EFFECTS OF PLANTING PRACTICES AND NITROGEN MANAGEMENT ON GRAIN SORGHUM PRODUCTION

by

ALASSANE MAIGA

M.S., Alabama A&M University, 1991

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy
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Manhattan, Kansas

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Abstract

Sorghum [*Sorghum bicolor* (L.) Moench] is a relatively drought- and heat-tolerant cereal crop. Global demand and consumption of agricultural crops for food, feed, and fuel is increasing at a rapid pace. To satisfy the growing worldwide demand for grain, production practices must be well optimized and managed. The objectives of the present study were: to optimize sorghum production by determining the best management practices (planting date, row spacing, seeding rate, hybrid maturity) for growth and yield, to evaluate the agronomic responsiveness of grain sorghum genotypes to nitrogen (N) fertilizer and to develop a partial financial budget to N fertilizer application based on best management practices. In order to meet these objectives, field experiments were conducted in 2009, 2010 and 2011 at Manhattan, Belleville, Ottawa, Hutchinson, Hays, at KSU Experiment Stations and Salina, and Randolph at Private Farms. Results indicated that early planting date (late May) and narrow row spacing (25 cm) providing the most equidistant spacing, produced better plant growth, light interception, yield components (number of grains per panicle, 300-grain weight), and biological yield. Results indicated that with increasing N rate, there was a proportional increase in chlorophyll SPAD meter reading, leaf color scores and number of green leaves. There was a significant difference among hybrids for N uptake, NUE and grain yield. However, there was no effect of N and no interaction between N and hybrid on grain yield. Over all, the genotypes with high NUE also had higher grain yield. Economic analysis using partial budget indicated that all N levels had positive gross benefit greater than control at all locations. However, the response varied across locations. Our research has shown that sorghum responds to changing management practices and opportunities exist to increase grain yield by optimizing planting date, seeding rate, row spacing, N application and selection of genotypes.

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Major Professor
Dr. P.V. Vara Prasad

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Dedication

I would like to dedicate this dissertation to Maiga and Coulibaly's families for their never ending love and ashirwad.

Your prayers to God have been answered (Amina)

Chapter 1 - Review of Literature

Sorghum [*Sorghum bicolor* (L.) Moench] is a relatively drought- and heat-tolerant cereal crop. Global demand and consumption of agricultural crops for food, feed, and fuel is increasing at a rapid pace. This demand for plant materials has been expanding for many years. To satisfy the growing worldwide demand for grain, two available options are: increasing area under production or increasing productivity per unit area on existing farmland. These two options are not mutually exclusive and both will need to be employed simultaneously to produce additional 200 million tones/year of sorghum, maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) estimated to be needed by 2017 (Kansas Agricultural Statistic, 2011). In the United States (U.S), breeders, agronomists, and farmers have a documented history of increasing yield. In U.S. average sorghum yields have increased from approximately 1.6 tones/ha in the first third of the 20th century to today's approximately 9.5 tones/ha (Kansas Agricultural Statistics, 2011). This dramatic yield improvement is due to the development and widespread use of new crop management technologies such as improved hybrids, use of synthetic inorganic fertilizers, and improved and efficient farm machinery. Cultivation of new acreage requires land clearing and subsequent tillage that results in significant greenhouse gas emissions (Fargione et al., 2008) and also has negative impacts upon biodiversity and water quality (Foley et al., 2005). Increasing the productivity of existing agricultural land will also have environmental consequences (Tillman et al., 2002), but the negative consequences are generally less onerous and in some cases can be positive, depending upon how the land was previously used.

Higher crop prices, prompted in part by rising demand, have increased costs for urban consumers, especially those in poorer countries. However, higher crop prices will also provide farmers with the economic incentive to invest in farming methods and technologies that improve crop yields (Von Braun, 2007; Gallagher, 2008).

Constraints of Grain Sorghum Production

Over the next two decades, climate change and climate variability will pose a significant challenge to crop production, including grain sorghum. Several sorghum producing regions in the U.S., Africa and Asia are predicted to have seasonal increase in air temperatures, the numbers and severity of adverse weather events (short episodes of high temperature and drought stress) will be higher, there may be increased occurrences insect pests and disease. These changes will result in greater crop yields losses (Hatfield et al., 2008). Rapid adaptation of crops to changing climatic conditions may help overcome some of the losses. Water deficits (drought) and temperature are most common environmental stresses that will influence growth and development of plants (Shaw, 1988; Sadras and Milroy, 1996; Aslam et al., 2006). Drought and high temperatures are important constraint to agricultural production in many developing countries, and an occasional cause of losses of agricultural production in developed ones (Ceccarelli and Grando, 1996). Drought and high temperature stress during crop growth periods, will causes significant yield losses in several sorghum producing regions of U.S. (e.g. Kansas and Texas) and West Africa (e.g. Nigeria, Mali Ghana and Niger).

Effects of drought stress on crop productivity depend on plant (or crop) species, genotype, timing, intensity, severity and duration of drought stress. Genotypes or crops with increased water use efficiency (WUE) and greater drought tolerance have greater success under drought stress conditions. In most of crops, greater WUE for grain is not due to an improvement in biomass, but, it is mostly due to increased yield or improved harvest index (HI). Yadav et al.

(1999) in an experiment under drought stress showed that (50%) of seed yield loss was related to decline in HI.

