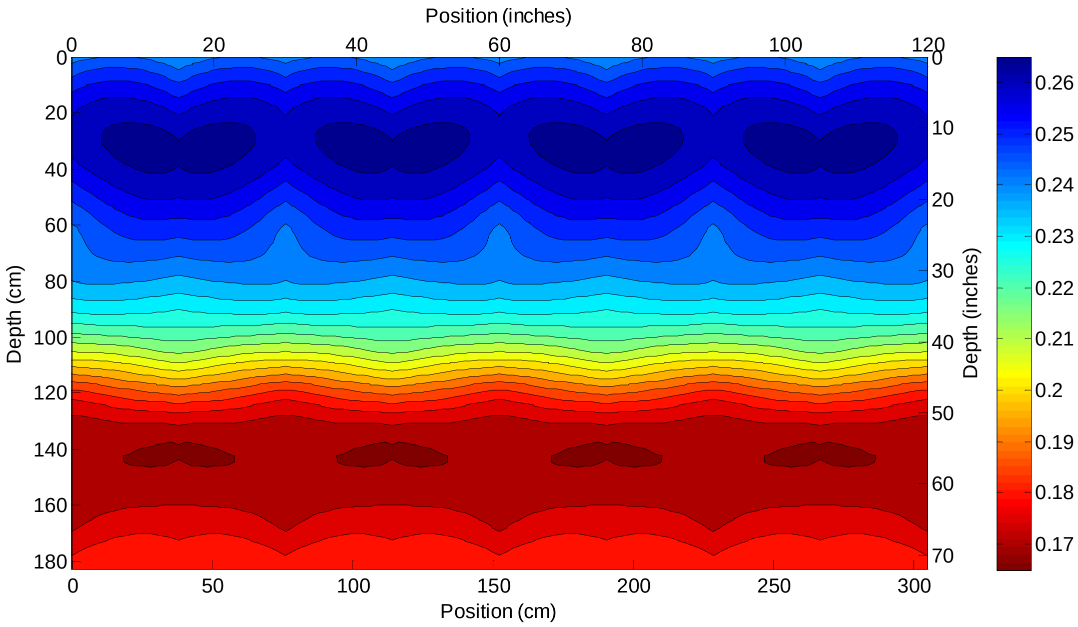

Figure A.208 - Corn planting soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

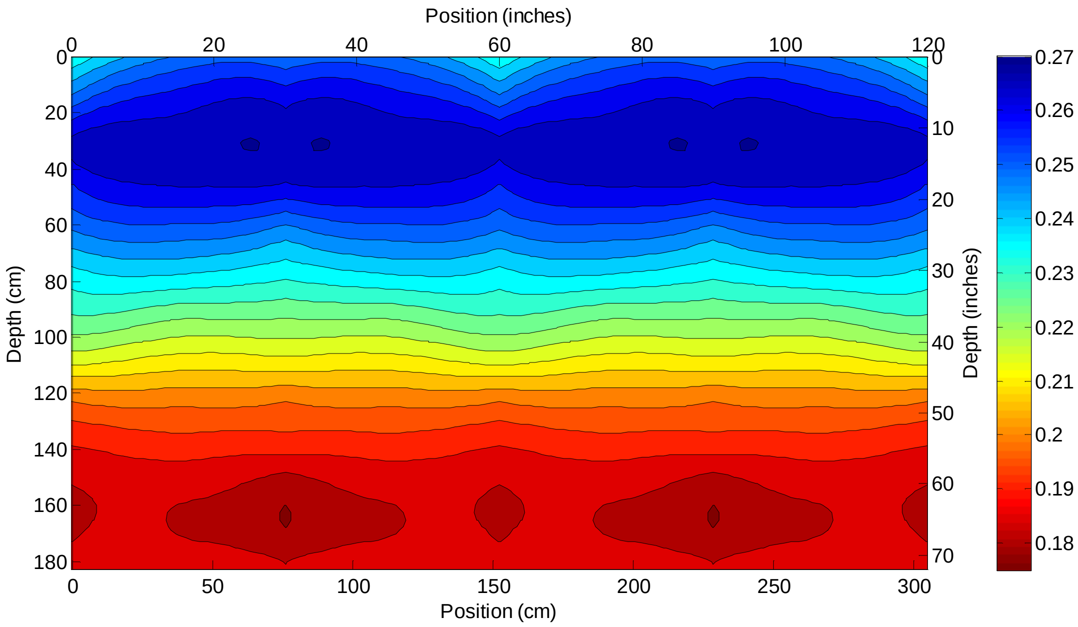

Figure A.209 - Corn planting soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

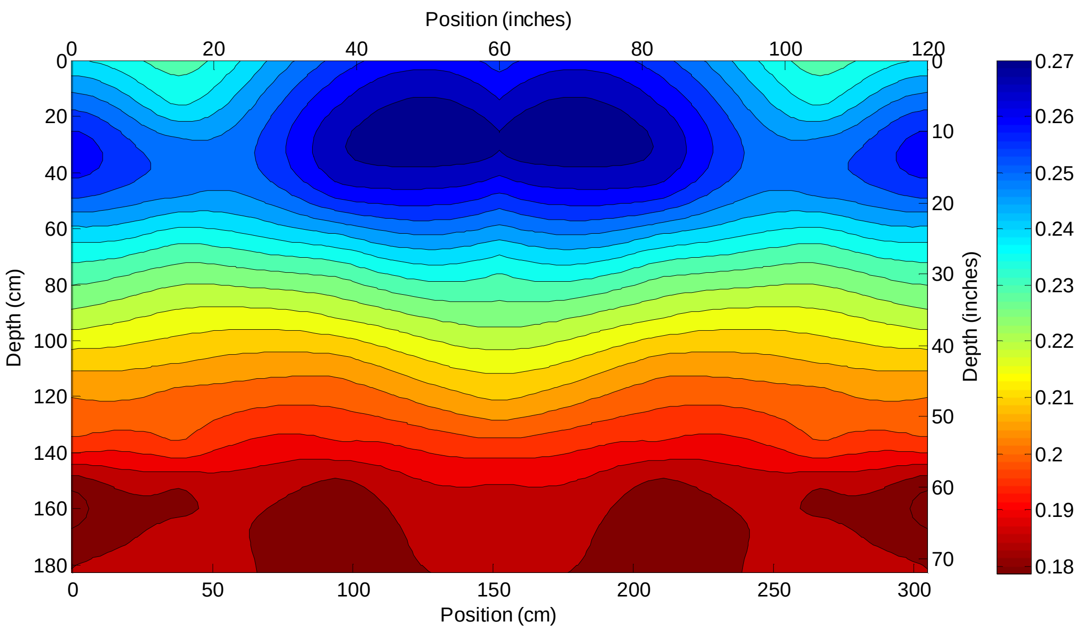

Figure A.210 - Corn planting soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

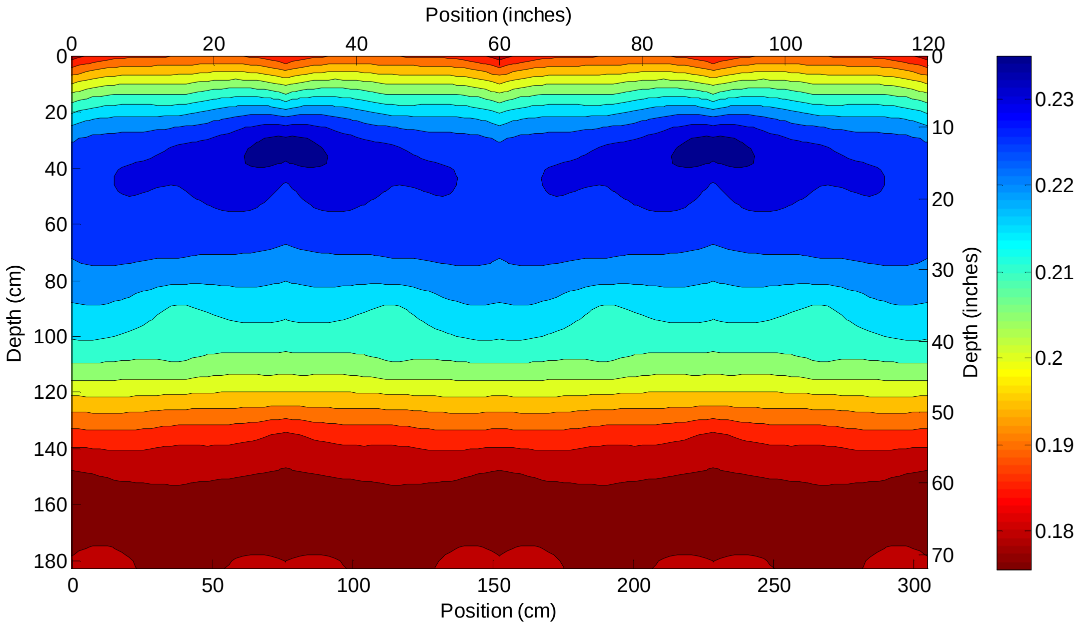

Figure A.211 - Corn early vegetative soil water content across years, contour step = 0.005 cm^3 cm^{-3}, clump geometry.

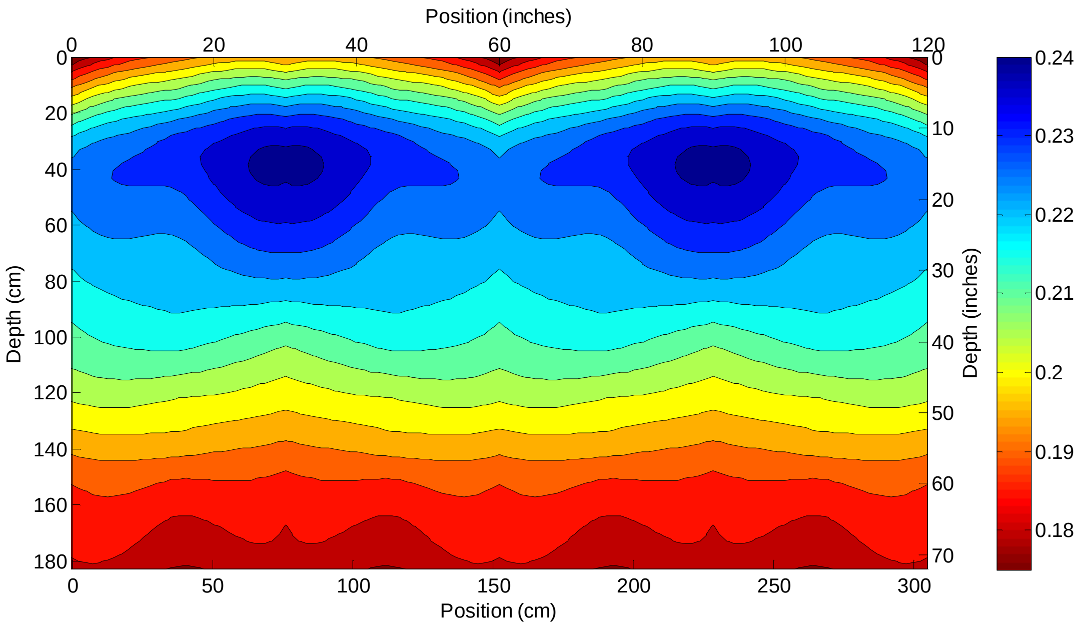

Figure A.212 - Corn early vegetative soil water content across years, contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

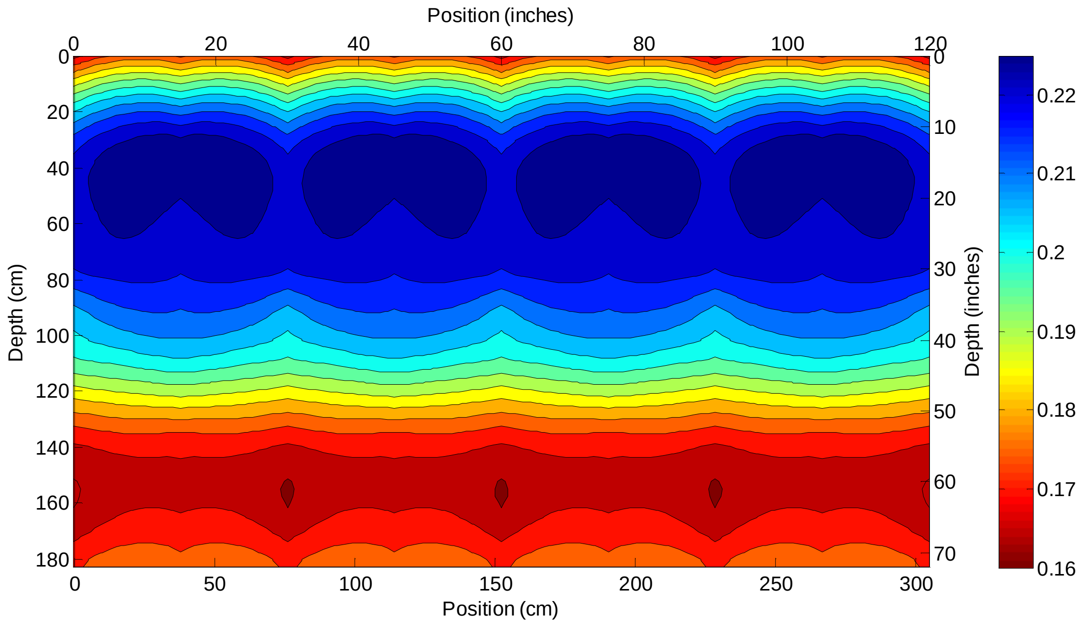

Figure A.213 - Corn early vegetative soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

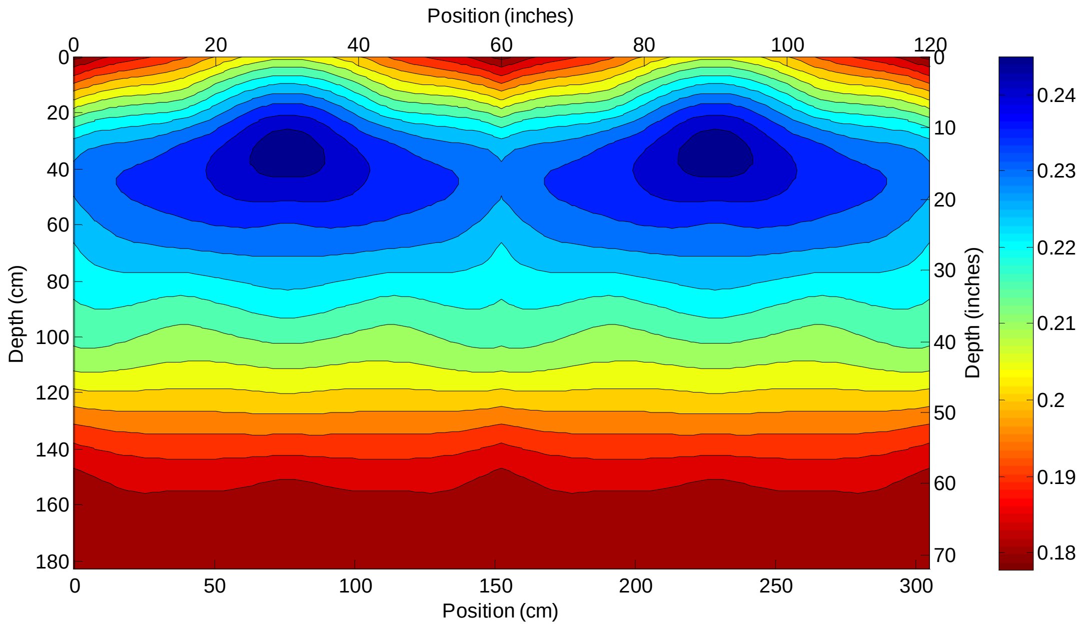

Figure A.214 - Corn early vegetative soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

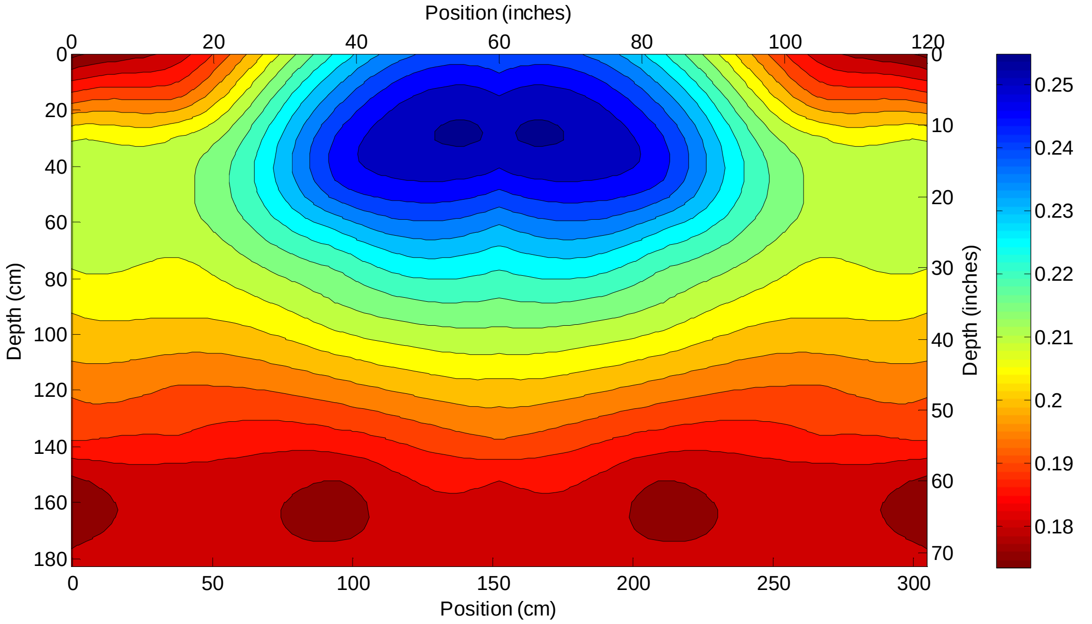

Figure A.215 - Corn early vegetative soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

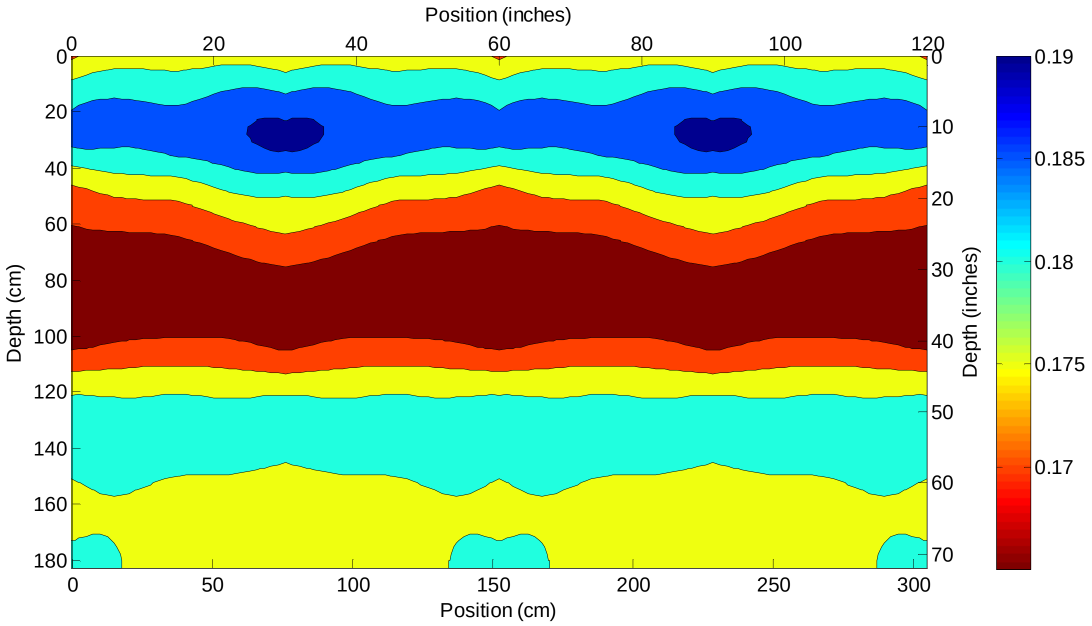

Figure A.216 - Corn tassel-silk soil water content across years, contour step = 0.005 cm^3 cm^{-3}, clump geometry.

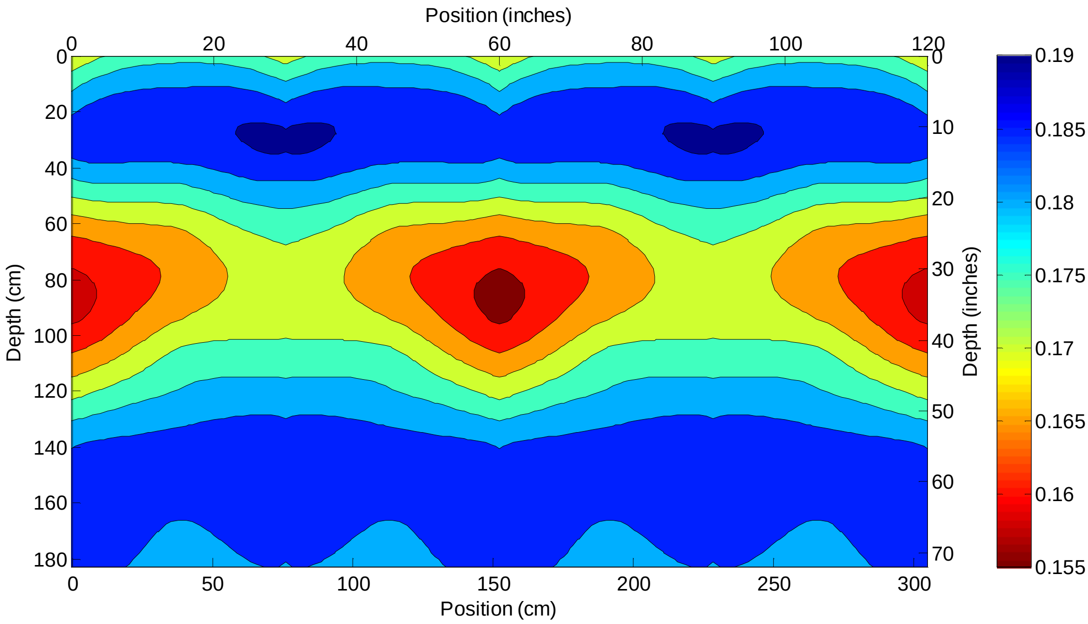

Figure A.217 - Corn tassel-silk soil water content across years, contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

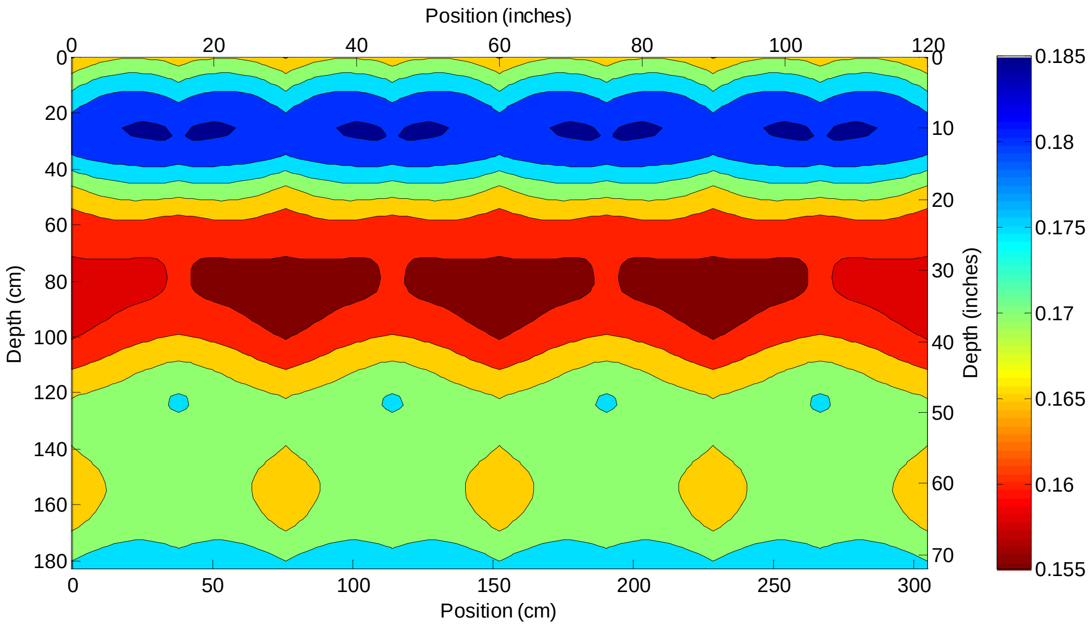

Figure A.218 - Corn tassel-silk soil water content across years, contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

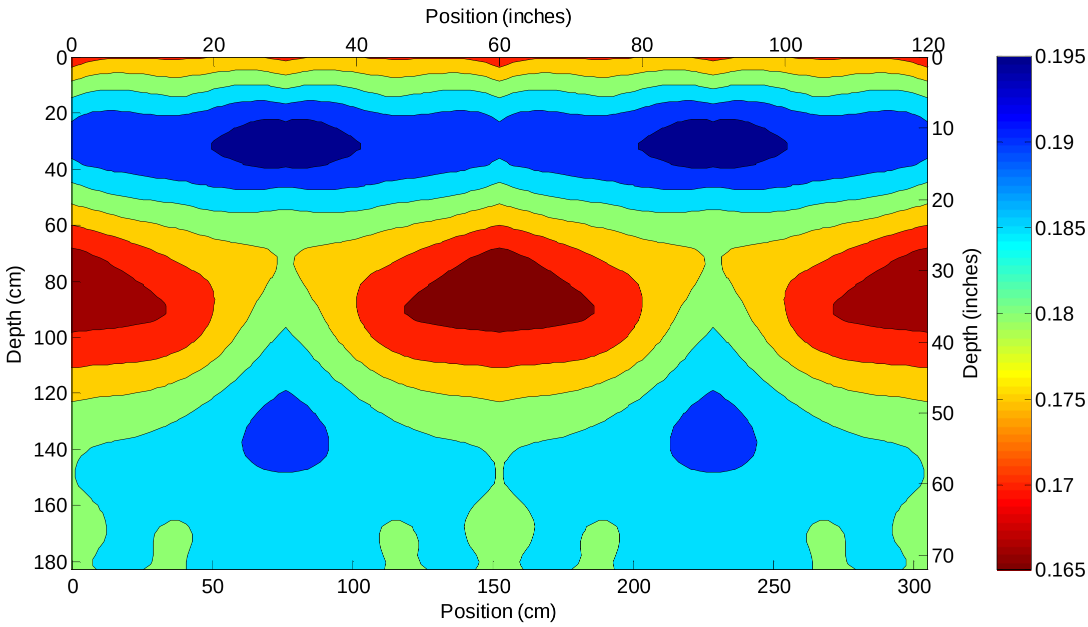

Figure A.219 - Corn tassel-silk soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

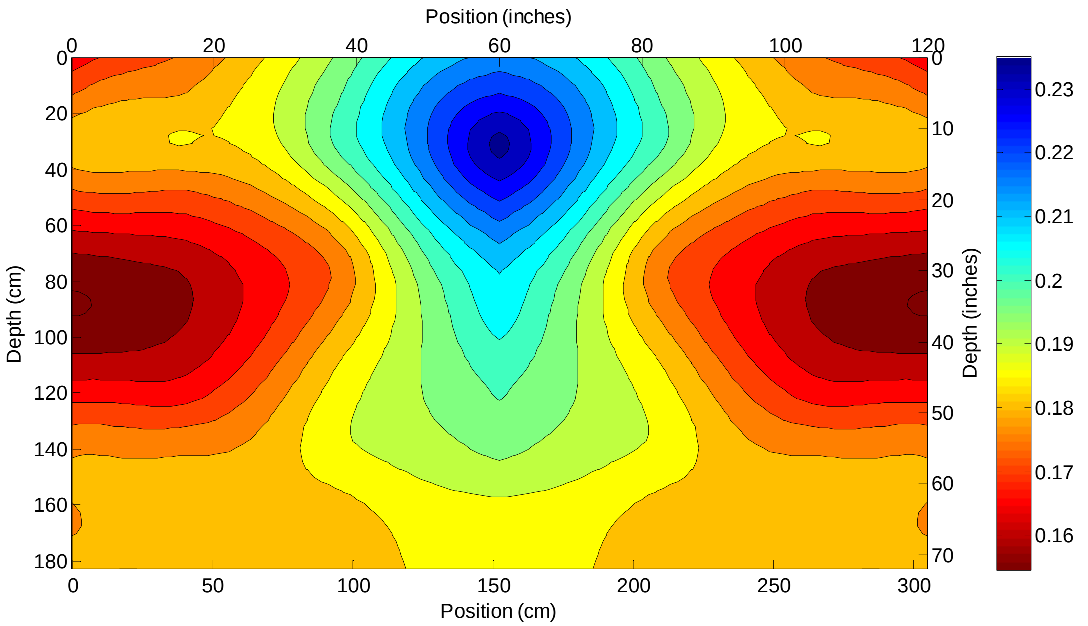

Figure A.220 - Corn tassel-silk soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

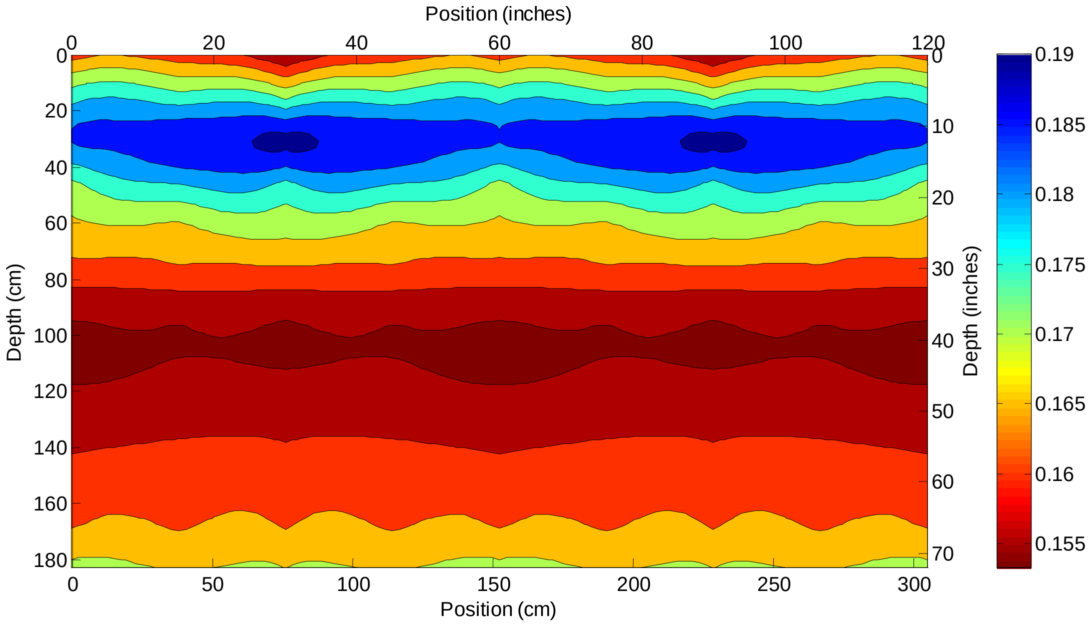

Figure A.221 - Corn harvest soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

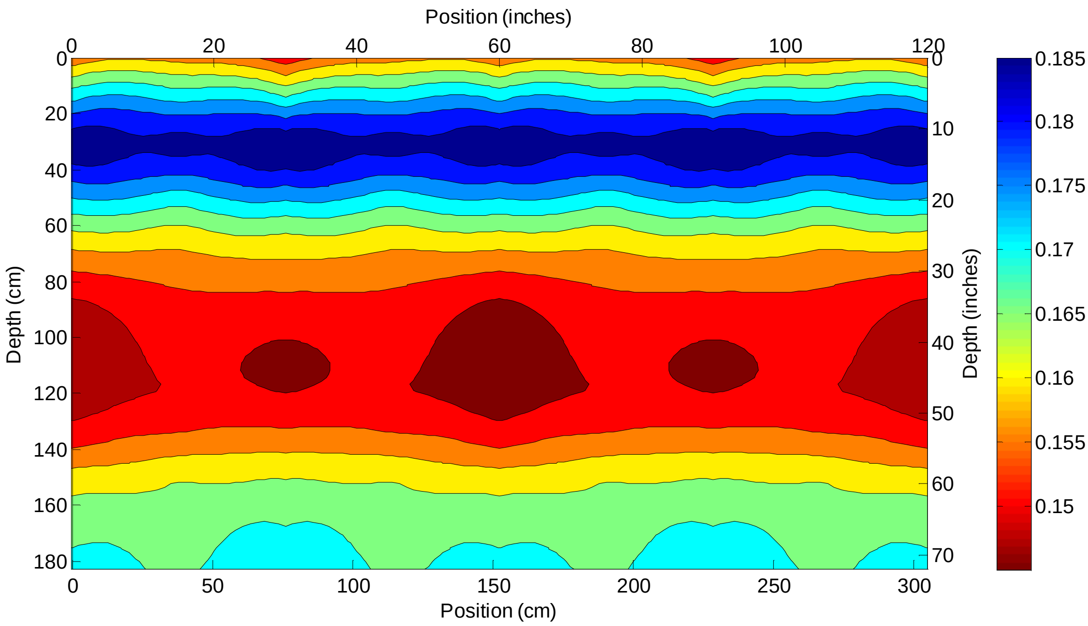

Figure A.222 - Corn harvest soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

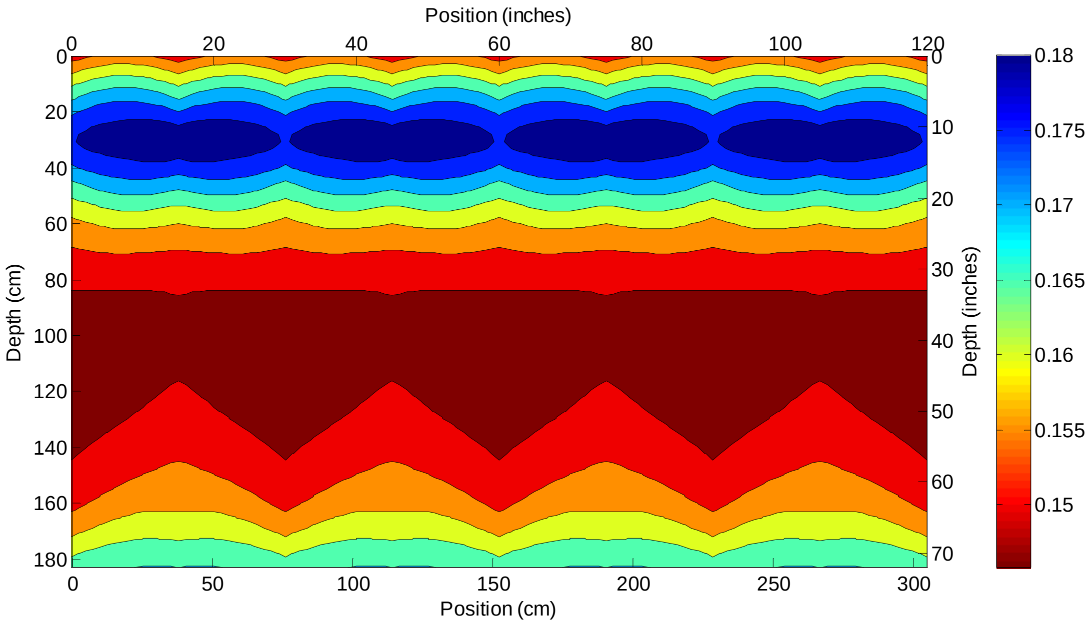

Figure A.223 - Corn harvest soil water content across years, contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

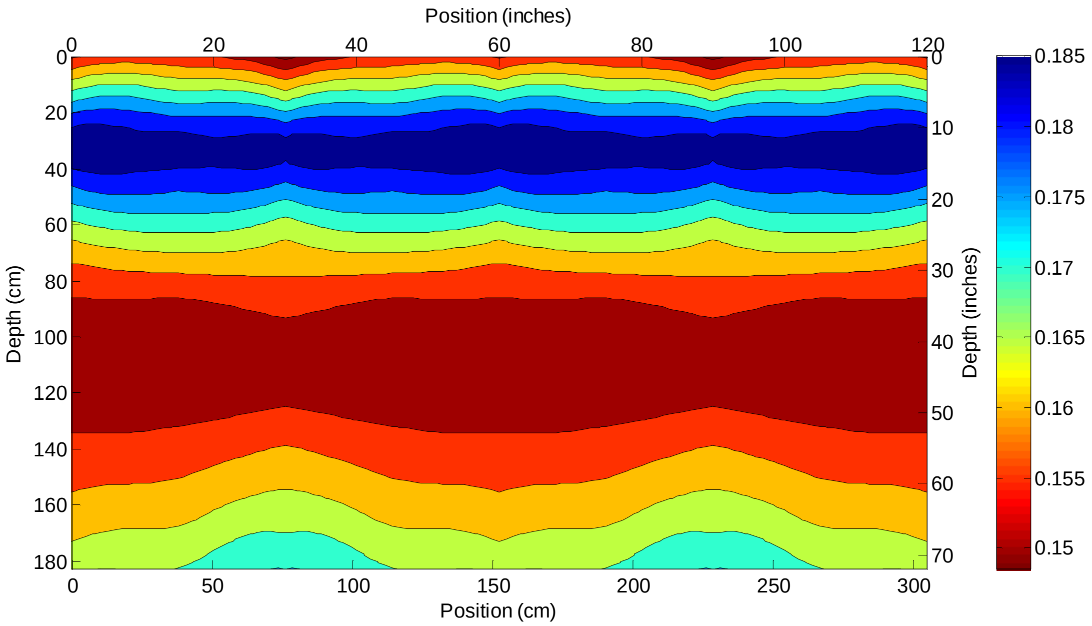

Figure A.224 - Corn harvest soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

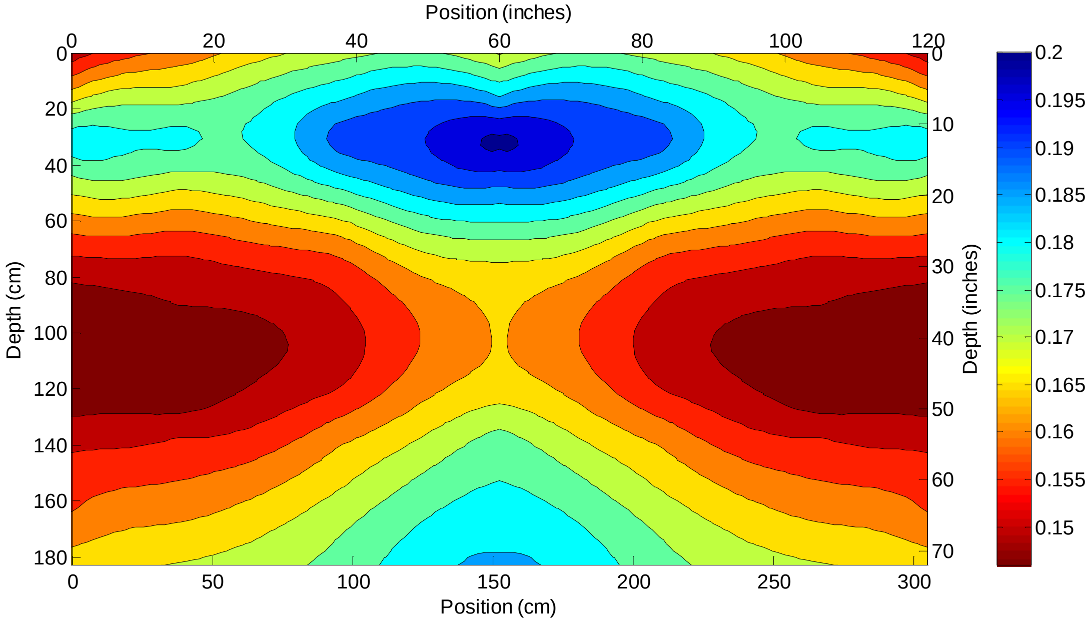

Figure A.225 - Corn harvest soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

Across-years changes in soil water content

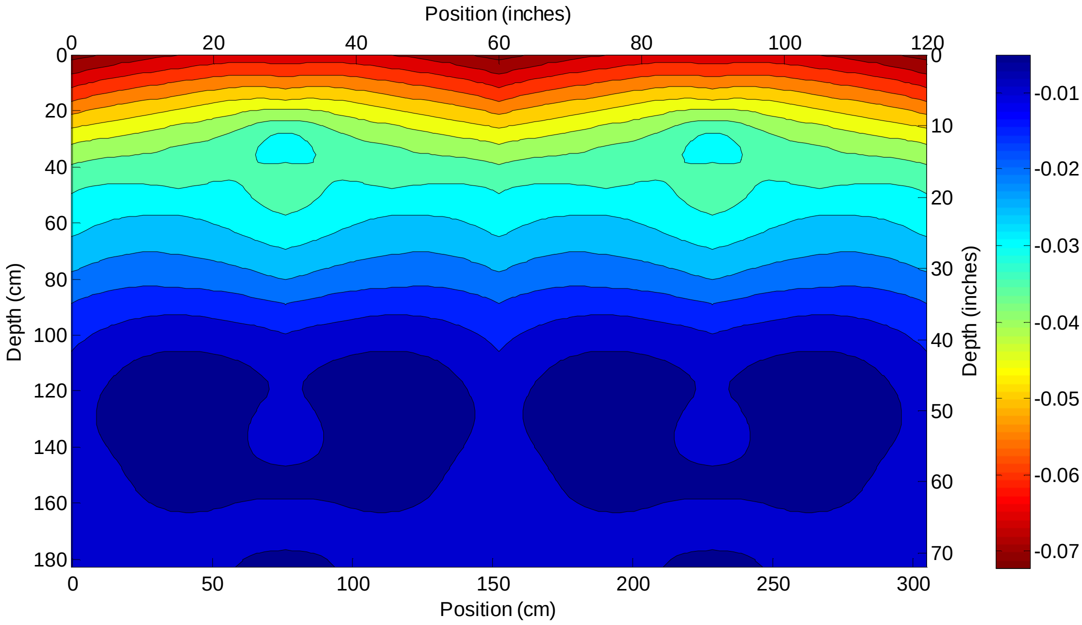

Figure A.226 - Corn planting to early vegetative change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

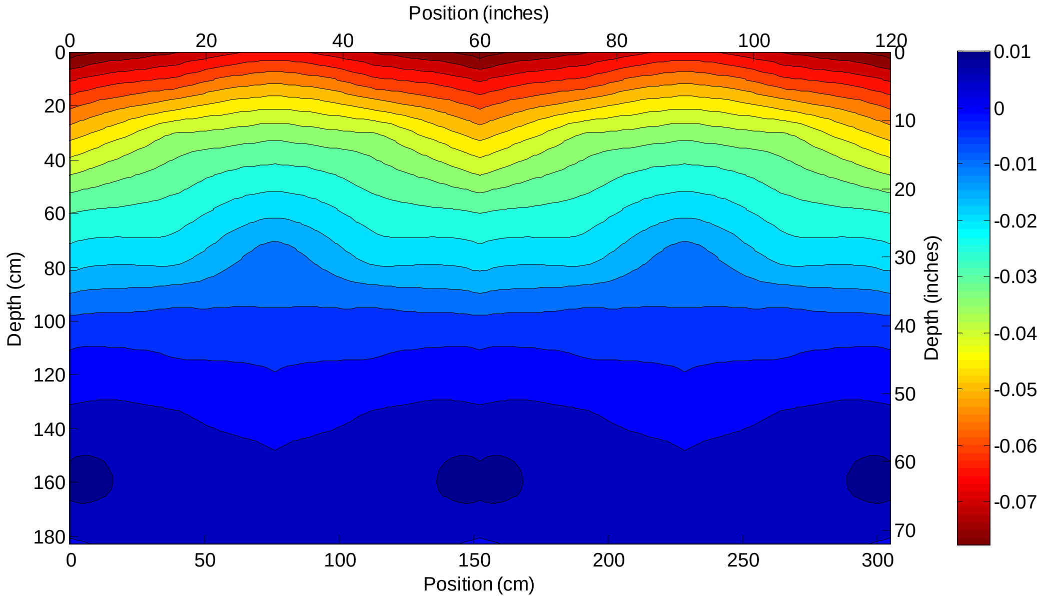

Figure A.227 - Corn planting to early vegetative change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

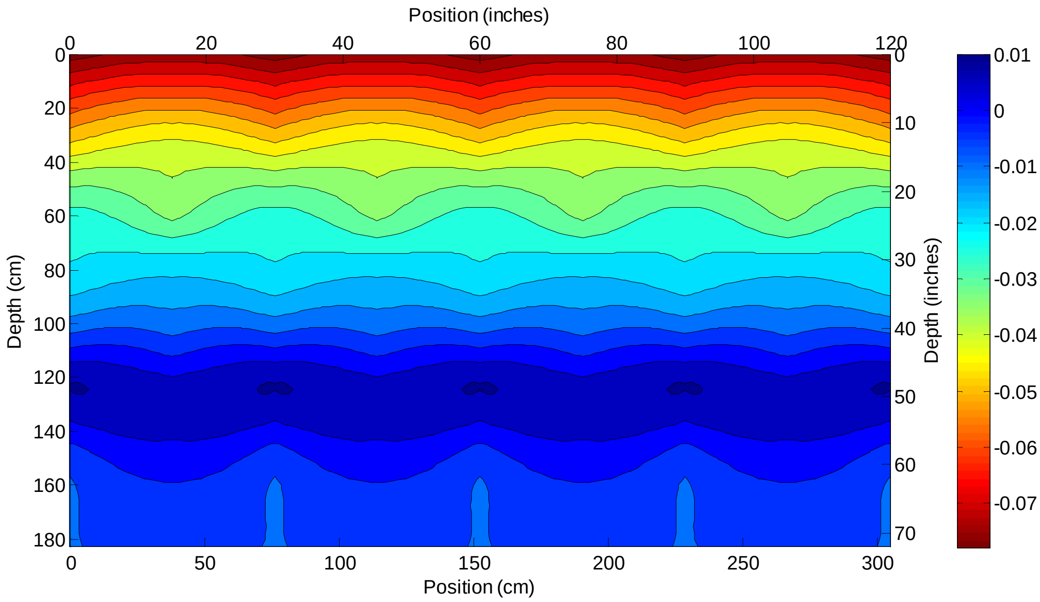

Figure A.228 - Corn planting to early vegetative change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

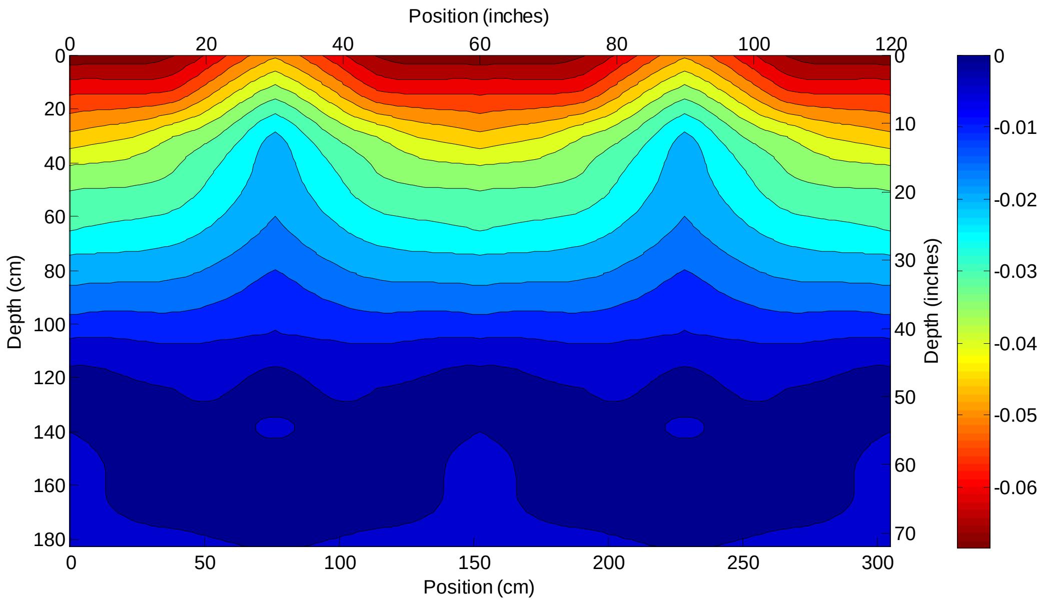

Figure A.229 - Corn planting to early vegetative change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

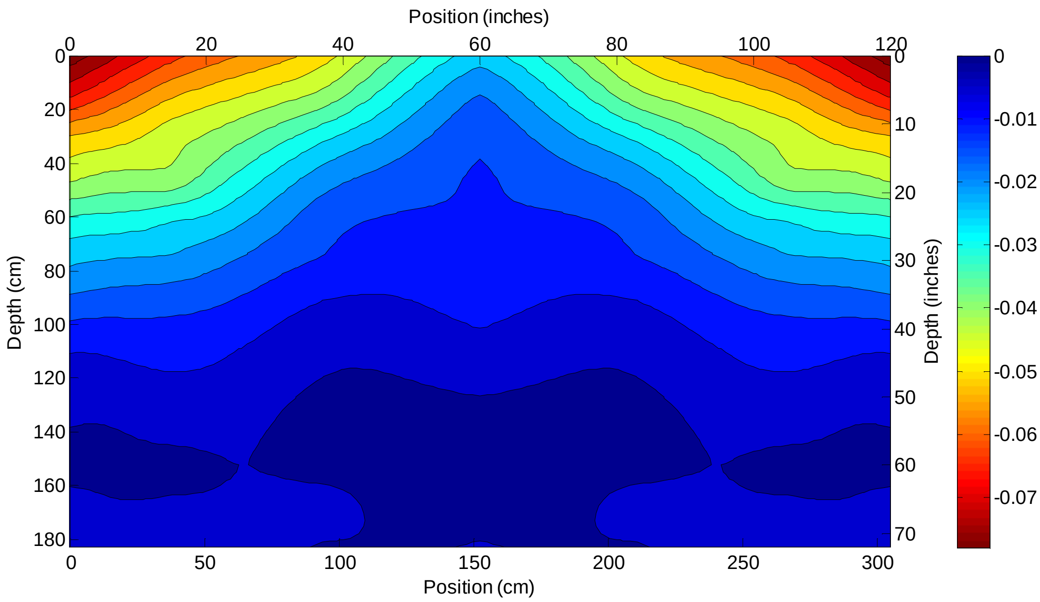

Figure A.230 - Corn planting to early vegetative change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

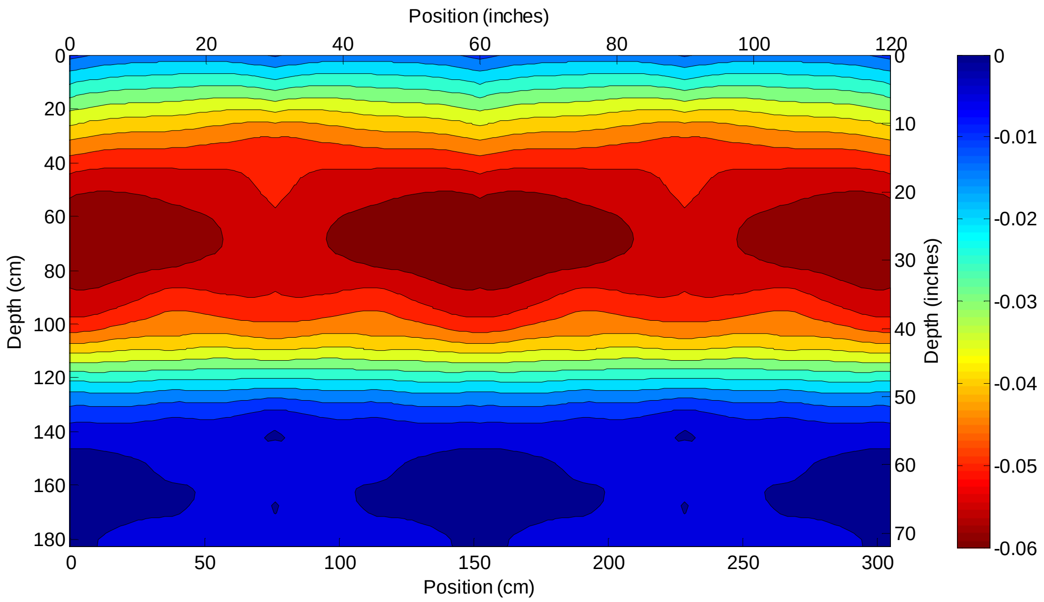

Figure A.231 - Corn early vegetative to tassel-silk change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, clump geometry.

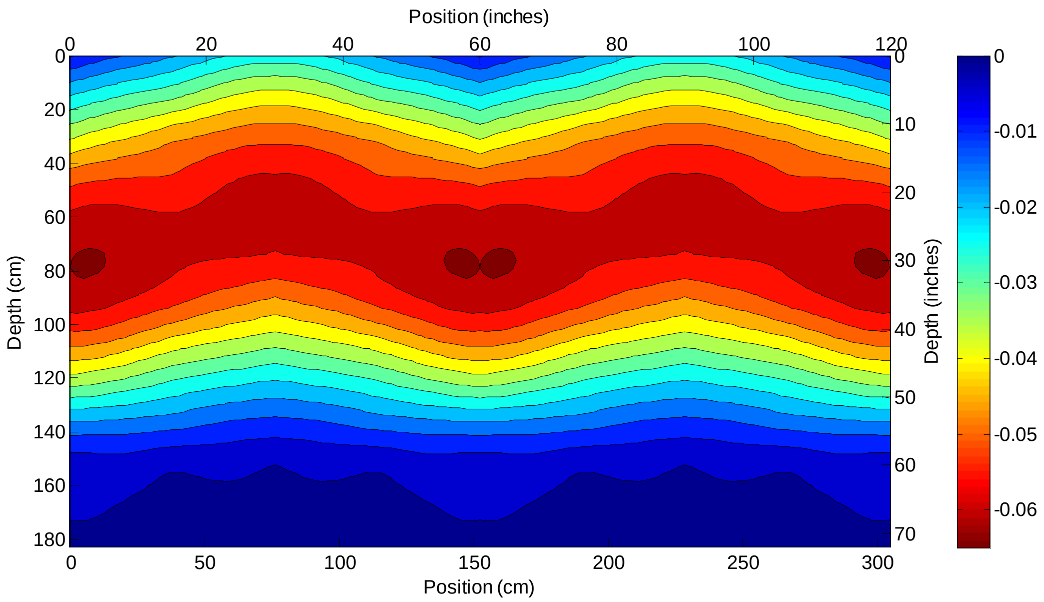

Figure A.232 - Corn early vegetative to tassel-silk change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

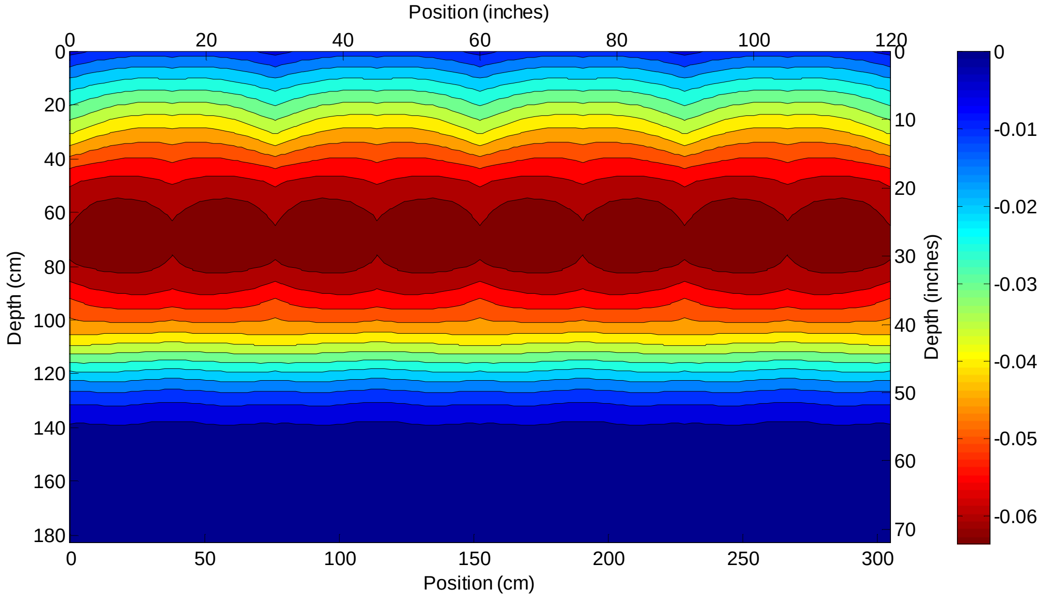

Figure A.233 - Corn early vegetative to tassel-silk change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

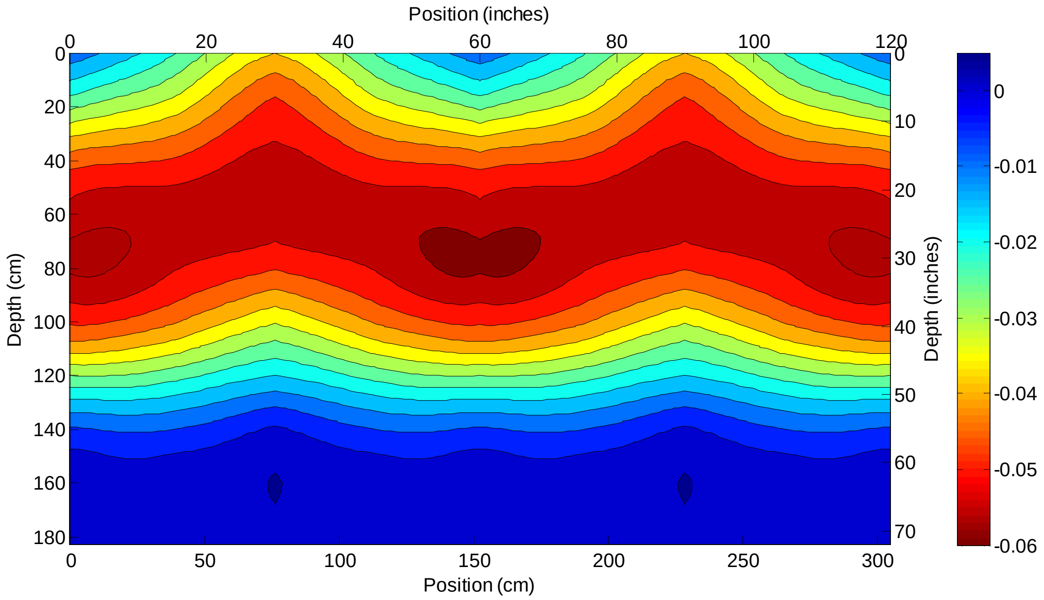

Figure A.234 - Corn early vegetative to tassel-silk change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

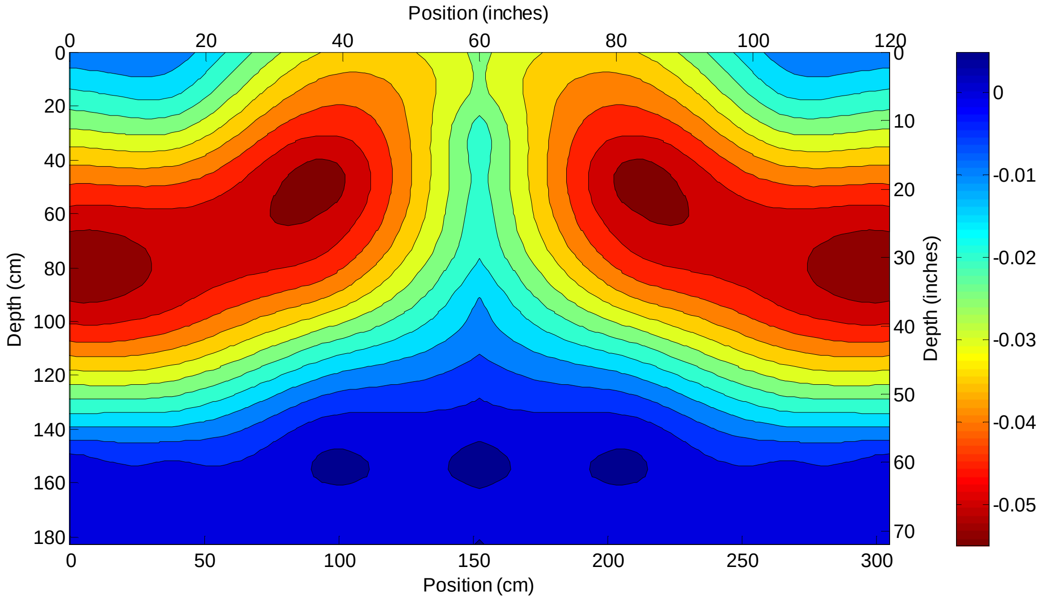

Figure A.235 - Corn early vegetative to tassel-silk change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

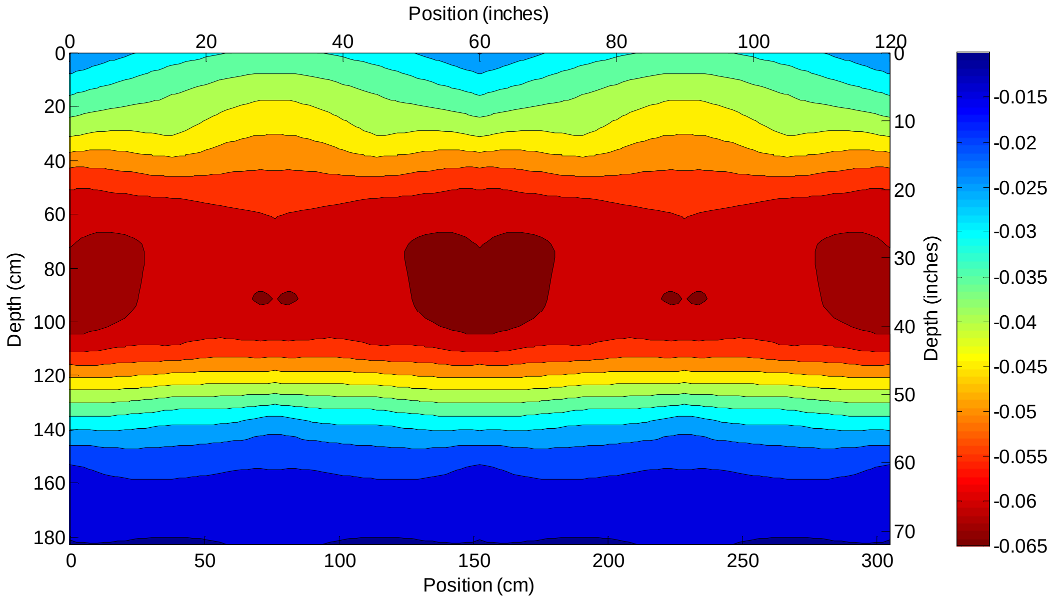

Figure A.236 - Corn early vegetative to harvest change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

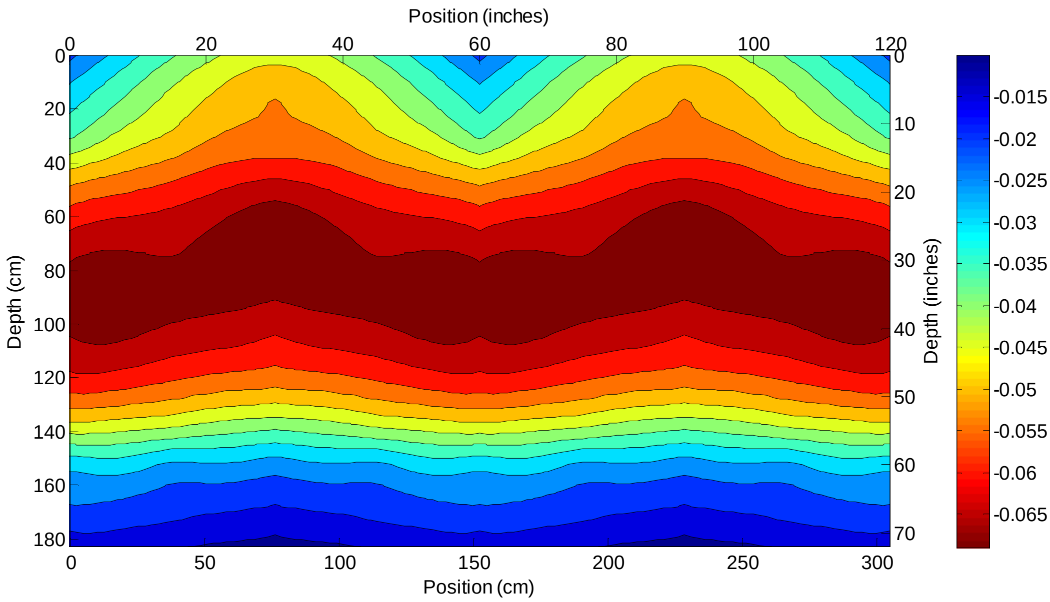

Figure A.237 - Corn early vegetative to harvest change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

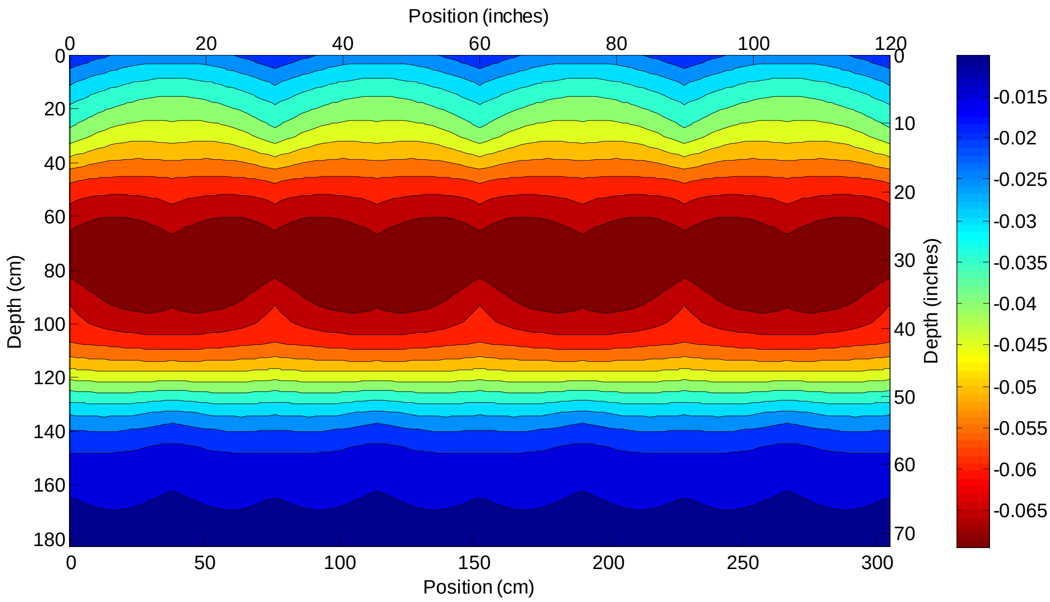

Figure A.238 - Corn early vegetative to harvest change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

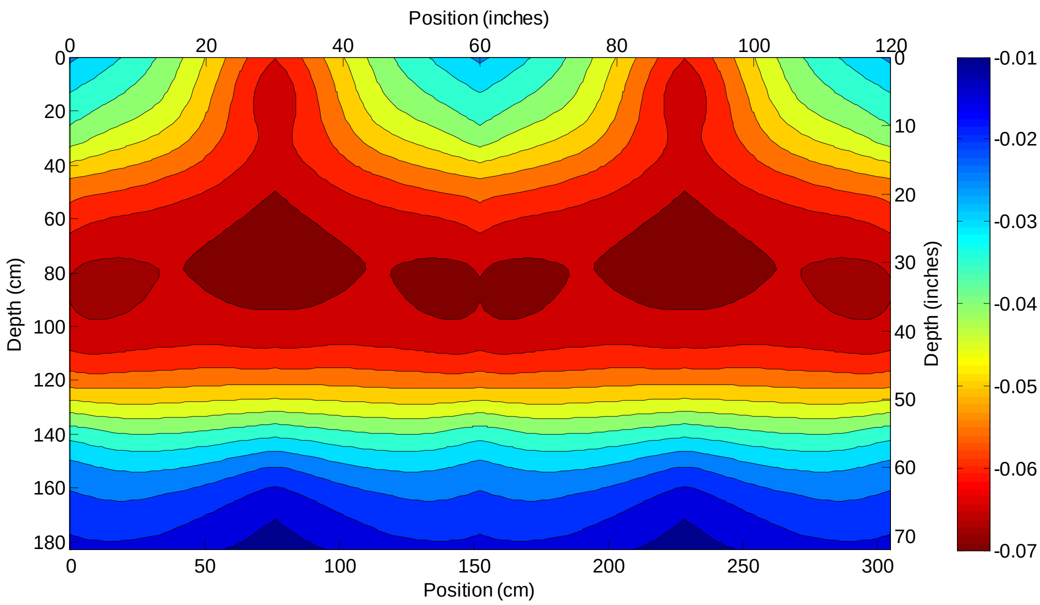

Figure A.239 - Corn early vegetative to harvest change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

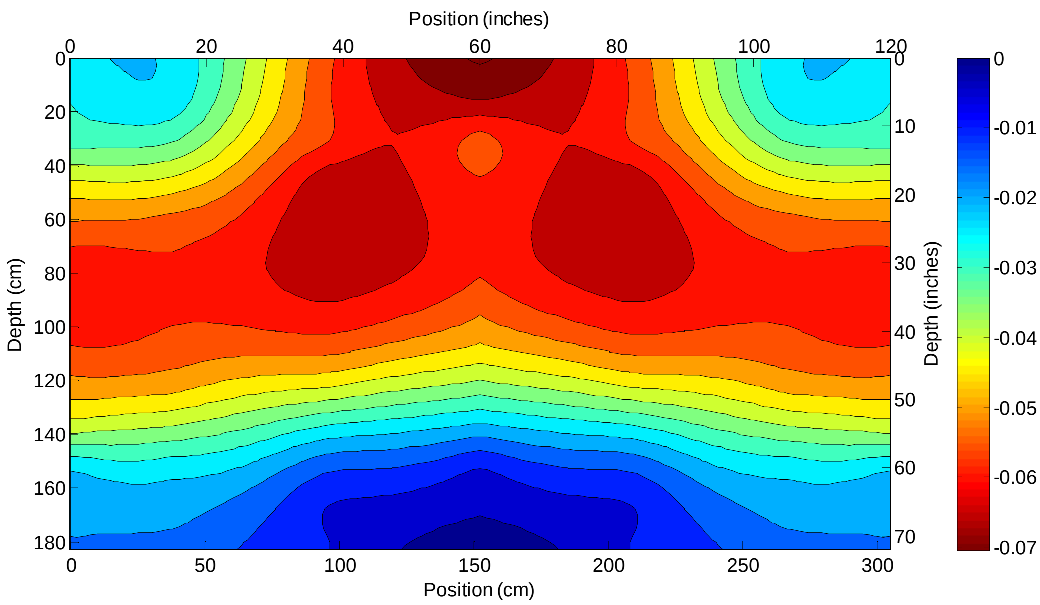

Figure A.240 - Corn early vegetative to harvest change in soil water content across years, contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

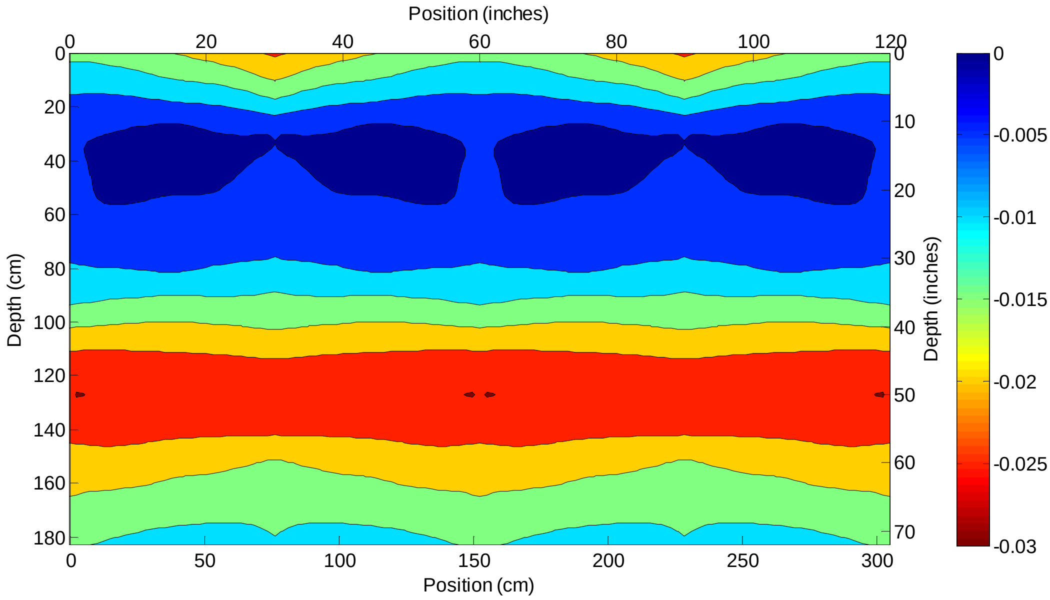

Figure A.241 - Corn tassel-silk to harvest change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

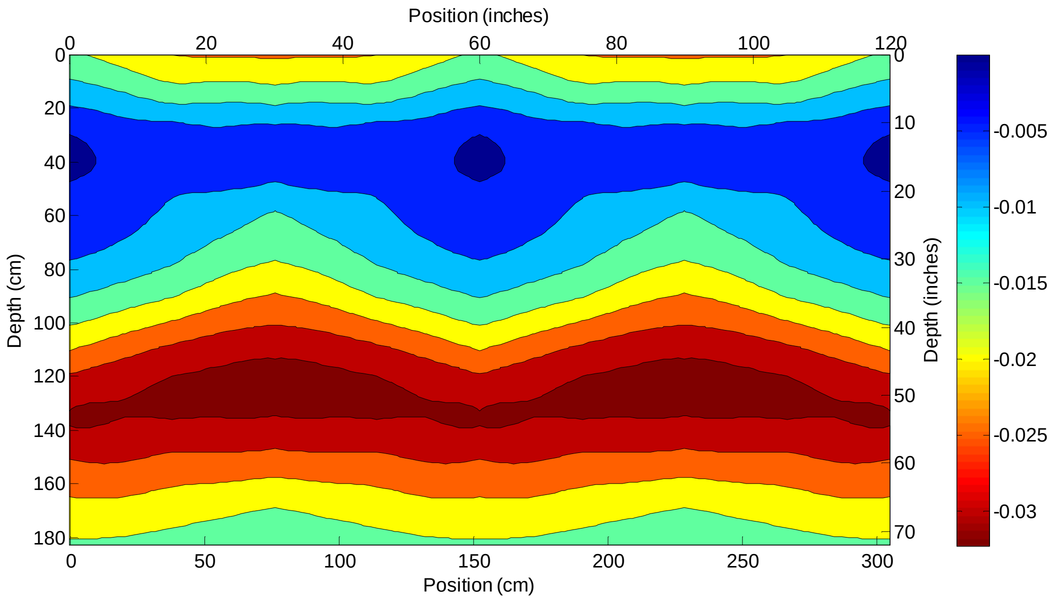

Figure A.242 - Corn tassel-silk to harvest change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

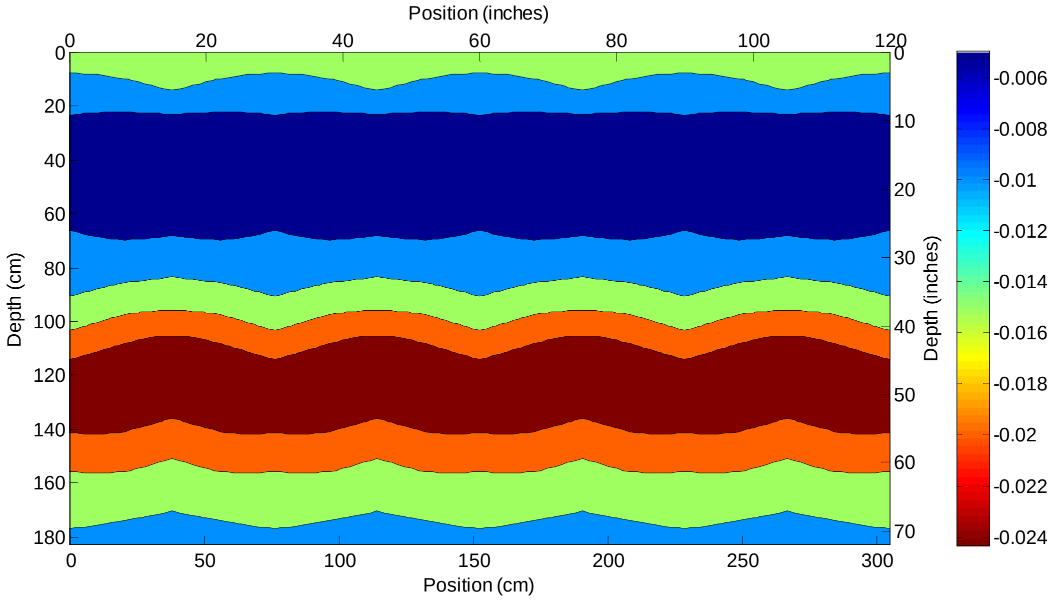

Figure A.243 - Corn tassel-silk to harvest change in soil water content across years, contour step = 0.005 $cm^3\,cm^{-3}$, conventional geometry.

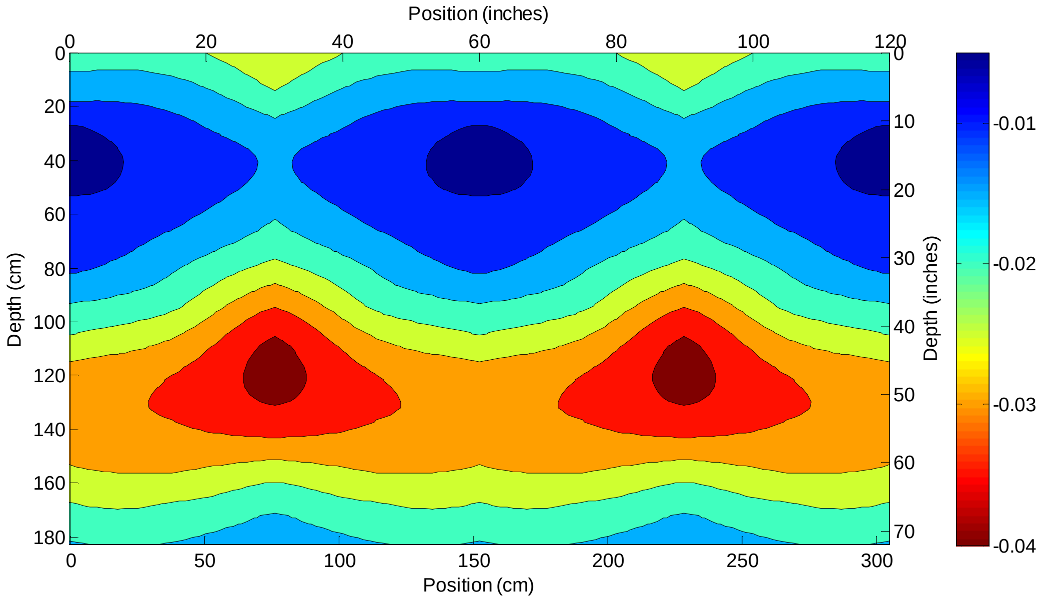

Figure A.244 - Corn tassel-silk to harvest change in soil water content across years, contour step = 0.005 $cm^3\,cm^{-3}$, P1S1 geometry.

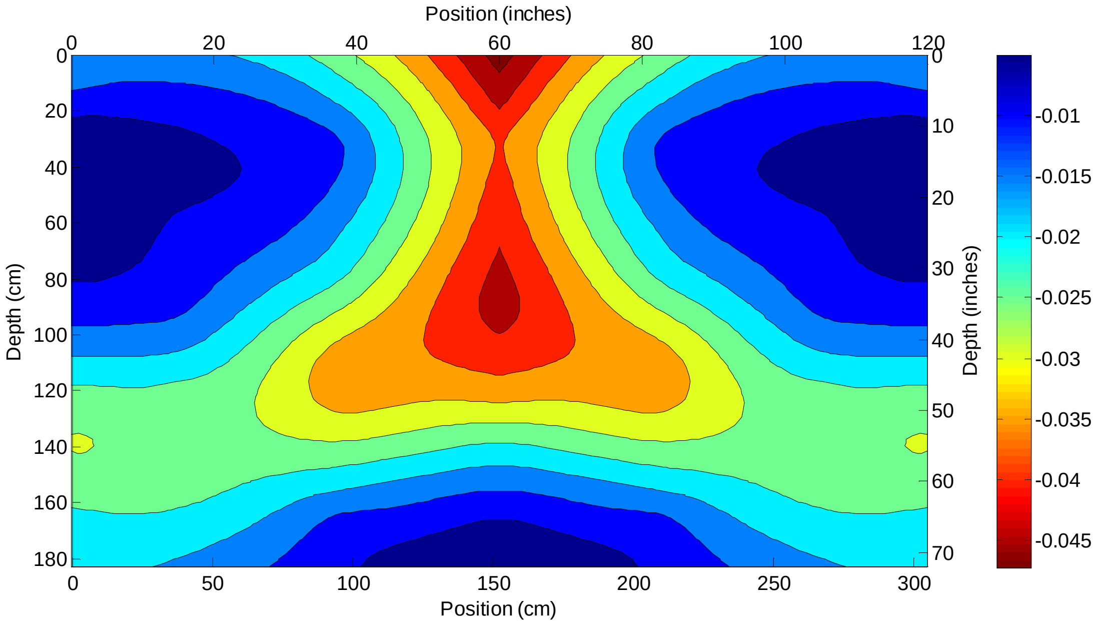

Figure A.245 - Corn tassel-silk to harvest change in soil water content across years, contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

Appendix B - Grain sorghum supplemental water data

2009 Interpolated soil water content

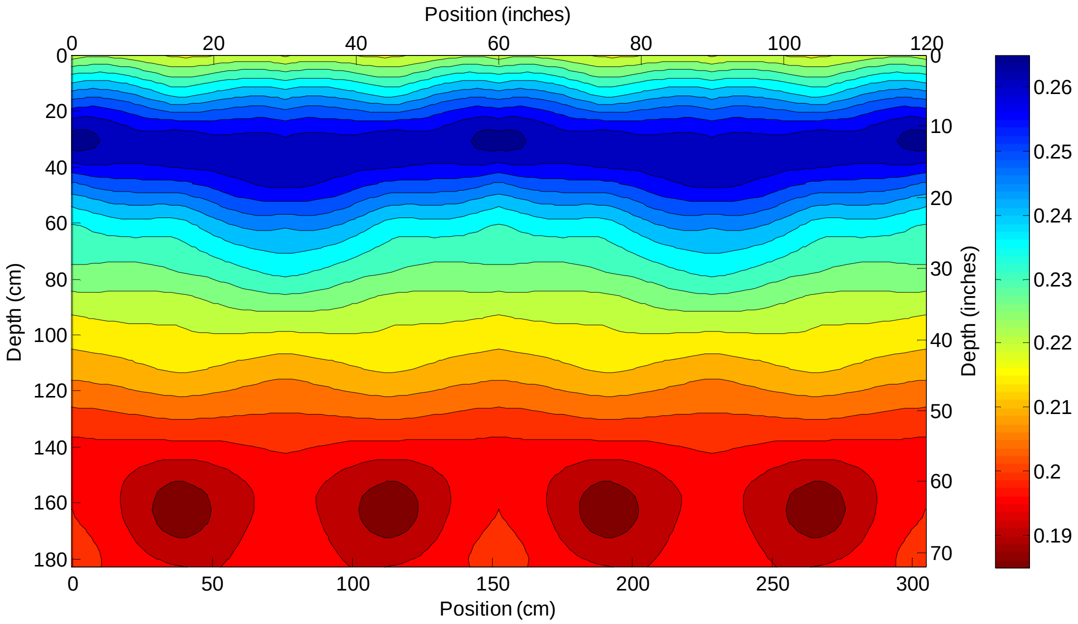

Figure B.1 - 2009 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, clump geometry.

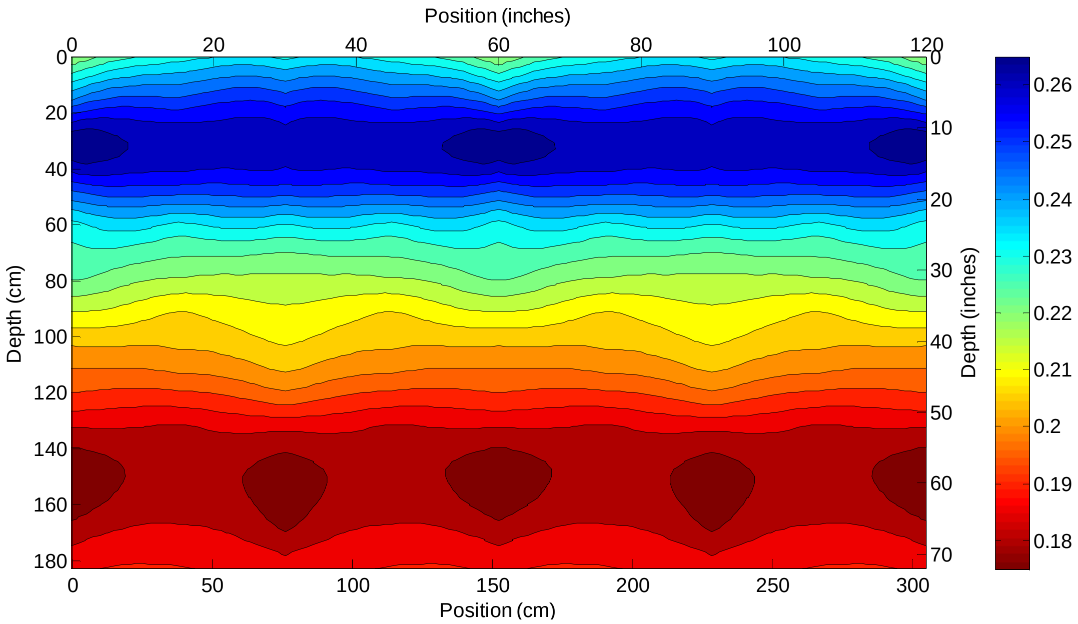

Figure B.2 - 2009 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

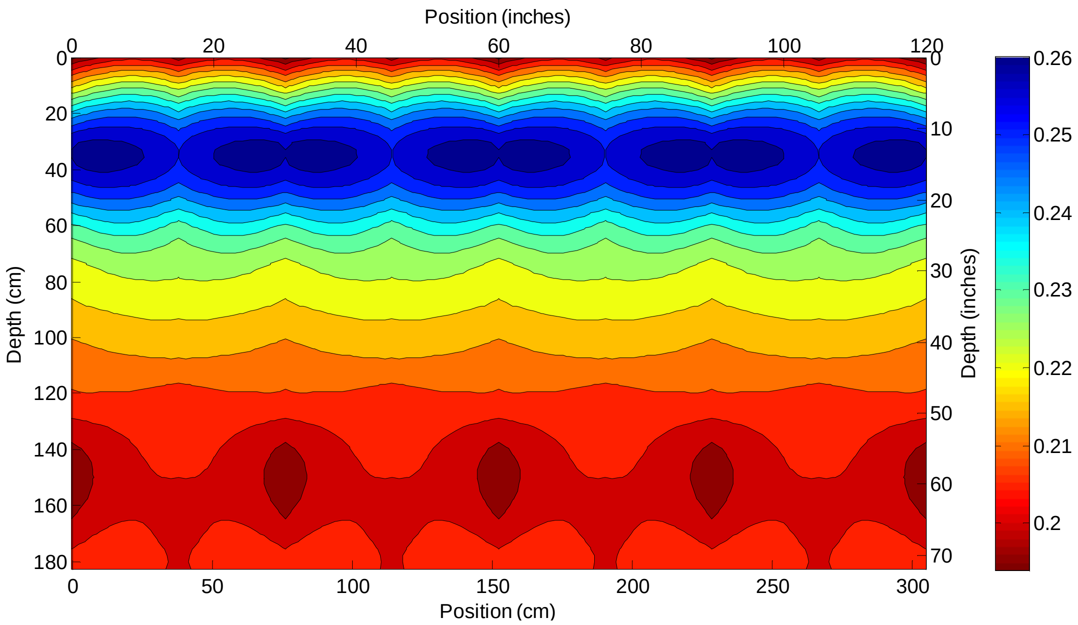

Figure B.3 - 2009 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

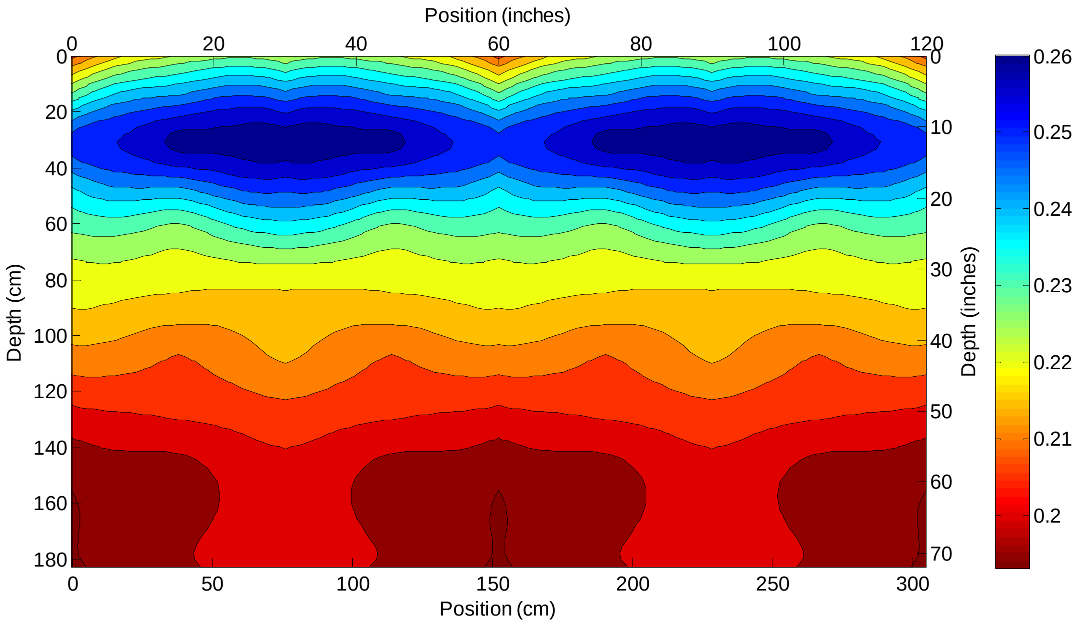

Figure B.4 - 2009 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

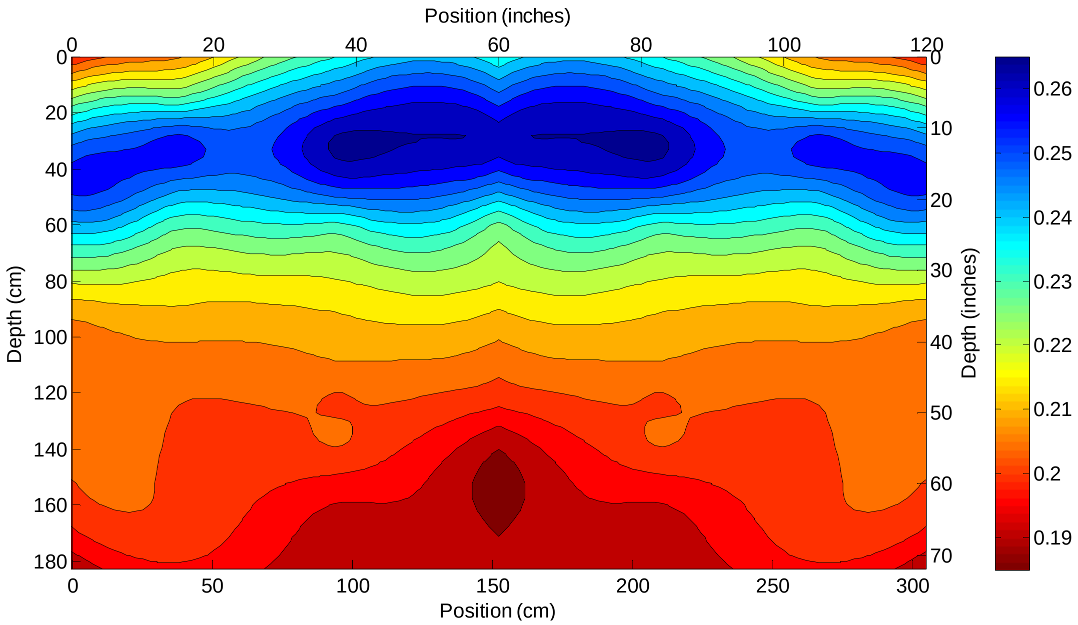

Figure B.5 - 2009 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

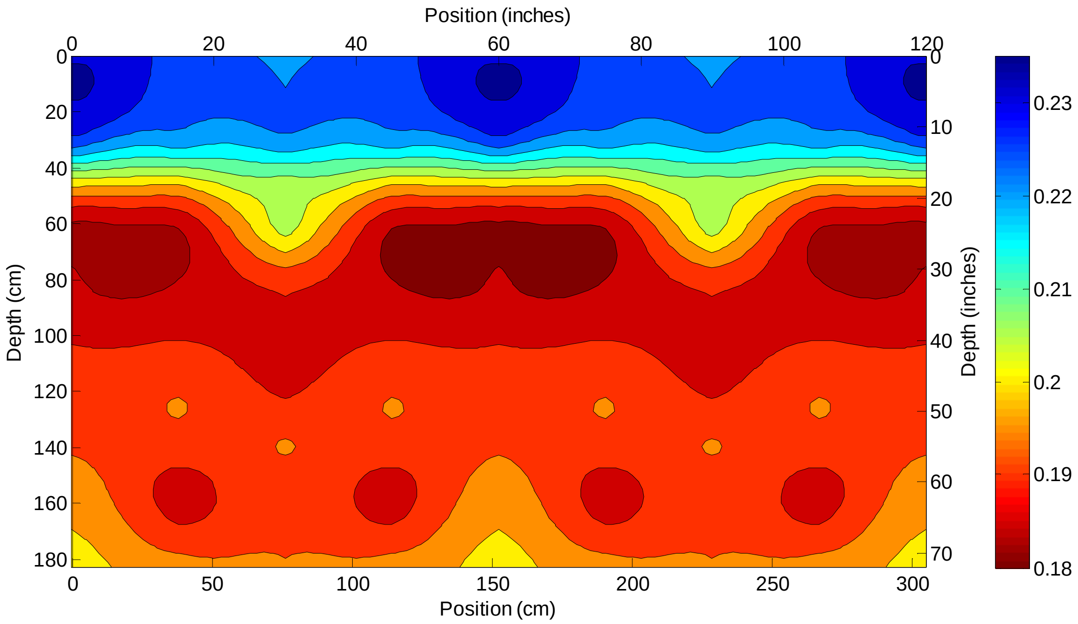

Figure B.6 - 2009 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

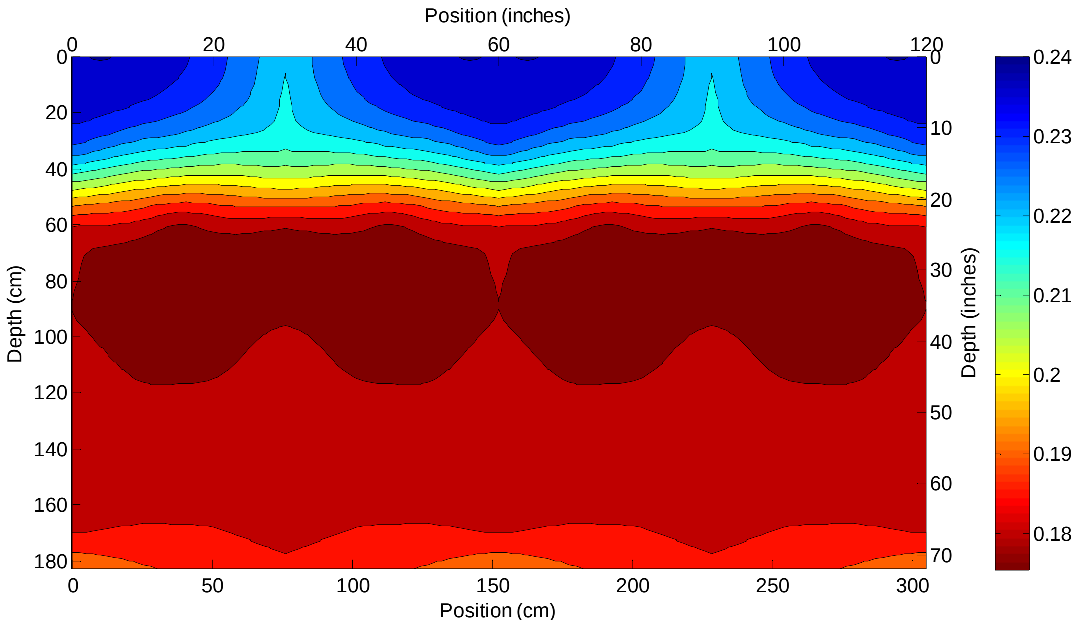

Figure B.7 - 2009 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

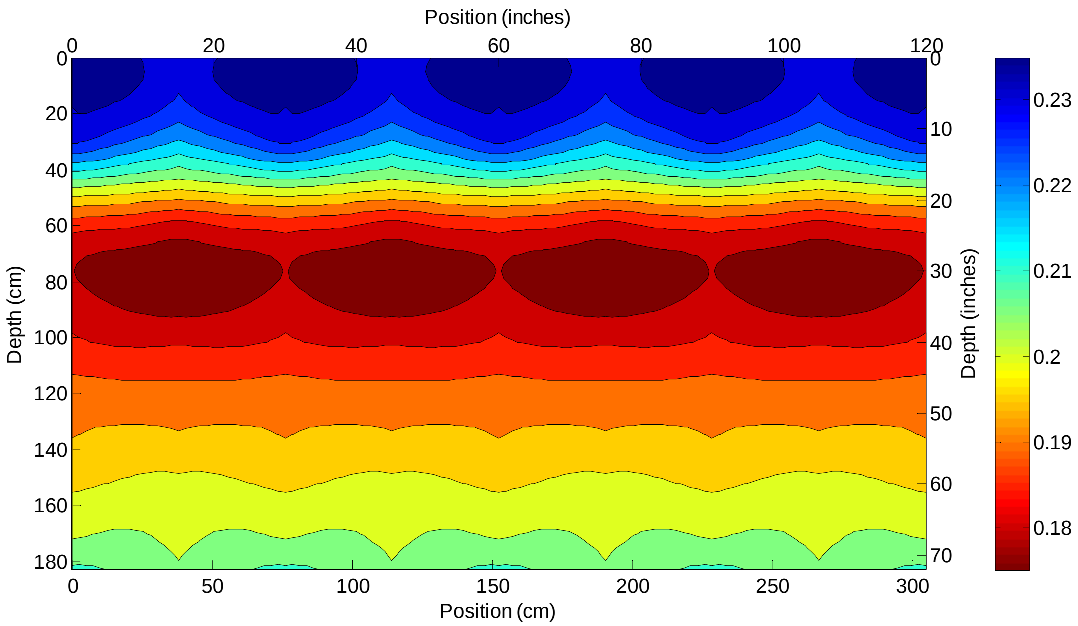

Figure B.8 - 2009 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

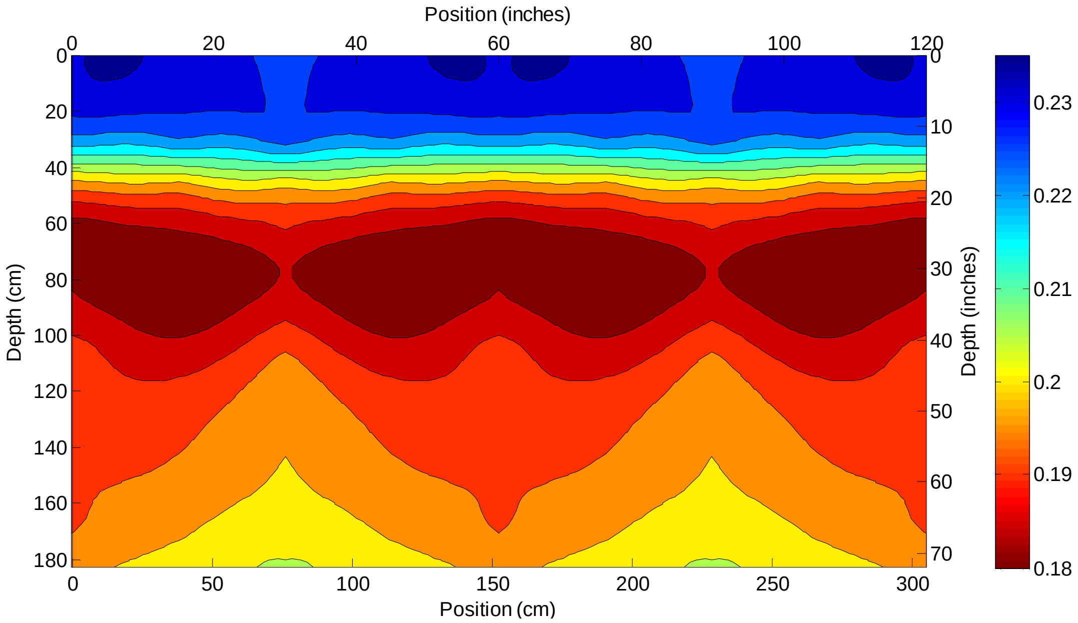

Figure B.9 - 2009 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

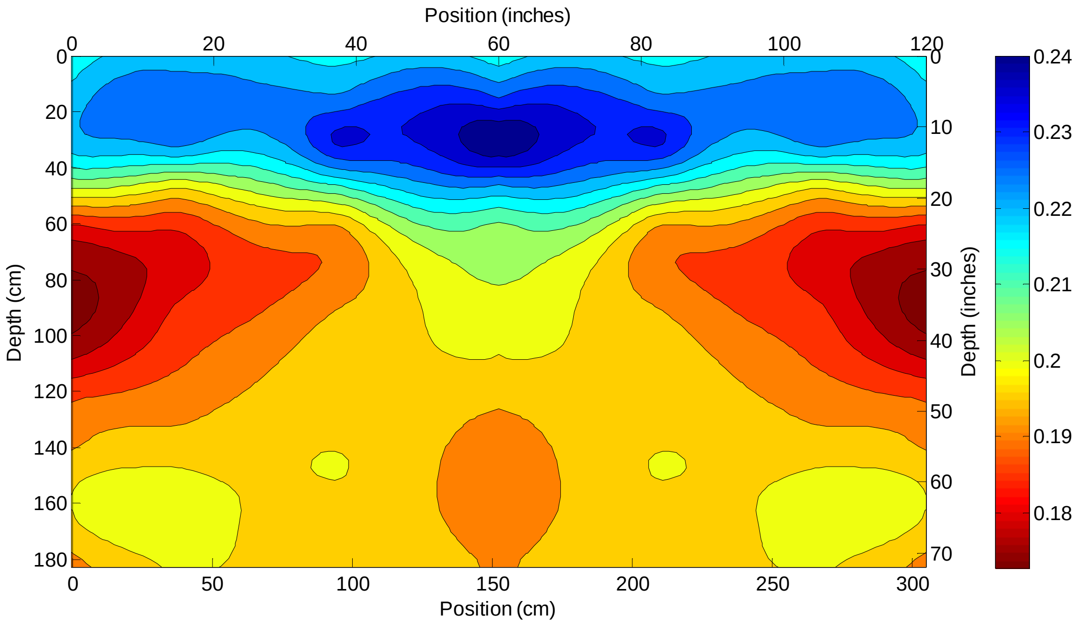

Figure B.10 - 2009 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

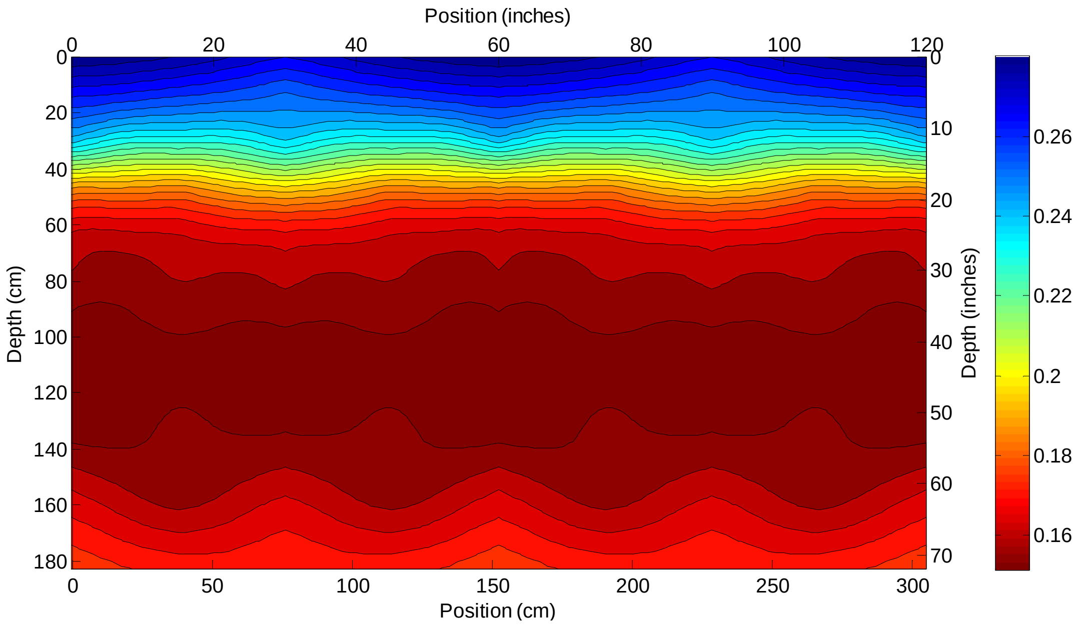

Figure B.11 - 2009 Sorghum harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