Cultural practices including planting date, row spacing, cultivar maturity, and seeding rate (plant population) selected for use in sorghum production typically vary from region to region. These differences are mainly due to variability in temperature, rainfall and availability of irrigation water. Under dryland conditions, Jones and Johnson (1991; 1997) demonstrated that the optimum planting date, population, variety, and row spacing for grain sorghum were interdependent by showing consistent grain yield reductions by late-maturing cultivars that were planted late and at higher populations. In Kansas, the use of earlier-maturing cultivars is recommended under water stress conditions to promote timely physiological maturity (Vanderlip et al., 1998). Studies at Bushland, Allen and Musick (1993) concluded that medium-maturity hybrids were better adapted for limited irrigation conditions than late-maturity hybrids, but they did not evaluate an early maturing hybrid. Likewise, yield potential for the late maturing hybrid was greatest when planted in late May to minimize cold temperature stress at planting and also extend the growing season, but this benefit was less pronounced in the medium-maturity hybrid and untested in early maturity hybrid. Also, the annual variability in growing season duration (144-220 days) and precipitation that varies from 89 to 580 mm makes it difficult to provide strict guidelines for genotype selection or crop management practices. Identify the best combination of cultural practices needs long term research and provide risk management strategies. Determining the planting date that gives best time for germination, establishment and survival seedling, increased early season growth, avoidance of stresses during sensitive stages of flowering and grain filling. In general any delay in planting will result in low potential yield of plant, as it will decrease the growing season for photosynthesis and growth thus resulting in lower dry matter production, grain yield and poor grain quality (Jose et al., 2004).

Among other important reason for lower grain yield in delayed planting date are reduction of canopy area and short length of vegetative period (Hocking and Stapper, 2001). Robertson et al. (2004) concluded that delay in planting date reduced the 1000-grain weight and its yield. The response of grain yield components to planting density or plant population is variable and is relatively compensable in a way that increase in density is accompanied by decreasing in grain number and weight of 1000 grain per panicle. Increase of plant population resulted in increasing number of panicle per area unit which ultimately leads to high yield. To achieve the highest yield, in addition to optimum density, consistent distribution of plant and consequently the structure of plant canopy are of greater importance (Egli et al., 1991). Studying row spacing, and plant density in sorghum, Bullock et al. (1998) found out that increase in yield in narrow rows is a result of increasing leaf area index (LAI) and crop growth rate (CGR) during vegetative growth. Decreasing row spacing at different plant densities produces a more equidistant plant distribution. This distribution decreases plant-to-plant competition for available water, nutrient, and light and increases radiation interception and biomass production (Shibles and Weber, 1990).

Global Nitrogen Consumption and Demand in Relation to Cereal Production

With the high variability in temperature, rainfall, yield, and increasing costs of inputs such as fuel and fertilizer, it seems logical that developing improved fertilizer management practices that can adjust mid-season to changes in weather and resulting yield potential could enhance profitability to sorghum growers. Nitrogen (N) is the element most frequently lacking for optimum sorghum production in several regions of Africa, Asia and also U.S. Nitrogen recommendation will vary with expected yield, soil texture, and cropping sequence. Nitrogen deficiency decreased leaf area, chlorophyll content and yield, resulting in lower dry matter accumulation. The average percentage of yield loss attributable to N fertilizer generally ranged from about 40 to 60% in the U.S. and tended to be much higher in the tropical region (Stewart et al., 2005).

Global consumption of N fertilizer has increased substantially since 1940. The consumption further doubled to 61 Mt by 1980 and, in 1988, it reached 80 Mt. Some of this increase was due to the rapid adoption of new short stature, N responsive, and high yielding cultivars with high HI, particularly of wheat and rice, that could be supplied with larger amounts of N (Evenson and Gollin, 2003). In 1993 and 1994, global use of N fertilizer dropped below 73 Mt because of the decline in demand in the former Soviet Union, post communist European economies, and most countries of the European Union (Frink et al., 1999). However, N consumption increased again to 84 Mt in 2002 (FAO, 2004). The global consumption of N has local and regional differences in terms of per capita fertilizer N use in crop production. For example, in 2001, annual N fertilizer consumption was 38 kg person^{-1} in the U.S., 11 kg person^{-1} in India, but only 1 kg person^{-1} in sub Saharan Africa (Mosier et al., 2004). Global consumption is projected to increase to more than 90 Mt N by 2008 to meet the increased food demand (Prud'homme, 2003). Nitrogen fertilizer consumption in Asia has grown dramatically, increasing about 17-fold in the last 40 years (Dobermann and Cassman, 2004). It rose steeply after the Green Revolution, mainly because of the availability of N fertilizer at low cost and the rapid adoption of modern high yielding rice and wheat cultivars. Large increases in N use have also occurred in Latin America and Africa. In Europe, the countries of the former Soviet Union, and

North America, N fertilizer use has remained either constant or has declined slightly during the past 20 years (FAO, 2004; Mosier et al., 2004). Synthetic fertilizer supplies approximately 45% of the total N input for global food production. The other annual inputs into crop production include BNF, recycling of N from crop residues, animal manure, and atmospheric deposition and irrigation water, which contribute about 33, 16, 20, and 24 Tg, respectively (Smil, 1999; Mosier et al., 2004). Of the total N input of about 170 Tg, approximately half (85 Tg) is removed by the harvested crop (*i.e.*, the same as fertilizer input). The remainder of the N is left in the soil, remains in crop residues, or is lost to other parts of the environment through leaching, runoff, and erosion (37 Tg); ammonia volatilization from animal wastes, soil, and vegetation (21 Tg); denitrification (14 Tg); and nitrous oxide and nitric oxide (NO) emissions from nitrification, denitrification (8 Tg) (Mosier et al., 2004). Global demand for N fertilizer is dictated by cereal grain production (Cassman et al., 2002). During 2001–2002, about 60% of global N fertilizer consumed was used for cereal production. Specifically, three cereals (rice, maize, and wheat) accounted for approximately 56% of the worldwide N fertilizer used (IFA, 2002). At a global scale, cereal yields and fertilizer N consumption have increased in a linear fashion during the past 40 years and both are highly correlated (Dobermann and Cassman, 2004). Wood et al. (2004) estimated that 50 to 70% more cereal grain would be required by 2050 to feed 9.3 billion people. This would require increasing N fertilizer the same (50–70%) magnitude. But, as NUE generally declines with increased fertilizer use, the requirement may be even double, as projected by Wood et al. (2004).

The Concept of N Use Efficiency

Currently, high-yielding grain sorghum varieties managed under identical N-fertilization regimes do not yield as well as maize, but take up more total N from the soil. This disparity is due primarily to the fact that grain sorghum translocates much less of its N from vegetative tissue to grain. This leaves grain sorghum stover with about 50% more total N than maize stover (Perry and Olson, 1975). Therefore, the possibility exists of developing grain sorghum hybrids with a propensity to accumulate relatively large quantities of N and translocate a larger portion of the accumulated N to the grain. The traditional approach to evaluating N utilization efficiency has been to consider fertilizer N as the input and dry matter production of the crop as the output. As applied to grain crops, it is the average change in grain yield obtained per unit change in the amount of N applied (Capurro and Voss, 1981). In plotting this relationship, yields tend to increase linearly with the first increments of fertilizer N input until a point is reached where yield levels tend toward a plateau. This is considered "the point of diminishing returns" where each additional increment of output (yield) requires a corresponding greater incremental increase of input (fertilizer N). Through genetic improvement, yield potential of cultivars has led to greater fertilizer N efficiency in terms of yield per unit N supply. The high yielding cultivars are not only more responsive to N fertilizer, but many exhibit equal or superior yields at all levels of N inputs (Fisher, 1981; Sherrard et al., 1984). An alternative approach in N-use efficiency study examines the ratio of plant dry matter yield to the concentration of N in the plant. Nitrogen absorbed by the plant is considered the input and dry matter production the output. Genotypes vary in their ability to metabolize N in relation to dry matter deposition. An efficient genotype would produce more dry matter per unit N absorbed by the plant or would produce equal dry matter with a lower average tissue N concentration. Unfortunately these ratios are not a constant property of a genotype but undergo large changes with N supply. Increases in N supply generally decrease the amount of dry matter produced per unit N absorbed by the plant and vice versa. In addition, plants tend to increase the ratio of dry matter produced to concentration with time as the proportion of structural material in the tissue increases (Myers and Asher, 1982). The efficiency of vegetative tissue dry matter production may not always be a good indicator of the efficiency of grain production, which has led to use of grain production per unit of N uptake as an index of N-use efficiency (Maranville et al., 1980; Rhoads and Stanley, 1984). Nutrient use efficiency for N as defined by Rhoads and Stanley (1984) was grain yield (kg/ha) divided by total nutrient uptake (kg/ha). Maranville et al. (1980) approximate that definition with their term expressed as g grain/g N. Further divisions have been made in an effort to separate acquisition of N from the rhizosphere "uptake efficiency," from the plants internal economy which may result from efficient redistribution within the plant and/or a lower requirement for N at functional sites, "utilization efficiency" (Moll et al., 1982). There also exists the evolutionary adaptive characteristic of growth rate adjustment to make it compatible with nutrient supply, however, this is more of a survival mechanism and is of little interest from a production standpoint (Clarkson and Hanson, 1980). Genetic control and genotype differences in N use nitrogen and other nutrient elements are transformed into biomass by crops through sequential chemical reactions emanating from the element in its ionic form. These processes of nutrient utilization may be divided into an uptake and an assimilation metabolic step mediated by carrier and enzyme proteins, respectively. Because proteins are involved in both steps, they are under genetic control. The degree to which regulation of uptake is coordinated with the assimilation step remains to be established. The two steps, however, can be considered as a consecutive reaction with the total efficiency.

Although genotypic differences for nutrient use efficiency have been recognized for some time, it is still not possible to completely explain how these genotypes can produce an equal amount of growth, satisfy all their biosynthetic and maintenance needs, but use a smaller amount of nutrient than required by other genotypes (Clarkson and Hanson, 1980). An important step toward explaining N-use efficiency is, therefore, identification of morphological, physiological, and biochemical parameters associated with genotypes which differ in N-use efficiency, as these traits are clues to how a genotype achieves efficiency in its use of N. Sherrard et al. (1984) have proposed a "ideotype" maize plant with a greater capacity for converting N supplied into increased yield with the following characteristics:

Current nitrogen management schemes for world cereal production systems have resulted in low nitrogen use efficiency, with estimates averaging only around 33% of fertilized N recovered (Raun and Johnson, 1999). At $850 per metric ton of N fertilizer, the unaccounted 67% represents a $28 billion annual loss of fertilizer N assuming fertilizer–soil equilibrium (Feinermam et al., 1990). Pathways for N losses from agroecosystems include gaseous plant emissions, soil denitrification, surface runoff, volatilization, and leaching (Raun and Johnson, 1999). With the exception of N denitrified to nitrification these pathways lead to an increased load of biologically reactive N into external environments (Cassman et al., 2002). Nitrogen use efficiency (NUE), defined as the percent of fertilizer N which is recovered or utilized by a fertilized crop, is estimated to be only 33% for grain production, and about 45% for forage production in the US (Raun and Johnson, 1999). Yet, according to work by Johnson (2000), N fertilizer use has increased yield more in the past few decades than any other agricultural input. Smith et al. (1990) reported that maize and sorghum yield would have dropped by 41 and 19%, respectively, without N fertilizer application. Nitrogen use efficiency and/or fertilizer recovery in crop production systems can be computed using many different methods. The components of nitrogen use efficiency, as initially discussed by Moll et al. (1982) include the efficiency of absorption or uptake (Nt/Ns) and the efficiency with which N absorbed is utilized to produce grain (Gw/Nt) where Nt is the total N in the plant at maturity (grain+stover), Ns is the nitrogen supply or rate of fertilizer N, and Gw is the grain weight (all expressed in the same units). Using the same components as Moll et al. (1982), Varvel and Peterson (1990) calculated the percent of fertilizer recovery by using the difference method. Here the total N uptake in maize from unfertilized plots is subtracted from the total N uptake in maize from the N fertilized plots, and then divided by the rate of fertilizer N applied. Cassman et al. (2002) discusses these components as well, however, he raises the issue of applying adequate N to maintain a soil N pool for sustainable production. Regardless of how NUE is measured, utilization of applied fertilizer N is generally low.

Causes of Low NUE for Current N Management Practices

One of the major causes for low NUE of current N management practices is poor synchrony between soil N supply and crop demand (Raun and Johnson, 1999; Cassman et al., 2002; Fageria and Baligar, 2005). Poor synchronization is mainly due to large pre-plant applications of fertilizer N. Cassman et al. (2002), for example, estimated from USDA statistics (USDA-NASS, 2003) that typical N application amounts in the U.S averaged (last 20 years) approximately 150 kg/ha, with farmer surveys indicating around 75% of the applications occurring prior to planting (including the previous fall) and only 25% of the applications made after planting. In the first three weeks after emergence. During that period, depending on weather and soil conditions, excess N may move from the rooting zone and ultimately be lost. During the next 75 days approximately constant maximal rates can be as high as 3.7 kg/ha/day (Andrade et al., 1996) with peaks of 6 kg/ ha/day (Schepers et al., 1993). The total N accumulated by plants is around 60% of total N absorbed at harvest (Aldrich and Leng, 1974, Andrade et al., 1996).

Hence, these large pre-plant N applications result in high levels of available soil profile N, well before active crop uptake occurs, resulting in poor synchrony between soil N supply and crop demand. Efficiency of use from a single pre-plant N-fertilizer application typically decreases in proportion to the amount of N fertilizer applied (Reddy and Reddy, 1993). Other studies have substantiated that in-season applied N results in a higher NUE than when N is pre-plant applied. Collectively, these results agree with the recommendations of Keeney (2005), who advocated that the most logical approach to increasing NUE is to supply N as it is needed by the crop. This reduces the opportunity for N loss because the plant is established and in the rapid uptake phase of growth. Thus, while research is rich with results supporting the point that NUE is improved by synchronizing applications with crop N use, adoption by farmers with this as the reason for changing has been minor. The barrier has primarily been a lack of cost-effective and/or practical technologies to implement in-season N applications (Cassman et al., 2002).

Another major factor contributing to low NUE in current schemes has been uniform application rates of fertilizer N to spatially-variable landscapes, even though numerous field studies have indicated economic and environmental justification for spatially variable N applications in many agricultural landscapes (Mamo et al., 2003; Hurley et al., 2004; Koch et al., 2004; Scharf et al., 2005; Shahandeh et al., 2005; Lambert et al., 2006). Uniform applications within fields discount the fact that N supplies from the soil, crop N uptake, and responses to N are not the same spatially (Inman et al., 2005). Thus, when N is applied as large pre-plant doses at field uniform rates it is at considerable risk for environmental loss. A third reason for low NUE is attributed to the way N fertilizer requirements are commonly derived. Many current fertilizer N recommendation procedures are yield-based, meaning they rely on expected yield (also called target yield or yield goal) multiplied by some constant factor, representing the N concentration of grain, to come up with the N fertilizer requirement. This calculation produces a number that is, in essence, an estimate of the amount of N that will be removed from the field due to harvest of the crop (Meisinger and Randall, 1991).

Approaches to Increase NUE

To increase NUE in crops, several approaches have been taken. These include:

a. Appropriate timing of N applications which synchronize N supply with need, but avoids potential periods of high N loss;
b. Proper placement of the fertilizer in the soil to minimize potential loss from immobilization, runoff or volatilization;
c. The use of specific fertilizer sources or additives to minimize loss through leaching, denitrification or volatilization;
d. The use of crop sensors during appropriate portions of the growing season to better estimate soil contributions to N supply available to the crop and determine additional fertilizer N need.