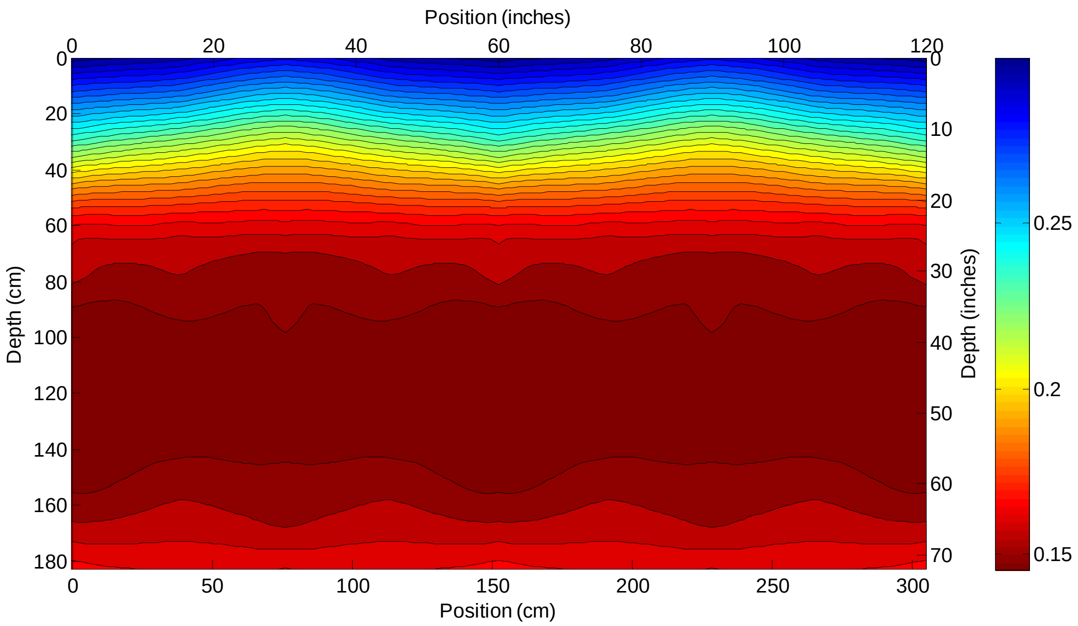

Figure B.12 - 2009 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

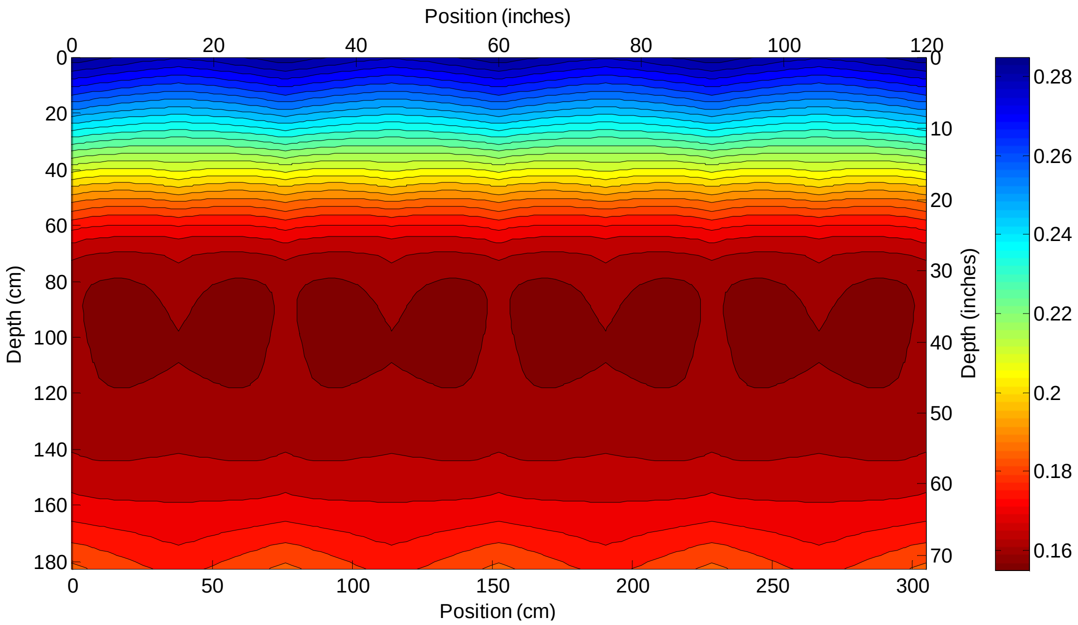

Figure B.13 - 2009 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

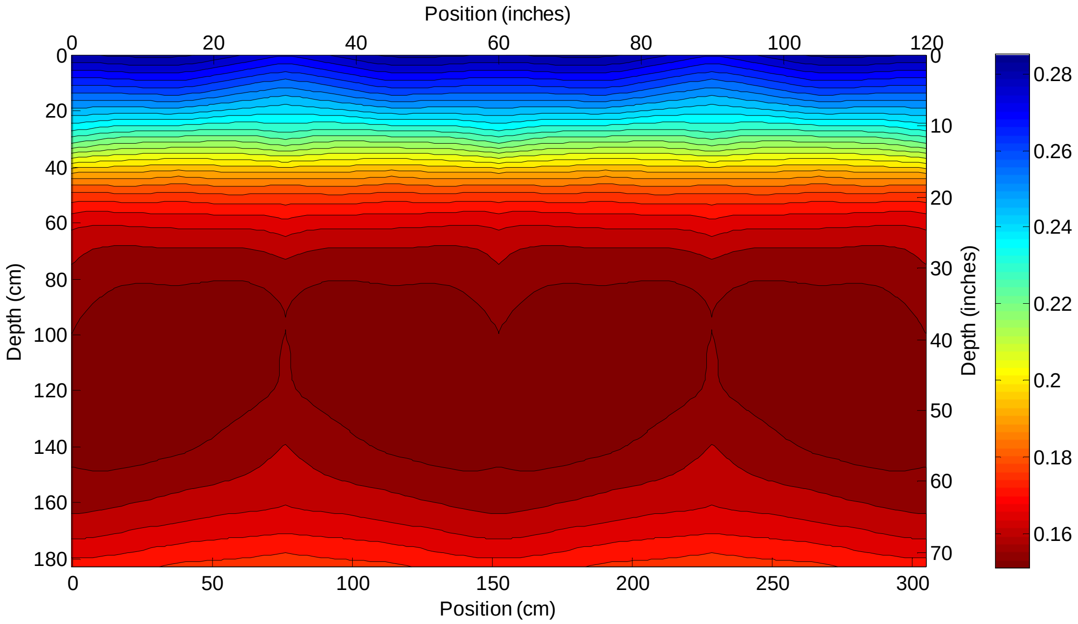

Figure B.14 - 2009 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

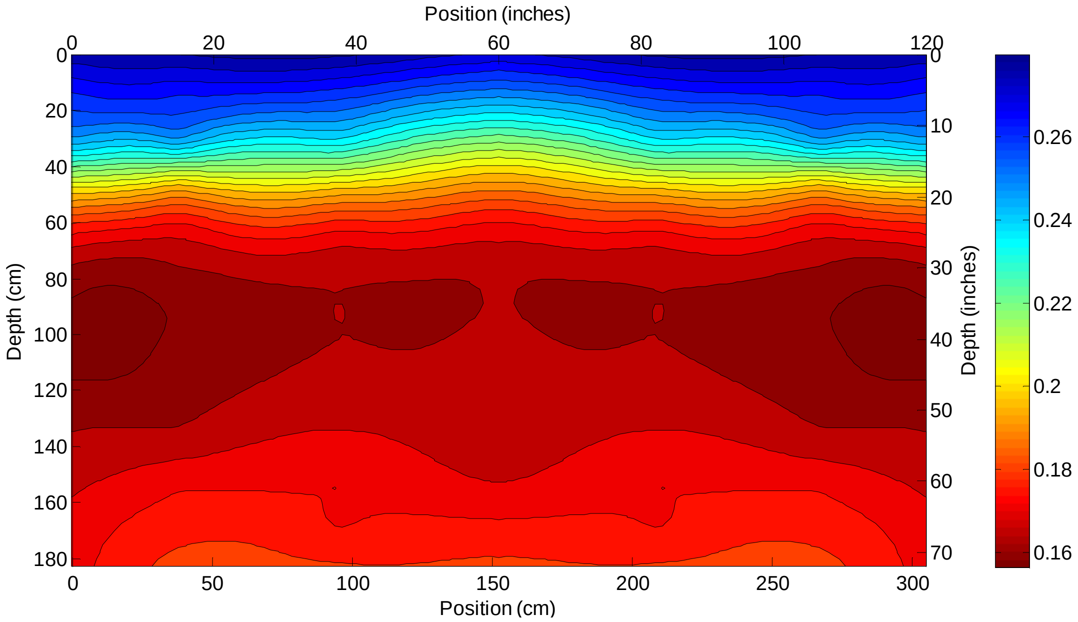

Figure B.15 - 2009 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

2009 Changes in soil water content

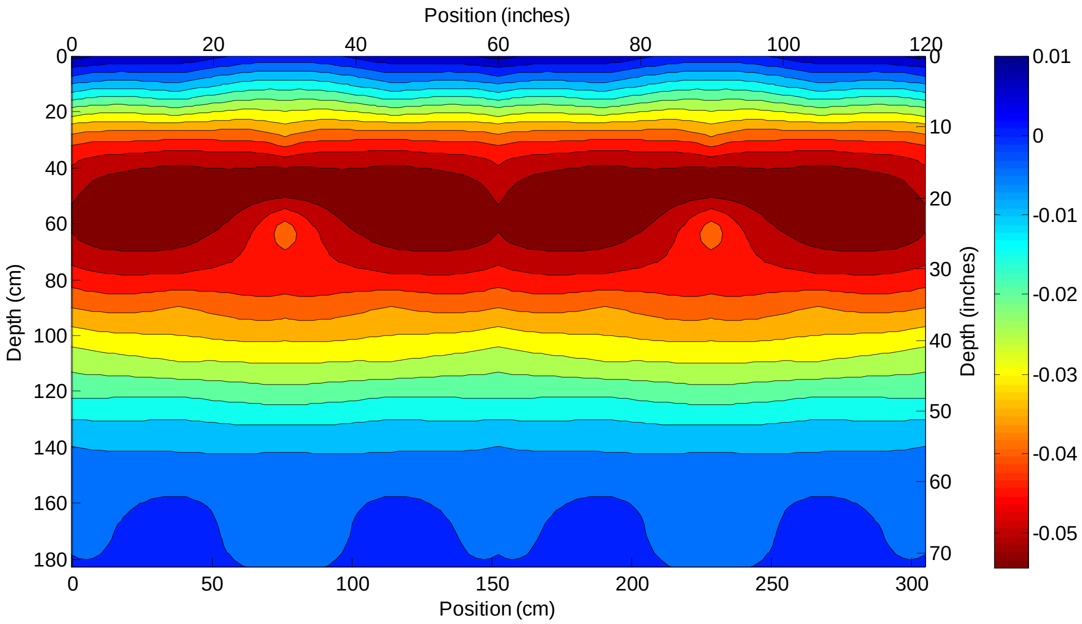

Figure B.16 - 2009 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

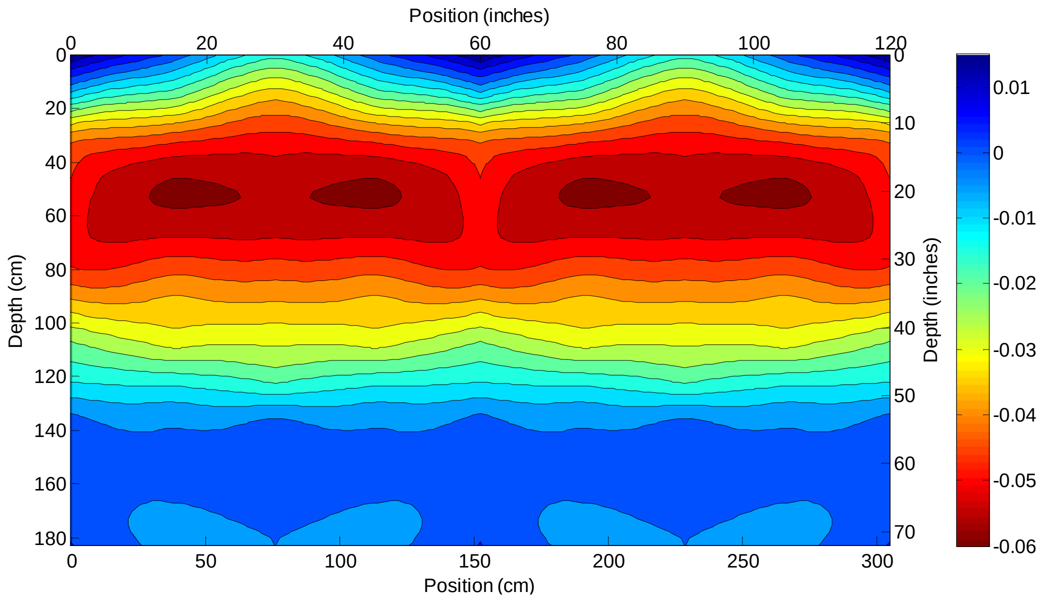

Figure B.17 - 2009 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

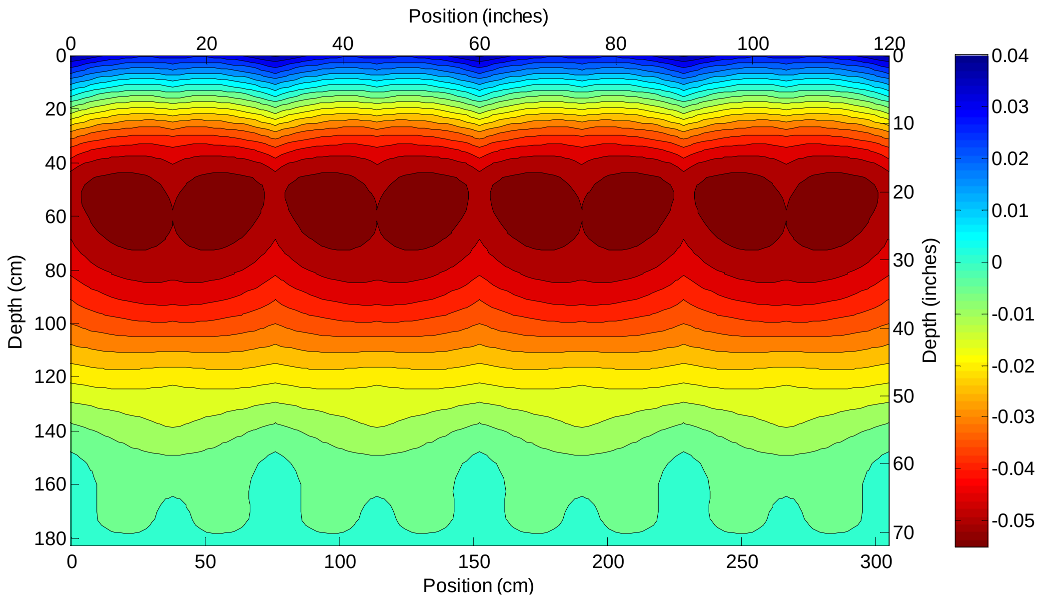

Figure B.18 - 2009 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

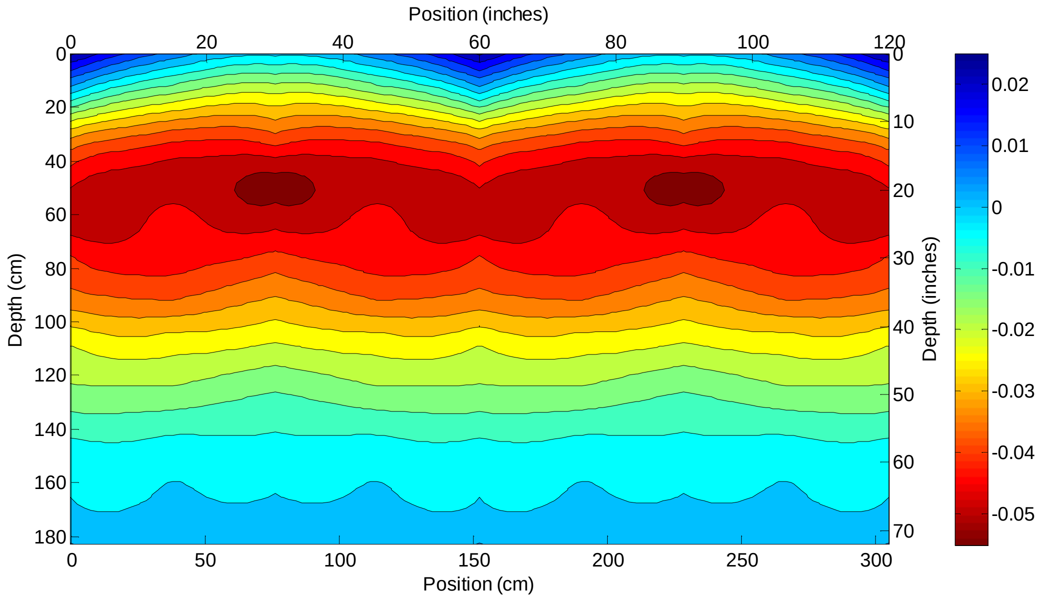

Figure B.19 - 2009 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

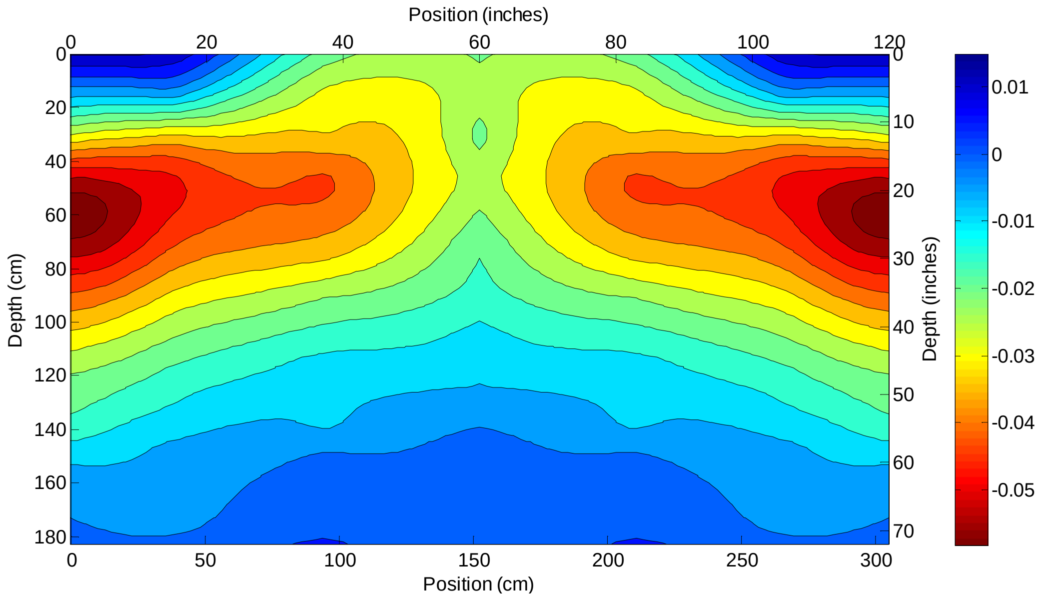

Figure B.20 - 2009 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

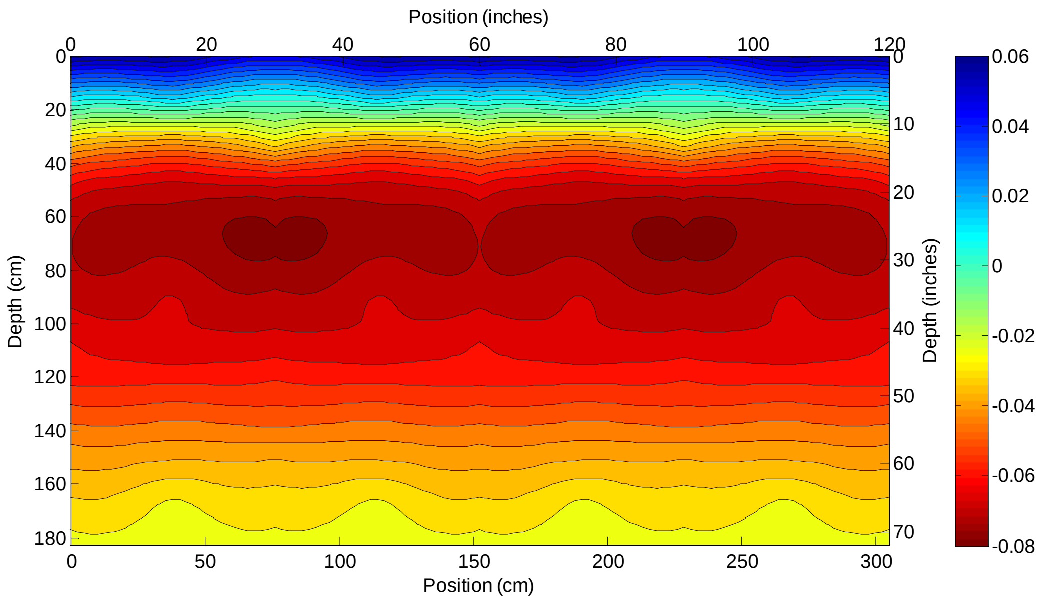

Figure B.21 - 2009 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

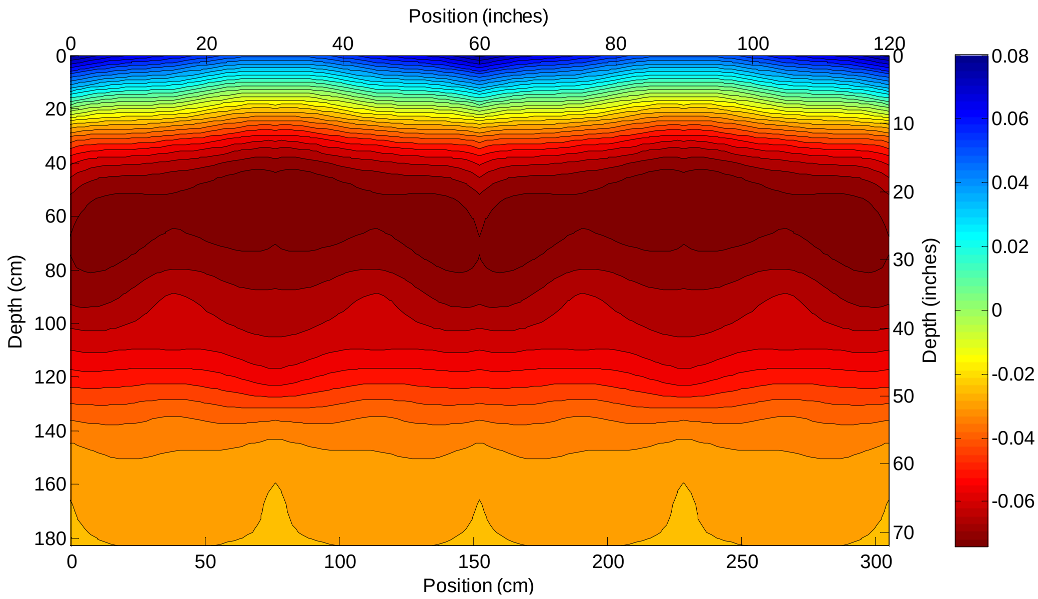

Figure B.22 - 2009 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

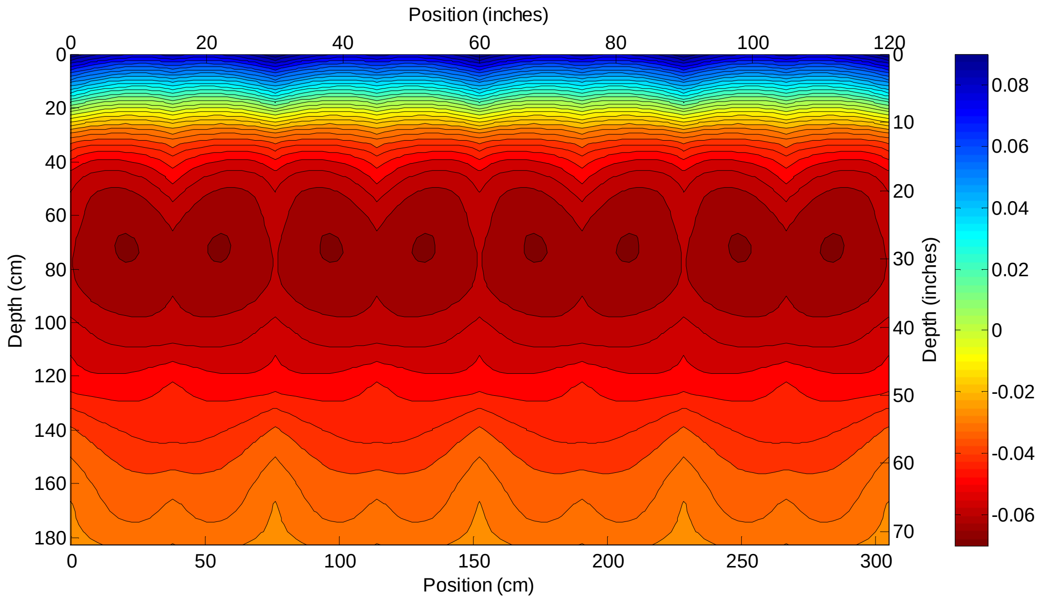

Figure B.23 - 2009 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

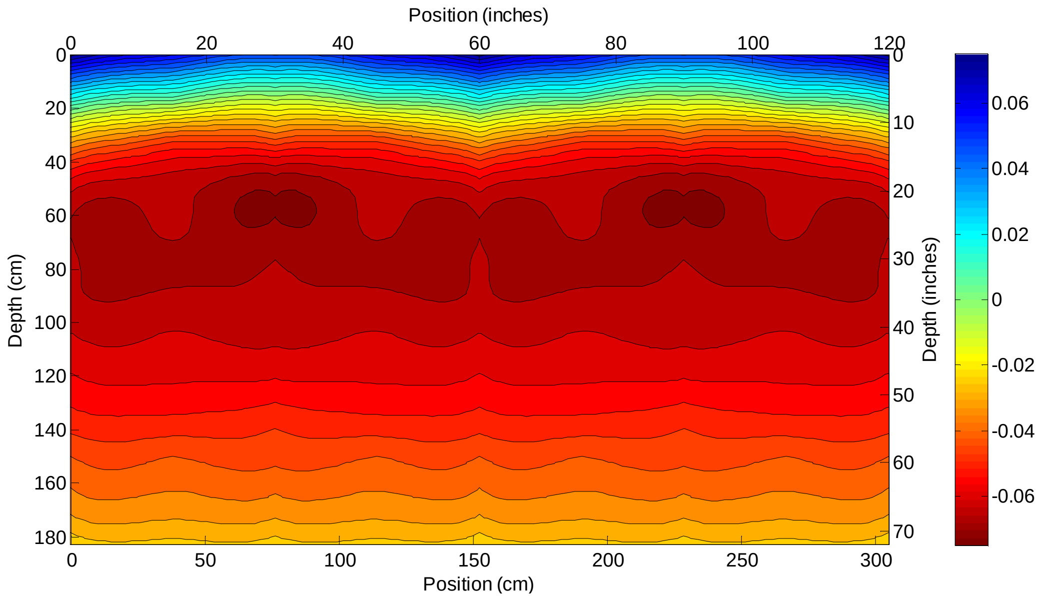

Figure B.24 - 2009 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

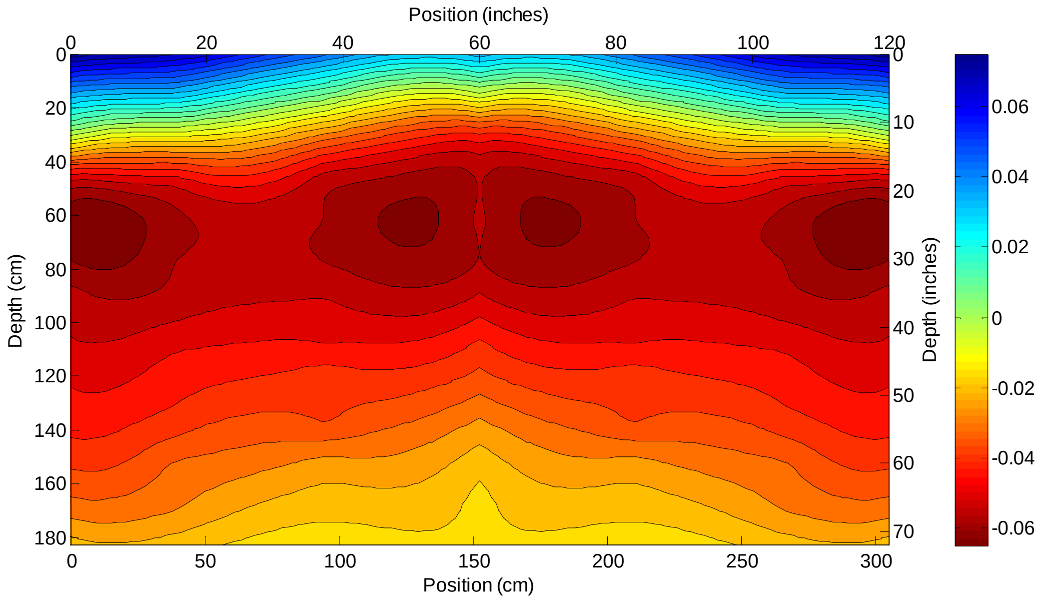

Figure B.25 - 2009 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

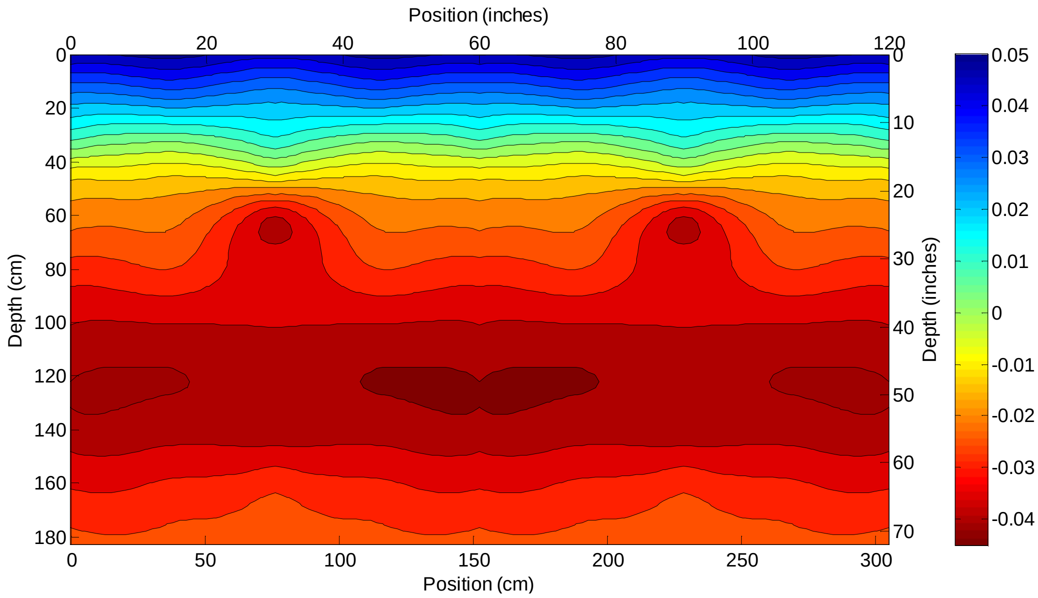

Figure B.26 - 2009 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

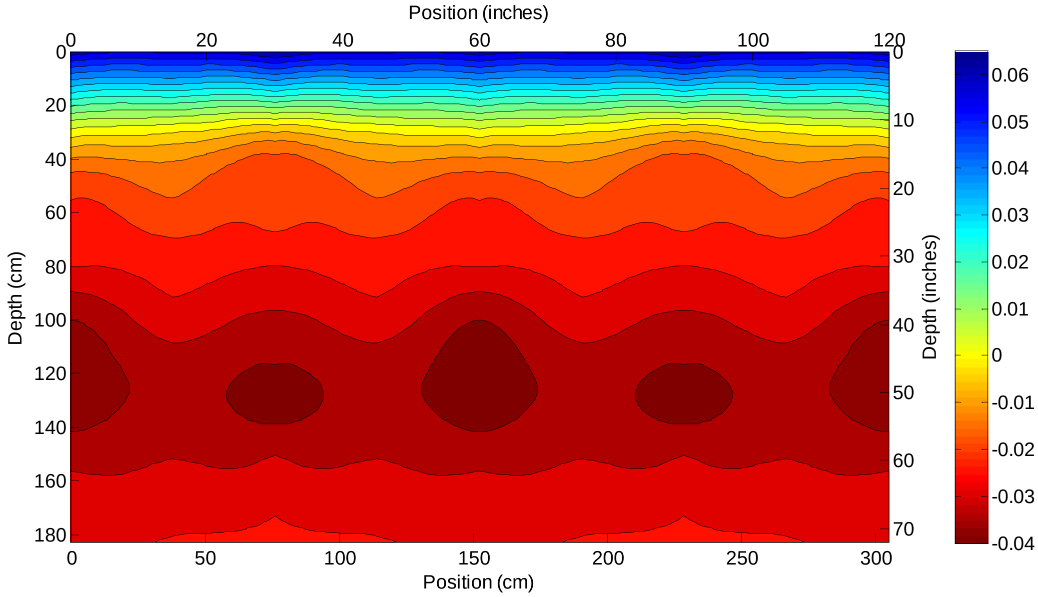

Figure B.27 - 2009 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

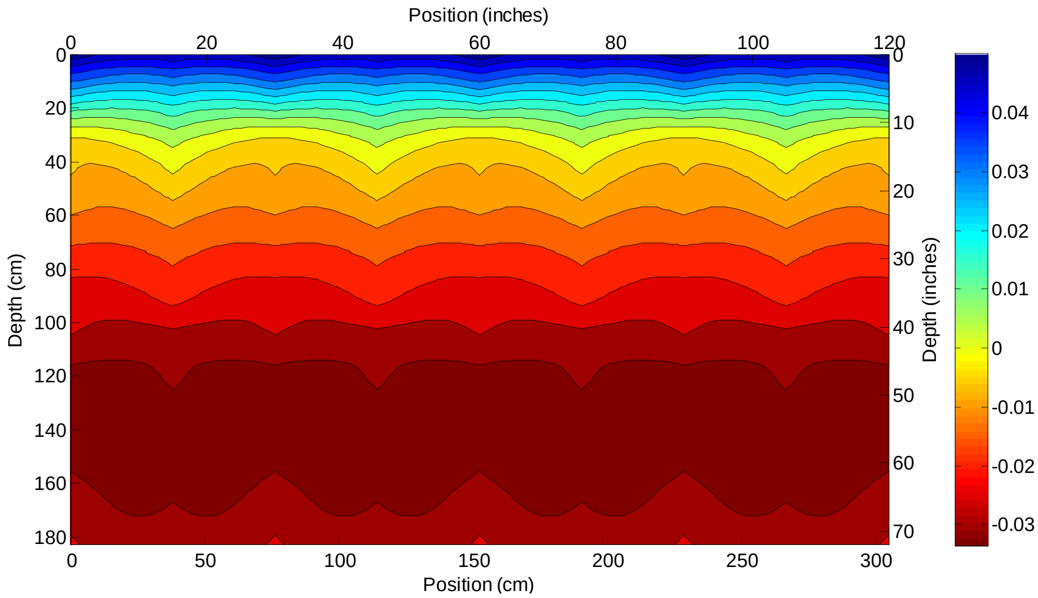

Figure B.28 - 2009 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

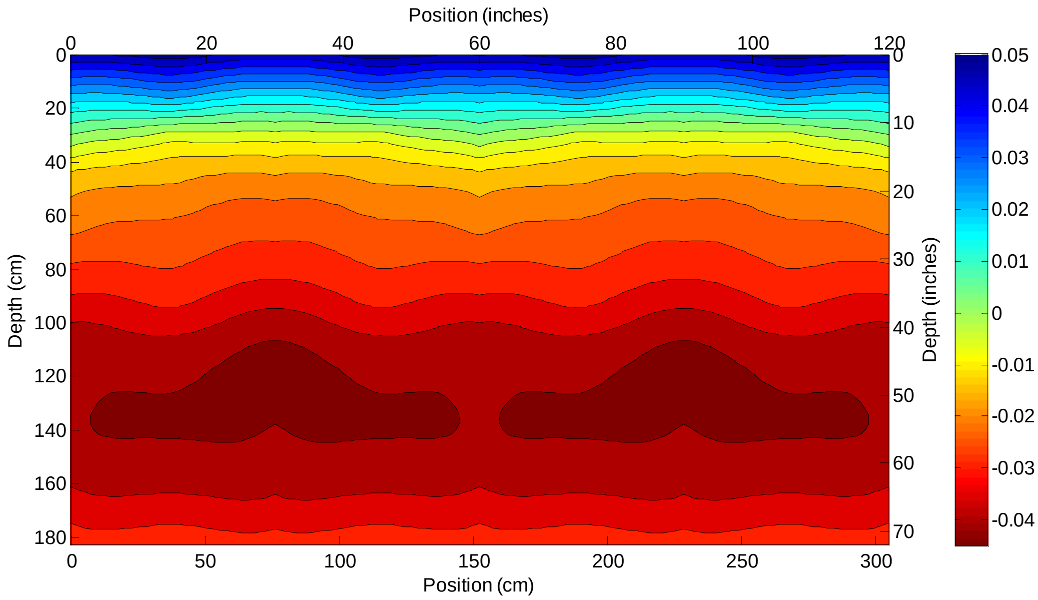

Figure B.29 - 2009 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

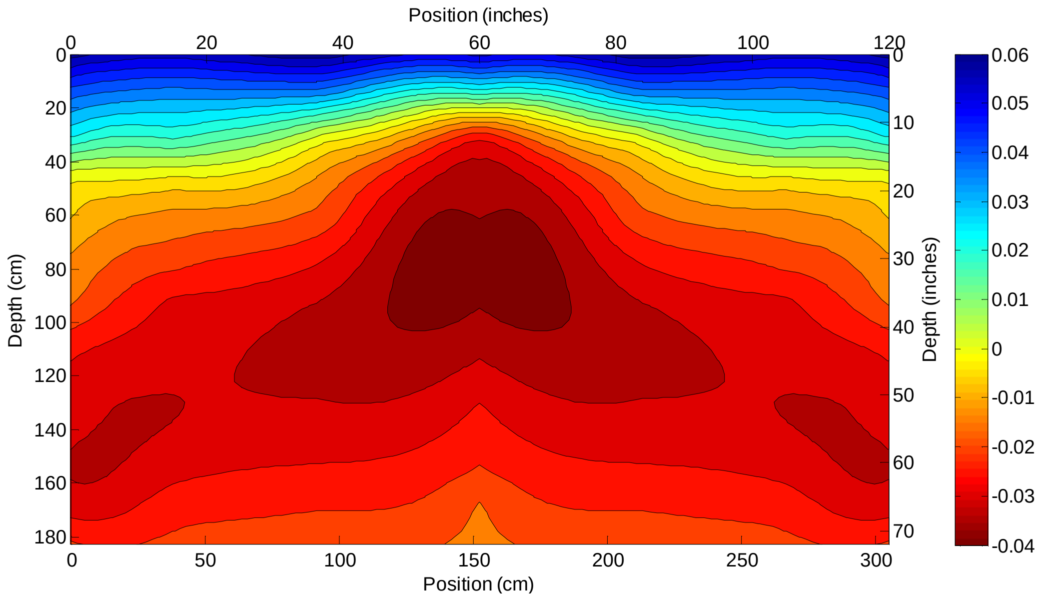

Figure B.30 - 2009 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

2010 Interpolated soil water content

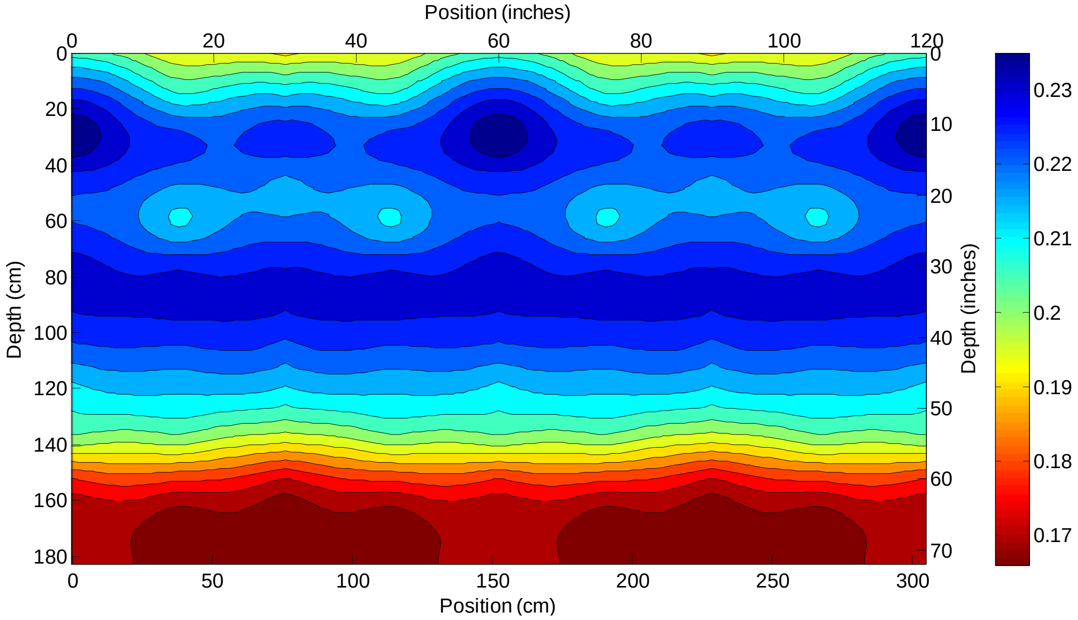

Figure B.31 - 2010 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, clump geometry.