Nitrogen Recommendation Systems

The current Kansas State University N recommendation for sorghum, as with many other systems used in the U.S., considers several components to calculate an N recommendation. These components include a yield goal or expected yield term to determine overall N need by the crop, from which expected soil N supply, estimated from mineralization of soil organic matter (SOM) and previous crop residue, and soil profile nitrate-N, is subtracted. The balance is the fertilizer N recommendation. For sorghum the N recommendation equation is: N needed in kg/ha

= (Yield Goal Mg/ha × 25.5) – (% SOM × 22) +/- Previous Crop Adjustments – Soil Profile Nitrate-N – Manure N – Other N Adjustments. The problem with this approach is that yield and N provided through mineralization are both strongly impacted by in-season weather. USDA National Agriculture Statistics state average yields for Kansas ranged from 2700-5080 kg/ha over the last five years (2004 - 2008). This huge variability in yield makes the determination of crop N need very difficult. Determining soil N supply is also difficult. While the recommendation system is designed to utilize a profile nitrate-N soil sample to a depth of 0.6 meters, records of the KSU Soil Testing Lab indicate that less than 10% of the samples submitted for maize or sorghum fertilizer recommendations include a profile sample for N, and only about 20% request soil organic matter tests. As a result the vast majority of the N recommendations made use generalized default values for profile nitrate-N and SOM, significantly reducing the accuracy of the N recommendation. The release of N through mineralization of SOM and crop residue is also quite variable and depends on soil moisture and temperature. If the soil is cool and dry, there will be less release than if the soil is warm and moist throughout the growing season. The other components including manure N and previous crop adjustments also exhibit variability. Another component that is not currently included in the KSU N recommendation is fertilizer recovery or N use efficiency (NUE). Currently NUE or fertilizer recovery, is built into the crop N need coefficient, and assumes a fertilizer recovery of 50%. Considerable research has shown that recovery varies as a function of N rate, fertilizer source used, timing and method of application and many other factors. Thus being able to adjust N rate when using more efficient N management practices, or for sites less prone to N loss would be advantageous. The final problem with the current N recommendation for KSU is that it was developed using maize N response data. As with many sorghum N recommendation systems used in the US, the original KSU recommendations were developed using the assumption that sorghum responded like maize to applied N.

Placement of N Fertilizer

Nitrogen fertilizers must be applied in a method that ensures a high level of N availability to the crop, and high NUE. Several studies (Eckert, 1987; Fox and Piekielek, 1987; Fox et al., 1986; Maddux et al., 1984; Bandel et al., 1980; Mengel et al., 1982) have examined placement methods for no-tillage maize production. They all reported that broadcast applications of UAN-N (urea-ammonium nitrate solutions) produced lower yields than injected or knifed UAN with surface-banded UAN includes solutions intermediate in performance. Possible N loss mechanisms noted with broadcast UAN includes ammonia volatilization from the urea component of the solution and immobilization of N in the surface residue. Thus, fertilizers placement below the soil surface should be more effective than broadcasting or banding fertilizers on the soil surface, both in ensuring quick availability and in enhancing N use efficiency.

The Use of Optical Crop Sensors

Using the proper timing and placement of fertilizer N does little to enhance efficiency and crop yields if a producer does not know both the amount of N needed by the crop, and N supply available in the soil. Determining N need and N supply is very difficult in any crop because of the large influence of weather on both. In sorghum production this is especially important as the yield, and subsequent N need can vary widely from year to year. A new tool slowly gaining adoption to help producers determine N need and N supply is the use of optical crop sensors. These crop sensors were developed based on research which has shown that indices based on red/near infrared ratios can be used to estimate leaf area index, green biomass, crop yield, and canopy photosynthetic capacity (Araus et al., 1996). The use of reflectance at 430, 550, 680 nm, and near infrared wavelengths have shown potential for assessing N status in wheat (Filella et al., 1995). Recent advances in technology have resulted in instruments that use these concepts to help increase NUE in crops. Some of these instruments that are currently available include: the SPAD Chlorophyll Meter (Konica Minolta, Inc. Tokyo, Japan) the GreenSeeker hand held optical sensor (NTech Industries, Ukiah, CA), and the Crop Circle ACS-210 hand held optical sensor (Holland Scientific, Lincoln, NE). These crop sensors rely on crop reflectance to determine N status in plants.

Crop reflectance is defined as the ratio of the amount of radiation that is reflected by an individual leaf or leaf canopy to the amount of incident radiation (Shroder et al., 2000). Plants that are dark green in color will typically exhibit very low reflectance and transmittance in the visible region of the spectrum due to strong absorption by photosynthetic tissue and plant pigments (Chappelle et al., 1992). The pigments involved in photosynthesis (chlorophyll *a*, and *b*) absorb visible light selectively. They absorb mainly the blue and red wavelengths of the visible spectrum, reflecting the green. Therefore, reflectance measurements at these wavelengths can potentially give a good indication of leaf greenness. On the contrary, reflectance and transmittance are usually high in the near-infrared (NIR) region of the spectrum (700-1400 nm) because there is little absorption by the photosynthetic tissue and plant pigments (Gausman, 1974; Gausman, 1977; Slaton et al., 2001). Near infrared light is more strongly absorbed by the soil than the crop, therefore, reflectance measurements that use these wavelengths can provide information on the amount of leaf area relative to the amount of uncovered soil. The color of the crop is not just determined by the color of the leaves. The color of the soil, moistness of the leaves, cloud cover, and temperature can also influence the readings obtained with these sensors. Nonetheless, combinations of reflectance in different wavelengths are used to estimate biophysical characteristics of vegetation. A vegetation index can be derived from reflectance with respect to different wavelengths, which could be a function of chlorophyll content in the leaves, leaf area index, green biomass, or some different background scattering. Several vegetation indexes for this estimation of biophysical characteristics of vegetation stands have been proposed. The Normalized Difference Vegetation Index (NDVI) has shown to be a very good estimator of the fraction of photosynthetically active radiation absorbed (Blackmer et al., 1996a; Osborne et al., 2002; Stone et al., 1996). The NDVI is the difference between the NIR and visible reflectance, which may be red, green, or amber, divided by the sum of these two reflectance values. With this information, it seems logical that the use of these real-time crop sensors could have huge potential in agriculture.