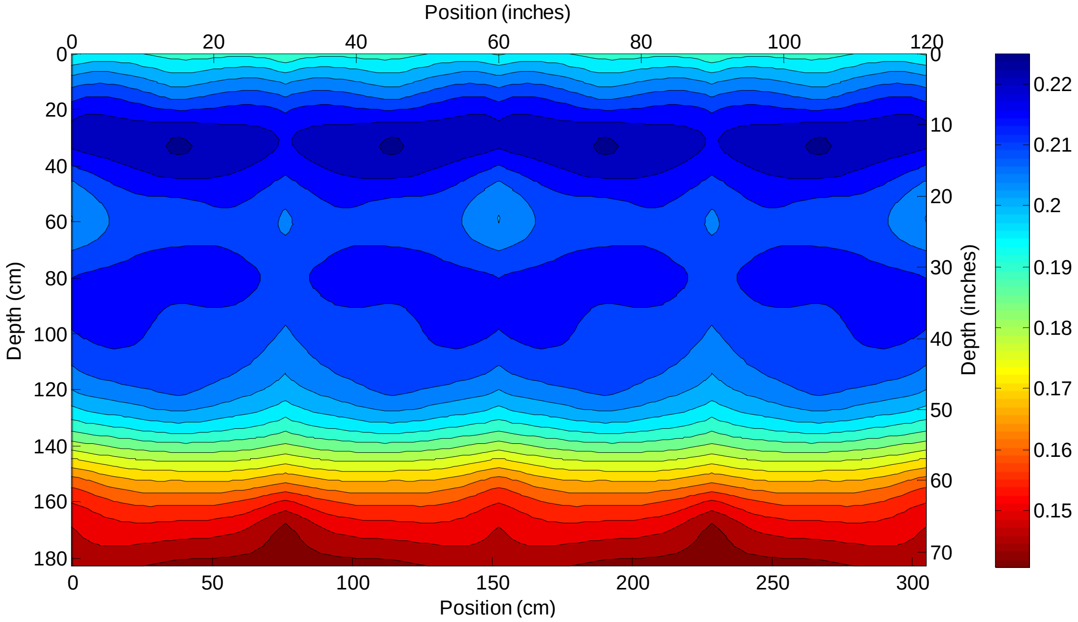

Figure B.32 - 2010 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

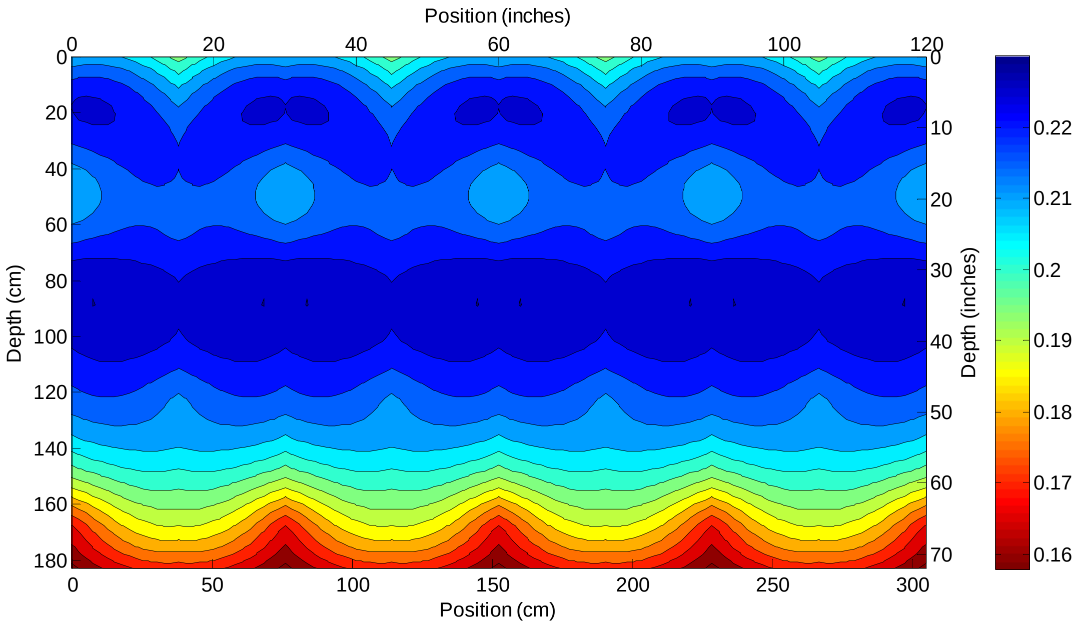

Figure B.33 - 2010 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

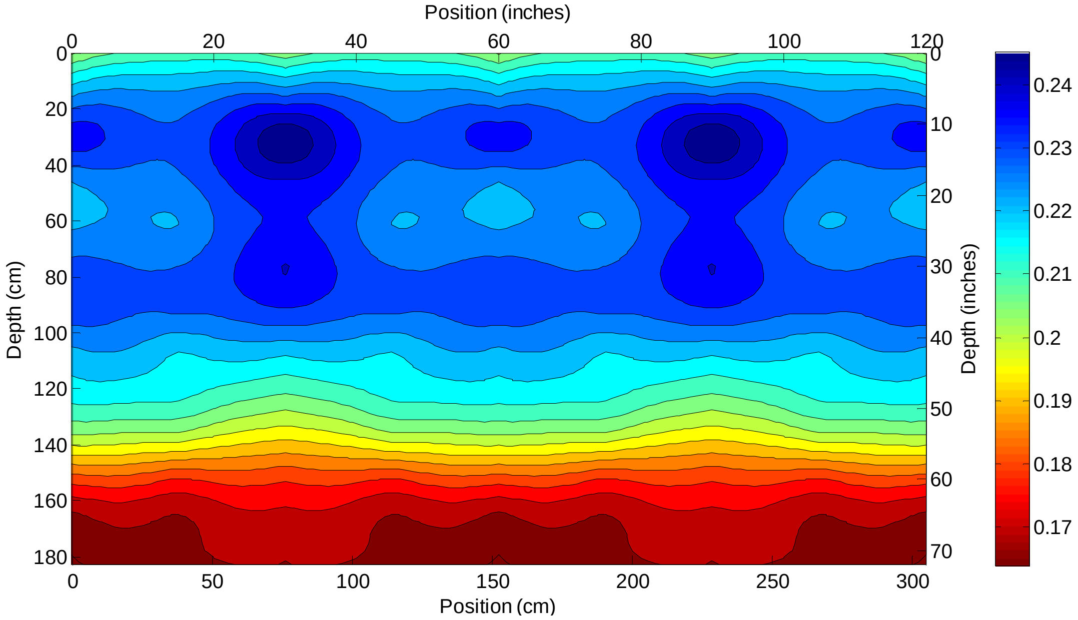

Figure B.34 - 2010 Sorghum early vegetative soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

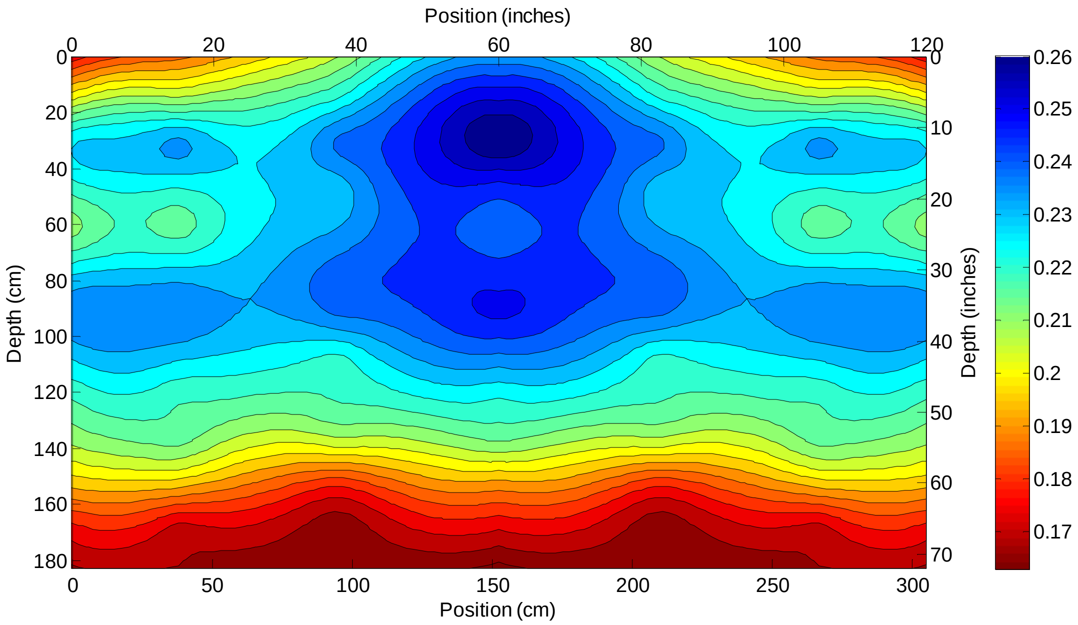

Figure B.35 - 2010 Sorghum early vegetative soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

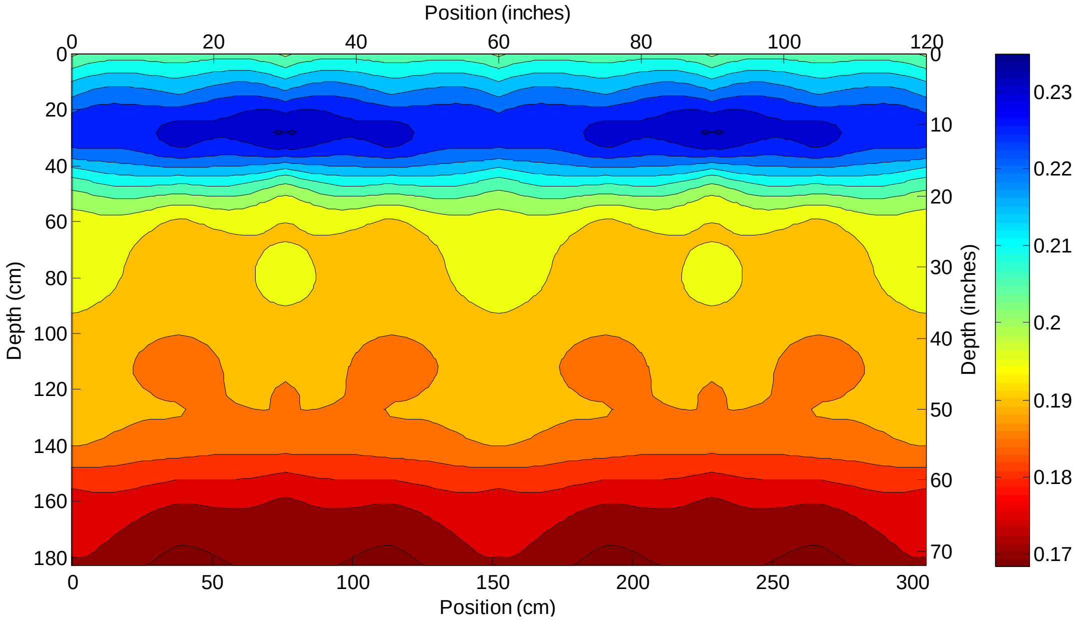

Figure B.36 - 2010 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

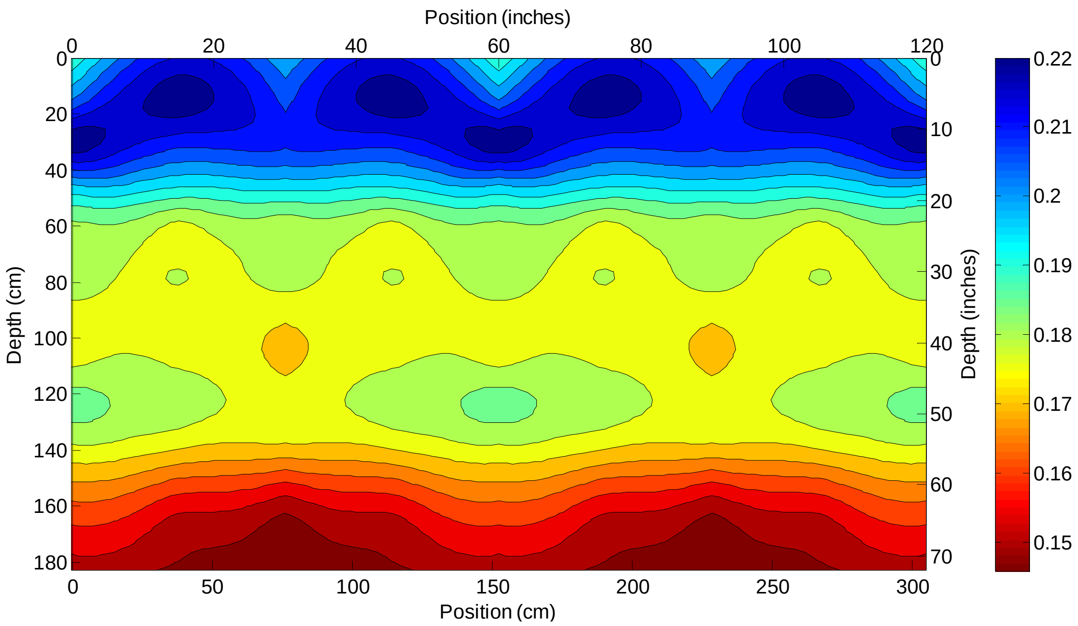

Figure B.37 - 2010 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

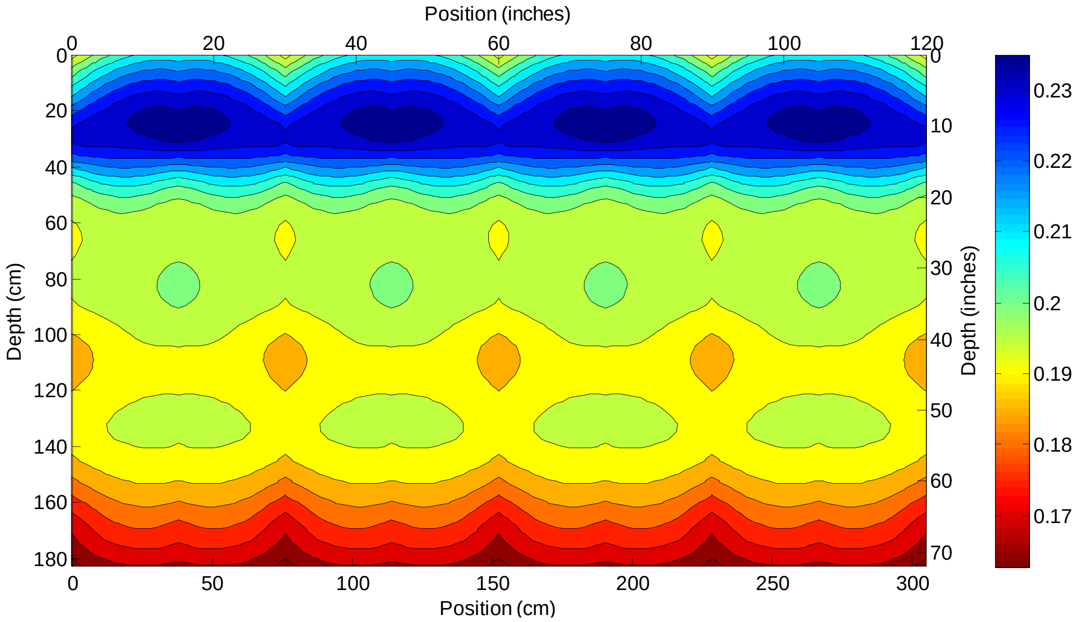

Figure B.38 - 2010 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

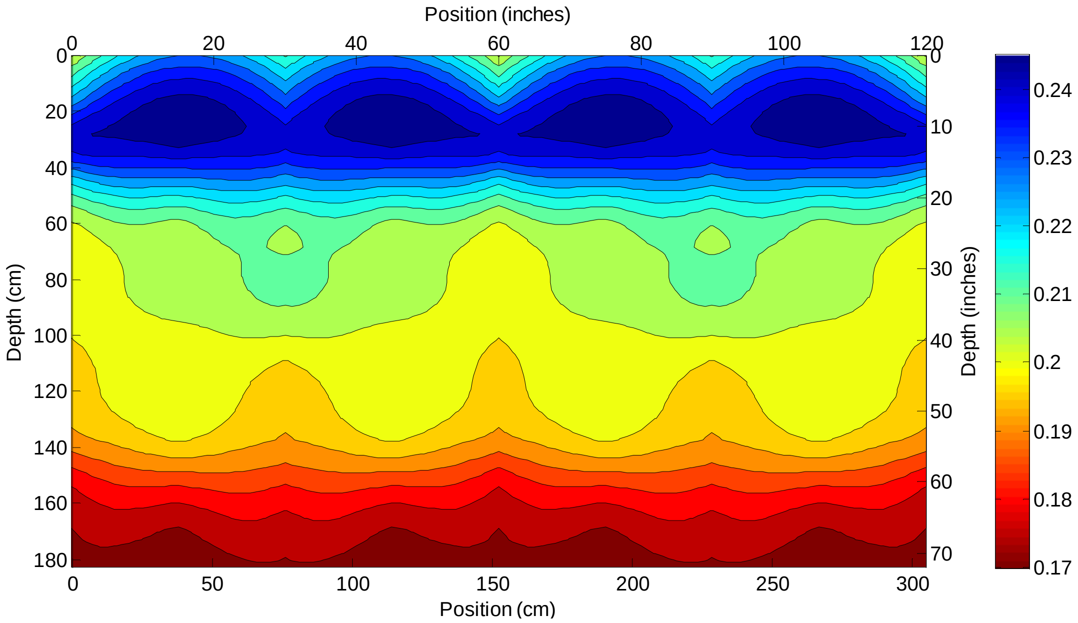

Figure B.39 - 2010 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

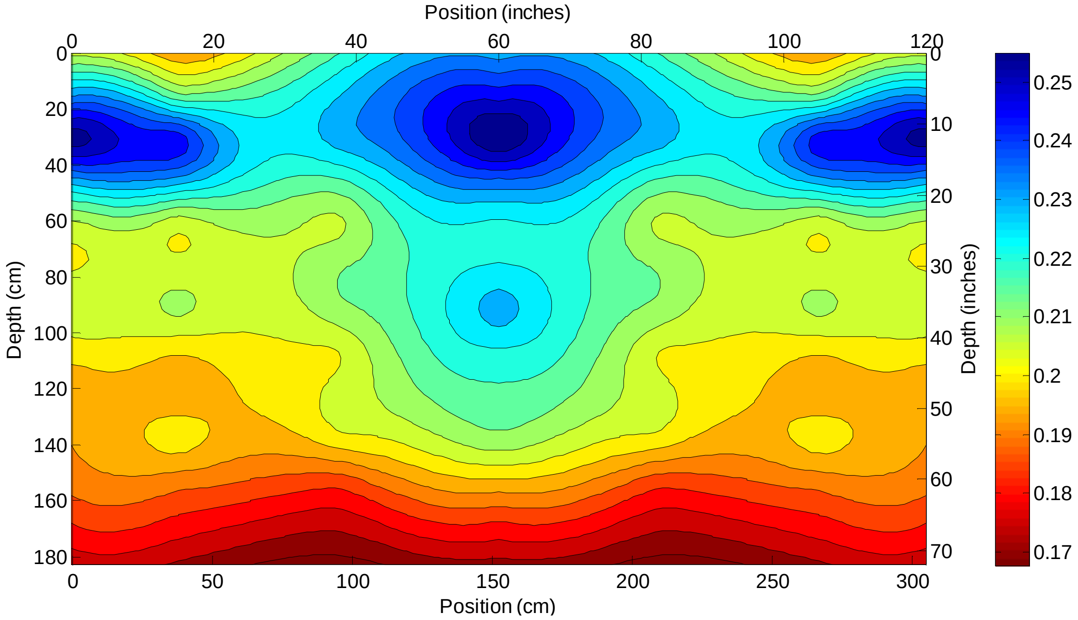

Figure B.40 - 2010 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

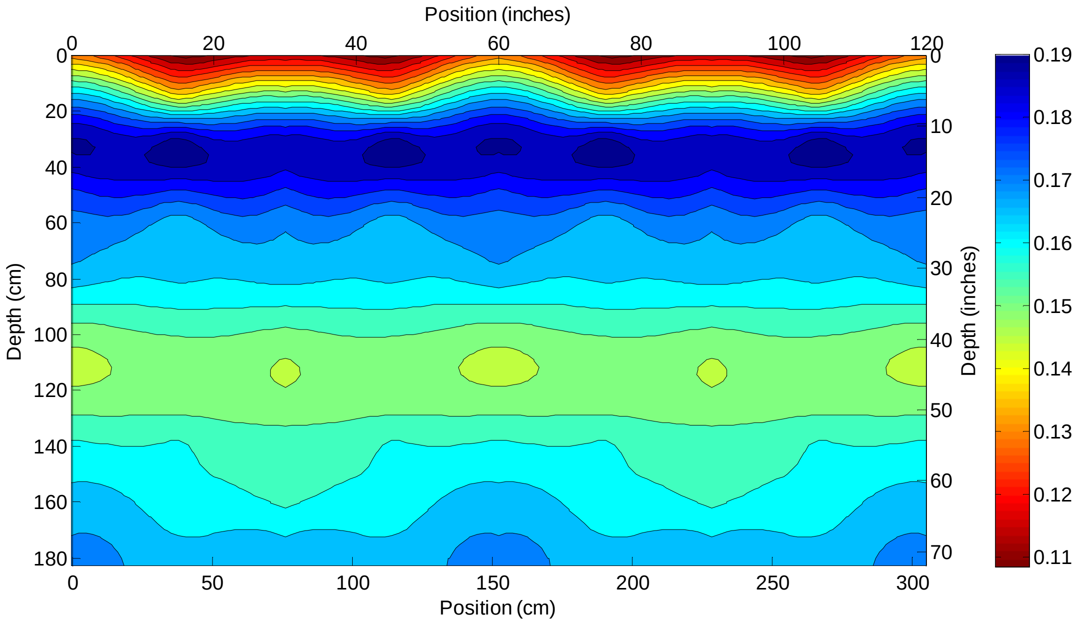

Figure B.41 - 2010 Sorghum harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

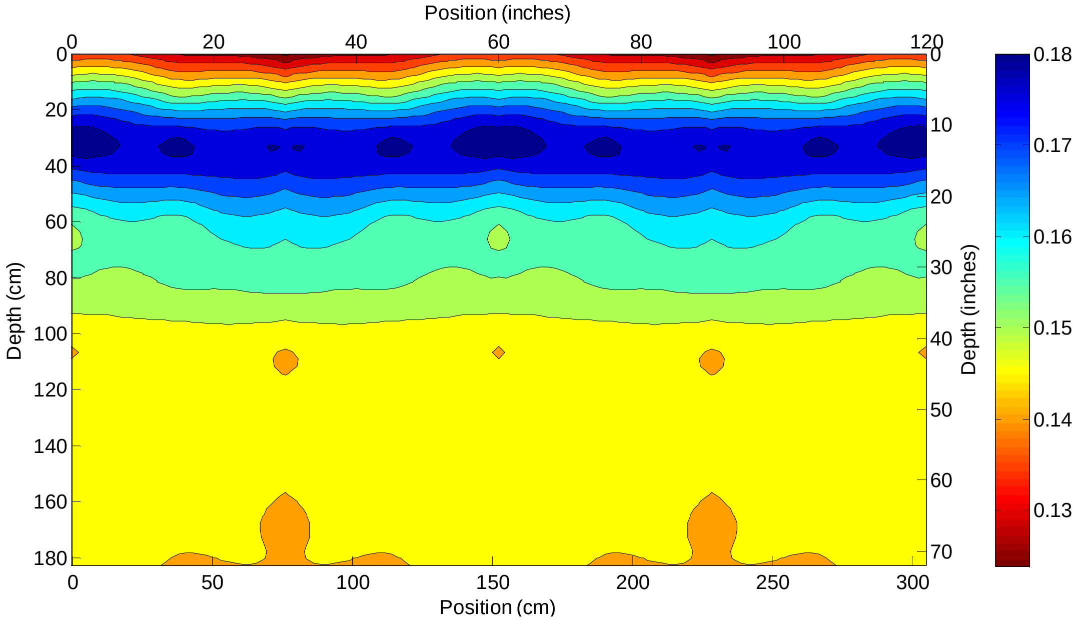

Figure B.42 - 2010 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

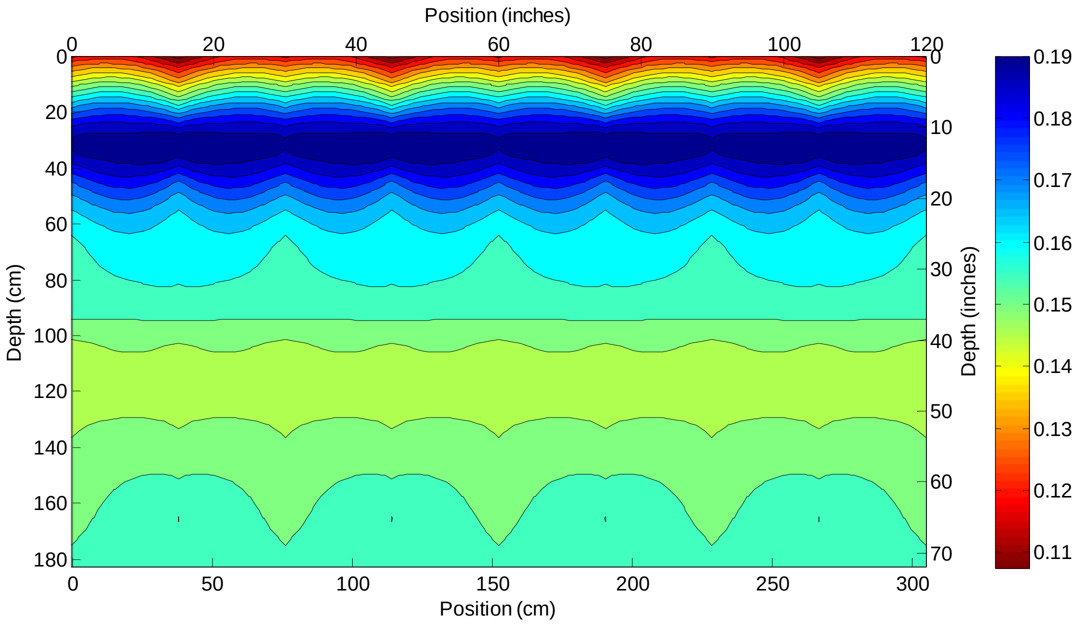

Figure B.43 - 2010 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

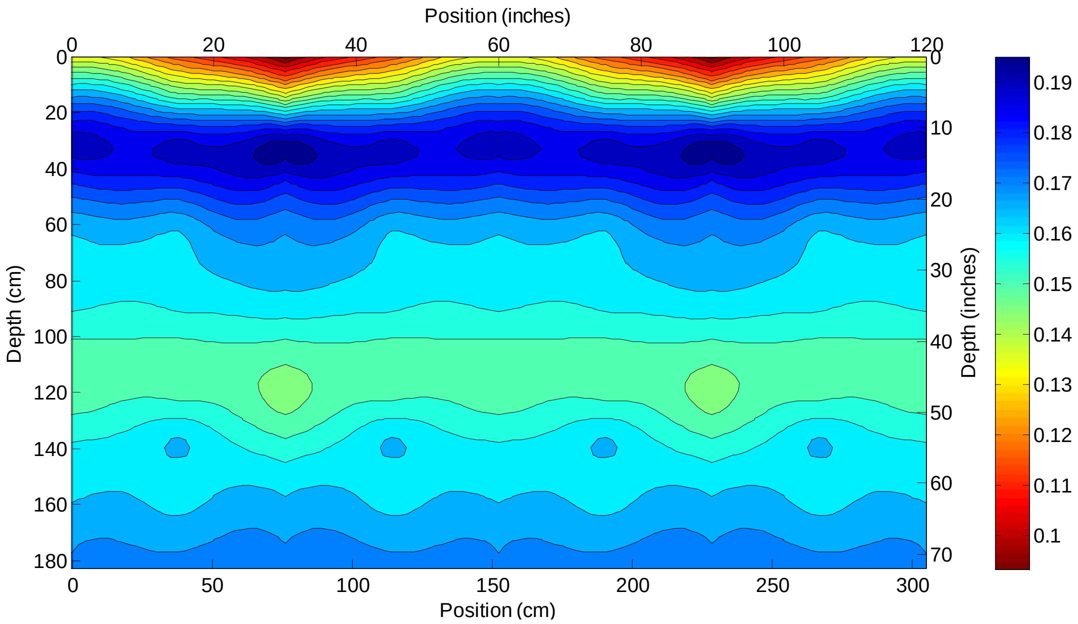

Figure B.44 - 2010 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

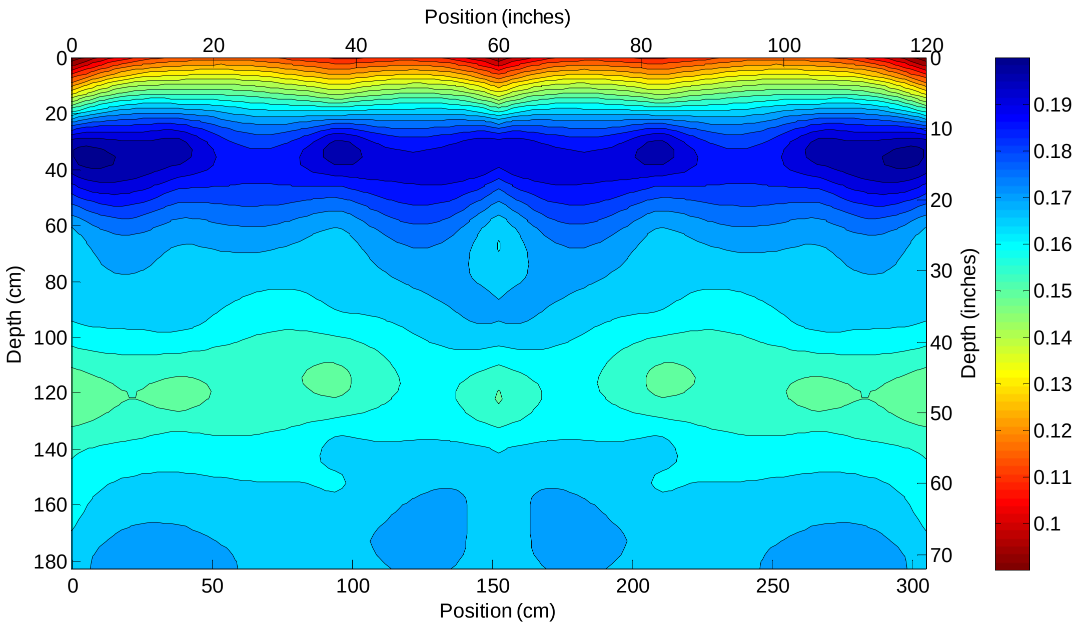

Figure B.45 - 2010 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

2010 Changes in soil water content

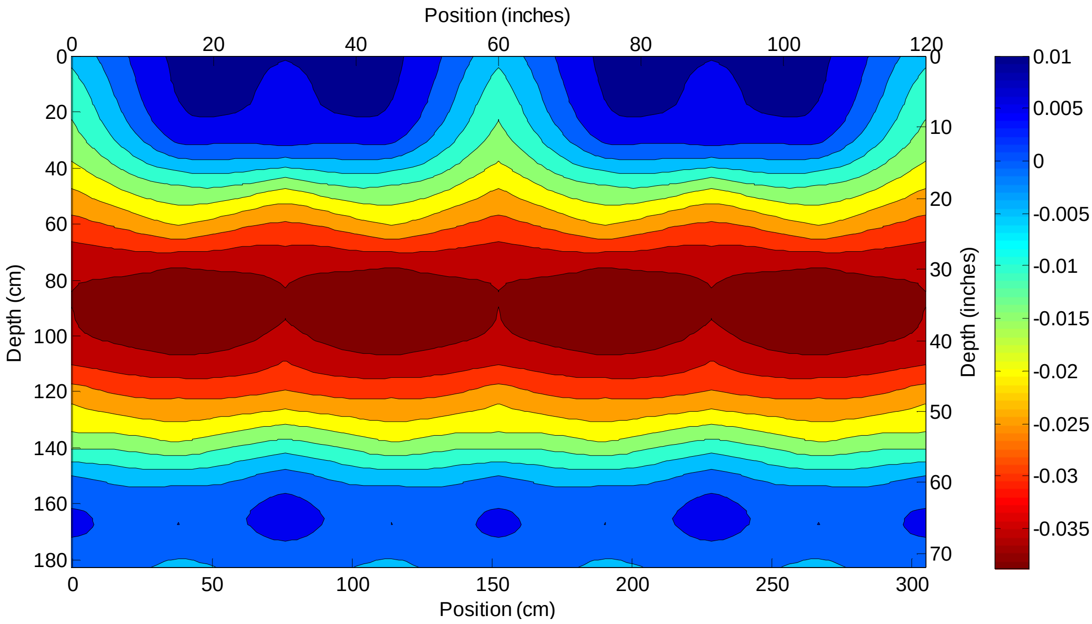

Figure B.46 - 2010 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

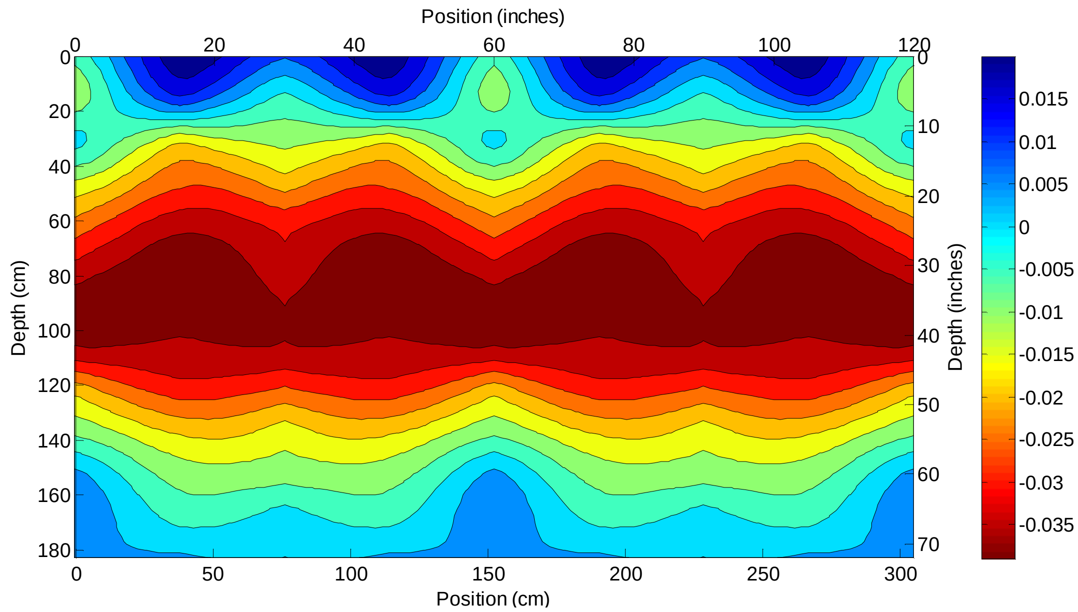

Figure B.47 - 2010 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

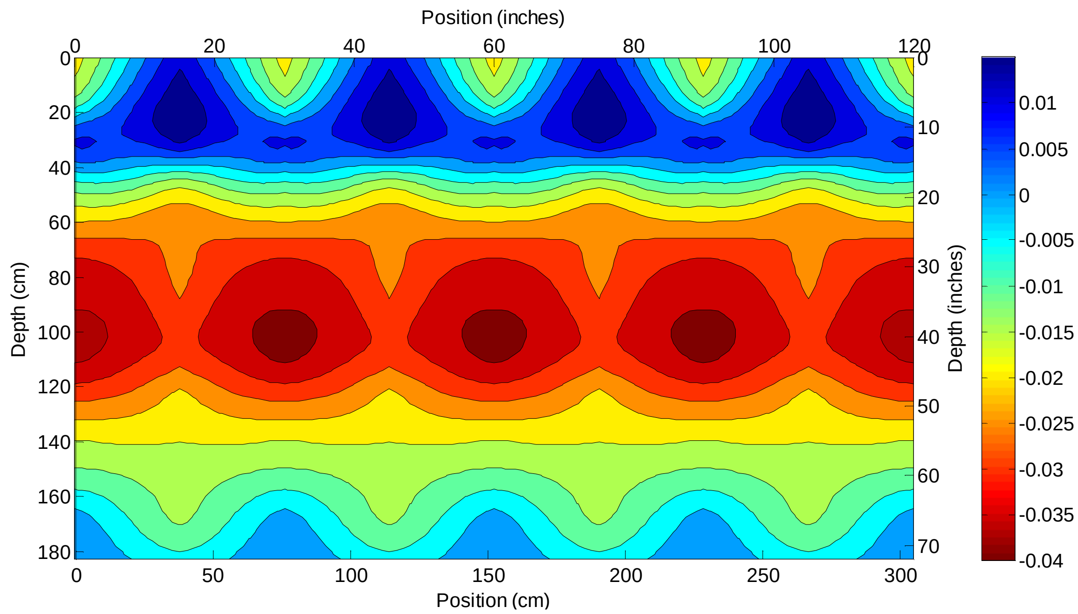

Figure B.48 - 2010 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

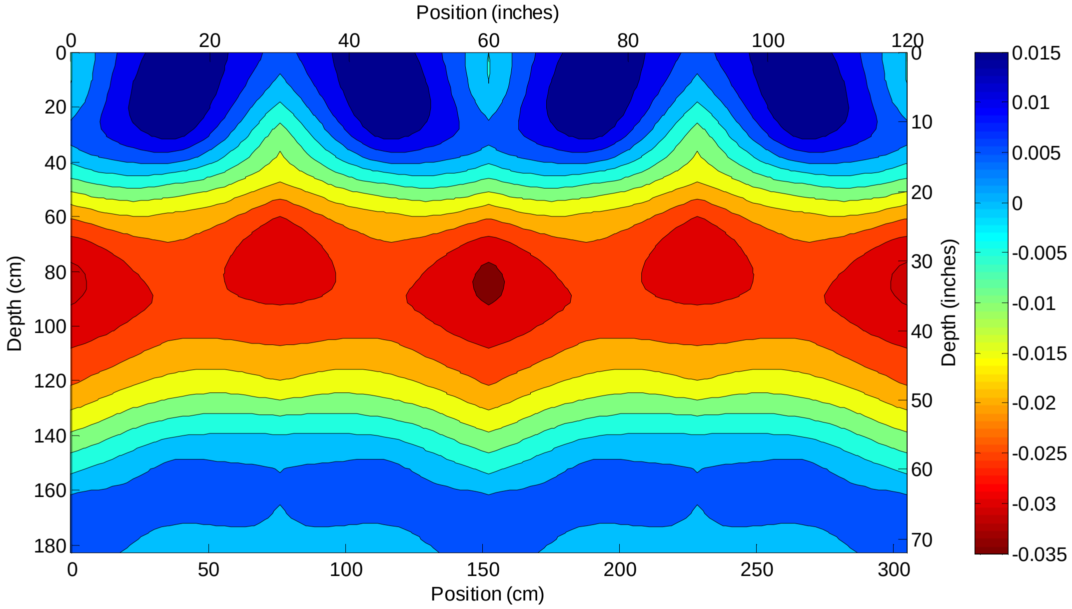

Figure B.49 - 2010 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

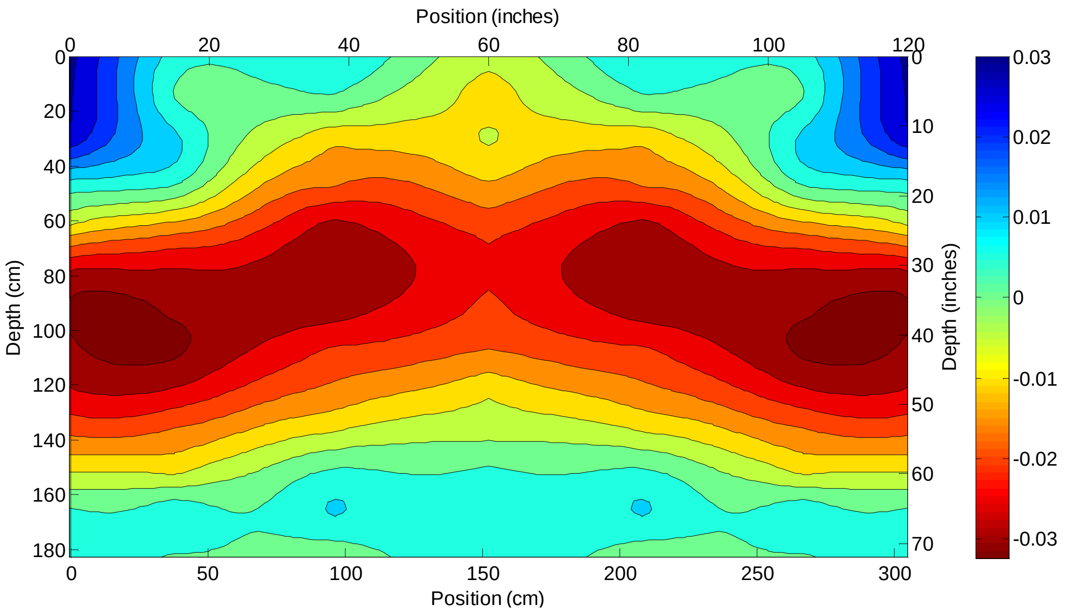

Figure B.50 - 2010 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

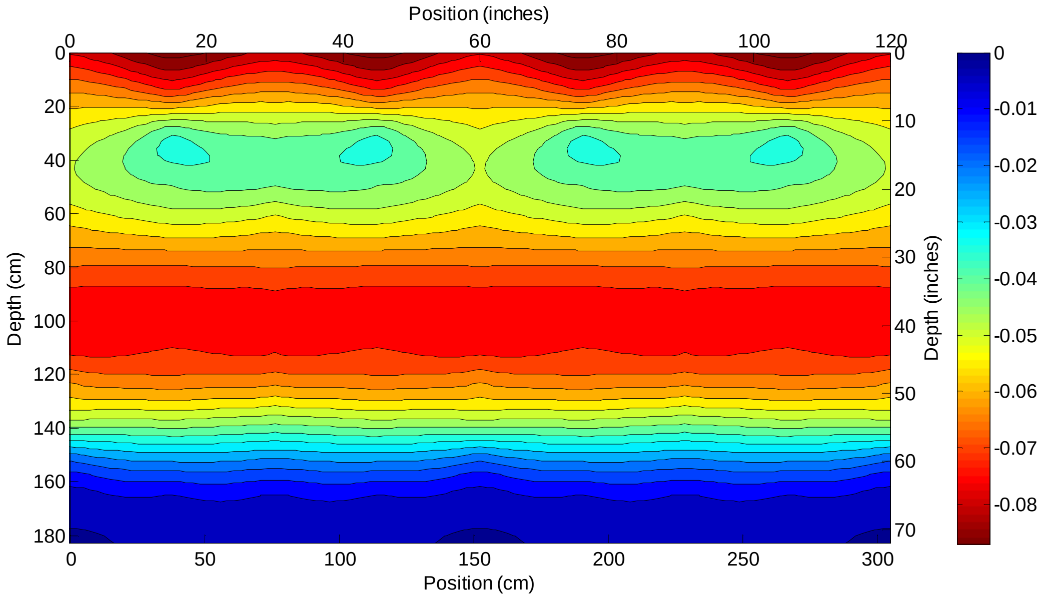

Figure B.51 - 2010 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^{3} cm^{-3}, clump geometry.

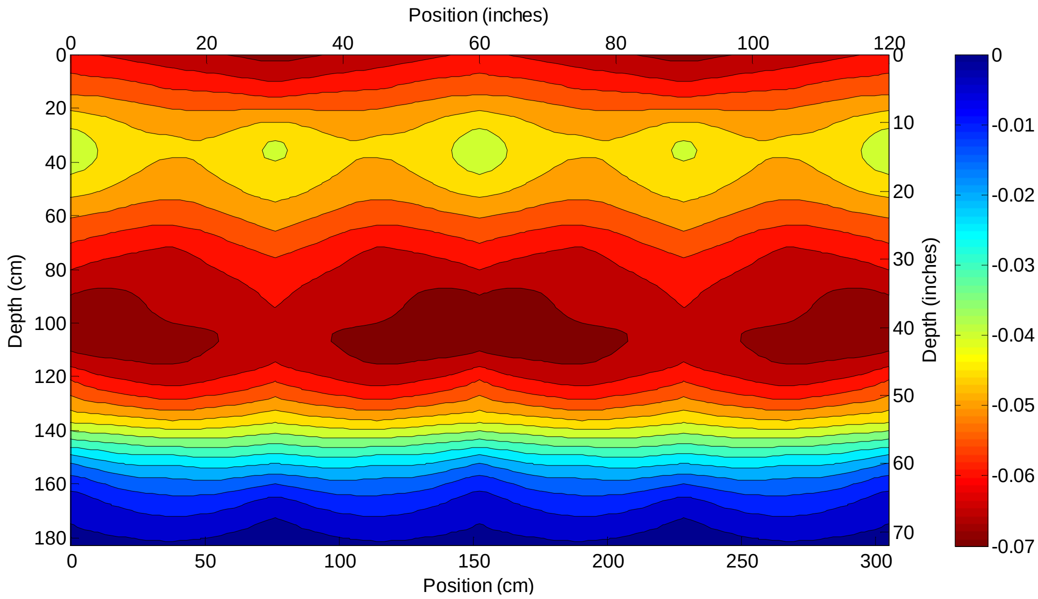

Figure B.52 - 2010 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^{3} cm^{-3}, cluster geometry.

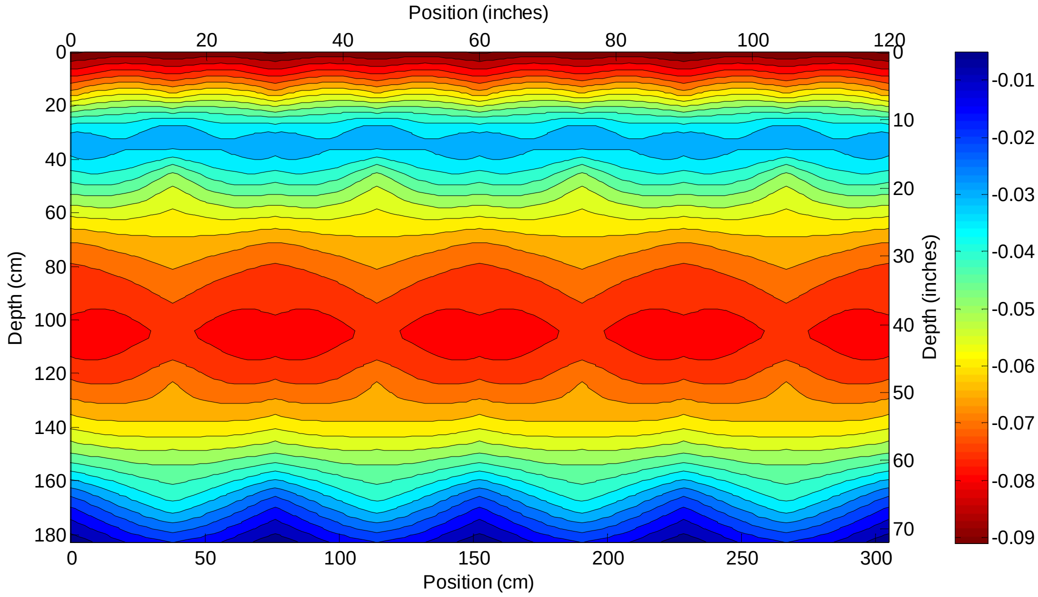

Figure B.53 - 2010 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

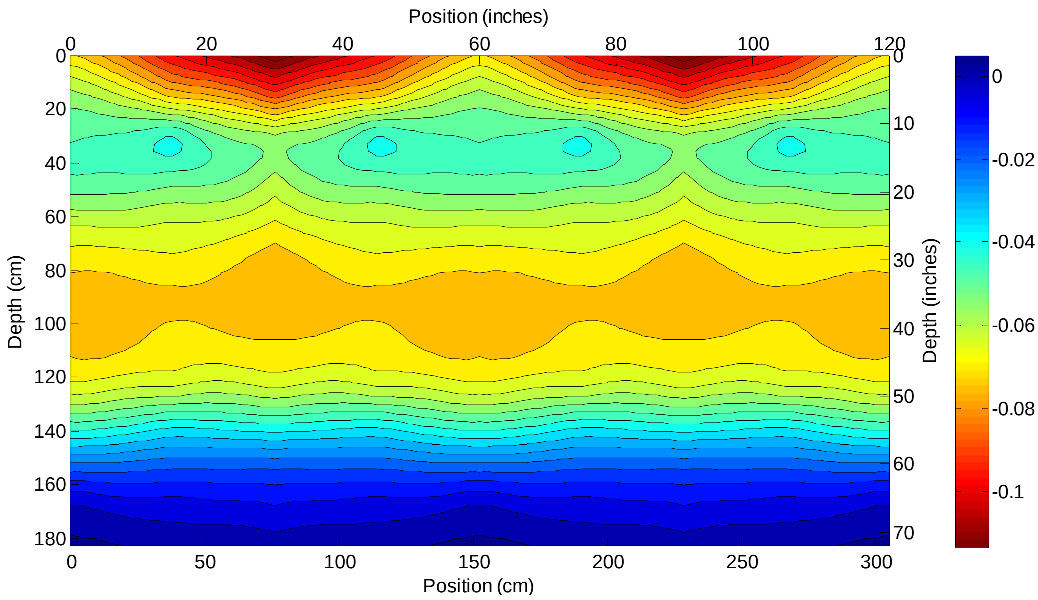

Figure B.54 - 2010 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

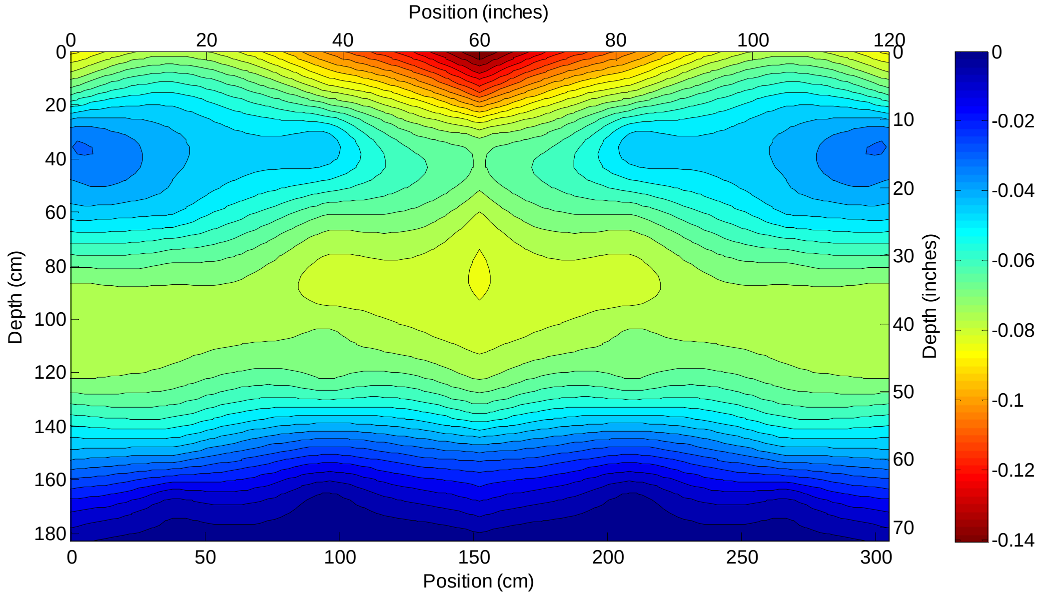

Figure B.55 - 2010 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

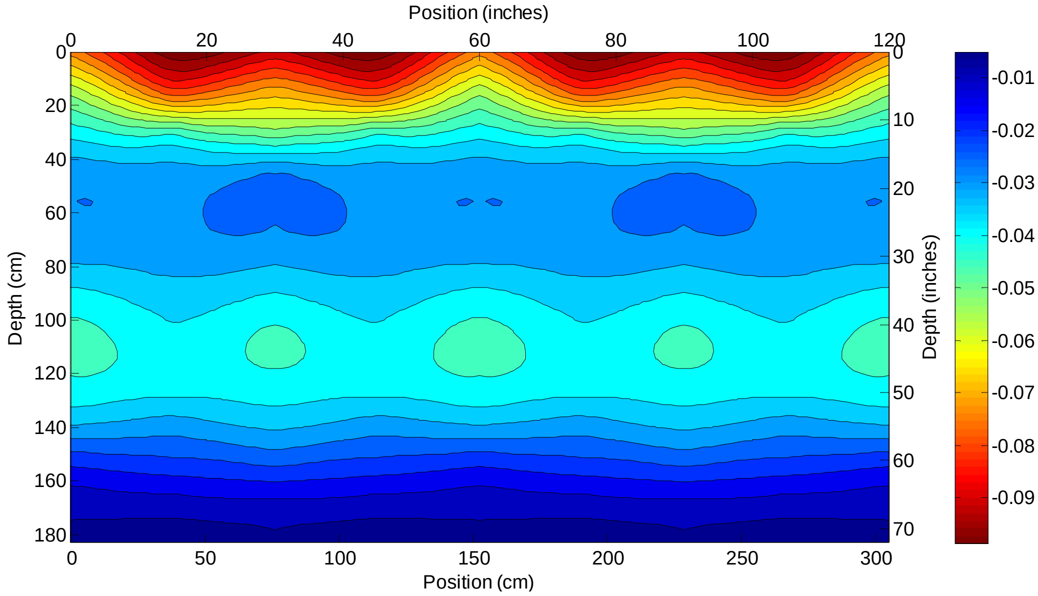

Figure B.56 - 2010 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

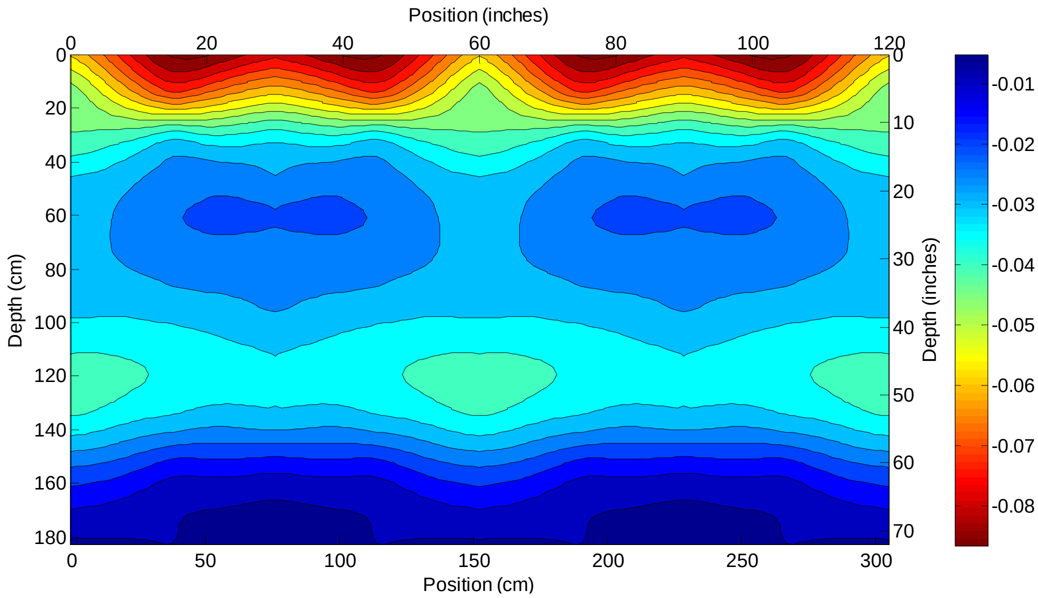

Figure B.57 - 2010 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, cluster geometry.

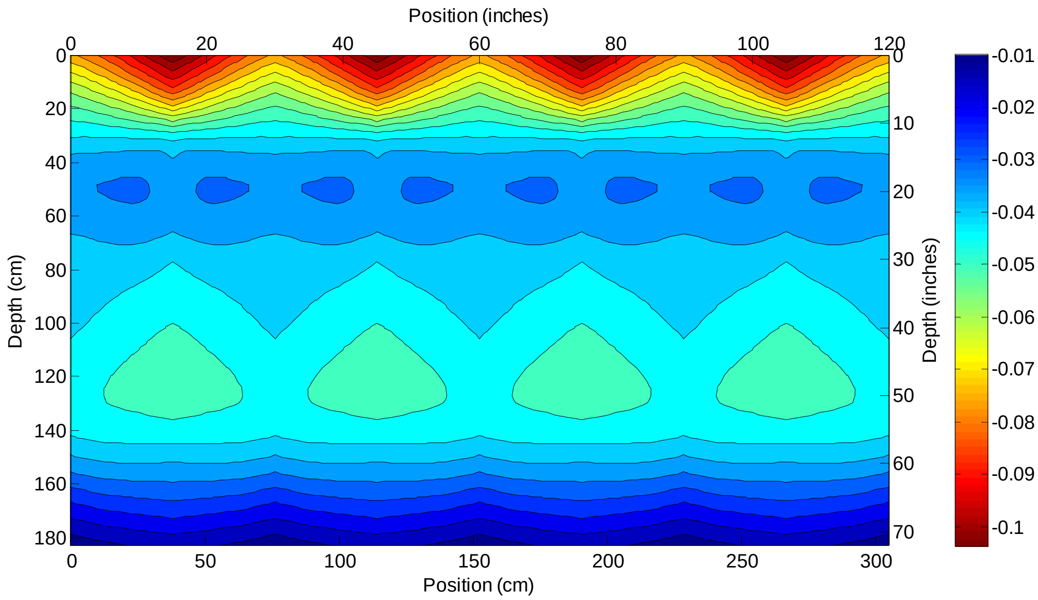

Figure B.58 - 2010 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, conventional geometry.

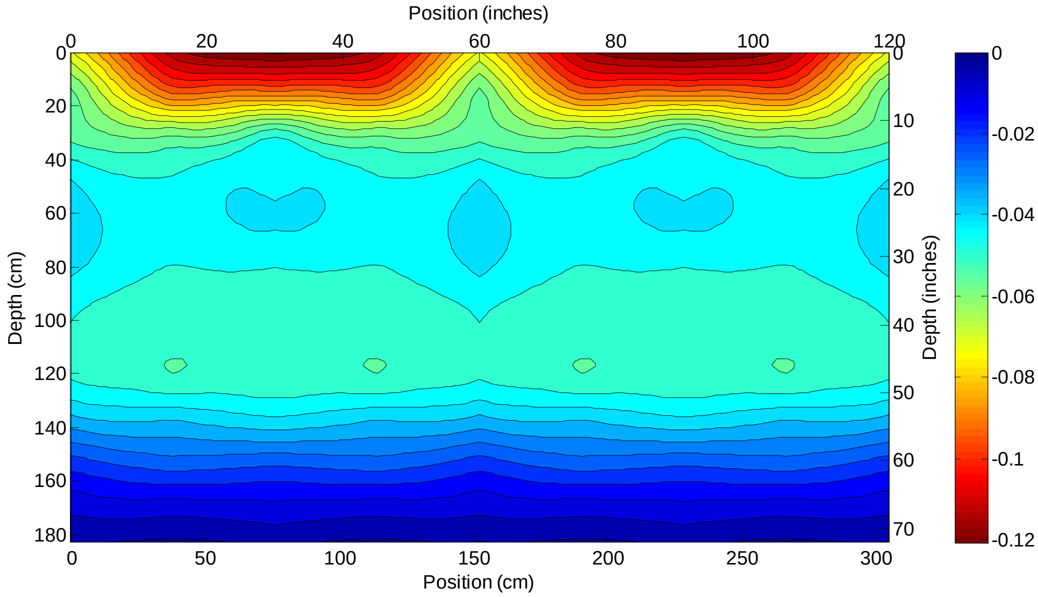

Figure B.59 - 2010 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

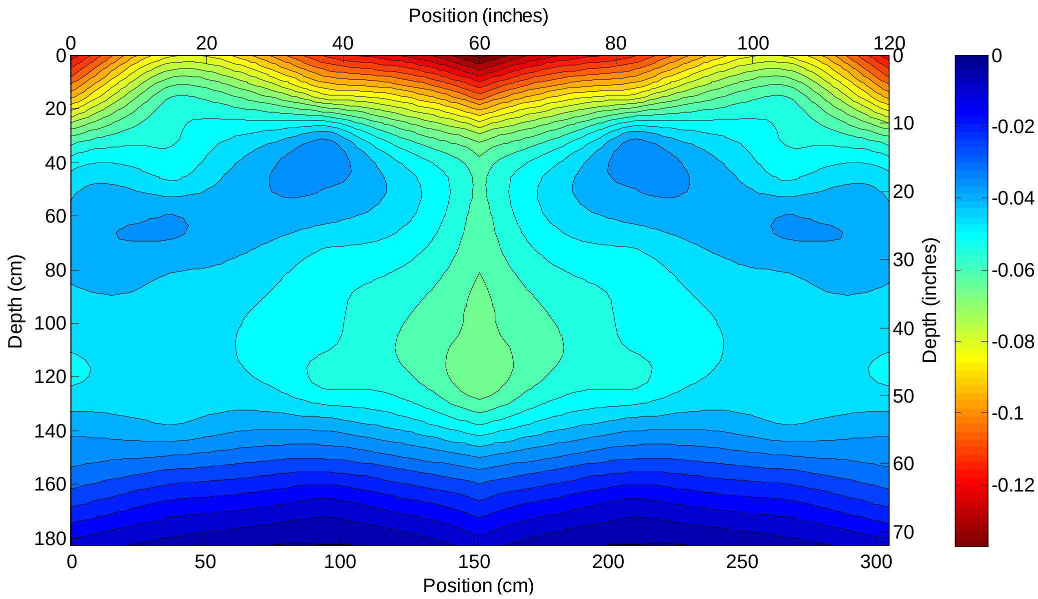

Figure B.60 - 2010 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

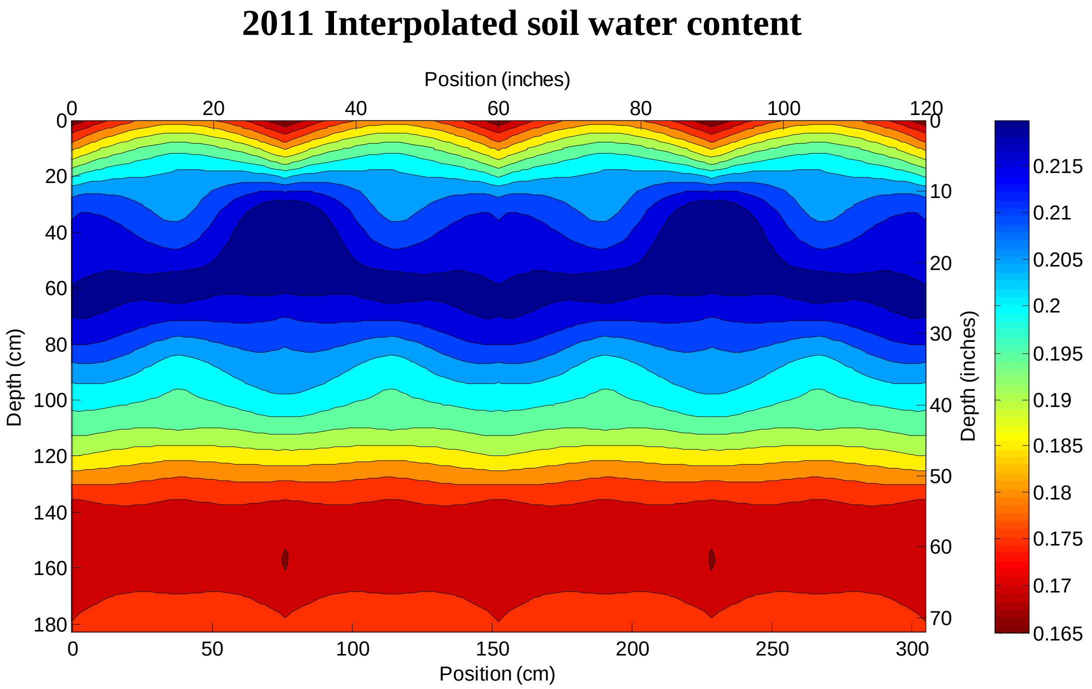

Figure B.61 - 2011 Sorghum early vegetative soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

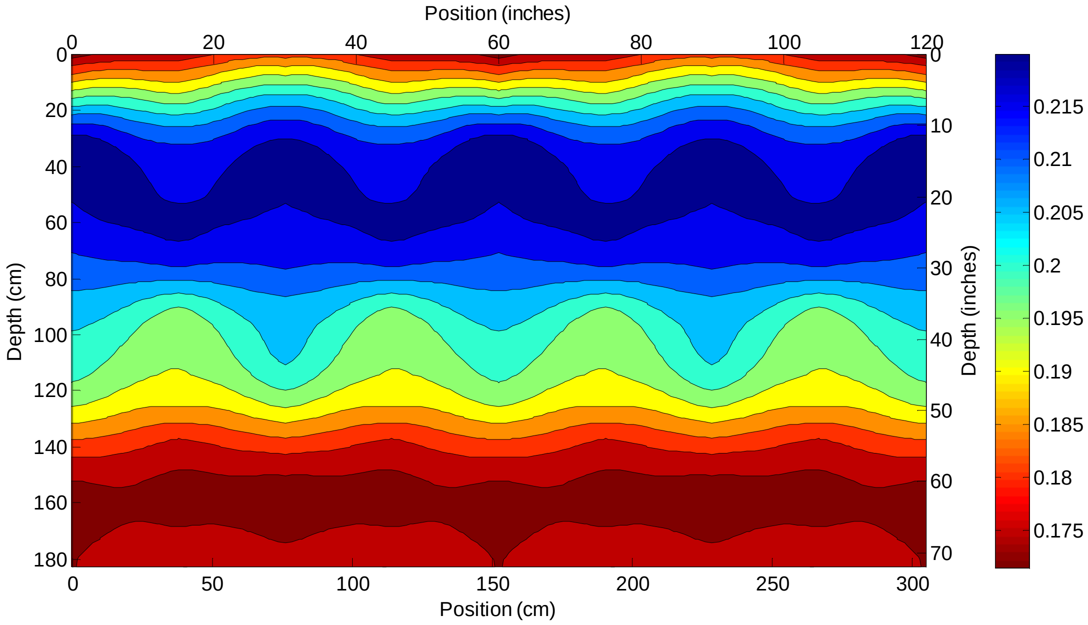

Figure B.62 - 2011 Sorghum early vegetative soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

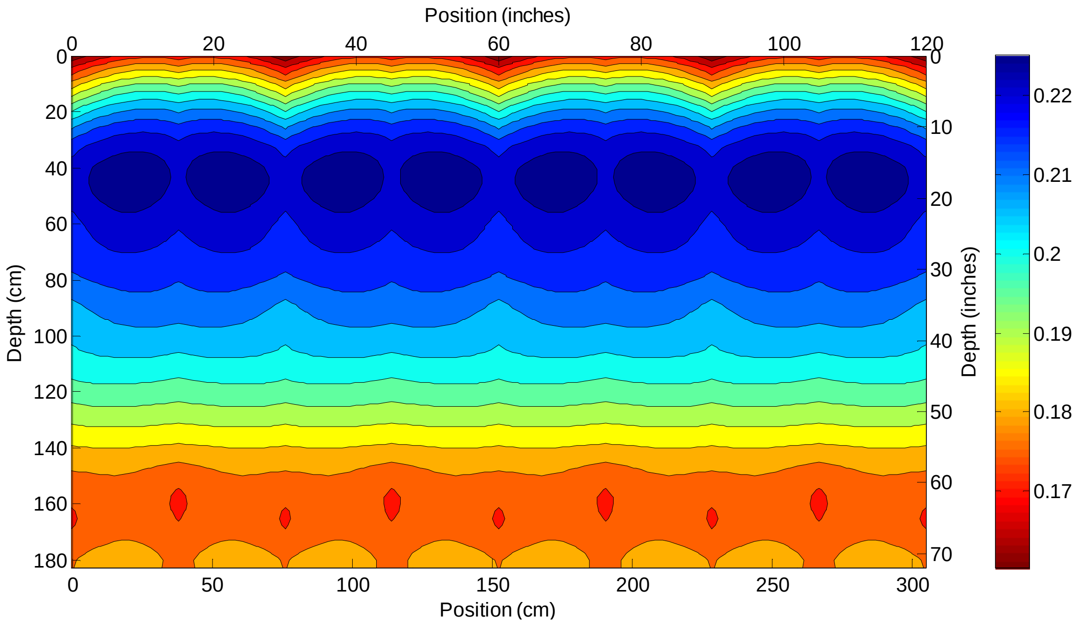

Figure B.63 - 2011 Sorghum early vegetative soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

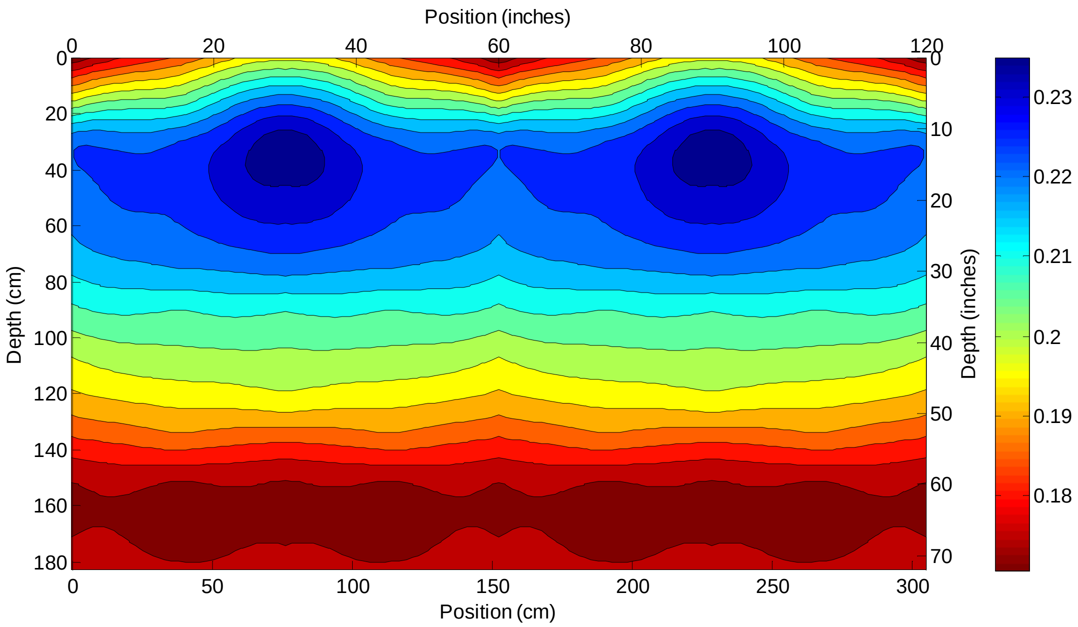

Figure B.64 - 2011 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

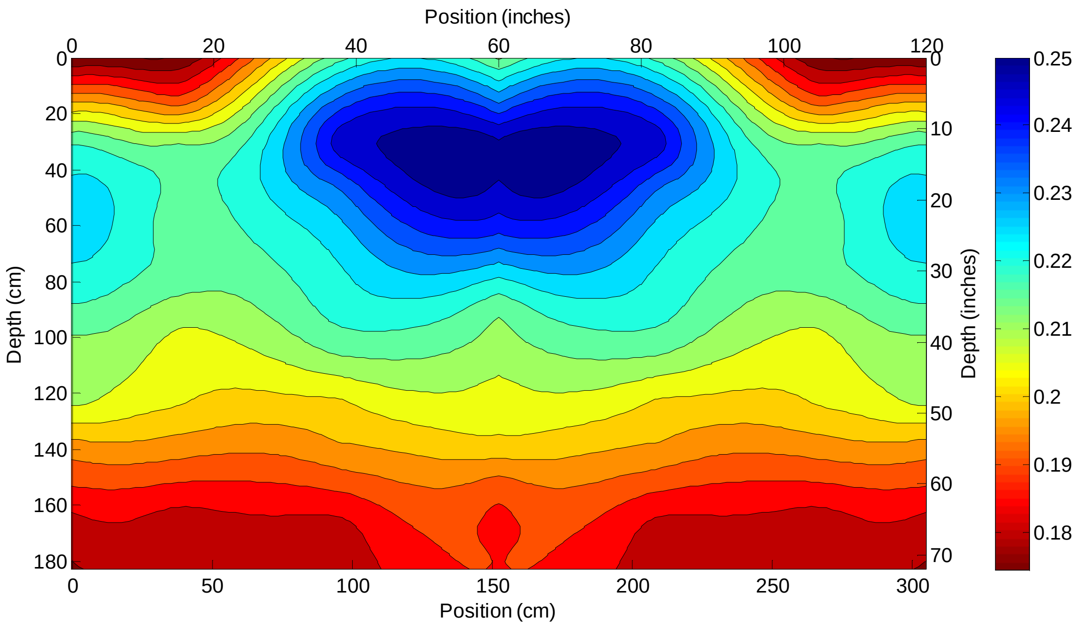

Figure B.65 - 2011 Sorghum early vegetative soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

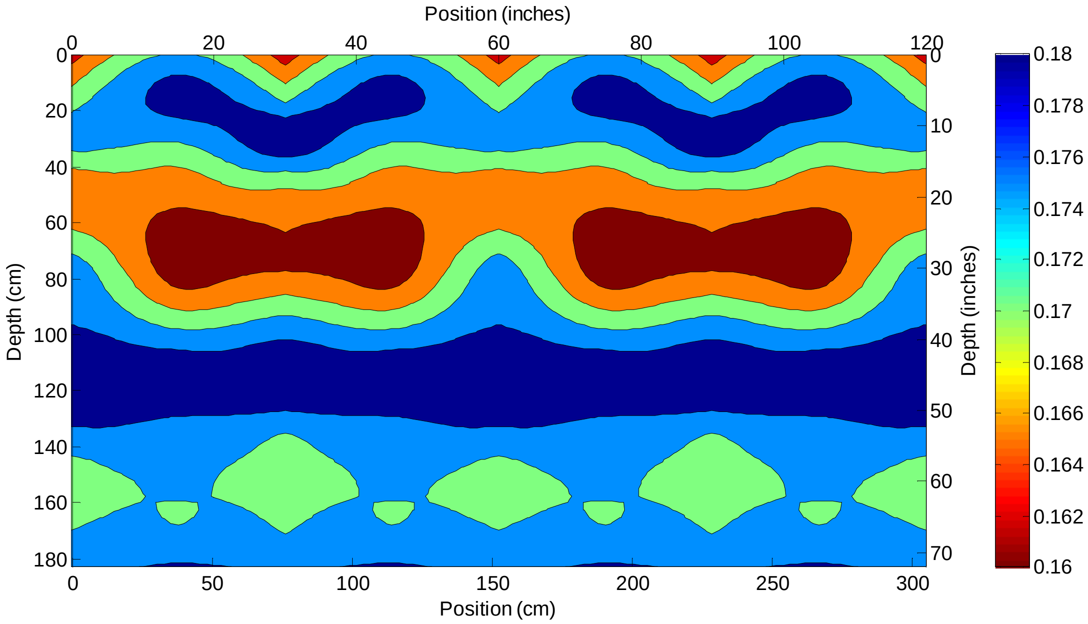

Figure B.66 - 2011 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

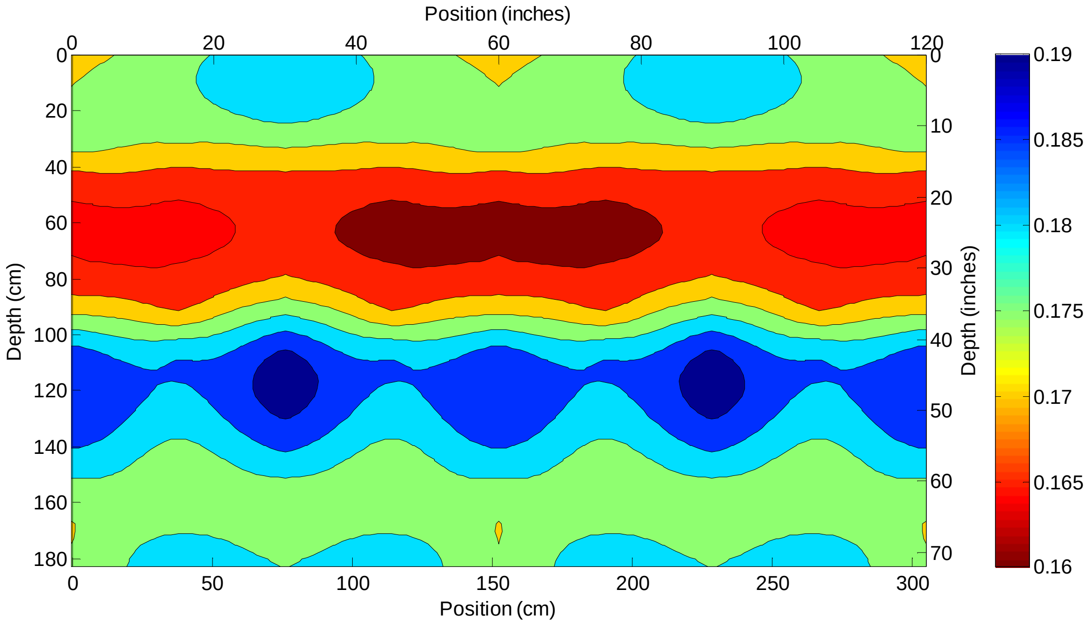

Figure B.67 - 2011 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

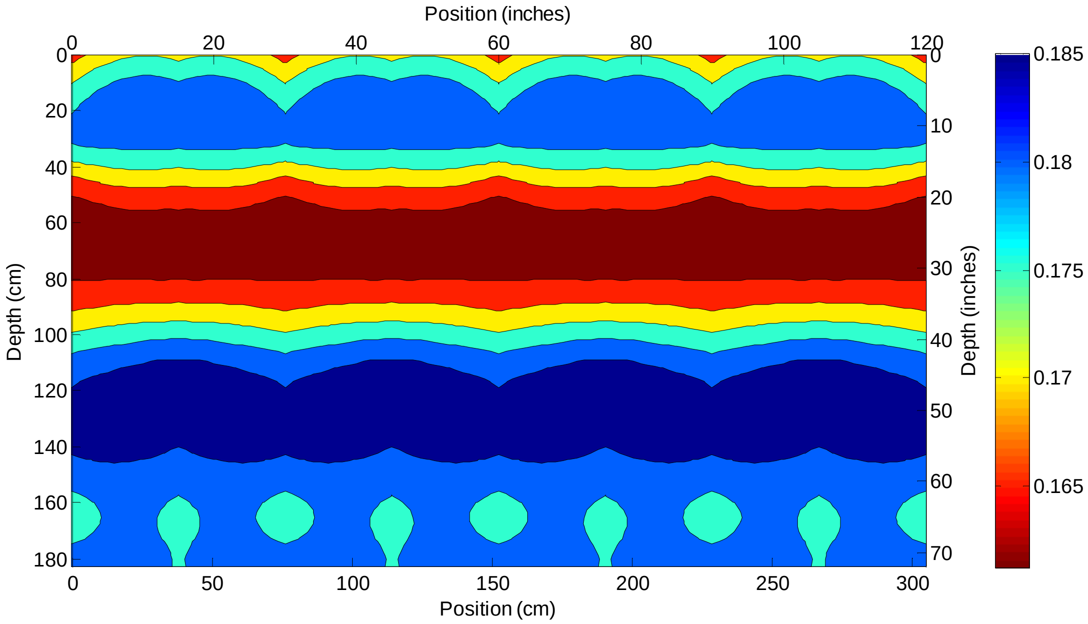

Figure B.68 - 2011 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

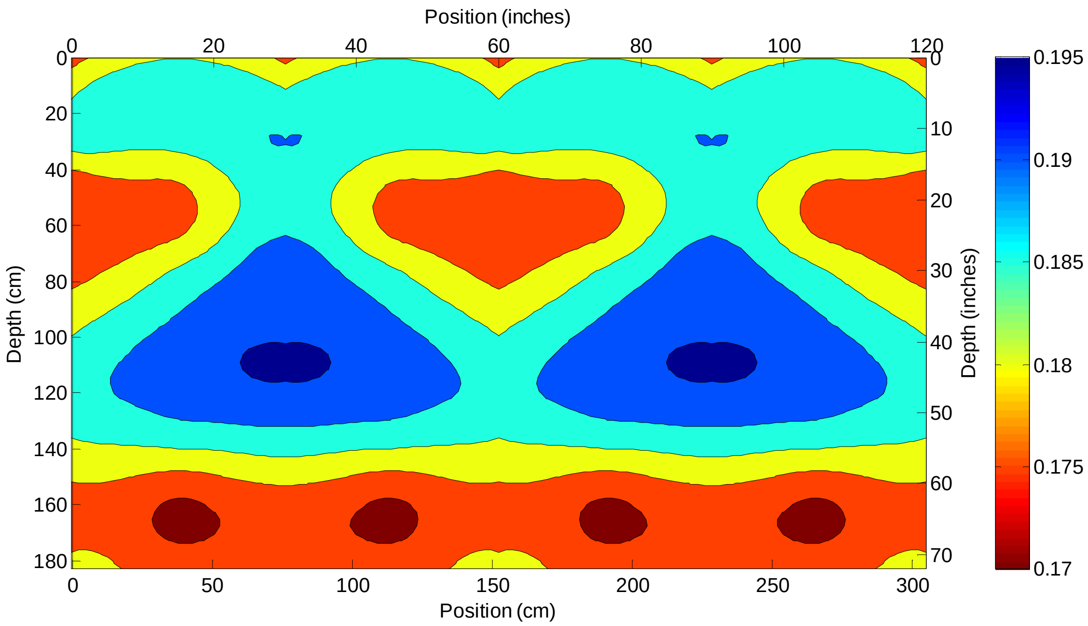

Figure B.69 - 2011 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

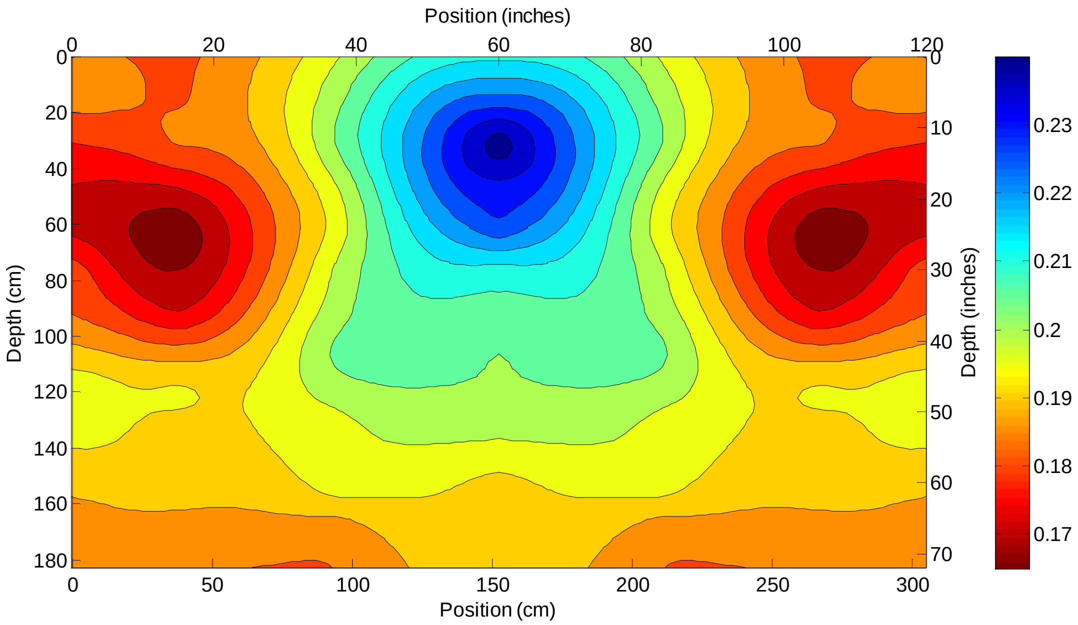

Figure B.70 - 2011 Sorghum flower-grain fill soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

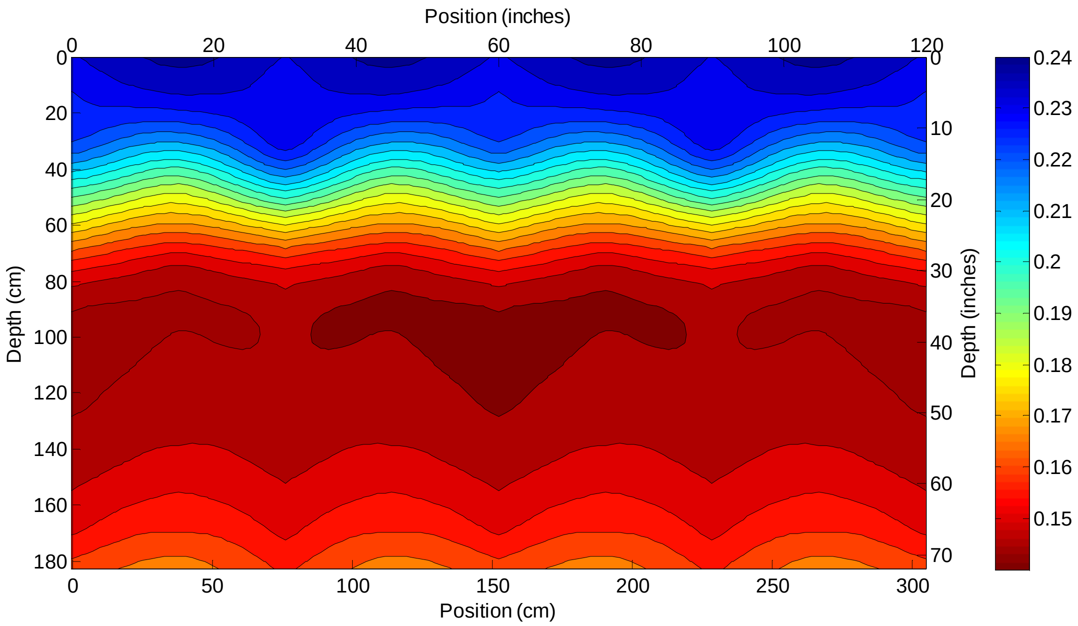

Figure B.71 - 2011 Sorghum harvest soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

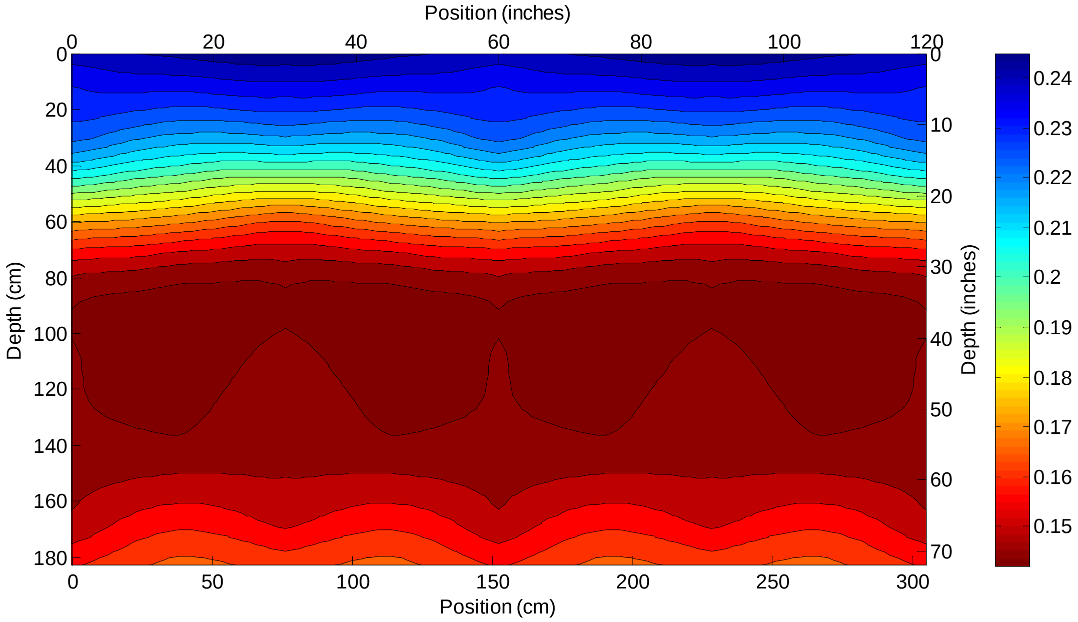

Figure B.72 - 2011 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

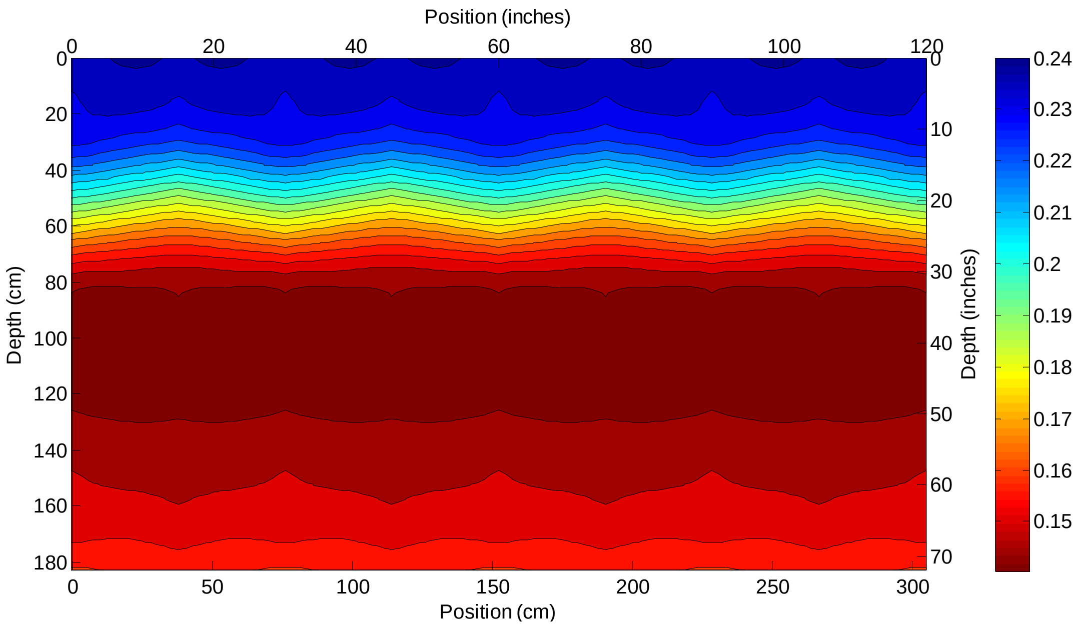

Figure B.73 - 2011 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

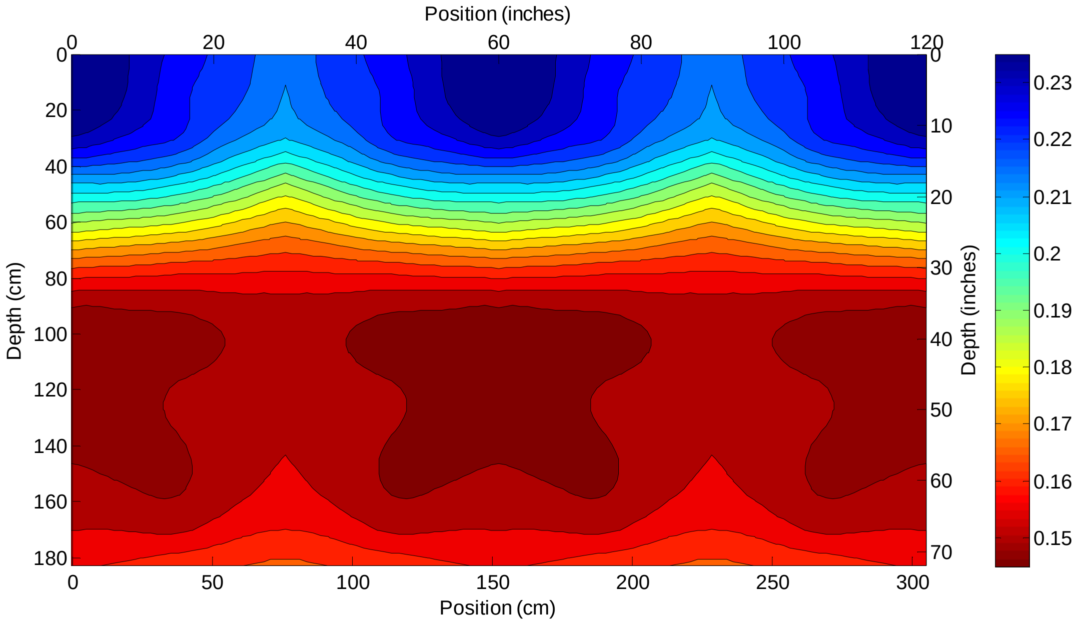

Figure B.74 - 2011 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

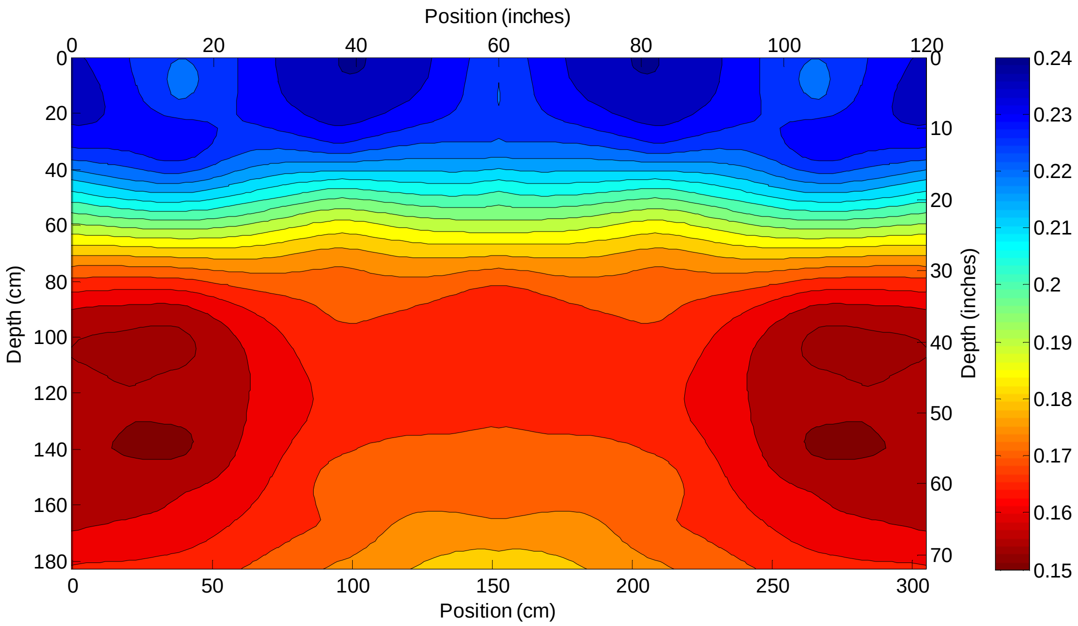

Figure B.75 - 2011 Sorghum harvest soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

2011 Changes in soil water content

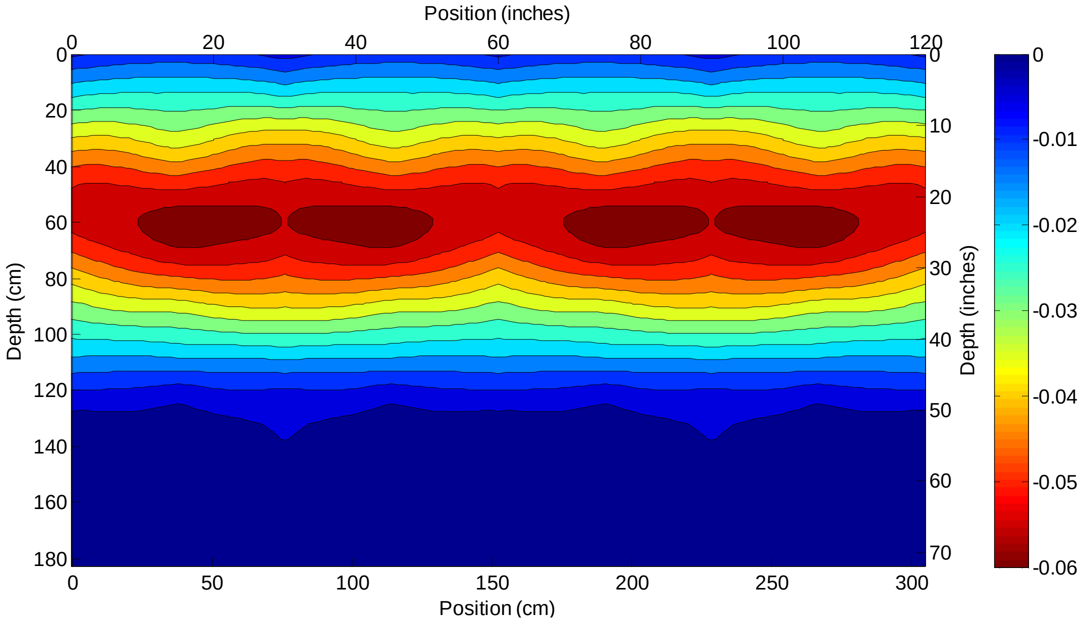

Figure B.76 - 2011 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

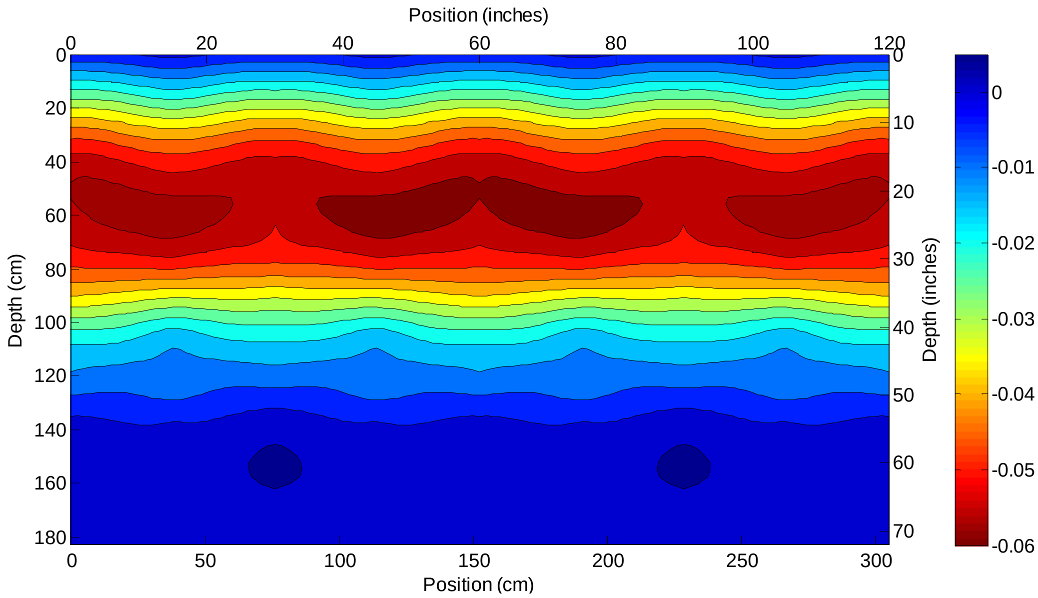

Figure B.77 - 2011 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, cluster geometry.

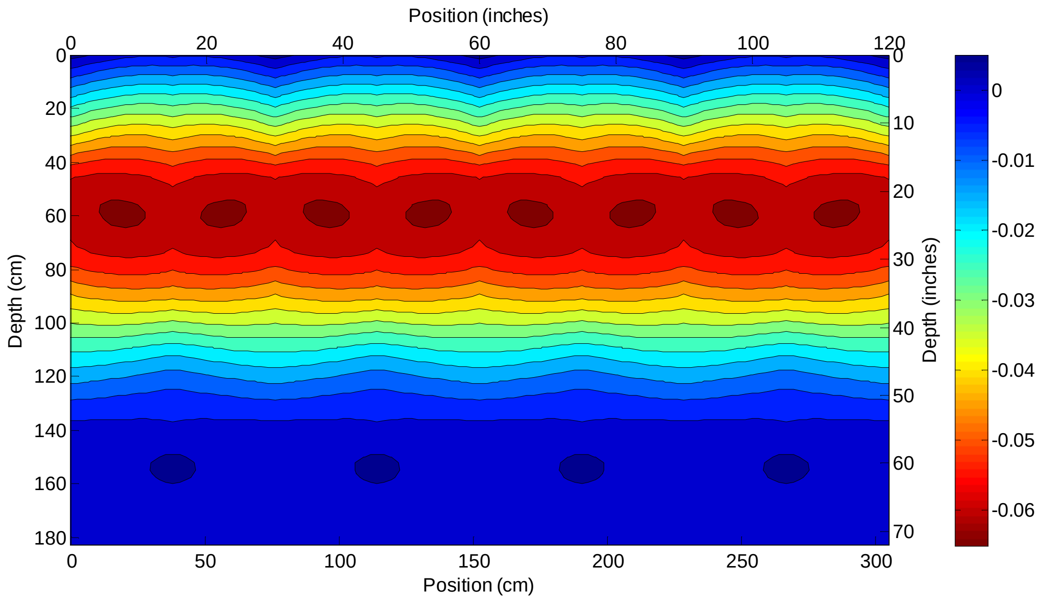

Figure B.78 - 2011 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, conventional geometry.