Remote sensing previously has been largely used in natural resources for land cover, biomass estimation, and to note changes in land uses (Deering et al., 1975; Sala et al., 2000; Kogan et al., 2004; Henebry et al., 2005). Within the last decade, attempts have been made to adopt this approach to commercial agriculture with some success. Several studies have shown good relationships between spectral reflectance, chlorophyll content, and N status in green vegetation (Bausch and Duke, 1996; Stone et al., 1996; Blackmer et al., 1996a; Osborne et al., 2002). Raun et al. (2001; 2002) proposed the use of optical sensors for in-season N management in winter wheat fields. Their work was done using the GreenSeeker hand held optical sensor, which uses light emitting diodes (LED) to generate light in the red and near infrared bands (NIR). This method of using light in the red and NIR bands gives not only an indication of plant biomass, but also, an indication of plant greenness. Their approach divides NDVI by GDD accumulated at time of sensing (also called in-season yield estimator (INSEY)) to estimate top-dress N rates. This in-season method for estimating top-dresses N rates is based on yield estimated from early-season sensor data rather than pre-season "yield goals". The in-season top-dress N rate is estimated by subtracting the projected N uptake for the predicted yield in the sensor area, from the projected N uptake in the non-N limiting reference strip, and then dividing by an efficiency factor. Early work in winter wheat showed that N uptake of winter wheat and NDVI are highly correlated (Stone et al., 1996). Further work has shown that yield potential can be predicted accurately about 50% of the time by the Greenseeker when readings are taken at the Feekes 5 growth stage. When fertilizing wheat based on yield potential and having the ability to apply variable rate fertilizer N, plant N use efficiency was increased by 15% as opposed to traditional fertilizer application methods (Raun et al., 2002). In spring wheat, correlations between sensor data and grain yield have not been near as good as in winter wheat. In addition, correlations between sensor readings and nitrogen uptake have also not been as good. Certain varieties however, have had better correlations than others Osborne et al. (2006). Work in maize, has shown that grain yield and NDVI were best correlated at the V8 growth stage. Categorizing sensor data by GDD did not improve the correlation. However, it did extend the critical sensing window two leaf stages (Teal et al., 2006). A more recent study found that when maize was younger and smaller, the sensor has the ability to detect more soil area of lower yielding plants compared to higher yielding plants. Conversely, at later stages of growth, maize plants were taller which required increased elevation of the sensor, and soil background had a diminished influence on NDVI. This resulted in NDVI explaining 64% of the variation in N uptake at early growth stages. However at later growth stages, NDVI was not as well correlated with N uptake

(Freeman et al., 2007). In sorghum, work has shown that grain yield and NDVI were best correlated at growth stage 3. When INSEY was used it did not improve the correlation and NDVI did not correlate as well with N concentration in the grain at harvest (Moges et al., 2007).

To date, the GreenSeeker sensor is the only active sensor currently commercially available for on the go N applications in grain crops. While acceptance has been good, it does have some limitations. One major limitation is that NDVI saturates once a leaf area index greater than 2 is met (Gitelson et al., 1996; Myneni et al., 1997). This presents problems when trying to use this sensor in high biomass production crops such as irrigated maize. But, is not an issue in lower biomass crops such as wheat, the crop the GreenSeeker was specifically developed for.

Timing of N Fertilizer

Having adequate N available to the crop early to ensure high yield potential, and having adequate N remaining late in the season are both important for optimum sorghum yield. Applying no N or minimal N rates at planting, can result in reduced yield potential through inadequate panicle size and reduced seed numbers, particularly in no-till systems. Application of starter-band fertilizer N within the rooting zone of the young seedlings has been shown to be efficient and beneficial to the crop (Lamond and Whitney, 1991). In a study in North Central KS, Gordon and Whitney (1995) reported an increase of 18% in the grain yields of sorghum by application of fertilizer N in a starter-band. In tilled systems, starter N responses are not as common, due to more rapid mineralization of crop residues. The period of rapid vegetative growth and nutrient uptake by sorghum plants begins about 25-30 days after emergence at the six to seven leaf growth stage and continues through pollination and early grain fill (Vanderlip, 1993). Side-dress application of N during the early portions of this period is feasible and could be beneficial for the crop. However, since sorghum is normally grown in low rainfall areas where N loss problems are minimal, this practice is not widely used. Most growers use preplant N applications as their primary N fertilization strategies. Little research could be found comparing the advantages or disadvantages of side dressing N in sorghum. However the application of N fertilizer after planting to sorghum should not be ignored, particularly in no-till planting systems. Delaying the N rate decision until later in the season, when the impact of weather on the crop and N availability may be better understood, could enhance efficiency and profitability. Agricultural inputs have to be managed efficiently, especially during periods of high dry matter production in the crop to maximize yield and profit, and to minimize environmental consequences (Feinerman et al., 1990). Pathways for N losses from agricultural ecosystems include gaseous plant emissions of ammonia, soil denitrification, surface runoff, volatilization of ammonia, and leaching of nitrates (Raun and Johnson, 1999). With the exception of N denitrified to N2, the remaining pathways all can lead to an increased load of biologically reactive N in the environment (Cassman et al., 2002). Continued low NUE in crops could have a drastic impact on land-use and food supplies worldwide (Frink et al., 1999).