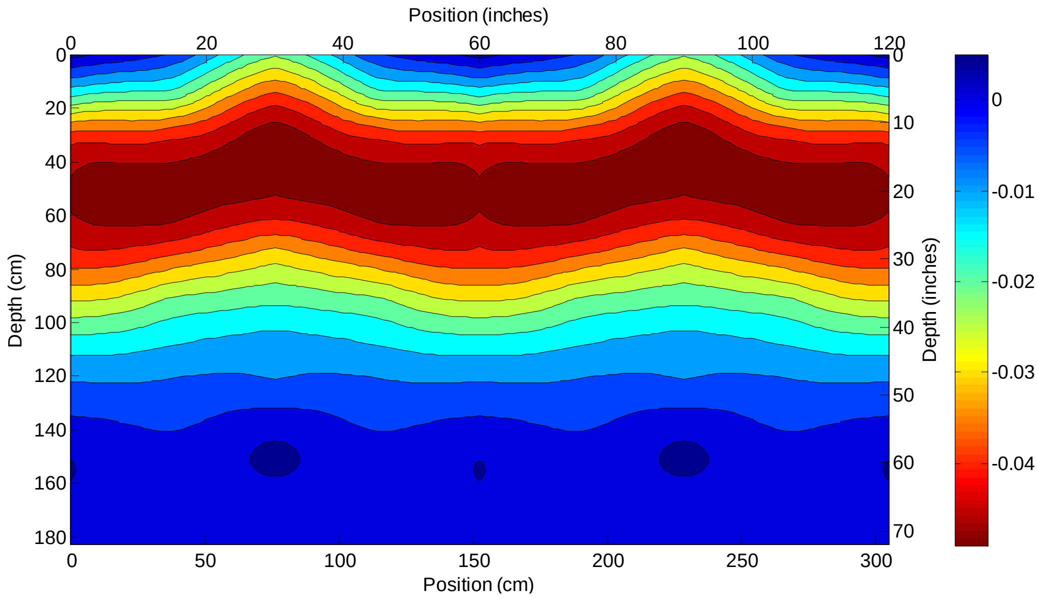

Figure B.79 - 2011 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

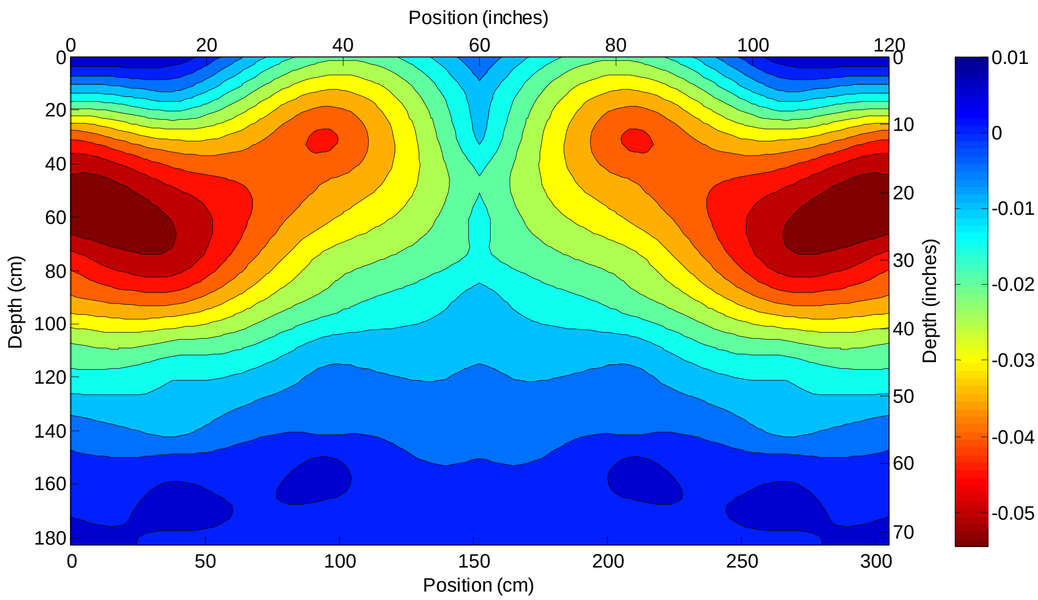

Figure B.80 - 2011 Sorghum early vegetative to flower-grain fill change in soil water content, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

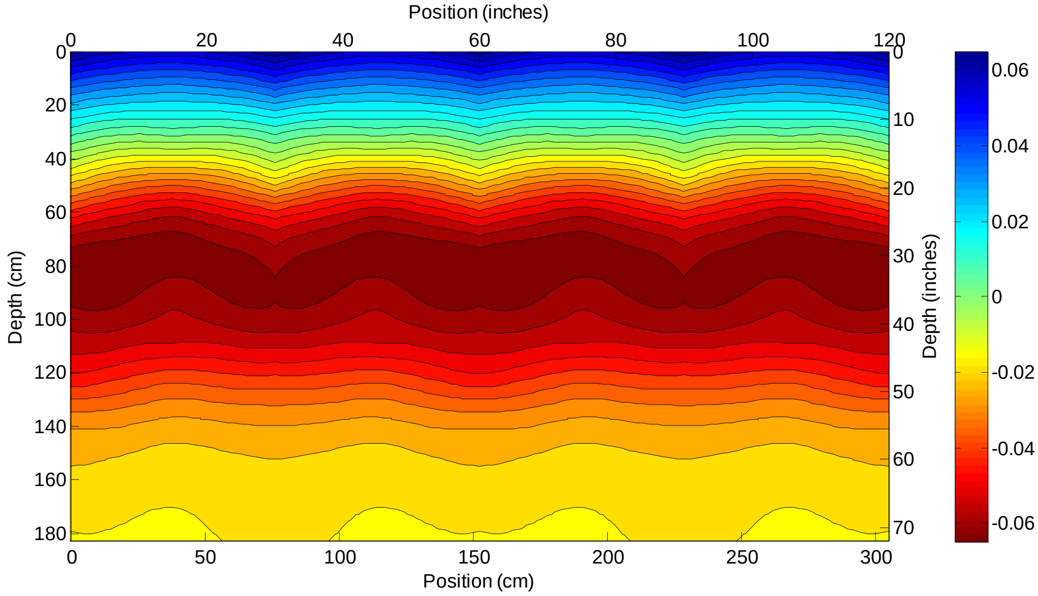

Figure B.81 - 2011 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

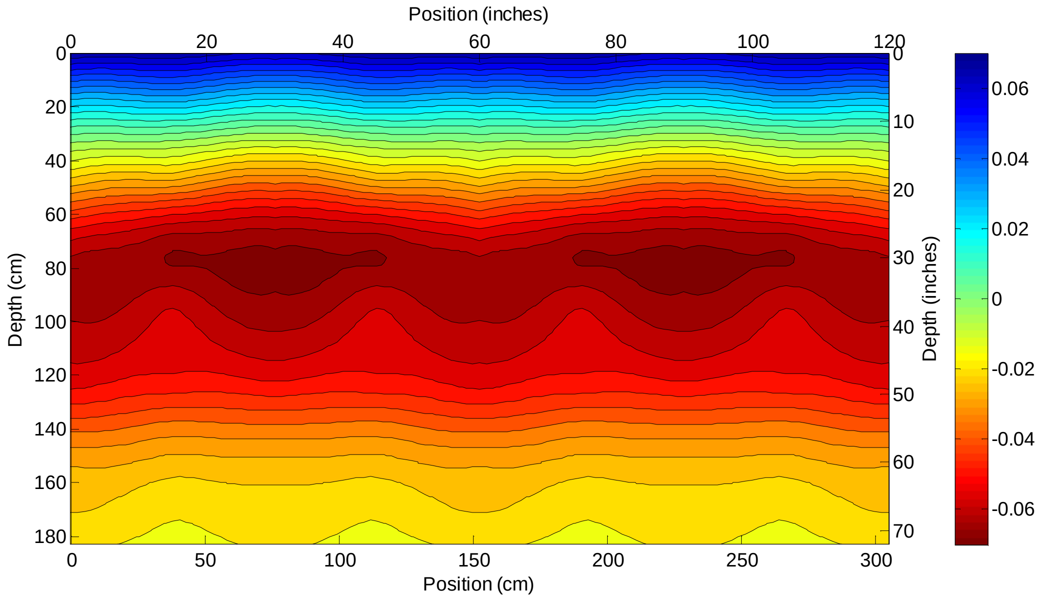

Figure B.82 - 2011 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

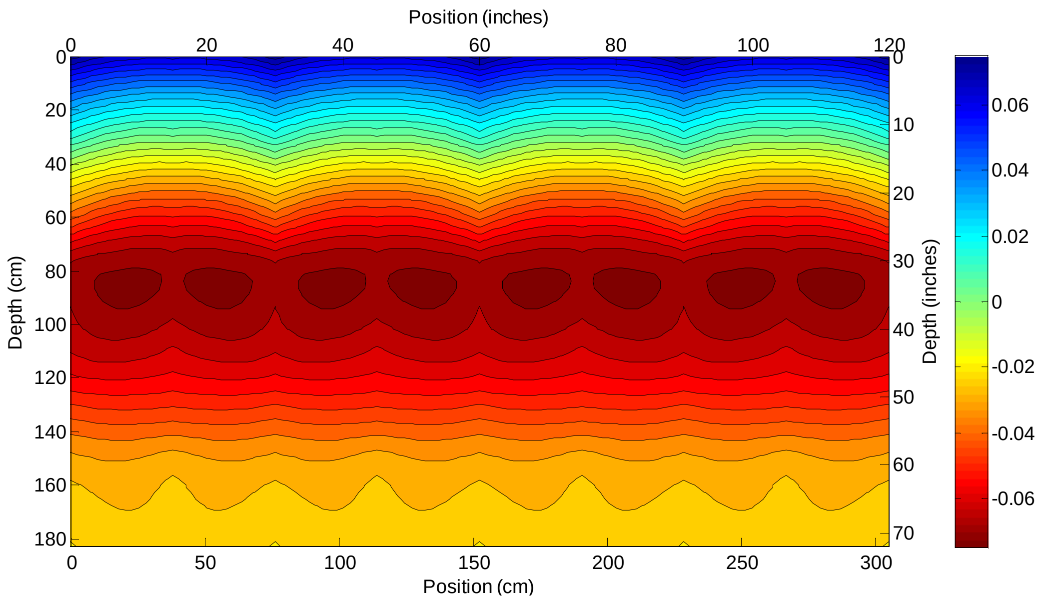

Figure B.83 - 2011 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

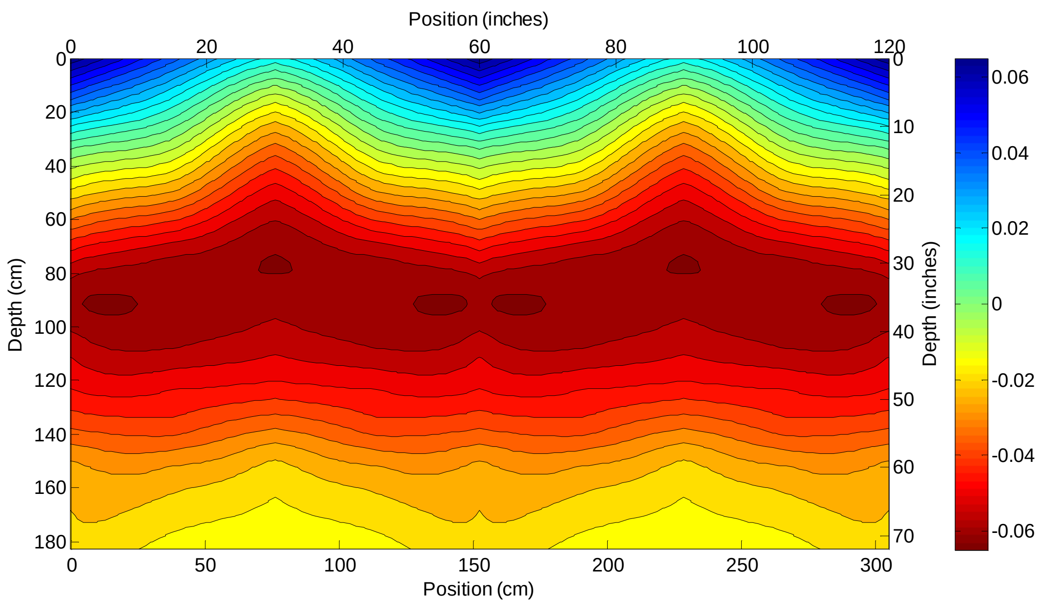

Figure B.84 - 2011 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

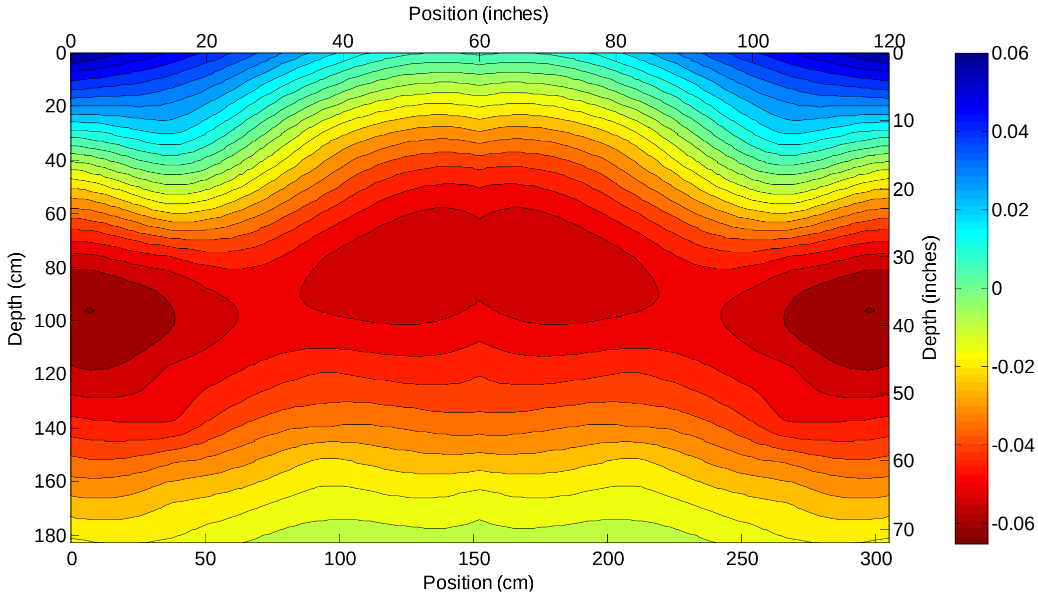

Figure B.85 - 2011 Sorghum early vegetative to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

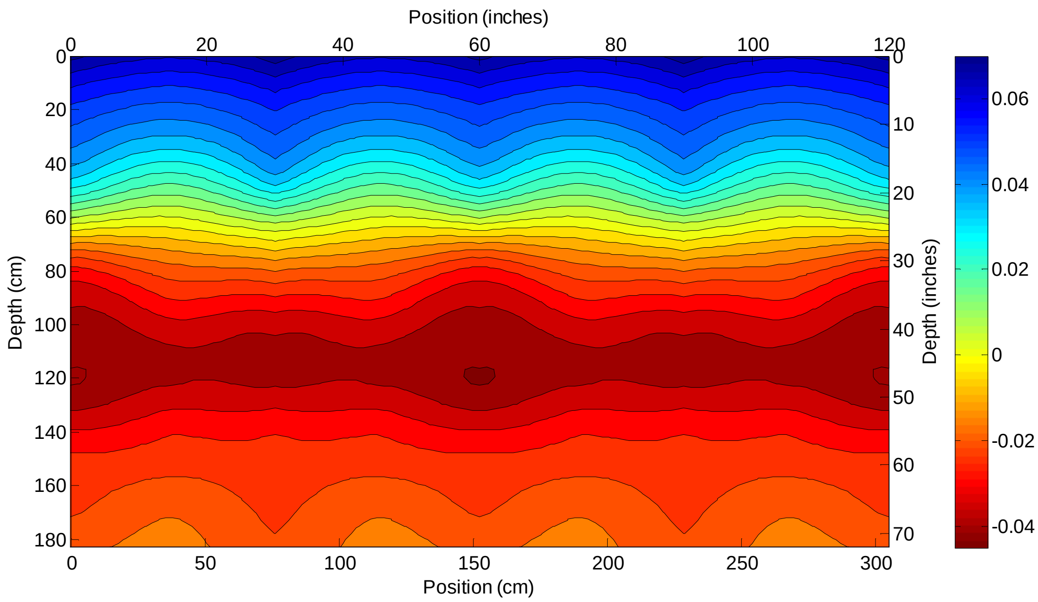

Figure B.86 - 2011 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

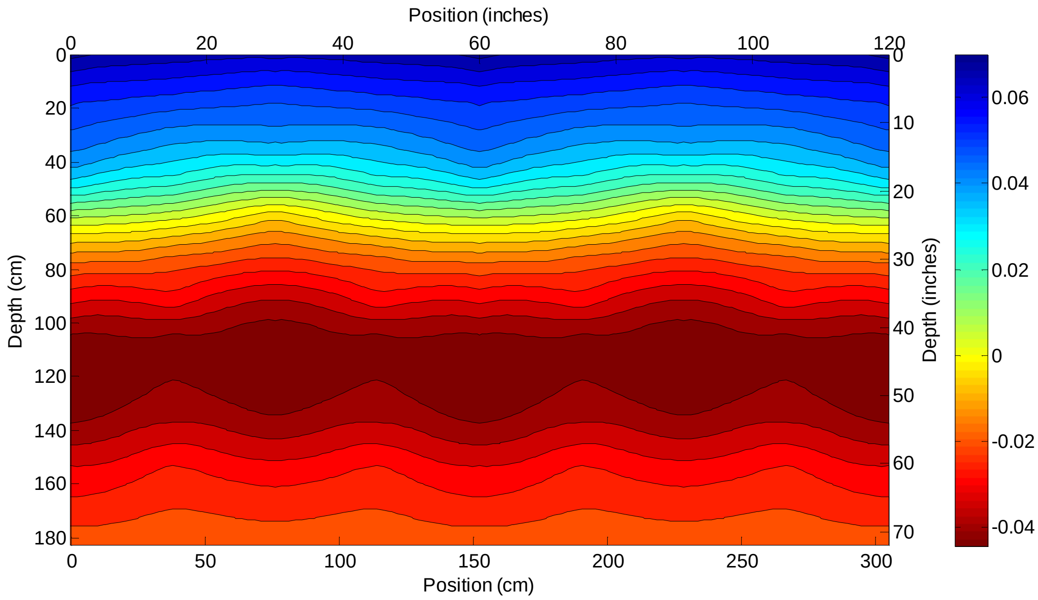

Figure B.87 - 2011 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, cluster geometry.

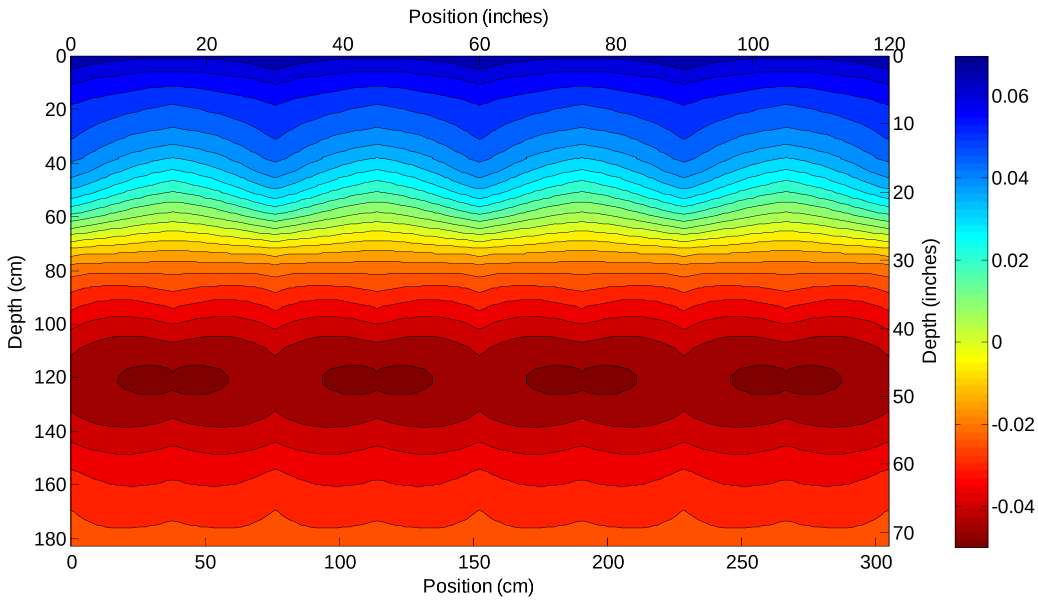

Figure B.88 - 2011 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 $cm^3 cm^{-3}$, conventional geometry.

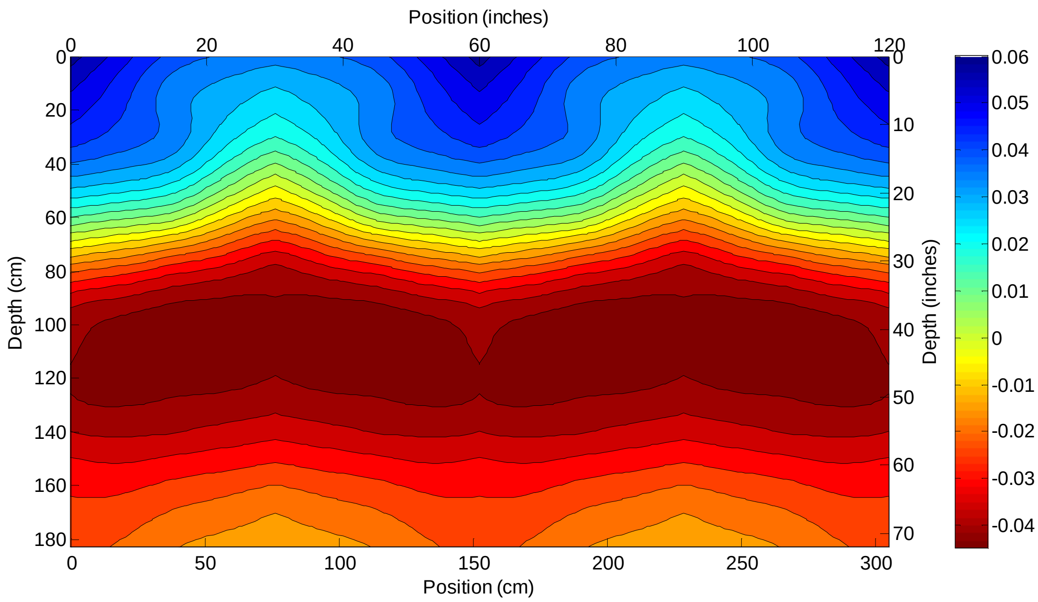

Figure B.89 - 2011 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

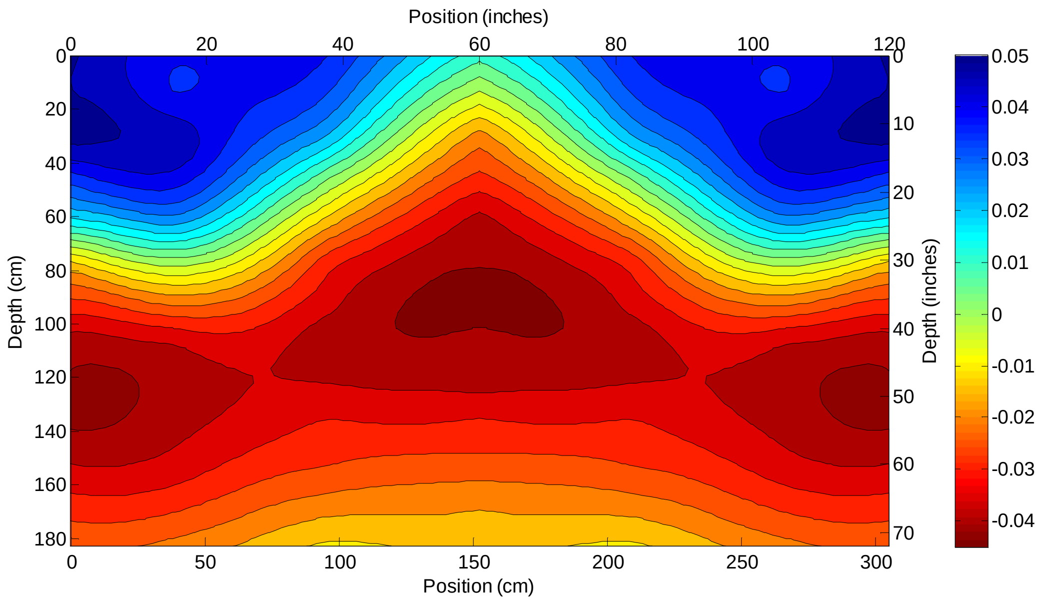

Figure B.90 - 2011 Sorghum flower-grain fill to harvest change in soil water content, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

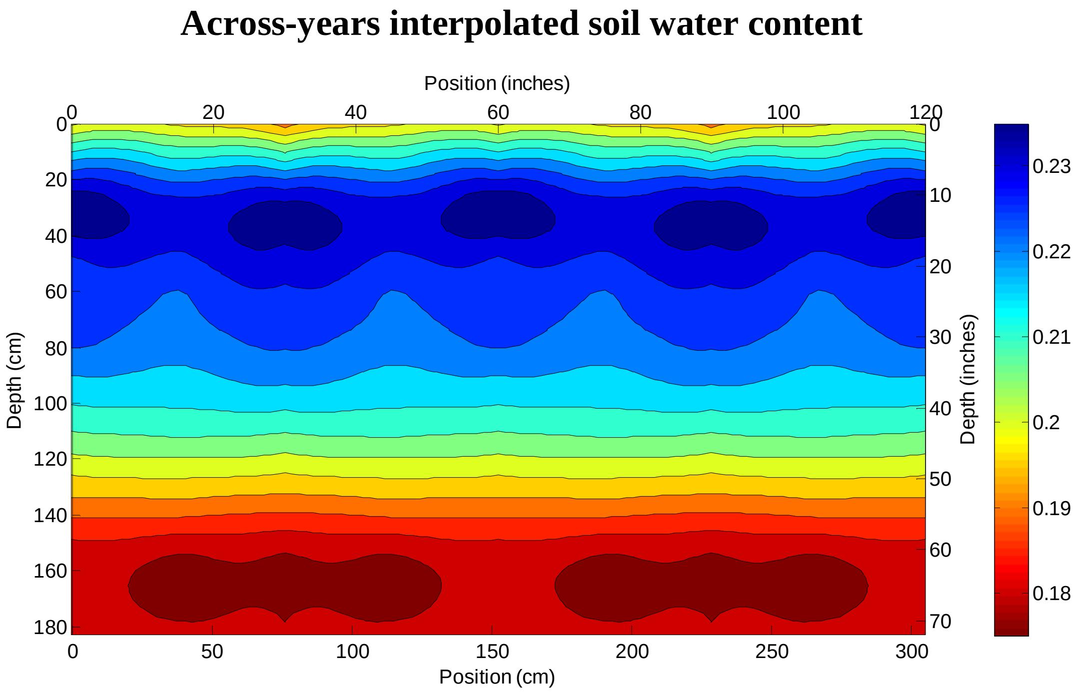

Figure B.91 - Sorghum early vegetative soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

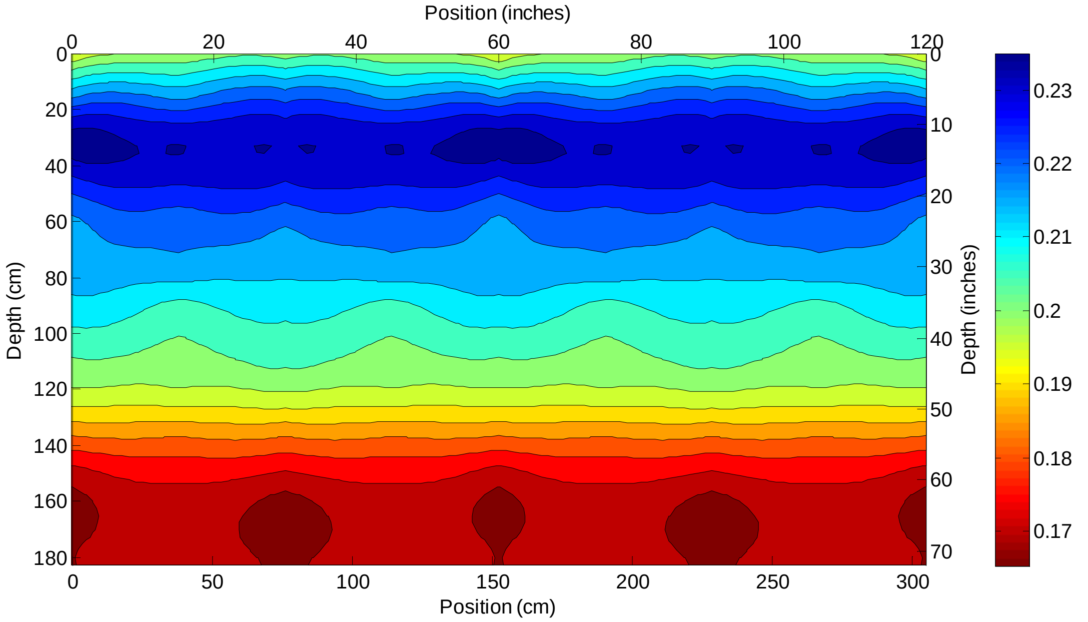

Figure B.92 - Sorghum early vegetative soil water content across years, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, cluster geometry.

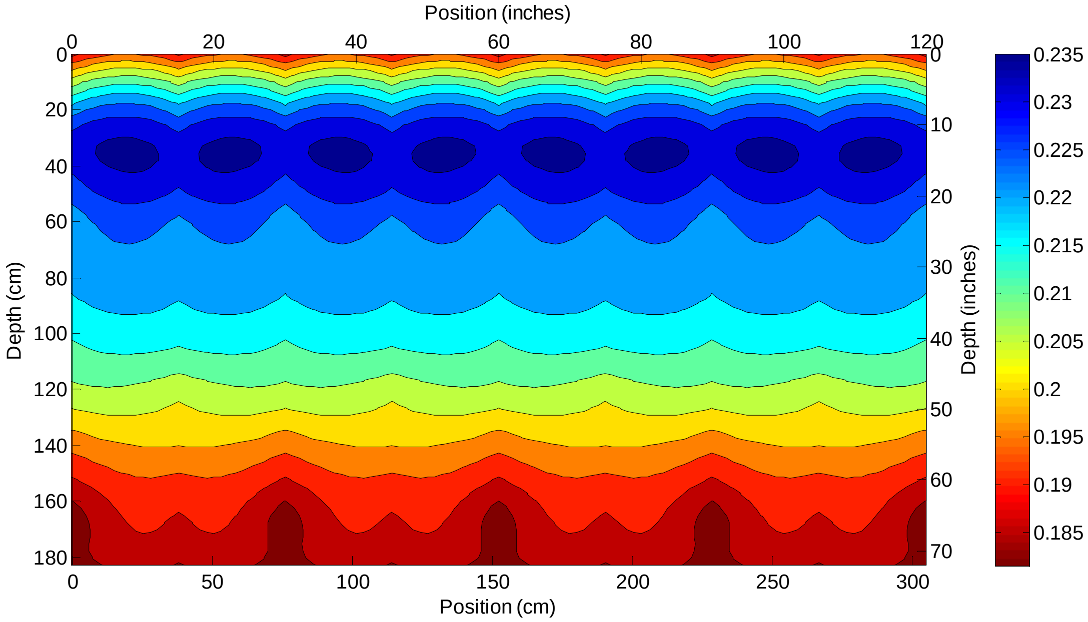

Figure B.93 - Sorghum early vegetative soil water content across years, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, conventional geometry.

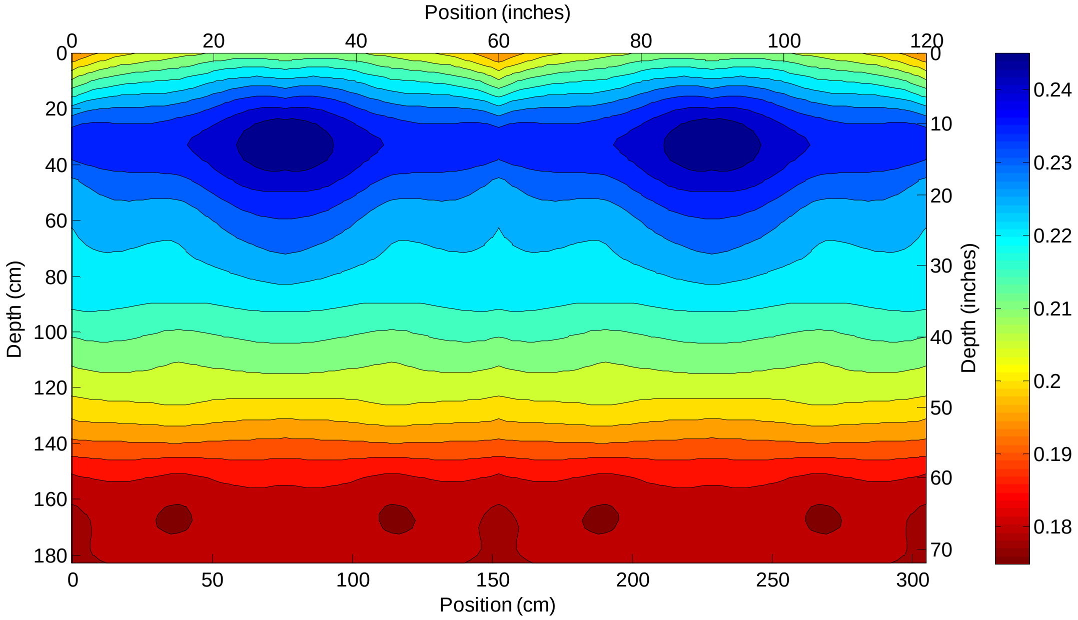

Figure B.94 - Sorghum early vegetative soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

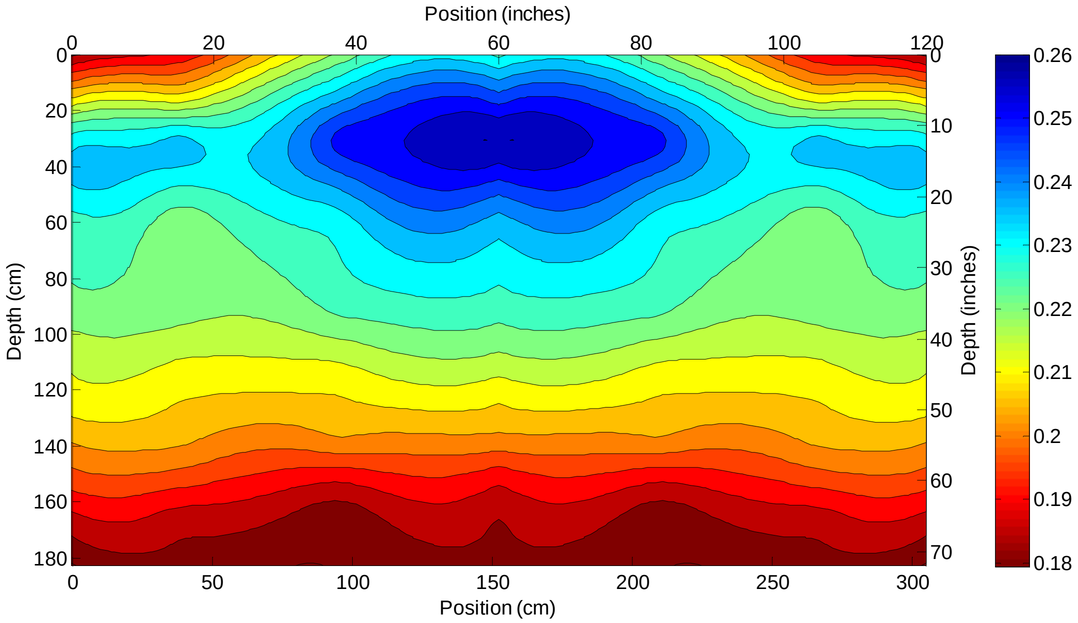

Figure B.95 - Sorghum early vegetative soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

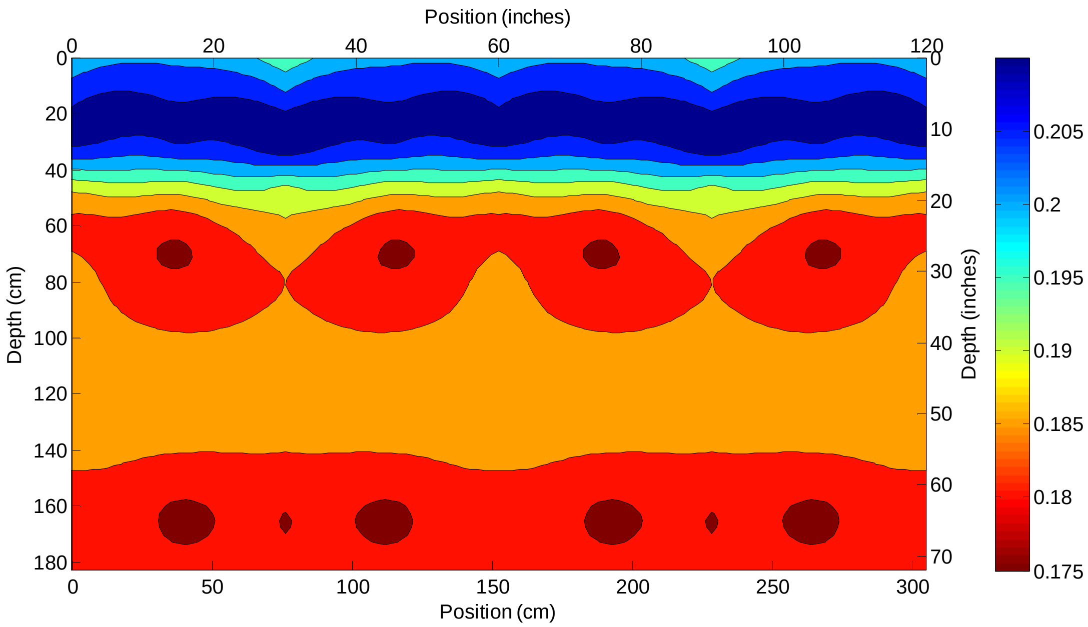

Figure B.96 - Sorghum flower-grain fill soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

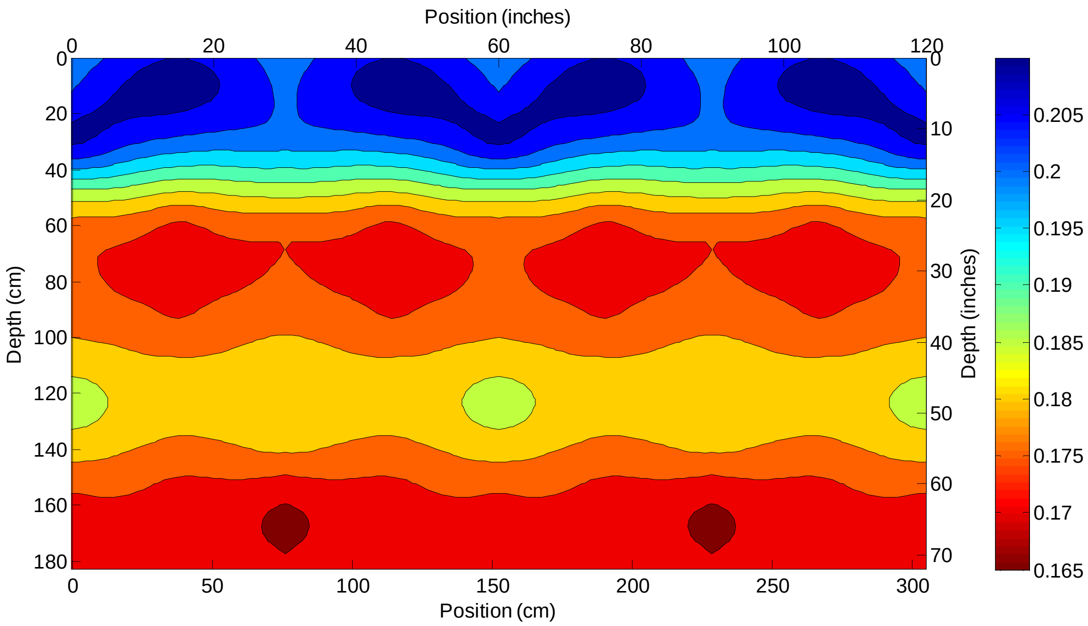

Figure B.97 - Sorghum flower-grain fill soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

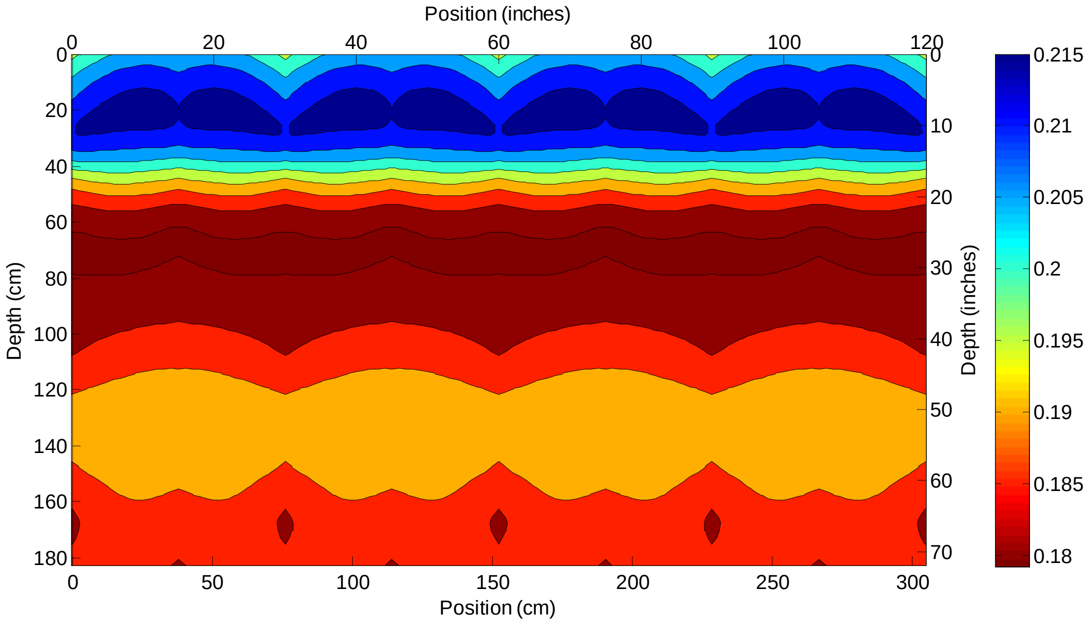

Figure B.98 - Sorghum flower-grain fill soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

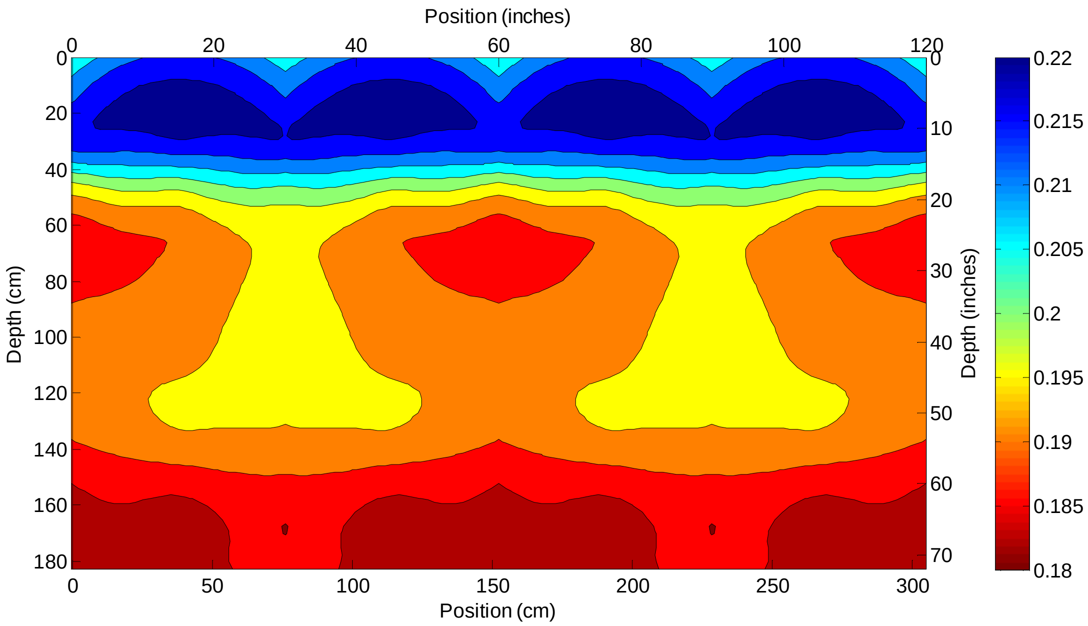

Figure B.99 - Sorghum flower-grain fill soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

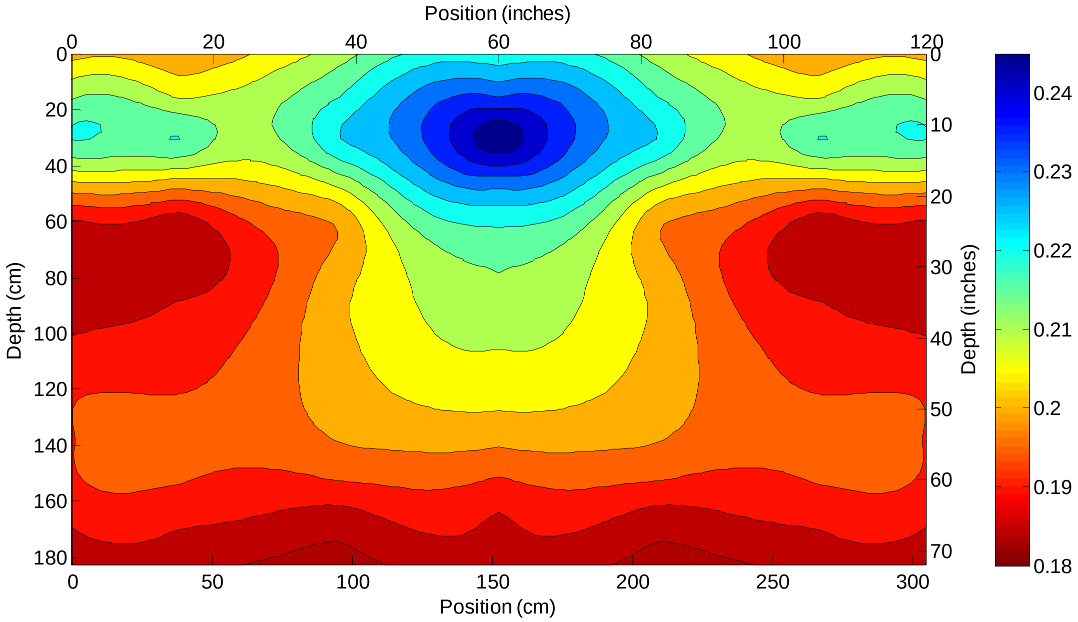

Figure B.100 - Sorghum flower-grain fill soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

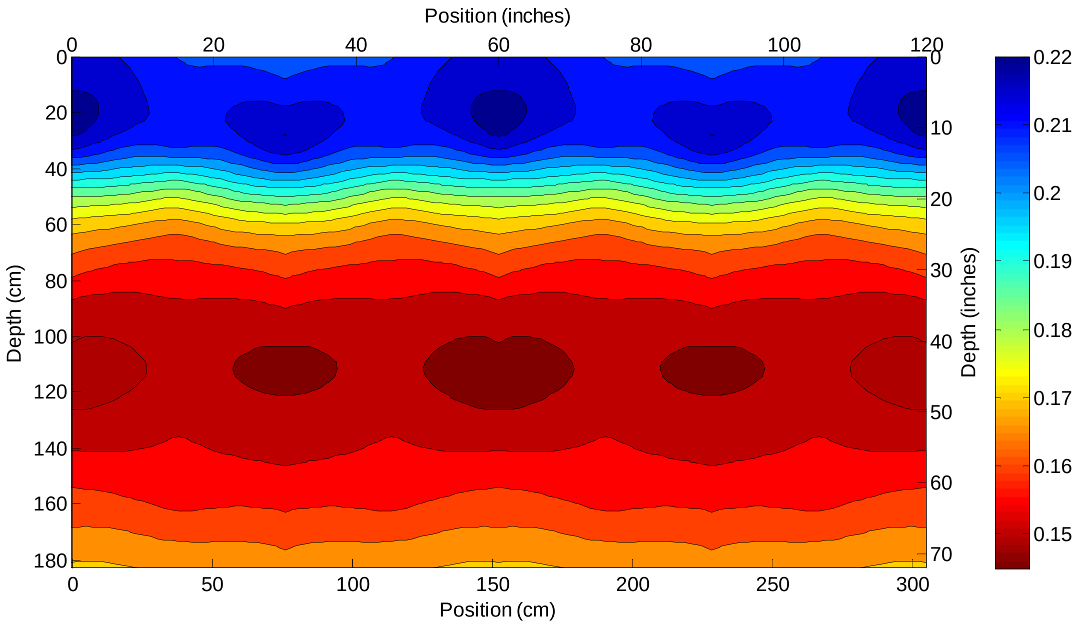

Figure B.101 - Sorghum harvest soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

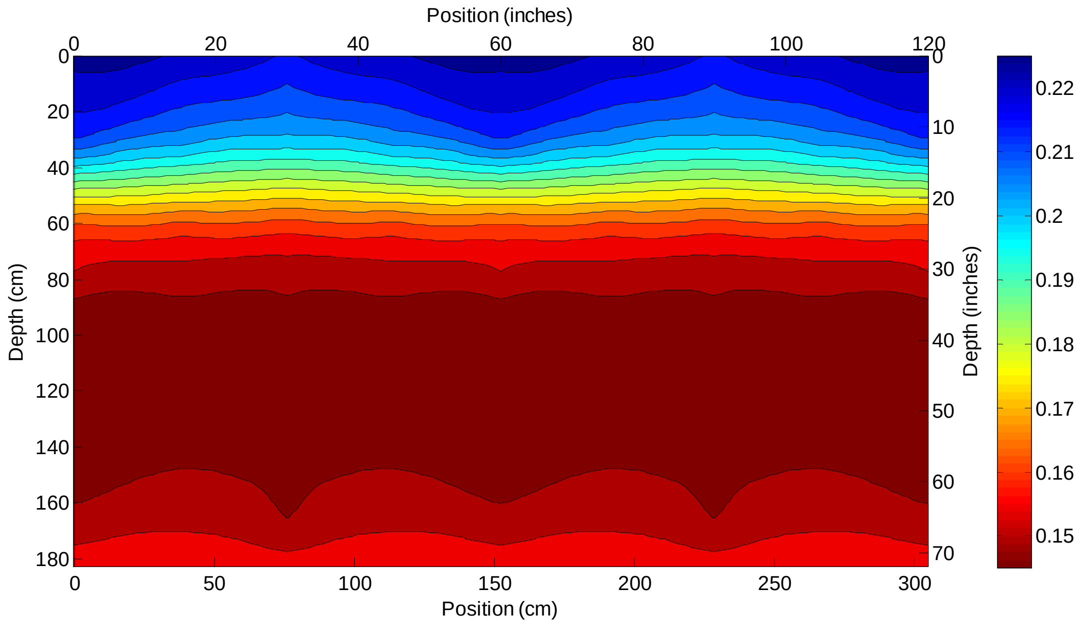

Figure B.102 - Sorghum harvest soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

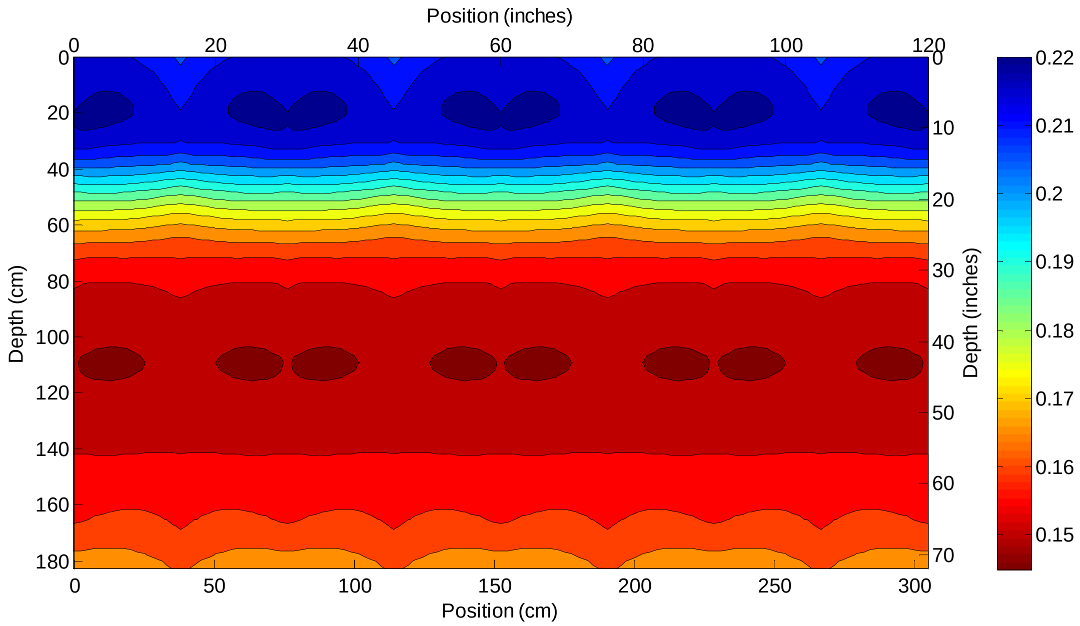

Figure B.103 - Sorghum harvest soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, conventional geometry.

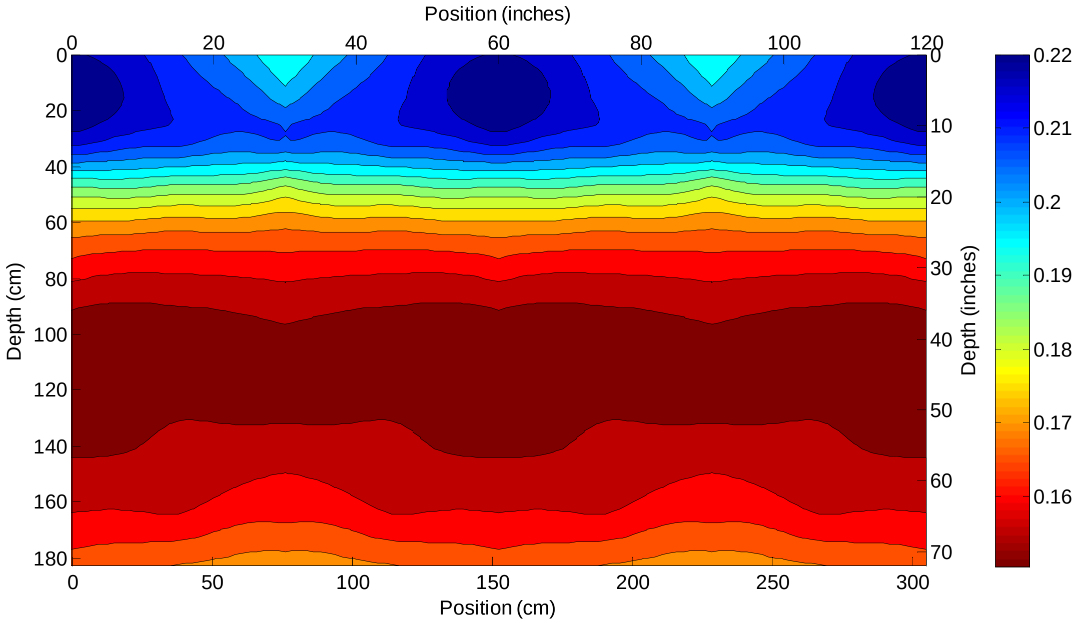

Figure B.104 - Sorghum harvest soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, P1S1 geometry.

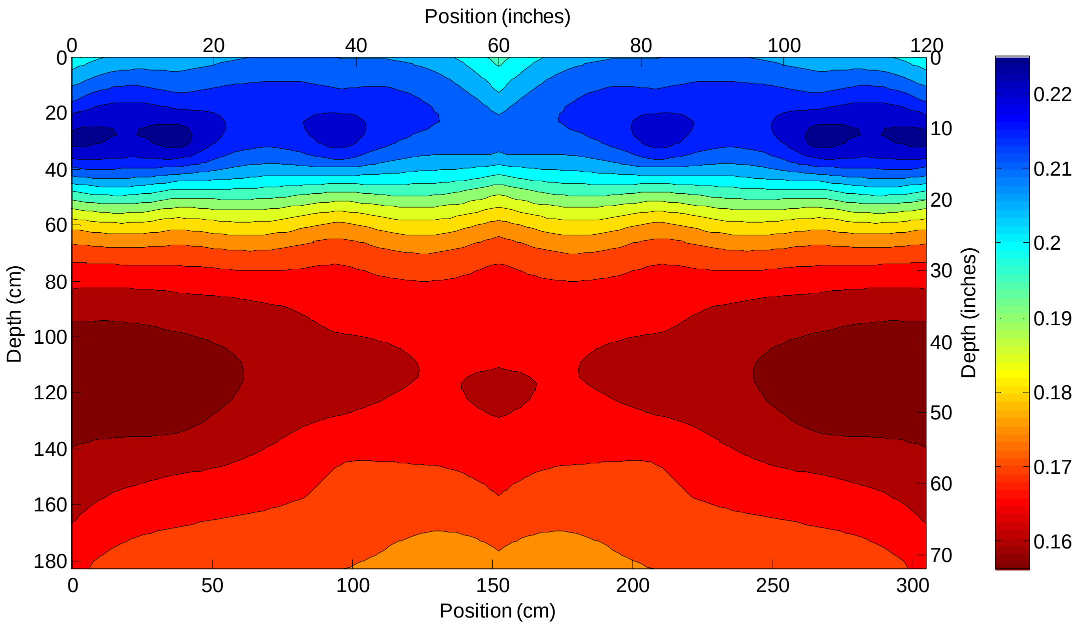

Figure B.105 - Sorghum harvest soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, P2S2 geometry.

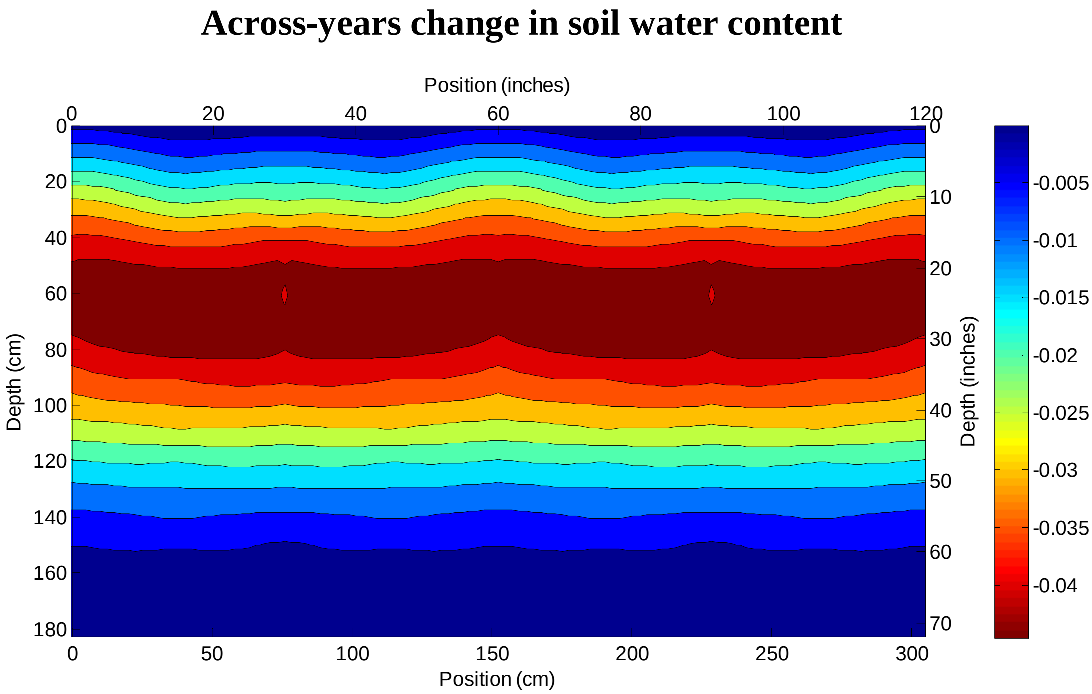

Figure B.106 - Sorghum early vegetative to flower-grain fill change in soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, clump geometry.

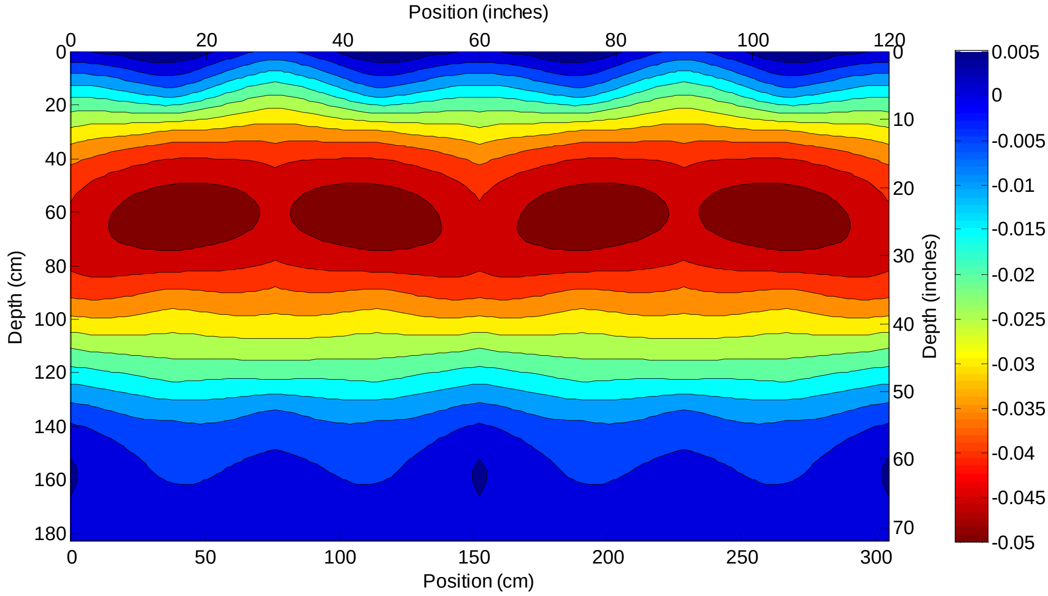

Figure B.107 - Sorghum early vegetative to flower-grain fill change in soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, cluster geometry.

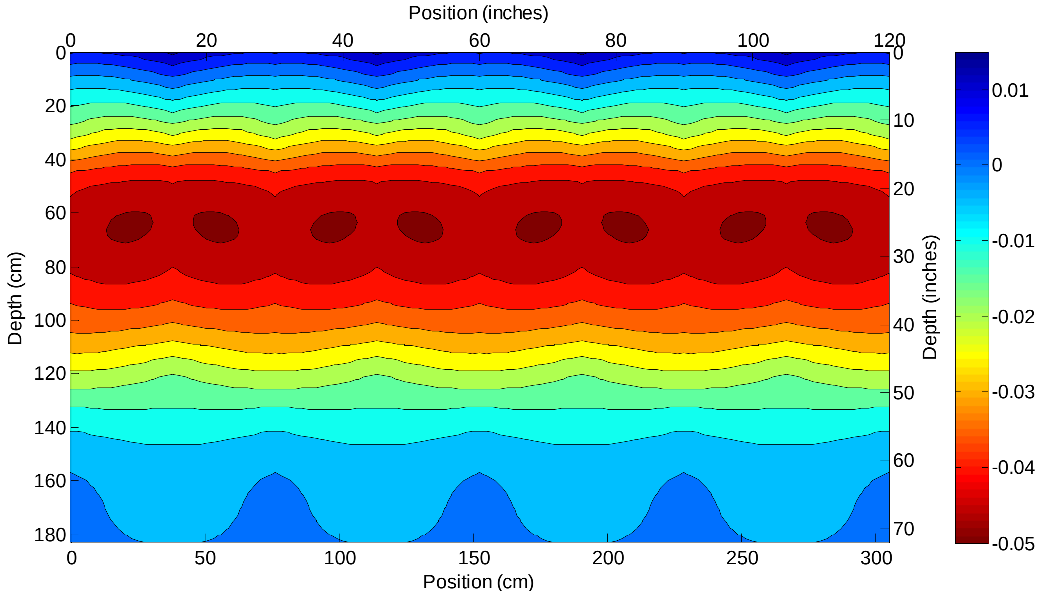

Figure B.108 - Sorghum early vegetative to flower-grain fill change in soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, conventional geometry.

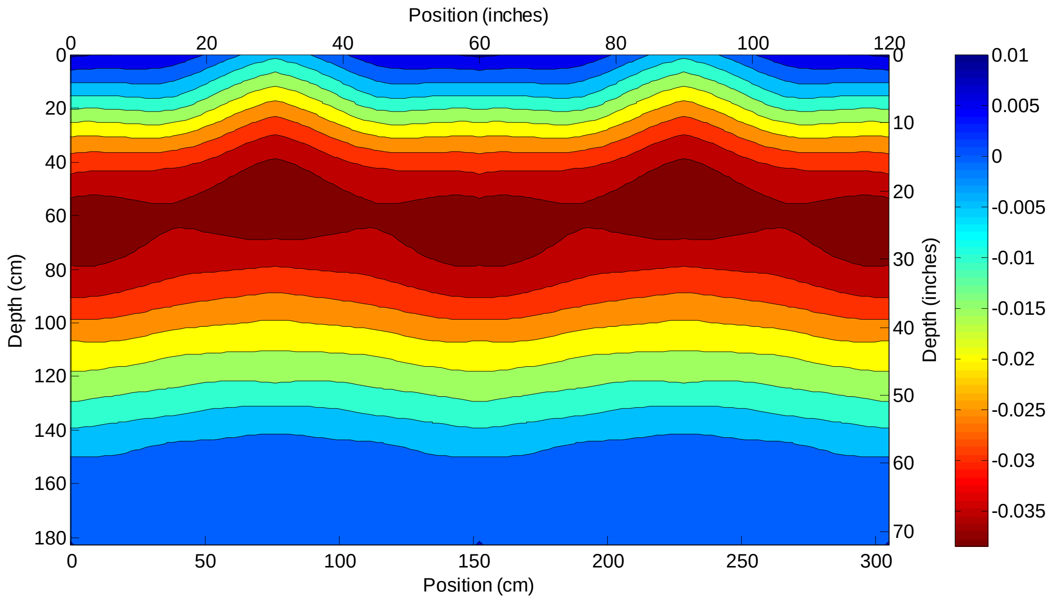

Figure B.109 - Sorghum early vegetative to flower-grain fill change in soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

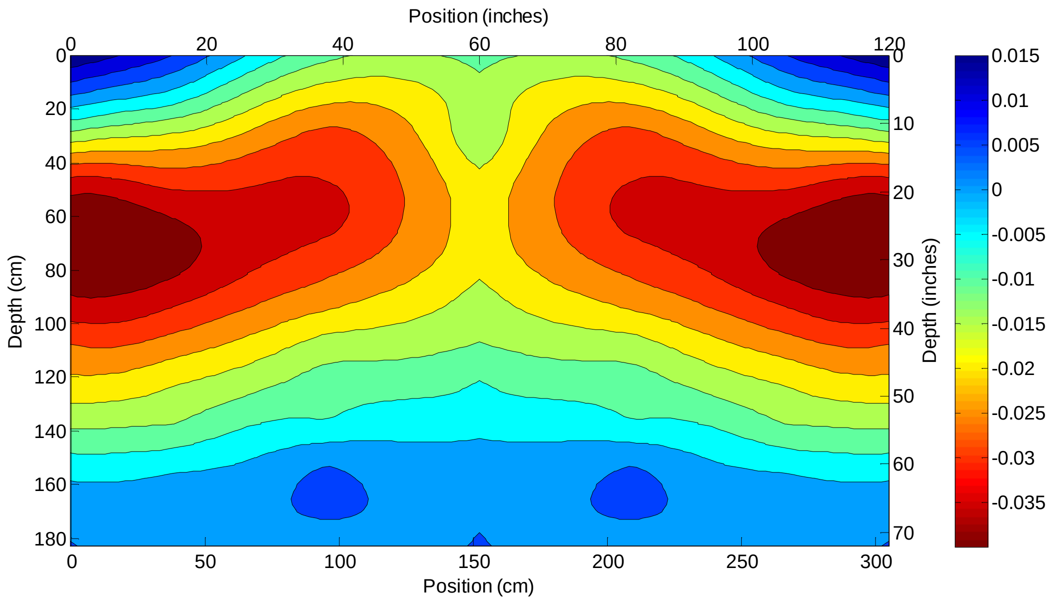

Figure B.110 - Sorghum early vegetative to flower-grain fill change in soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

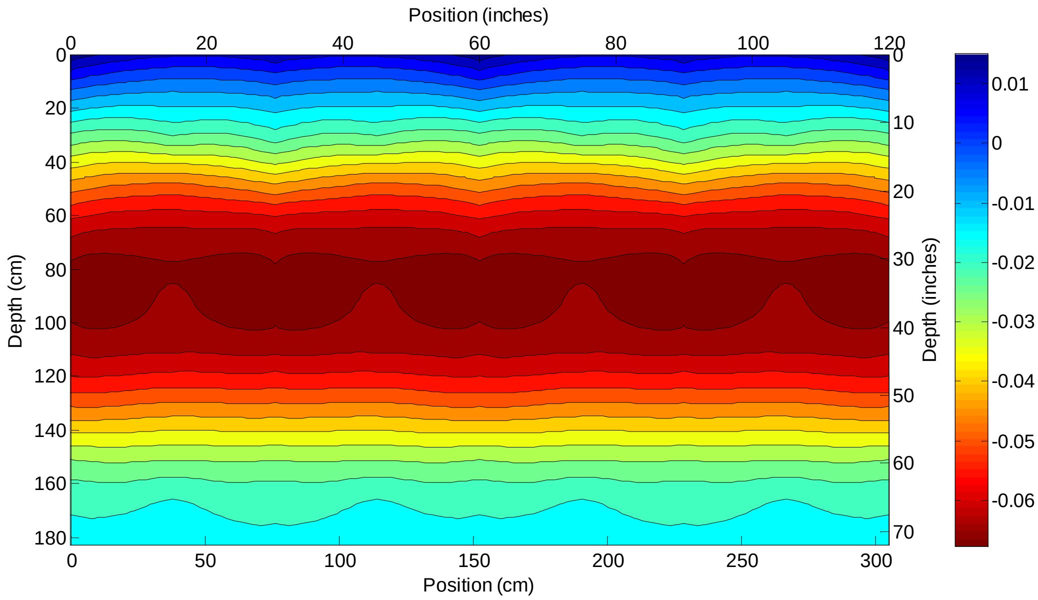

Figure B.111 - Sorghum early vegetative to harvest change in soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, clump geometry.

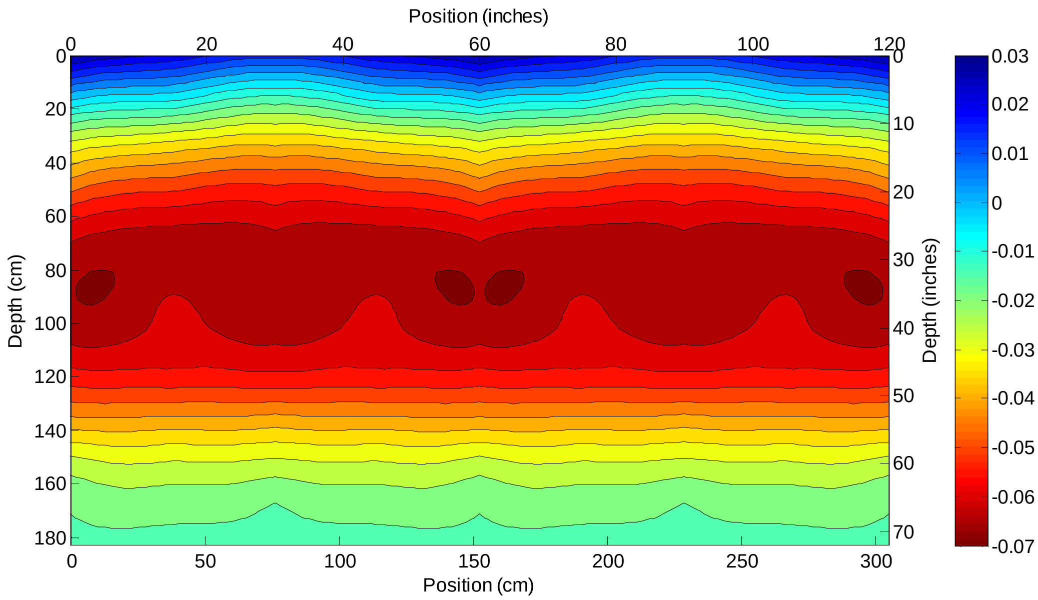

Figure B.112 - Sorghum early vegetative to harvest change in soil water content across years, drawn with contour step = 0.005 cm^3 cm^{-3}, cluster geometry.

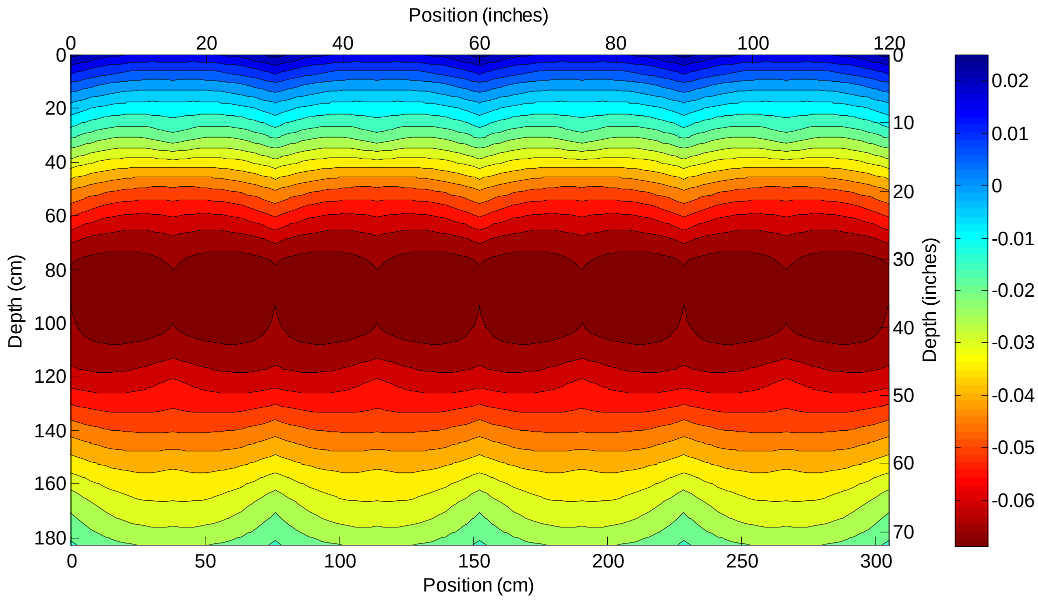

Figure B.113 - Sorghum early vegetative to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3 cm^{-3}$, conventional geometry.

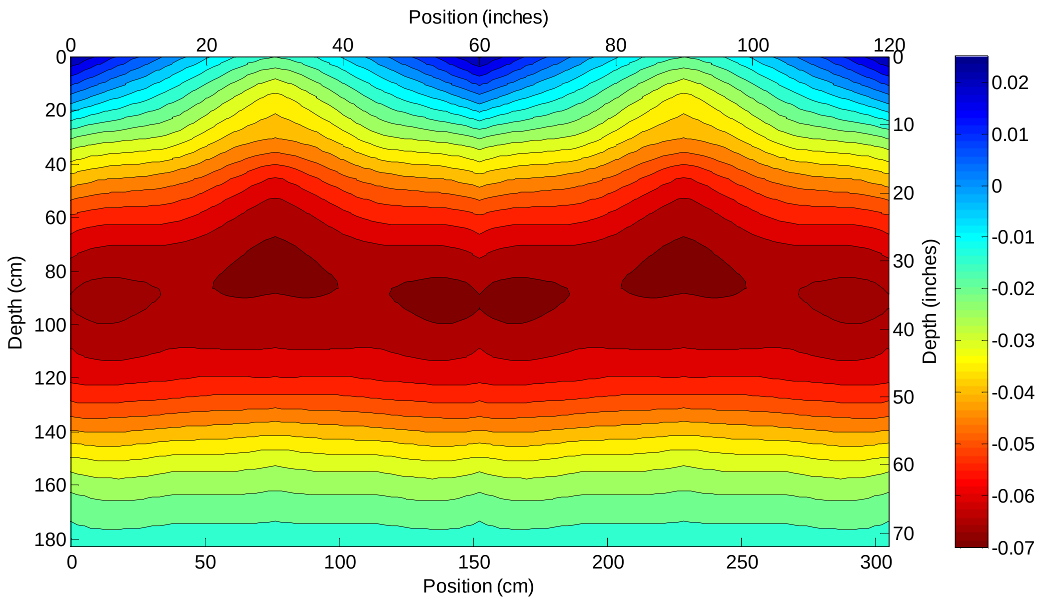

Figure B.114 - Sorghum early vegetative to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3 cm^{-3}$, P1S1 geometry.

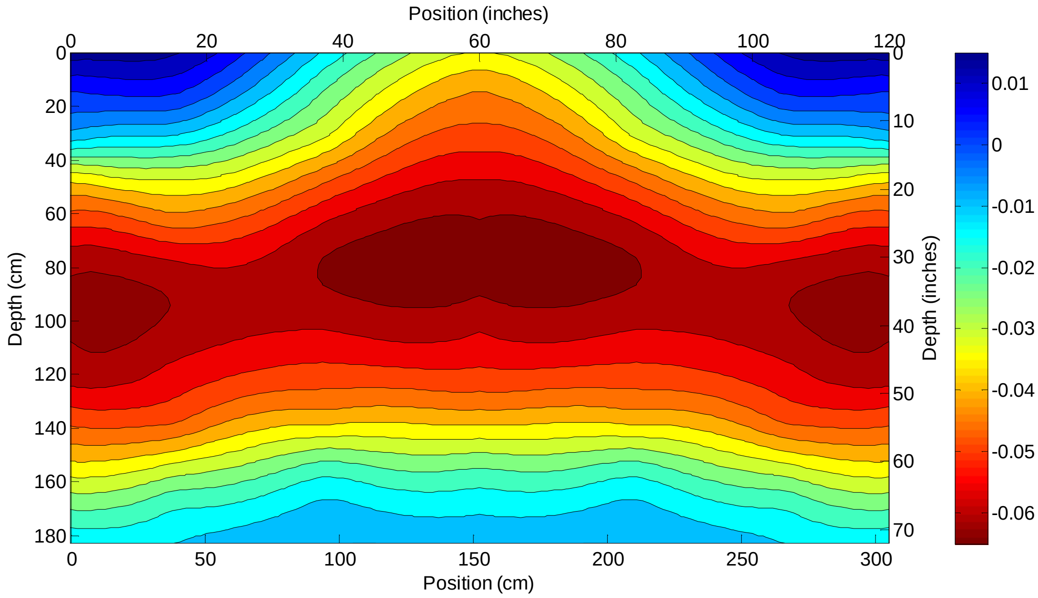

Figure B.115 - Sorghum early vegetative to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3 cm^{-3}$, P2S2 geometry.

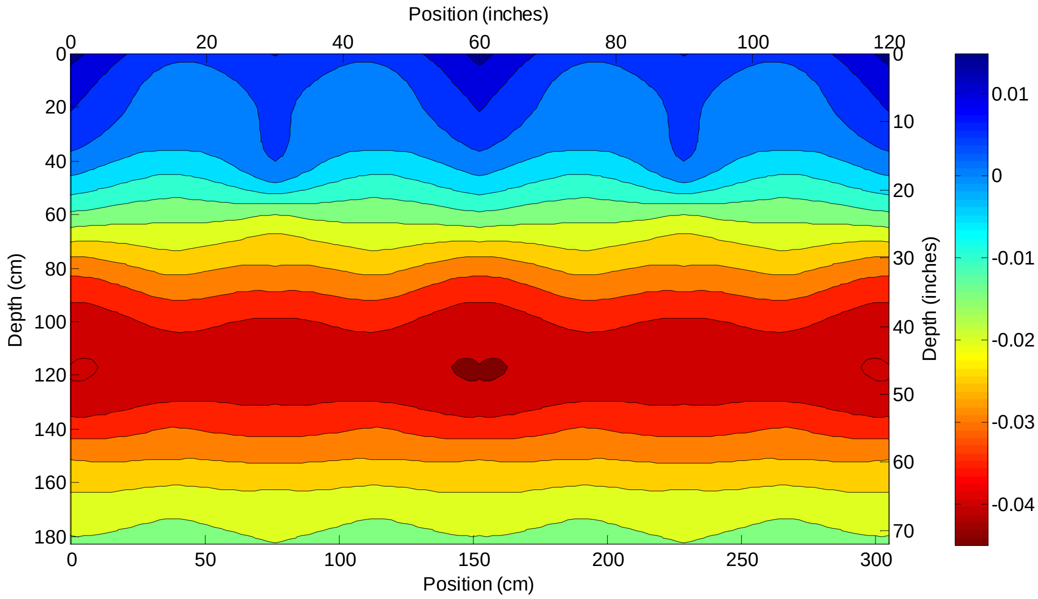

Figure B.116 - Sorghum flower-grain fill to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3 cm^{-3}$, clump geometry.

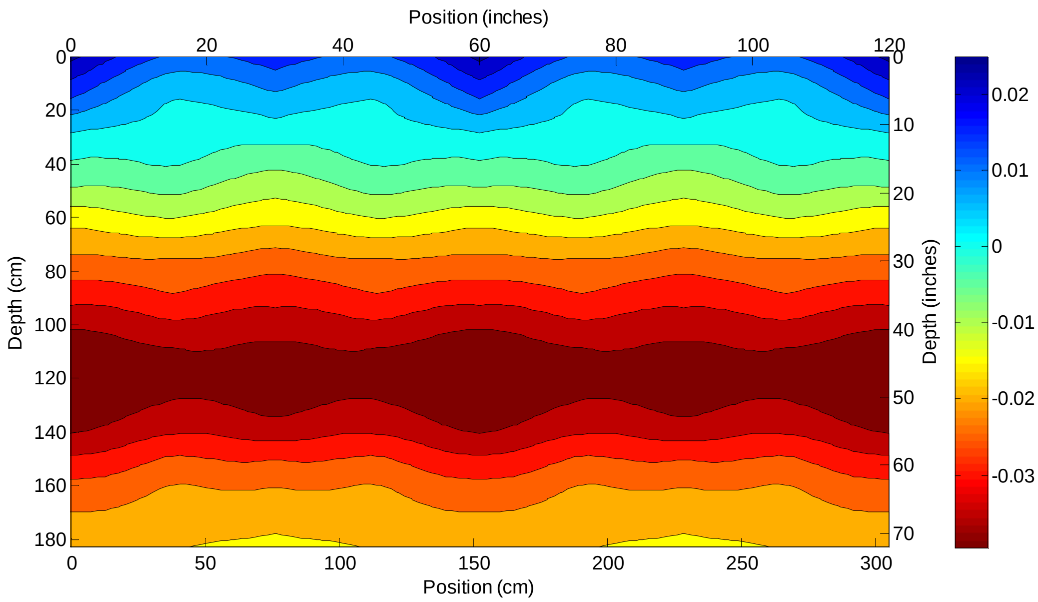

Figure B.117 - Sorghum flower-grain fill to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, cluster geometry.

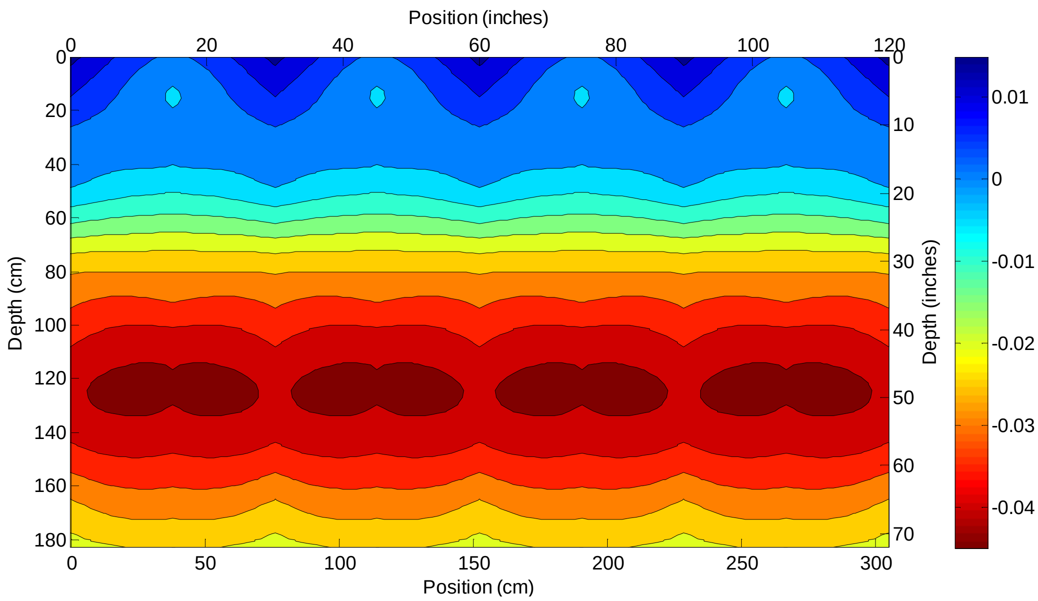

Figure B.118 - Sorghum flower-grain fill to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3\,cm^{-3}$, conventional geometry.

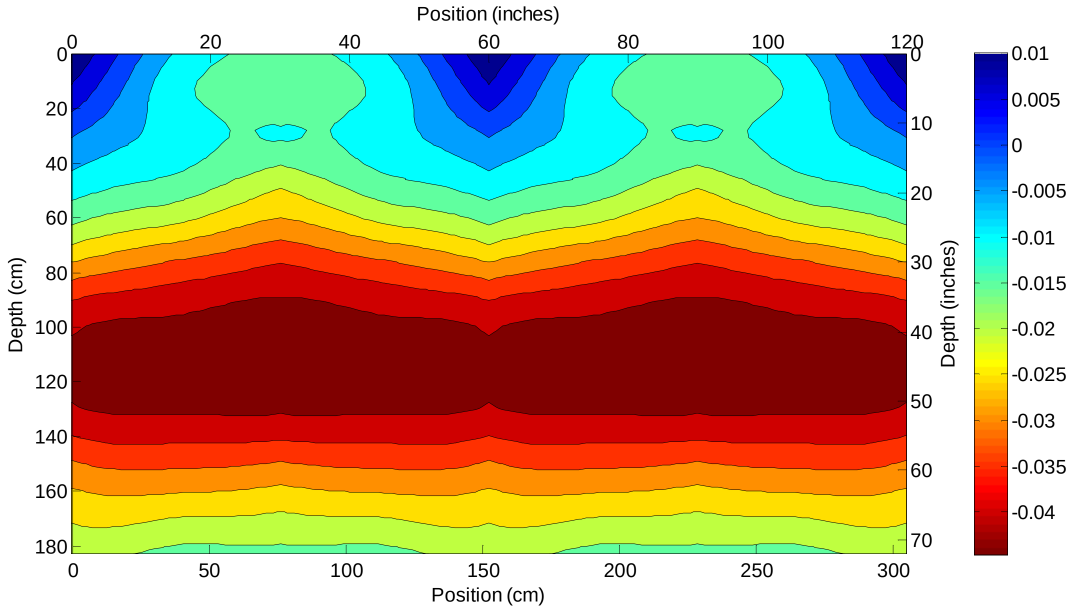

Figure B.119 - Sorghum flower-grain fill to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P1S1 geometry.

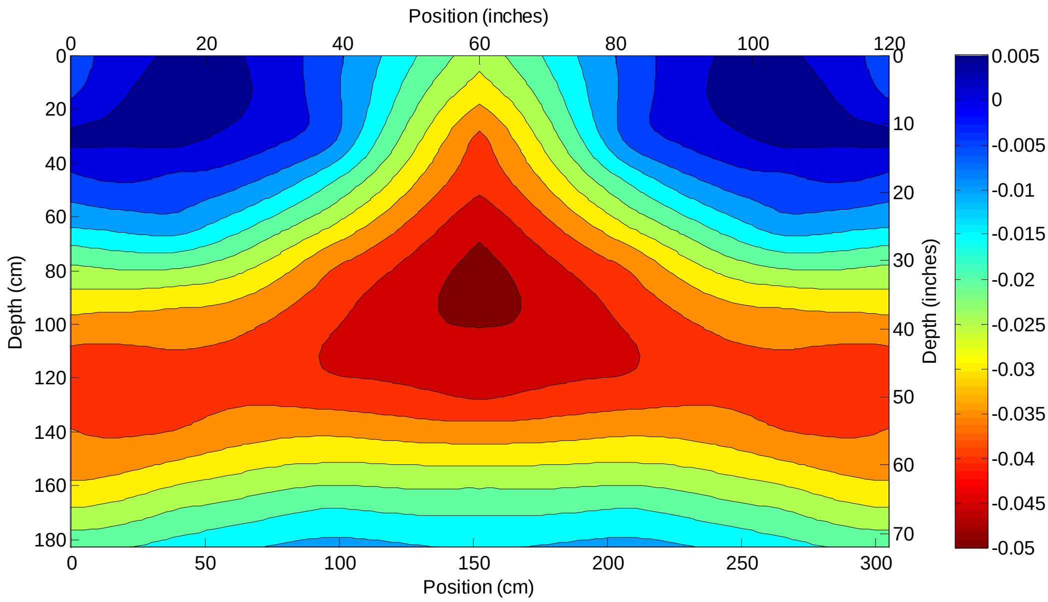

Figure B.120 - Sorghum flower-grain fill to harvest change in soil water content across years, drawn with contour step = 0.005 $cm^3\ cm^{-3}$, P2S2 geometry.

Appendix C - MatLab Code Routines For Processing Soil Water Data

SkipClumpThetaData.m

This code is the base program for taking in neutron soil water data that has already been converted into values of theta. This program determines the geometry of each data read based upon its properties and applies the correct interpolation procedure. This code also performs mirroring of the various interpolations and generates composite data layers for a 120 inch wide and 72 inch deep soil profile.

```
% SkipClumpThetaData - Written to process neutron data of the form
key,x,y,theta
% into an interpolated cross section of soil water. key is a unique key to
% each tube and read event. .mat files are created that contain the
% interpoliated grid of values for each tube at each read event. These can
% then be averaged, subtracted, etc.

% Written by Gerard Kluitenberg and Lucas Haag
% K-State Research & Extension, Fall 2012 / Spring 2013


% Clear MATLAB environment
clear all;
close all;
clc;

% Load in-season precipiation data that is later merged with summary data
% of each plot after interpolation
load YearCropTime.mat;

% Read input data from Excel spreadsheet - NOT CURRENTLY IN USE
% format is xlsread('FileName','SheetName','upper left colrow..lower right
% colrow'), if only a single return arguement is used only numerical data
% is returned, 2 arguments are needed if text is to be returned, i.e.
% [data, key] returns numerical informaton to an array called data, and key
% returns text information to a cell array
%[data, key] = xlsread('MatlabSoilWaterInput',1,'a2:e19297'); % upload
complete data set

% The cell array "key" contains the CropYear/CropTime/TRT/Plot key
% Column 1 of matrix "data" contains horizontal space coordinate, X
% Column 2 of matrix "data" contains vertical space coordinate, Y
% Column 3 of matric "data" contains measured water contents, theta

%Read Data though txt file - CURRENTLY IN USE
%fileID holds integer value to identfy files, 0-2 are reserved by Matlab so
```

```
%likely is assigned value 3
fileID=fopen('MatlabSoilWaterInput.txt');
%textscan reads in from fileID, string, float, float, float, float
data=textscan(fileID, '%s %f %f %f %f')

%close open file
fclose(fileID);


% Create individual column vectors by subsampling matrix "data"
% data brought in through the textscan are placed into cell arrays
% use the cell2mat to convert cell arrays into numeric vectors or arrays
key = cell(data{1,1}); %creates key cell array by reading out of cell 1,1 in
data cell array
x = cell2mat(data(:,2)); %creates x position vector of x by 1 (where x is
number of data lines read)
y = cell2mat(data(:,3)); %creates y position vector of y by 1 (where y is
number of data lines read)
z = cell2mat(data(:,4)); %creates theta vector of z by 1 (where z is number
of data lines read)


%Generates a cell array with unique keys, uniquekeys
%Generates two column vectors with the row of first occourance (UKidx) not
used, and
%a vector that references each entry in key to its accompanying line in
uniquekeys
[uniquekeys, UKidx, UKnumber] = unique(key, 'first');

%Save a uniquekeys matlab file that serves as the lookup datasource for
%postprocessing script
save('KeyFile.mat','uniquekeys');

% Determine the number of unique keys
L = length(uniquekeys);

% Create a cell array with dimensions to fit summary data
SummaryData = cell(L,8);


% Select interpolation method
% method = 'linear'; % default interpolation method
% method = 'cubic';
% method = 'nearest';
 method = 'v4';

for k=1:L %Loop through all unique keys

  % Determine indices for data set of interest
  % idx is a column vector of indicies that match the current k (key)
  idx = find(UKnumber==k);

  % Create filename for output
  filename = uniquekeys{k}
```

```
% Subsample column vectors "x", "y", and "z"
% x, y, and z contain all data read in from .txt or .xls file
xx = x(idx);
yy = y(idx);
zz = z(idx);


% Determine length of vector "idx". The scalar "LL" is used as a proxy
% for determining the tube configuration of the data set of interest.
LL = length(idx);

% Assign variables that control size and shape of grided mesh
% All values have units of inches

%If statement for TRT 42-P2S2, i.e. 48 entries under the current key
if LL==48
  Xmin = 0.0;
  Xstep = 1.0;
  Xmax = 60.0;
  Ymin = 0.0;
  Ystep = 1.0;
  Ymax = 72.0;
%If statement for TRT 22-SwinR, 32-P1S1, and 52-Clump
elseif LL==36
  Xmin = 0.0;
  Xstep = 1.0;
  Xmax = 30.0;
  Ymin = 0.0;
  Ystep = 1.0;
  Ymax = 72.0;
%If LL dosent match the above then it has to be TRT 12-Conventional
else
  Xmin = 0.0;
  Xstep = 1.0;
  Xmax = 15.0;
  Ymin = 0.0;
  Ystep = 1.0;
  Ymax = 72.0;
end

% Create grid of points at which water content is to be interpolated
% pull x and y min max and steps from variables dependent on specific
% key/geometry being evaluated in this loop step
[X,Y] = meshgrid(Xmin:Xstep:Xmax,Ymin:Ystep:Ymax);

% Interpolate water content at grid points using real data xx, yy, zz
% and estimating at points X, Y
Z = griddata(xx,yy,zz,X,Y,method);

% Calculate volumes of water and soil in the control section
% 3.16.2013 LH - Note that due to spacing of interpolation points and
% cells for summing it is necessary to sum 1/2 of the Vw and Vs for the
% endpoint cells, and 1/4 for the corner cells both horizontally (X) and
% with depth (Y), summing with dA for all points will result in
```

```
  % overestimation of Vw and Vs and will unfairly weight end cells

  dA = Xstep*Ystep;    %calculate the "area" of each interpolation cell;
  [a,b] = size(Z); %size command returns number of rows=a and columns=b in
matrix Z


  %Vw = sum(sum(Z))*dA;  %multiply sum of matrix water contents by area, eq.
19 in handout
              %where dA is delta x by delta z

  %Calculate Vw that was created in interpolation but is located in areas
  %outside the intended domain (x<0 and x>30, y<0 and y>72

  %Remove 0.50 of Vw located in first and last rows
  XVwr = 0.5*(sum(Z(1,1:b))+sum(Z(a,1:b)));
  %Remove 0.50 of Vw located in first and last columns
  XVwc = 0.5*(sum(Z(1:a,1))+sum(Z(1:a,b)));
  %In this approach the 0.25 of the corner cell values are subtracted
  %twice, need to calculate those for inclusion in the sum later
  XVwx = (0.25*(Z(1,1)+Z(1,b)+Z(a,1)+Z(a,b)));

  %Calculate total Vw by summing entire Z (interpolation domain) then
  %subtracting out water that lies outside the indended summing domain,
  %subtract extra water on outside edge rows and columns and add back
  %in water that was subtracted twice as part of the process, i.e.
  %corners

  Vw = sum(sum(Z))-XVwr-XVwc+XVwx;

  Vs = (a-1)*(b-1)*dA; %calculate Vs, subtract 1 from a and b to get to cross
sectional area instead of fully interpolated area

  % Calculate depths of water and soil in the control section at each
  % interpolation point, NOTE: If summed it will result in an area that
  % reflects the interpolation domain, not the true control section.
  Dw = sum(Z)*Xstep; %sum the columns of interpolated data matrix Z to get
depth of water across the transect
  Ds = a*Xstep; %depth of soil

  save(filename,'xx','yy','zz','X','Y','Z','Vw','Vs','Dw','Ds');

  % Match first 6 characters (Year and CropTime) of current key to
  % in-season precipitation table and return location of occourance
  YCT=strncmpi(YearCropTime(:,1), filename,6);

  %Add values for key, Vw, Vs, Dw, Ds, and cum. precip to master result file
  SummaryData{k,1}=uniquekeys{k};
  SummaryData{k,2}=Vw;
  SummaryData{k,3}=Vs;
  SummaryData{k,4}=Vw/Vs;
  SummaryData{k,5}=YearCropTime{YCT,4}; %matched precipiation value
  SummaryData{k,6}=max(Z(:)); % Max value from interpolation
  SummaryData{k,7}=min(Z(:)); % Min value from interpolation
```

```
  SummaryData{k,8}=std(Z(:)); % StdDev of values from interpolation



end

save('Summary.mat','SummaryData');


% SkipClumpThetaAveraging
% Written by Lucas Haag
% K-State Research & Extension, Dept. of Agronomy
% Written to provide postprocessing of neutron data after interpolation has
% been performed. Averages plots within each Year/CropTime/TRT combination
% and produces a file with average interpolated values.

% Clear MATLAB environment
clear all;
close all;
clc;

% Load file named "FileKeys.mat" which contains the cell array of unique
% keys
load KeyFile.mat

%Create

% Extract YearCropTime entries from uniquekeys
% Define search expression
expression = '\d\d\d\d\S\S\d\d';
[YCT] = regexp(uniquekeys,expression,'match','once');
%Generates a cell array with unique YearCropTime entries, uniqueYCT
%Generates two column vectors with the row of first occourance (UKYCTidx) not
used, and
%a vector that references each entry in key to its accompanying line in
%uniquekeys (UKYCTnumber)
uniqueYCT = unique(YCT);

% Loop through uniqueYCT values, load files for each
% cropyear/croptime/treatment combination and produce a mean treatment
% dataset
for CurrentYCT = 1:length(uniqueYCT);
  CurrentYCTExpression=strcat((uniqueYCT{CurrentYCT}),'\d\d\d');

  %Select keys from uniquekeys that match currentYCT
  Selectedkeys =
find(~cellfun(@isempty,(regexp(uniquekeys,CurrentYCTExpression,'start'))));


  for CurrentSK = 1:length(Selectedkeys);

    % Load *.mat file selected in dialog box
    Selectedkeyfile=uniquekeys{Selectedkeys(CurrentSK)}
    load(Selectedkeyfile, '-mat');
```

```
    %On first iteration just copy variables, this also sets up arrays
    %when CurrentSK=1, add to exisitng if CurrentSK>1
    if CurrentSK==1;
      AvgX=X;
      AvgY=Y;
      AvgZ=Z;
      AvgVw=Vw;
      AvgVs=Vs;
      AvgDw=Dw;
      AvgDs=Ds;
      AvgMax=max(Z(:));
      AvgMin=min(Z(:));
      AvgStd=std(Z(:));
    else
      AvgX=AvgX+X;
      AvgY=AvgY+Y;
      AvgZ=AvgZ+Z;
      AvgVw=AvgVw+Vw;
      AvgVs=AvgVs+Vs;
      AvgDw=AvgDw+Dw;
      AvgDs=AvgDs+Ds;
      AvgMax=AvgMax+max(Z(:));
      AvgMin=AvgMin+min(Z(:));
      AvgStd=AvgStd+std(Z(:));
    end;

    % Clear all variables in workspace created by the execution of the
    % "load" command before loading another file.
    clear X Y Z xx yy zz Dw Ds Vw Vs;

  end;

  %Variables have been summed across plots, now divide to get mean
  Plots=length(Selectedkeys);
  X=AvgX/Plots;
  Y=AvgY/Plots;
  Z=AvgZ/Plots;
  Vw=AvgVw/Plots;
  Vs=AvgVs/Plots;
  Dw=AvgDw/Plots;
  Ds=AvgDs/Plots;
  Max=AvgMax/Plots;
  Min=AvgMin/Plots;
  Std=AvgStd/Plots;


  %clear temp averaging variables
  clear Avgxx Avgyy Avgzz AvgX AvgY AvgZ AvgVw AvgVs AvgDw AvgDs AvgMax...
    AvgMin AvgStd;

  %Save means to file
  AVGfilename=strcat((uniqueYCT{CurrentYCT}),'AVG');

save(AVGfilename,'X','Y','Z','Vw','Vs','Dw','Ds','Max','Min','Std','Plots');
```

```
  %Create composite dataset

  %Flip X, Y, and Z matricies (mirrors) for use in building 120 inch
composite

  %IX=fliplr(X); don't want to flip X, just add spacing interger to it
  %IY=fliplr(Y); no need to flip Y
  IZ=fliplr(Z);

  %Build composite matrix for P2S2
  if regexp(AVGfilename,'......42|......94')==1;
    CX=[X,(X(:,2:end)+60)];
    CY=[Y,Y(:,2:end)];
    CZ=[Z,IZ(:,2:end)];

  %Build composite matrix for P1S1, Clump, or Cluster
  elseif
regexp(AVGfilename,'......52|......95|......22|......92|......32|......93')==
1;
    CX=[X,(X(:,2:end)+30),(X(:,2:end)+60),(X(:,2:end)+90)];
    CY=[Y,Y(:,2:end),Y(:,2:end),Y(:,2:end)];
    CZ=[Z,IZ(:,2:end),Z(:,2:end),IZ(:,2:end)];

  %Build composite matrix for Conventional
  elseif regexp(AVGfilename,'......12|......91')==1;
    CX=[X,(X(:,2:end)+15),(X(:,2:end)+30),(X(:,2:end)+45),...
      (X(:,2:end)+60),(X(:,2:end)+75),(X(:,2:end)+90),(X(:,2:end)+105)];

CY=[Y,Y(:,2:end),Y(:,2:end),Y(:,2:end),Y(:,2:end),Y(:,2:end),Y(:,2:end),Y(:,2
:end)];

CZ=[Z,IZ(:,2:end),Z(:,2:end),IZ(:,2:end),Z(:,2:end),IZ(:,2:end),Z(:,2:end),IZ
(:,2:end)];
  end

  %Move CX, CY, and CZ into standard variable names X, Y, and Z
  X=CX; Y=CY; Z=CZ;
  clear CX;
  clear CY;
  clear CZ;

  %Save Composite data to file
  Cfilename=strcat((uniqueYCT{CurrentYCT}),'CMP')
  save(Cfilename,'X','Y','Z');
  clear X;
  clear Y;
  clear Z;

end;
```