The Use of Chlorophyll Meter (SPAD)

The concept of using the crop to assess crop N status is not new. Effective N management is a major challenge for grain crop producers. Yet, factors like weather that affect its efficiency are beyond a producer's control. Fertilizer N is becoming more expensive, but deficiencies can result in substantial yield reductions and lost profits. As a result, producers are inclined to manage fertilizer N to minimize risk of deficiency, which can led to excessive fertilizer applications and subsequent continuation of the environment. Researchers have been developing ways to increase fertilizer use efficiency. Used of soil test to adjust fertilizer N rates for residual nitrate works well. Research over the past decade indicates a close link between leaf chlorophyll content and leaf N content, which makes sense because the majority of leaf N is contained in chlorophyll molecules. The Minolta chlorophyll meter (model SPAD 502 Soil Plant Analysis Development) enables users to quickly and easily measure potential photosynthetic activity, which is closely linked to leaf chlorophyll content, crop N status and leaf greenness. Essentially the meter exposes a small portion of the leaf to abundant light and measures how much was captured by chlorophyll in the photosynthetic process. The SPAD utilize two light-emiting diodes (650 nm and 990 nm) and a photodiode detector to sequentially measure transmission of red and infrared light through leaves. The obtained SPAD values are proportional to the chlorophyll content of leaves (Kapotis et al., 2003; Yamamoto et al., 2002; Earl and Tollenaar, 1997) found a close correlation (R^2=0.98) between SPAD reading and maize leaf absorptance. Recent research indicates a link between chlorophyll content, leaf N status and crop yield (Cartel et al., 2005; Lopez et al., 2004). The SPAD can be used to monitor N status and potentially increase N use efficiency. Many factors affect chlorophyll meter readings. Variety or hybrid differences can greatly affect meter readings in that some adequately fertilized maize and sorghum hybrids are darker green than others. The stage of growth can affect leaf greenness, as can recent environment conditions such as temperature, moisture stress and sunlight. Plant diseases, nutrient deficiencies and nearly any others kind of plant stress can affect the plant's ability to produce chlorophyll, thus affecting leaf greenness. The SPAD enhances a producer's ability to make N management decisions but does not replaces others aspects of good N management. The high cost of the chlorophyll meter keeps it out of reach of many farmers. Excessive nitrogen and its application at an inappropriate growth stage can reduce yields, reduce market value of some varieties, and increase disease incidence. In contrast, suboptimal nitrogen levels at discrete growth stages may substantially reduce plant productivity. Nitrogen status in the leaf varies throughout the life cycle of plant transitions through the most nitrogen sensitive growth stages within a few days. Thus, it is essential that plants be sampled at a consistent growth stage for nitrogen management. Furthermore, time of sampling must be based on the actual plant growth stage, not days after planting. Days after planting to panicle initiation, for example, may vary between years due to weather. Estimating tissue N status at critical points of the plant's life cycle can greatly improve the economics of production. Therefore, fertility management decisions must frequently be made for numerous large fields in a short period of time.

The Use of Green Leaves

A method of counting the number of green leaves was developed with the hopes of potentially using this information to help producers make informed management decisions quickly with virtually little or no cost. Research was done in 2010, using plots established to assess nitrogen use efficiency of a range of N management practices, to determine if there was a strong relationship between the number of green leaves remaining , SPAD and leaf color chart shortly during different growth stages and yield and N products and different levels Hence, the present study was formulated with an objective to determine the relationship between LCC scores, SPAD values and green leaves counting to estimate leaf nitrogen status of sorghum. Deficiencies of N during the growth of sorghum results in fired leaves, the premature death of lower leaves. The death of each leaf progresses from the leaf to the stalk and is preceded by a change in color from green to yellow. The death of leaves progresses and the number of leaves affected at any stage of maturity tend to increase with the severity of the deficiency. Most sorghum producers associate firing with N deficiencies and use it as a convenient indicator of N status. Lack of interest in describing relationships between firing and yields probably is best explained by widespread recognition that amounts of firing are influences by moisture availability and other factors in addition to N availability. Also, tissue analysis generally has been accepted as a superior tool for evaluating N status (Binford, 1993). The method of using tissue analysis is useful in determining if nitrogen is limiting, but can be costly to the producer based on the time and money needed to collect samples, and in most cases, the cost incurred to have a testing facility prepare the samples for analysis as well as the analysis cost itself. On farm research was done at Ohio State University by La Barge (1999) to observe yield response and post-mortem stalk nitrate nitrogen concentration when different nitrogen rates were applied. Measurements were taken when maize was at the R4 growth stage and the number of green, healthy leaves below the ear leaf was counted. This provided an index of firing, a common system of nitrogen deficiency. This research hypothesized that leaf health could provide an efficient means of determining if adequate nitrogen nutrition was provided. When field check strips were established using varying N rates, research has shown that the index of leaf health can be as accurate as lab analyzed leaf tissue to identify low/sufficient nitrogen conditions. La Barge (1999) believed that this index may provide farmers a tool to observe field response to nitrogen. His research showed that the trend was for more healthy green-leaf counts below the ear leaf as N rates increased. The value of a tool for evaluating N status, however, is determined more by its ability to function across a reasonable range of conditions than by its ability to function within individual fields. Binford and Blackmer (1999) found that relatively poor performance of leaf ratings in the pooled models supported the generally accepted idea that factors other than N deficiencies (e.g. moisture stresses, maize diseases, differences between hybrids) can influence the amount of firing. Relatively good performance of adjusted leaf ratings is noteworthy because leaf ratings require much less time, effort and expense than do leaf N analyses.