DifferenceGUI2.m

This code creates a graphical user interface to select the data of interest, control which plots are generated, and perform the mathematical functions of subtracting data from different dates and supplying that information to the plotting routines.

```
function varargout = DifferenceGUI2(varargin)
% DIFFERENCEGUI2 MATLAB code for DifferenceGUI2.fig
%   DIFFERENCEGUI2, by itself, creates a new DIFFERENCEGUI2 or raises the
existing
%   singleton*.
%
%   H = DIFFERENCEGUI2 returns the handle to a new DIFFERENCEGUI2 or the
handle to
%   the existing singleton*.
%
%   DIFFERENCEGUI2('CALLBACK',hObject,eventData,handles,...) calls the local
%   function named CALLBACK in DIFFERENCEGUI2.M with the given input
arguments.
%
%   DIFFERENCEGUI2('Property','Value',...) creates a new DIFFERENCEGUI2 or
raises the
%   existing singleton*. Starting from the left, property value pairs are
%   applied to the GUI before DifferenceGUI2_OpeningFcn gets called. An
%   unrecognized property name or invalid value makes property application
%   stop. All inputs are passed to DifferenceGUI2_OpeningFcn via varargin.
%
%   *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
%   instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help DifferenceGUI2

% Last Modified by GUIDE v2.5 25-Mar-2013 19:27:39

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',     mfilename, ...
          'gui_Singleton', gui_Singleton, ...
          'gui_OpeningFcn', @DifferenceGUI2_OpeningFcn, ...
          'gui_OutputFcn', @DifferenceGUI2_OutputFcn, ...
          'gui_LayoutFcn', [] , ...
          'gui_Callback',  []);
if nargin && ischar(varargin{1})
  gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
  [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
```

```
  gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before DifferenceGUI2 is made visible.
function DifferenceGUI2_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject  handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles  structure with handles and user data (see GUIDATA)
% varargin  command line arguments to DifferenceGUI2 (see VARARGIN)

% Choose default command line output for DifferenceGUI2
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

%Start of PostProcessCode - Load keyfile produced in ThetaData
load keyfile.mat;
YearExpression = '\d\d\d\d';
UniqueYears=unique(regexp(uniquekeys,YearExpression,'match','once'));
UniqueYears=vertcat('....',UniqueYears);
%Fill year list boxes with UniqueYears
set(handles.lstECropYear, 'string', UniqueYears);
set(handles.lstBCropYear, 'string', UniqueYears);
%Set AVG and CMP as potential input data types;
%InputOptions={'AVG','CMP'};
InputOptions={'AVG','CMP'};
set(handles.lstInput,'string',InputOptions);
%Set to calculate differences by default;
set(handles.chkCalcDiff,'value',1);





% UIWAIT makes DifferenceGUI2 wait for user response (see UIRESUME)
% uiwait(handles.figure1);


% --- Outputs from this function are returned to the command line.
function varargout = DifferenceGUI2_OutputFcn(hObject, eventdata, handles)
% varargout cell array for returning output args (see VARARGOUT);
% hObject  handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles  structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;


% --- Executes on button press in btnCancel.
```

```matlab
function btnCancel_Callback(hObject, eventdata, handles)
% hObject    handle to btnCancel (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)



% --- Executes on button press in btnCalculate.
function btnCalculate_Callback(hObject, eventdata, handles)
% hObject    handle to btnCalculate (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

%Determine if use has selected AVG or CMP as input data type
InputType=get(handles.lstInput,'value');
InputOptions=get(handles.lstInput,'string');
InputFileExt=InputOptions{get(handles.lstInput,'value')};

%check to see if directories needed for dataoutput exist
% Directory for individual difference plots
if exist('DiffPlots')~=7
  mkdir('DiffPlots');
end
% Directory for individual theta plots
if exist('ThetaPlots')~=7
  mkdir('ThetaPlots');
end;
% Directory for composite difference plots
if exist('MultiDiffPlots')~=7
  mkdir('MultiDiffPlots');
end;
% Directory for composite theta plots
if exist('MultiThetaPlots')~=7
  mkdir('MultiThetaPlots');
end;

%load list of potential keys
load keyfile.mat;

%Build expression mask from selections in list box
ECropYear=get(handles.lstECropYear,'string');
ECropTime=get(handles.lstECropTime,'string');
ETrt=get(handles.lstETrt,'string');
EndingFile=strcat(ECropYear(get(handles.lstECropYear,'value')),...
  ECropTime(get(handles.lstECropTime,'value')),...
  ETrt(get(handles.lstETrt,'value')));
ECT=ECropTime{get(handles.lstECropTime,'value')};

% Build list of EndingFiles
EndingFiles=regexp(uniquekeys,EndingFile,'match','once');
EndingFiles=unique(EndingFiles(~cellfun('isempty',EndingFiles)));

% Query Beginning File CropTime selection from list box
BCropTime=get(handles.lstBCropTime,'string');
BCT=BCropTime{get(handles.lstBCropTime,'value')};
```

```
% Begin Processing Loop
  LastEF=length(EndingFiles);
  for CurrentEF=1:LastEF;

    %Process ending files for geometries and time period selected
    EFile=strcat(EndingFiles{CurrentEF},InputFileExt);
    load(EFile);
    EX=X;
    EY=Y;
    EZ=Z;
    MultiEX(:,:,CurrentEF)=X;
    MultiEY(:,:,CurrentEF)=Y;
    MultiEZ(:,:,CurrentEF)=Z;

    %Process beginning files for geometries and time period selected
    BFile=strcat(strrep(EndingFiles{CurrentEF},ECT,BCT),InputFileExt);
    load(BFile);

    BX=X;
    BY=Y;
    BZ=Z;
    MultiBX(:,:,CurrentEF)=X;
    MultiBY(:,:,CurrentEF)=Y;
    MultiBZ(:,:,CurrentEF)=Z;


    %Process data for generating difference plots


        Z=EZ-BZ;
        MultiZ(:,:,CurrentEF)=Z;
        MultiX(:,:,CurrentEF)=X;
        MultiY(:,:,CurrentEF)=Y;
        DFile=strcat(strrep(EndingFiles{CurrentEF},ECT,BCT),'-DIFF-
',EndingFiles{CurrentEF});
        MultiNames{CurrentEF}=DFile;
        %Convert MultiNames strings to treatment text

expr='\d\d\d\d\S\S12\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S91\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='Conventional';
          MultiNames=regexprep(MultiNames,expr,TName);

expr='\d\d\d\d\S\S22\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S92\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='Cluster';
          MultiNames=regexprep(MultiNames,expr,TName);

expr='\d\d\d\d\S\S32\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S93\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='P1S1';
          MultiNames=regexprep(MultiNames,expr,TName);

expr='\d\d\d\d\S\S42\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S94\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='P2S2';
```

```
          MultiNames=regexprep(MultiNames,expr,TName);

expr='\d\d\d\d\S\S52\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S95\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='Clump';
          MultiNames=regexprep(MultiNames,expr,TName);
        set(handles.txtFileName,'string',DFile);

        %If user has selected individual input file graphs then
        %generate EFile and BFile plots
        if get(handles.chkInputGraph,'value')==1
          ColorCode=1;
          if CurrentEF==1;
            BPlotTitle=input(strcat('Enter plot title for individual
beginning input file ',BFile,' :'),'s');
          end;
          BFullPlotTitle={BPlotTitle;'Soil Water Content, Contour Step =
0.005 v v^{-1}';[MultiNames{CurrentEF},' Geometry']}
          PlotSingleTheta(BX,BY,BZ,strcat('ThetaPlots\',BPlotTitle,'
',MultiNames{CurrentEF},'.emf'),BFullPlotTitle,MultiNames{CurrentEF},ColorCod
e,'Soil Water Content, Contour Step = 0.005 v v ^{ -1}');
          if CurrentEF==1;
            EPlotTitle=input(strcat('Enter plot title for individual ending
input file',EFile,' :'),'s');
          end;
          EFullPlotTitle={EPlotTitle;'Soil Water Content, Contour Step =
0.005 v v^{-1}';[MultiNames{CurrentEF},' Geometry']}
          PlotSingleTheta(EX,EY,EZ,strcat('ThetaPlots\',EPlotTitle,'
',MultiNames{CurrentEF},'.emf'),EFullPlotTitle,MultiNames{CurrentEF},ColorCod
e,'Soil Water Content, Contour Step = 0.005 v v ^{ -1}');


        end;


        %If user has selected individual difference graphs then generate plot
        if get(handles.chkDiffGraph,'value')==1
          ColorCode=1;
          if CurrentEF==1;
            DiffPlotTitle=input(strcat('Enter plot title for individual diff
file',DFile,' :'),'s');
          end;
          DiffFullPlotTitle={DiffPlotTitle;'Change in Soil Water Content,
Contour Step = 0.005 v v^{-1}';[MultiNames{CurrentEF},' Geometry']};
          IndDFile=['DiffPlots\',DFile,'.emf']

%PlotSingleTheta(X,Y,Z,FileName,PlotTitle,Geometry,ColorCode,DataTitle)

PlotSingleTheta(X,Y,Z,IndDFile,DiffFullPlotTitle,MultiNames{CurrentEF},ColorC
ode,'Change in Soil Water Content, Contour Step = 0.005 v v ^{ -1}');
        end;
        DFileMat=strcat(DFile,'.mat');
        save(DFileMat, 'X', 'Y', 'Z');


  end;
```

```
%Convert MultiNames strings to treatment text
expr='\d\d\d\d\S\S12\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S91\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='Conventional';
MultiNames=regexprep(MultiNames,expr,TName);
expr='\d\d\d\d\S\S22\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S92\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='Cluster';
MultiNames=regexprep(MultiNames,expr,TName);
expr='\d\d\d\d\S\S32\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S93\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='P1S1';
MultiNames=regexprep(MultiNames,expr,TName);
expr='\d\d\d\d\S\S42\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S94\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='P2S2';
MultiNames=regexprep(MultiNames,expr,TName);
expr='\d\d\d\d\S\S52\S\S\S\S\S\S\d\d\d\d\S\S\d\d|\d\d\d\d\S\S95\S\S\S\S\S\S\d
\d\d\d\S\S\d\d'; TName='Clump';
MultiNames=regexprep(MultiNames,expr,TName);


%If user has selected input composite graphs then process
  if get(handles.chkInputSubplot,'value')==1
    ColorCode=1;
    if get(handles.chkInputGraph,'value')~=1
      EPlotTitle=({input(strcat('Enter graph title for: ',EFile,' :
'),'s');'Soil Water Content, Contour Step = 0.01 v v^{-1}'});
      BPlotTitle=({input(strcat('Enter graph title for: ',BFile,' :
'),'s');'Soil Water Content, Contour Step = 0.01 v v^{-1}'});
    else
      EPlotTitle={EPlotTitle;'Soil Water Content, Contour Step = 0.01 v v^{-
1}'};
      BPlotTitle={BPlotTitle;'Soil Water Content, Contour Step = 0.01 v v^{-
1}'};
    end;

PlotMultiTheta(MultiEX,MultiEY,MultiEZ,strcat('MultiThetaPlots\',EFile),Color
Code,EPlotTitle,MultiNames);

PlotMultiTheta(MultiBX,MultiBY,MultiBZ,strcat('MultiThetaPlots\',BFile),Color
Code,BPlotTitle,MultiNames);
  end;




%If user has selected difference composite then process
  if get(handles.chkDiffSubplot,'value')==1
    ColorCode=1;
    if get(handles.chkDiffGraph,'value')~=1
      GraphTitle=({input(['Enter graph title! for:',DFile,' : '],'s');'Change
in Soil Water Content, Contour Step = 0.01 v v^{-1}'});
    else
      GraphTitle={DiffPlotTitle;'Change in Soil Water Content, Contour Step =
0.01 v v^{-1}'};
    end;
    PlotFileName=strcat('MultiDiffPlots\',DFile,'.emf');
```

```
    %function [] =
PlotMultiTheta(X,Y,Z,PlotFileName,ColorCode,GraphTitle,DataTitle)

PlotMultiTheta(MultiX,MultiY,MultiZ,PlotFileName,ColorCode,GraphTitle,MultiNa
mes);
  end;

% %Build expression mask from selections in list box
% BCropYear=get(handles.lstBCropYear,'string');
% BCropTime=get(handles.lstBCropTime,'string');
% BTrt=get(handles.lstBTrt,'string');
% BeginningFile=strcat(BCropYear(get(handles.lstBCropYear,'value')),...
%   BCropTime(get(handles.lstBCropTime,'value')),...
%   BTrt(get(handles.lstBTrt,'value')))
% BCT=BCropTime(get(handles.lstBCropTime,'value'));



% Build list of BeginningFiles
%BeginningFiles=regexp(uniquekeys,BeginningFile,'match','once')
%BeginningFiles=unique(BeginningFiles(~cellfun('isempty',BeginningFiles)));



% --- Executes on selection change in lstBCropYear.
function lstBCropYear_Callback(hObject, eventdata, handles)
% hObject  handle to lstBCropYear (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles  structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns lstBCropYear
contents as cell array
%    contents{get(hObject,'Value')} returns selected item from lstBCropYear

% If user selectes a different year fill CT and TRT listboxes with actual
% options
ListItems=get(handles.lstBCropYear,'string');
Current=get(handles.lstBCropYear,'value');
[CTlist,TRTlist]=CT(ListItems(Current));
set(handles.lstBCropTime,'string',vertcat('..',CTlist));
set(handles.lstBTrt,'string',vertcat('..',TRTlist));

% --- Executes during object creation, after setting all properties.
function lstBCropYear_CreateFcn(hObject, eventdata, handles)
% hObject  handle to lstBCropYear (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles  empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
  set(hObject,'BackgroundColor','white');
end



% --- Executes on selection change in lstBCropTime.
```

```
function lstBCropTime_Callback(hObject, eventdata, handles)
% hObject    handle to lstBCropTime (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns lstBCropTime
contents as cell array
%        contents{get(hObject,'Value')} returns selected item from lstBCropTime


% --- Executes during object creation, after setting all properties.
function lstBCropTime_CreateFcn(hObject, eventdata, handles)
% hObject    handle to lstBCropTime (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on selection change in lstBTrt.
function lstBTrt_Callback(hObject, eventdata, handles)
% hObject    handle to lstBTrt (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns lstBTrt contents
as cell array
%        contents{get(hObject,'Value')} returns selected item from lstBTrt


% --- Executes during object creation, after setting all properties.
function lstBTrt_CreateFcn(hObject, eventdata, handles)
% hObject    handle to lstBTrt (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on selection change in lstECropYear.
function lstECropYear_Callback(hObject, eventdata, handles)
% hObject    handle to lstECropYear (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
```

```
% Hints: contents = cellstr(get(hObject,'String')) returns lstECropYear
contents as cell array
%    contents{get(hObject,'Value')} returns selected item from lstECropYear

% If user selectes a different year fill CT and TRT listboxes with actual
% options
ListItems=get(handles.lstECropYear,'string');
Current=get(handles.lstECropYear,'value');
[CTlist,TRTlist]=CT(ListItems(Current));
set(handles.lstECropTime,'string',vertcat('..',CTlist));
set(handles.lstETrt,'string',vertcat('..',TRTlist));



% --- Executes during object creation, after setting all properties.
function lstECropYear_CreateFcn(hObject, eventdata, handles)
% hObject  handle to lstECropYear (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles  empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
  set(hObject,'BackgroundColor','white');
end


% --- Executes on selection change in lstECropTime.
function lstECropTime_Callback(hObject, eventdata, handles)
% hObject  handle to lstECropTime (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles  structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns lstECropTime
contents as cell array
%    contents{get(hObject,'Value')} returns selected item from lstECropTime


% --- Executes during object creation, after setting all properties.
function lstECropTime_CreateFcn(hObject, eventdata, handles)
% hObject  handle to lstECropTime (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles  empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
  set(hObject,'BackgroundColor','white');
end
```

```
% --- Executes on selection change in lstETrt.
function lstETrt_Callback(hObject, eventdata, handles)
% hObject    handle to lstETrt (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns lstETrt contents
as cell array
%        contents{get(hObject,'Value')} returns selected item from lstETrt


% --- Executes during object creation, after setting all properties.
function lstETrt_CreateFcn(hObject, eventdata, handles)
% hObject    handle to lstETrt (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
  set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in chkInputSubplot.
function chkInputSubplot_Callback(hObject, eventdata, handles)
% hObject    handle to chkInputSubplot (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of chkInputSubplot


% --- Executes on button press in chkInputGraph.
function chkInputGraph_Callback(hObject, eventdata, handles)
% hObject    handle to chkInputGraph (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of chkInputGraph


% --- Executes on selection change in lstInput.
function lstInput_Callback(hObject, eventdata, handles)
% hObject    handle to lstInput (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns lstInput contents
as cell array
%        contents{get(hObject,'Value')} returns selected item from lstInput
```

```
% --- Executes during object creation, after setting all properties.
function lstInput_CreateFcn(hObject, eventdata, handles)
% hObject    handle to lstInput (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: listbox controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in chkDiffSubplot.
function chkDiffSubplot_Callback(hObject, eventdata, handles)
% hObject    handle to chkDiffSubplot (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of chkDiffSubplot


% --- Executes on button press in chkDiffGraph.
function chkDiffGraph_Callback(hObject, eventdata, handles)
% hObject    handle to chkDiffGraph (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of chkDiffGraph


% --- Executes on button press in chkCalcDiff.
function chkCalcDiff_Callback(hObject, eventdata, handles)
% hObject    handle to chkCalcDiff (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of chkCalcDiff
```

PlotMultiTheta.m

This code accepts data passed to it from the GUI and generates the requested plots. This subroutine generates a figure with five subplots on it, one for each geometry at a single time or for a specific difference calculation. Scaling and isoline placement are determined based on the data range supplied to the subroutine.

```
function [] =
PlotMultiTheta(MultiX,MultiY,MultiZ,PlotFileName,ColorCode,GraphTitle,MultiNa
mes)
 % Profile water plotter
 % This program generates countour plots interpolated neutron access data
 % that has been generated by SkipClumpThetaData
 % It is currenlty setup to read a composite file where variables are
 % CX,CY,and CZ
 % Lucas Haag, K-State Research & Extension, 2013.


 % Calculate isoline increment based on range, round range to outside
 % integers, and generate vector of isolines for use on contourf
 HighIso=ceil(max(MultiZ(:))*100)/100;
 LowIso=floor(min(MultiZ(:))*100)/100;
 RangeMax=max(MultiZ(:));
 RangeMin=min(MultiZ(:));
 IsoV=(LowIso:0.010:HighIso);

 %Determine number of diminsions present in MultiZ for loop
 MultiCount=size(MultiZ,3);

 %Setup Figure
 delete(figure(2));
 figure(2);
 set(figure(2),'Position',[1305 9 740 932]);

% set(figure(2),'Position',[23 272 963 667]);

for CMulti=1:MultiCount;
  subtightplot(MultiCount,1,CMulti,[0.04],[0.05,0.10],[0.10])
  contourf(MultiX(:,:,CMulti),MultiY(:,:,CMulti),MultiZ(:,:,CMulti),IsoV);
  set(gca,'ActivePositionProperty','Position','LineWidth',0.1); %keeps things
aspect ratio
  if CMulti==1
    %set(gca,'clipping','off','OuterPosition',[0 0 1 1.1]);
    title(GraphTitle, 'FontSize',12);
    StdAxis=gca;
    xlabel(StdAxis,'Position (inches)','FontSize',10);
  end;
  StdAxis=gca; %Assign handle to current axis
  set(StdAxis,'box','off'); %cleans up box lines and tick marks involved with
double axis
  set(StdAxis,'FontSize',10);
```

```
  if ColorCode==1
    colormap(flipud(jet)); %reverse jet colormap so that low theta is red,
high theta blue
  end;

  cb=colorbar('YLim',[RangeMin RangeMax]); %give cb handle to colorbar
  ylabel(cb,MultiNames{CMulti},'FontSize',12)

  %revese Y axis to properly display with depth, and put standard
  %measurements on top and right positions

set(StdAxis,'YDir','reverse','XAxisLocation','top','YAxisLocation','right');
  set(gca,'DataAspectRatio',[1 1 1]);
  set(gca,'PlotBoxAspectRatio',[1 1 1]);



  % Create metric axis for y and x
  MetricAxis=axes('Position',get(StdAxis,'Position'),'XAxisLocation',...
    'Bottom','YAxisLocation','left','Color','none','XLim',...

get(StdAxis,'XLim')*2.54,'YLim',get(StdAxis,'YLim')*2.54,'YDir','reverse');
  if CMulti==MultiCount;
    xlabel(MetricAxis,'Position (cm)','FontSize',10);
  end;
  set(MetricAxis,'box','off')
  set(MetricAxis,'FontSize',10);
  ylabel(StdAxis,'Depth (inches)','FontSize',10);
  ylabel(MetricAxis,'Depth (cm)','FontSize',10);



  set(StdAxis,'DataAspectRatio',[1 1 1]); % force proper relative scale
between x and y axis
  set(StdAxis,'PlotBoxAspectRatio',[1 1 1]); % force proper relative scale
between x and y axis
  set(MetricAxis,'ActivePositionProperty','Position');
  set(MetricAxis,'DataAspectRatio',[1 1 1]);
  set(MetricAxis,'PlotBoxAspectRatio',[1 1 1]);
%drawnow;
%hold on;




end;
%[ax4,h3]=suplabel(GraphTitle,'t');
%set(h3,'FontSize',12)

saveas(gcf,PlotFileName,'emf');
```

PlotSingleTheta.m

This code accepts data passed to it from the GUI and generates the requested plots. This subroutine generates a figure for a single geometry and time of measurement or difference calculation. Scaling and isoline placement are determined based on the data range supplied to the subroutine.

```
function [] =
PlotSingleTheta(X,Y,Z,FileName,PlotTitle,Geometry,ColorCode,DataTitle)
 % Profile water plotter
 % This program generates countour plots interpolated neutron access data
 % that has been generated by SkipClumpThetaData
 % It is currenlty setup to read a composite file where variables are
 % CX,CY,and CZ
 % Lucas Haag, K-State Research & Extension, 2013.


 % Calculate isoline increment based on range, round range to outside
 % integers, and generate vector of isolines for use on contourf
 HighIso=ceil(max(Z(:))*100)/100;
 LowIso=floor(min(Z(:))*100)/100;
 IsoV=(LowIso:0.005:HighIso);


 % PlotTitle = 'Planting Geometry Neat Plot'



  delete(figure(2));
  figure(2);
  set(figure(2),'Position',[23 272 963 667]);
  contourf(X,Y,Z,IsoV);
%  title({PlotTitle;['Change in Volumetric Soil Water Content'];[Geometry,'
Geometry']}, 'FontSize',16);
  title(PlotTitle,'FontSize',16);
  %FileName=strcat('DiffPlots\',PlotTitle,' ',Geometry,'.emf')
  StdAxis=gca; %Assign handle to current axis

  set(StdAxis,'ActivePositionProperty','position'); %keeps things aspect
ratio
  set(StdAxis,'box','off'); %cleans up box lines and tick marks involved with
double axis
  set(gca,'DataAspectRatio',[1 1 1]); % force proper relative scale between x
and y axis
  set(gca,'PlotBoxAspectRatio',[1 1 1]); % force proper relative scale
between x and y axis
  %plot3(xx1,yy1,zz1,'o') Can't use for composite as XX,YY,ZZ data has
  %been dropped

  if ColorCode==1
```

```
    colormap(flipud(jet)); %reverse jet colormap so that low theta is red,
high theta blue
  end;

  cb=colorbar; %give cb handle to colorbar
  %ylabel(cb,DataTitle,'FontSize',12)  - Did have provision for title on
  %colorbar but then removed and moved that title to 2nd line of plot
  %title

  %revese Y axis to properly display with depth, and put standard
  %measurements on top and right positions

set(StdAxis,'YDir','reverse','XAxisLocation','top','YAxisLocation','right');
  set(gca,'DataAspectRatio',[1 1 1]);
  set(gca,'PlotBoxAspectRatio',[1 1 1]);

  % Create metric axis for y and x
  MetricAxis=axes('Position',get(StdAxis,'Position'),'XAxisLocation',...
    'Bottom','YAxisLocation','left','Color','none','XLim',...

get(StdAxis,'XLim')*2.54,'YLim',get(StdAxis,'YLim')*2.54,'YDir','reverse');
  set(MetricAxis,'ActivePositionProperty','position');
  set(MetricAxis,'box','off')
  ylabel(StdAxis,'Depth (inches)','FontSize',12);
  xlabel(StdAxis,'Position (inches)','FontSize',12);
  ylabel(MetricAxis,'Depth (cm)','FontSize',12);
  xlabel(MetricAxis,'Position (cm)','FontSize',12);
  set(gca,'DataAspectRatio',[1 1 1]);
  set(gca,'PlotBoxAspectRatio',[1 1 1]);
  set(StdAxis,'FontSize',12)
  set(MetricAxis,'FontSize',12)
  saveas(gcf,FileName,'emf');



end
```

Groupings.m

This subroutine is used to consolidate individual interpolation datasets into 3-demensional data arrays for grouping of like soil water measurements, based on time of measurement, across years. Using a loop within the routine the layers of the 3-d array are individually fed to plotting routines.

```
%Groupings.m written by Lucas Haag, K-State Research & Extension March,
%2013, this code manually pulls together selected individual datasets that
%have been produced by SkipClumpThetaData dn SkipClumpThetaPostProcess and
%generates across-year plots for selected growth stages by calling the
%PlotMultiTheta function. Currently not setup to generate individual
%treatment plots.

%****** CORN GROUP 0
% Load individual years then average to create group data
load('2009CP12CMP.mat')
Z1=Z
load('2010CP12CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG0-12','X','Y','Z');

load('2009CP22CMP.mat')
Z1=Z
load('2010CP22CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG0-22','X','Y','Z');

load('2009CP32CMP.mat')
Z1=Z
load('2010CP32CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG0-32','X','Y','Z');

load('2009CP42CMP.mat')
Z1=Z
load('2010CP42CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG0-42','X','Y','Z');

load('2009CP52CMP.mat')
Z1=Z
load('2010CP52CMP.mat')
Z2=Z
```

```
ZM=(Z1+Z2)/2
Z=ZM
save('CG0-52','X','Y','Z');

%******* CORN GROUP 01 - same as CG1 except 2011 data is removed, use for
%difference calculations with CG0 which contains data only from 2009, 2010
load('2009C112CMP.mat')
Z1=Z
load('2010C112CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG01-12','X','Y','Z');

load('2009C122CMP.mat')
Z1=Z
load('2010C122CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG01-22','X','Y','Z');

load('2009C132CMP.mat')
Z1=Z
load('2010C132CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG01-32','X','Y','Z');

load('2009C142CMP.mat')
Z1=Z
load('2010C142CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG01-42','X','Y','Z');

load('2009C152CMP.mat')
Z1=Z
load('2010C152CMP.mat')
Z2=Z
ZM=(Z1+Z2)/2
Z=ZM
save('CG01-52','X','Y','Z');


%******* CORN GROUP 1
load('2009C112CMP.mat')
Z1=Z
load('2010C112CMP.mat')
Z2=Z
load('2011CP12CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
```

```
Z=ZM
save('CG1-12','X','Y','Z');

load('2009C122CMP.mat')
Z1=Z
load('2010C122CMP.mat')
Z2=Z
load('2011CP22CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG1-22','X','Y','Z');

load('2009C132CMP.mat')
Z1=Z
load('2010C132CMP.mat')
Z2=Z
load('2011CP32CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG1-32','X','Y','Z');

load('2009C142CMP.mat')
Z1=Z
load('2010C142CMP.mat')
Z2=Z
load('2011CP42CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG1-42','X','Y','Z');

load('2009C152CMP.mat')
Z1=Z
load('2010C152CMP.mat')
Z2=Z
load('2011CP52CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG1-52','X','Y','Z');

%********* CORN GROUP 2
load('2009C412CMP.mat')
Z1=Z
load('2010C212CMP.mat')
Z2=Z
load('2011C112CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG2-12','X','Y','Z');

load('2009C422CMP.mat')
Z1=Z
```

```
load('2010C222CMP.mat')
Z2=Z
load('2011C122CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG2-22','X','Y','Z');

load('2009C432CMP.mat')
Z1=Z
load('2010C232CMP.mat')
Z2=Z
load('2011C132CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG2-32','X','Y','Z');

load('2009C442CMP.mat')
Z1=Z
load('2010C242CMP.mat')
Z2=Z
load('2011C142CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG2-42','X','Y','Z');

load('2009C452CMP.mat')
Z1=Z
load('2010C252CMP.mat')
Z2=Z
load('2011C152CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG2-52','X','Y','Z');

%********** CORN GROUP 3
load('2009CH12CMP.mat')
Z1=Z
load('2010CH12CMP.mat')
Z2=Z
load('2011CH12CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG3-12','X','Y','Z');

load('2009CH22CMP.mat')
Z1=Z
load('2010CH22CMP.mat')
Z2=Z
load('2011CH22CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
```

```
Z=ZM
save('CG3-22','X','Y','Z');

load('2009CH32CMP.mat')
Z1=Z
load('2010CH32CMP.mat')
Z2=Z
load('2011CH32CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG3-32','X','Y','Z');

load('2009CH42CMP.mat')
Z1=Z
load('2010CH42CMP.mat')
Z2=Z
load('2011CH42CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG3-42','X','Y','Z');

load('2009CH52CMP.mat')
Z1=Z
load('2010CH52CMP.mat')
Z2=Z
load('2011CH52CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('CG3-52','X','Y','Z');

%******* SORGHUM GROUP 1
load('2009S191CMP.mat')
Z1=Z
load('2010SP91CMP.mat')
Z2=Z
load('2011SP91CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG1-91','X','Y','Z');

load('2009S192CMP.mat')
Z1=Z
load('2010SP92CMP.mat')
Z2=Z
load('2011SP92CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG1-92','X','Y','Z');

load('2009S193CMP.mat')
Z1=Z
```

```
load('2010SP93CMP.mat')
Z2=Z
load('2011SP93CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG1-93','X','Y','Z');

load('2009S194CMP.mat')
Z1=Z
load('2010SP94CMP.mat')
Z2=Z
load('2011SP94CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG1-94','X','Y','Z');

load('2009S195CMP.mat')
Z1=Z
load('2010SP95CMP.mat')
Z2=Z
load('2011SP95CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG1-95','X','Y','Z');

%******** SORGHUM GROUP 2
load('2009S391CMP.mat')
Z1=Z
load('2010S191CMP.mat')
Z2=Z
load('2011S191CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG2-91','X','Y','Z');

load('2009S392CMP.mat')
Z1=Z
load('2010S192CMP.mat')
Z2=Z
load('2011S192CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG2-92','X','Y','Z');

load('2009S393CMP.mat')
Z1=Z
load('2010S193CMP.mat')
Z2=Z
load('2011S193CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
```

```
Z=ZM
save('SG2-93','X','Y','Z');

load('2009S394CMP.mat')
Z1=Z
load('2010S194CMP.mat')
Z2=Z
load('2011S194CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG2-94','X','Y','Z');

load('2009S395CMP.mat')
Z1=Z
load('2010S195CMP.mat')
Z2=Z
load('2011S195CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG2-95','X','Y','Z');

% ********** SORGHUM GROUP 3

load('2009SH91CMP.mat')
Z1=Z
load('2010SH91CMP.mat')
Z2=Z
load('2011SH91CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG3-91','X','Y','Z');

load('2009SH92CMP.mat')
Z1=Z
load('2010SH92CMP.mat')
Z2=Z
load('2011SH92CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG3-92','X','Y','Z');

load('2009SH93CMP.mat')
Z1=Z
load('2010SH93CMP.mat')
Z2=Z
load('2011SH93CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG3-93','X','Y','Z');
```

```
load('2009SH94CMP.mat')
Z1=Z
load('2010SH94CMP.mat')
Z2=Z
load('2011SH94CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG3-94','X','Y','Z');

load('2009SH95CMP.mat')
Z1=Z
load('2010SH95CMP.mat')
Z2=Z
load('2011SH95CMP.mat')
Z3=Z
ZM=(Z1+Z2+Z3)/3
Z=ZM
save('SG3-95','X','Y','Z');


% Take treatment/group files and build a multi-dimension array for each
% group with X,Y,Z where Z is each treatment
load('CG0-12.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('CG0-22.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('CG0-32.mat')
MultiEZ(:,:,3)=Z;
MultiEX(:,:,3)=X;
MultiEY(:,:,3)=Y;
load('CG0-42.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('CG0-52.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('CG0.mat','MultiEX','MultiEY','MultiEZ')

load('CG01-12.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('CG01-22.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('CG01-32.mat')
MultiEZ(:,:,3)=Z;
MultiEX(:,:,3)=X;
```

```
MultiEY(:,:,3)=Y;
load('CG01-42.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('CG01-52.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('CG01.mat','MultiEX','MultiEY','MultiEZ')


load('CG1-12.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('CG1-22.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('CG1-32.mat')
MultiEZ(:,:,3)=Z;
MultiEX(:,:,3)=X;
MultiEY(:,:,3)=Y;
load('CG1-42.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('CG1-52.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('CG1.mat','MultiEX','MultiEY','MultiEZ')


load('CG2-12.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('CG2-22.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('CG2-32.mat')
MultiEZ(:,:,3)=Z;
MultiEX(:,:,3)=X;
MultiEY(:,:,3)=Y;
load('CG2-42.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('CG2-52.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('CG2.mat','MultiEX','MultiEY','MultiEZ')
```

```
load('CG3-12.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('CG3-22.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('CG3-32.mat')
MultiEZ(:,:,3)=Z;
MultiEX(:,:,3)=X;
MultiEY(:,:,3)=Y;
load('CG3-42.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('CG3-52.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('CG3.mat','MultiEX','MultiEY','MultiEZ')

%******** SORGHUM
load('SG1-91.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('SG1-92.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('SG1-93.mat')
MultiEZ(:,:,3)=Z;
MultiEX(:,:,3)=X;
MultiEY(:,:,3)=Y;
load('SG1-94.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('SG1-95.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('SG1.mat','MultiEX','MultiEY','MultiEZ')

load('SG2-91.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('SG2-92.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('SG2-93.mat')
MultiEZ(:,:,3)=Z;
```

```
MultiEX(:,:,3)=X;
MultiEY(:,:,3)=Y;
load('SG2-94.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('SG2-95.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('SG2.mat','MultiEX','MultiEY','MultiEZ')


load('SG3-91.mat')
MultiEX(:,:,1)=X;
MultiEY(:,:,1)=Y;
MultiEZ(:,:,1)=Z;
load('SG3-92.mat')
MultiEZ(:,:,2)=Z;
MultiEY(:,:,2)=Y;
MultiEX(:,:,2)=X;
load('SG3-93.mat')
MultiEZ(:,:,3)=Z;
MultiEX(:,:,3)=X;
MultiEY(:,:,3)=Y;
load('SG3-94.mat')
MultiEY(:,:,4)=Y;
MultiEX(:,:,4)=X;
MultiEZ(:,:,4)=Z;
load('SG3-95.mat')
MultiEZ(:,:,5)=Z;
MultiEX(:,:,5)=X;
MultiEY(:,:,5)=Y;
save('SG3.mat','MultiEX','MultiEY','MultiEZ')


%Load MultiNames which contains geometries
load('MultiNamesTemp.mat');

%Calculate corn differences and plot graphics
load('CG0.mat')
X0=MultiEX;
Y0=MultiEY;
Z0=MultiEZ;
load('CG01.mat')
X01=MultiEX;
Y01=MultiEY;
Z01=MultiEZ;
load('CG1.mat')
X1=MultiEX;
Y1=MultiEY;
Z1=MultiEZ;
load('CG2.mat')
X2=MultiEX;
Y2=MultiEY;
Z2=MultiEZ;
```

```
load('CG3.mat')
X3=MultiEX;
Y3=MultiEY;
Z3=MultiEZ;

CG3CG1=Z3-Z1;
CG2CG1=Z2-Z1;
CG3CG2=Z3-Z2;
CG01CG0=Z01-Z0;

%Corn Group Theta Plots - Subplot graphics using PlotMultiTheta function
PlotMultiTheta(X0,Y0,Z0,'MultiThetaPlots\CG0.emf',1,{'2009-2010 Corn -
Planting';'Soil Water Content, Contour Step = 0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,Z1,'MultiThetaPlots\CG1.emf',1,{'2009-2011 Corn - Early
Vegetative';'Soil Water Content, Contour Step = 0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,Z2,'MultiThetaPlots\CG2.emf',1,{'2009-2011 Corn -
Tassel/Silk';'Soil Water Content, Contour Step = 0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,Z3,'MultiThetaPlots\CG3.emf',1,{'2009-2011 Corn -
Harvest';'Soil Water Content, Contour Step = 0.01 v v^{-1}'},MultiNames)


%Corn Group Difference Plots - Subplot graphics with PlotMultiTheta function
%PlotMultiTheta(MultiX,MultiY,MultiZ,PlotFileName,ColorCode,GraphTitle,MultiN
ames)
PlotMultiTheta(X1,Y1,CG01CG0,'MultiDiffPlots\CG01CG0.emf',1,{'2009-2010 Corn
- Planting to Early Vegetative';'Change in Soil Water Content, Contour Step =
0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,CG3CG1,'MultiDiffPlots\CG3CG1.emf',1,{'2009-2011 Corn -
Early Vegetative to Harvest';'Change in Soil Water Content, Contour Step =
0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,CG2CG1,'MultiDiffPlots\CG2CG1.emf',1,{'2009-2011 Corn -
Early Vegetative to Tassel/Silk';'Change in Soil Water Content, Contour Step
= 0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,CG3CG2,'MultiDiffPlots\CG3CG2.emf',1,{'2009-2011 Corn -
Tassel/Silk to Harvest';'Change in Soil Water Content, Contour Step = 0.01 v
v^{-1}'},MultiNames)

%Corn Individual - using PlotSingleTheta function

%Assume that array dimensions are the same for all inputs, loop is for
%different geometries which are in Z dimension of array

%Determine number of diminsions present in MultiZ for loop
MultiCount=size(Z1,3);
for CMulti=1:MultiCount;
  %function [] =
PlotSingleTheta(X,Y,Z,FileName,PlotTitle,Geometry,ColorCode,DataTitle)
  % Plot individual theta plot for geometry CMulti

  %Plot theta plots

PlotSingleTheta(X0(:,:,CMulti),Y0(:,:,CMulti),Z0(:,:,CMulti),['ThetaPlots\CG0
-',MultiNames{CMulti},'.emf'],{'2009-2010 Corn - Planting';'Soil Water
Content, Contour Step = 0.005 v v^{-1}';[MultiNames{CMulti},'
Geometry']},'.',1,'.');
```

```
PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),Z1(:,:,CMulti),['ThetaPlots\CG1
-',MultiNames{CMulti},'.emf'],{'2009-2011 Corn - Early Vegetative';'Soil
Water Content, Contour Step = 0.005 v v^{-1}';[MultiNames{CMulti},'
Geometry']},'.',1,'.');

PlotSingleTheta(X2(:,:,CMulti),Y2(:,:,CMulti),Z2(:,:,CMulti),['ThetaPlots\CG2
-',MultiNames{CMulti},'.emf'],{'2009-2011 Corn - Tassel/Silk';'Soil Water
Content, Contour Step = 0.005 v v^{-1}';[MultiNames{CMulti},'
Geometry']},'.',1,'.');

PlotSingleTheta(X3(:,:,CMulti),Y3(:,:,CMulti),Z3(:,:,CMulti),['ThetaPlots\CG3
-',MultiNames{CMulti},'.emf'],{'2009-2011 Corn - Harvest';'Soil Water
Content, Contour Step = 0.005 v v^{-1}';[MultiNames{CMulti},'
Geometry']},'.',1,'.');

  %Plot diff plots

PlotSingleTheta(X0(:,:,CMulti),Y0(:,:,CMulti),CG01CG0(:,:,CMulti),['DiffPlots
\CG01CG0-',MultiNames{CMulti},'.emf'],{'2009-2010 Corn - Planting to Early
Vegetative';'Change in Soil Water Content, Contour Step = 0.005 v v^{-
1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),CG3CG1(:,:,CMulti),['DiffPlots\
CG3CG1-',MultiNames{CMulti},'.emf'],{'2009-2011 Corn - Early Vegetative to
Harvest';'Change in Soil Water Content, Contour Step = 0.005 v v^{-
1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),CG2CG1(:,:,CMulti),['DiffPlots\
CG2CG1-',MultiNames{CMulti},'.emf'],{'2009-2011 Corn - Early Vegetative to
Tassel/Silk';'Change in Soil Water Content, Contour Step = 0.005 v v^{-
1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),CG3CG2(:,:,CMulti),['DiffPlots\
CG3CG2-',MultiNames{CMulti},'.emf'],{'2009-2011 Corn - Tassel/Silk to
Harvest';'Change in Soil Water Content, Contour Step = 0.005 v v^{-
1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

end;


% Calculate sorghum differences and plot graphics
load('SG1.mat')
X1=MultiEX;
Y1=MultiEY;
Z1=MultiEZ;
load('SG2.mat')
X2=MultiEX;
Y2=MultiEY;
Z2=MultiEZ;
load('SG3.mat')
X3=MultiEX;
Y3=MultiEY;
Z3=MultiEZ;

SG3SG1=Z3-Z1;
```

```
SG2SG1=Z2-Z1;
SG3SG2=Z3-Z2;

%Sorghum Group Theta Plots
PlotMultiTheta(X1,Y1,Z1,'MultiThetaPlots\SG1.emf',1,{'2009-2011 Sorghum -
Early Vegetative';'Soil Water Content, Contour Step = 0.01 v v^{-
1}'},MultiNames)
PlotMultiTheta(X1,Y1,Z2,'MultiThetaPlots\SG2.emf',1,{'2009-2011 Sorghum -
Flower/Grain Fill';'Soil Water Content, Contour Step = 0.01 v v^{-
1}'},MultiNames)
PlotMultiTheta(X1,Y1,Z3,'MultiThetaPlots\SG3.emf',1,{'2009-2011 Sorghum -
Harvest';'Soil Water Content, Contour Step = 0.01 v v^{-1}'},MultiNames)

%Sorghum Group Difference Plots
%PlotMultiTheta(MultiX,MultiY,MultiZ,PlotFileName,ColorCode,GraphTitle,MultiN
ames)
PlotMultiTheta(X1,Y1,SG3SG1,'MultiDiffPlots\SG3SG1.emf',1,{'2009-2011 Sorghum
- Early Vegetative to Harvest';'Change in Soil Water Content, Contour Step =
0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,SG2SG1,'MultiDiffPlots\SG2SG1.emf',1,{'2009-2011 Sorghum
- Early Vegetative to Flower/Grain Fill';'Change in Soil Water Content,
Contour Step = 0.01 v v^{-1}'},MultiNames)
PlotMultiTheta(X1,Y1,SG3SG2,'MultiDiffPlots\SG3SG2.emf',1,{'2009-2011 Sorghum
- Flower/Grain Fill to Harvest';'Change in Soil Water Content, Contour Step =
0.01 v v^{-1}'},MultiNames)

%Sorghum Individual - using PlotSingleTheta function

%Assume that array dimensions are the same for all inputs, loop is for
%different geometries which are in Z dimension of array

%Determine number of diminsions present in MultiZ for loop
MultiCount=size(Z1,3);
for CMulti=1:MultiCount;
  %function [] =
PlotSingleTheta(X,Y,Z,FileName,PlotTitle,Geometry,ColorCode,DataTitle)
  % Plot individual theta plot for geometry CMulti

  %Plot theta plots

PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),Z1(:,:,CMulti),['ThetaPlots\SG1
-',MultiNames{CMulti},'.emf'],{'2009-2011 Sorghum - Early Vegetative';'Soil
Water Content, Contour Step = 0.005 v v^{-1}';[MultiNames{CMulti},'
Geometry']},'.',1,'.');

PlotSingleTheta(X2(:,:,CMulti),Y2(:,:,CMulti),Z2(:,:,CMulti),['ThetaPlots\SG2
-',MultiNames{CMulti},'.emf'],{'2009-2011 Sorghum - Flowering/Grain
Fill';'Soil Water Content, Contour Step = 0.005 v v^{-
1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

PlotSingleTheta(X3(:,:,CMulti),Y3(:,:,CMulti),Z3(:,:,CMulti),['ThetaPlots\SG3
-',MultiNames{CMulti},'.emf'],{'2009-2011 Sorghum - Harvest';'Soil Water
Content, Contour Step = 0.005 v v^{-1}';[MultiNames{CMulti},'
Geometry']},'.',1,'.');
```

```
  %Plot diff plots

PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),SG3SG1(:,:,CMulti),['DiffPlots\
SG3SG1-',MultiNames{CMulti},'.emf'],{'2009-2011 Sorghum - Early Vegetative to
Harvest';'Change in Soil Water Content, Contour Step = 0.005 v v^{-
1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),SG2SG1(:,:,CMulti),['DiffPlots\
SG2SG1-',MultiNames{CMulti},'.emf'],{'2009-2011 Sorghum - Early Vegetative to
Flowering/Grain Fill';'Change in Soil Water Content, Contour Step = 0.005 v
v^{-1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

PlotSingleTheta(X1(:,:,CMulti),Y1(:,:,CMulti),SG3SG2(:,:,CMulti),['DiffPlots\
SG3SG2-',MultiNames{CMulti},'.emf'],{'2009-2011 Sorghum - Flowering/Grain
Fill to Harvest';'Change in Soil Water Content, Contour Step = 0.005 v v^{-
1}';[MultiNames{CMulti},' Geometry']},'.',1,'.');

end;
```