The Use of Leaf Color Chart (LCC)

Another simple, quick, and non-destructive method for estimating leaf N status is a Leaf Color Chart (LCC). The most common one are those developed by the International Rice Research Institute, China, and the University of California, Davis. The gamut of green colors is visually different among the three LCCs. Unlike the SPAD, this measures light absorption, LCC measures leaf greenness, and the associated leaf N by visually comparing light reflection from the surface of leaves and the LCC. Even though LCC has been tested for real time N management in the farmers fields in several countries (Balasubramanian et al., 1999), and very limited information is available on the accuracy of LCC in estimating leaf N status of grain sorghum plants. Japanese scientists developed a N management tool called leaf color chart (LCC) (Furuya et al., 1987) which was subsequently modified by Chinese scientists. The international Rice Research Institute (IRRI) and the Philippine Rice Research Institute (PRRI) used the concept and jointly further improved the LCC in late 1990s to assist farmers to apply N fertilizer at right amount as and when needed by the plant (Shula et al., 2004). The LCC is inexpensive (less than US$ 1.00 per unit) and a simple technology easy to understand and use. It has been used for decade on rice. The color panels of the LCC are designed to indicate whether rice plants are hungry or over-fed by nitrogen fertilizer. By matching the color of the rice leaf to the color on the LCC, farmers can decide proper time and amount of N fertilizer for application.

LCC validation experiments in Vietnam and other countries have shown that farmers can save a substantial amount of nitrogen without any reduction in grain yield, which subsequently led to its adoption (Alam et al., 2005, 2006; Balasubramanian et al., 2000; Singh et al., 2002). It has been successfully used for rice (Balasubramanian et al., 1999; Hussain et al., 2000), maize (Peterson et al., 1993), and wheat (Follett et al., 1992). Two approaches have been used to apply fertilizer N in rice using chlorophyll meter: when sufficient index (defined as SPAD value of the plot in question divided by that of a well-fertilized reference plot or trip) falls below 0.90 (Hussain et al., 2000) and when SPAD value is less than the set critical reading. The sufficient index approach of Hussain et al. (2000) may disadvantageous because it requires a well-fertilized area.

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Chapter 2 - Effects of Planting Date, Hybrid Maturity, Row Spacing and Seeding Density on Growth and Yield of Grain Sorghum

2.1 Abstract

Grain sorghum is well adapted to semi-arid environments, but production practices must be optimized. A three year study was conducted at four locations to determine the effects of planting date, hybrid maturity, row spacing and plant density on sorghum growth and yield. The hypothesis was that the combination of hybrid maturity, row spacing and plant density that maximizes yields will differ depending on planting date, latitude, available moisture and light intercepted. The experiments were conducted at Belleville, Ottawa, Hutchinson and Manhattan in 2009, 2010 and 2011. Two planting dates (late-May and mid-June), two hybrid maturity group (Medium Early, DKS 44-20 and Medium Late, DKS 53-67), two row spacing (25 and 75 cm) and 4 seeding densities (50000, 80000, 110000 and 140000 plants ha^{-1}) were used. Dry matter, light interception, and leaf area index (LAI) were recorded at 45, 60 and 95 days after planting. Hybrid maturity did not influence grain yield in all environments. Results indicated that the early planting date (late May) and narrow row spacing (25 cm) produced the best plant growth, number of panicles, number of grains per panicle, 300-grain weight, and biological yield. Therefore, early planting at plant population of 80000 plants ha^{-1} in narrow rows (25 cm) can maximize light interception, total dry weight, grain yields and yield components. In dry conditions where water will be more limiting than light, planting fewer seeds ha^{-1} in wider rows (75 cm) will maximize yield of grain sorghum in dry land production in Kansas.

2.2 Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is well adapted to the southern Great Plains and is grown extensively as a feed grain under dryland and irrigated conditions. In the US, grain sorghum is considered by most to be a feed grain. More than 90 percent of sorghum consumed in the U.S. is used for livestock (USDA-NASS-2009). Kansas historically has been a leading producer of grain sorghum. From 1990 to 1999 Kansas was the number one or two grain producing state in the U.S. (Kansas Agricultural Statistics, 2011), accounted for 27.6 to 50.8 percent of the total grain sorghum produced in the US. In recent years, however, maize (*Zea mays* L) acreage in Kansas has increased, and the yield potential of maize and maize prices relative to sorghum prices have increased the popularity of maize in Kansas (USDA-NASS-2009). Global demand and consumption of agricultural crops for food, feed, and fuel is increasing at a rapid pace (Michael and Edgeston, 2009). This demand for plant materials has been expanding for many years. In the U.S., breeders, agronomists, and farmers have a documented history of increasing yield. Average sorghum yields in U.S. have increased from approximately 1.6 tones/ha in the first third of the 20th century to today’s approximately 9.5 tones/ha (Kansas Agricultural Statistics, 2011). This dramatic yield improvement is due to the development and widespread use of new farming technologies such as hybrids, synthetic inorganic fertilizers, and improved farm machinery and improved crop management practices (Von Braun, 2007).

Crop growth rate is directly related to the amount of radiation intercepted by the crop (Monteith, 1977). The response of grain yield to narrow rows can be analyzed in terms of the effect on the amount of radiation intercepted at critical growth periods. In some cases, full radiation interception during these periods may not be achieved with wide rows. Narrow row configuration originally was suggested for grain sorghum in order to control wind erosion, aid in moisture conservation, reduce surface crusting and improve weed control. Since it has been generally accepted that water availability is the primary factor limiting grain sorghum yields under dryland conditions, planting configuration has been considered as a way to use available moisture most efficiency (Ceccarelli and Grando, 1990). Changing that configuration may affect leaf area index and canopy closure, altering portioning of available evapotranspiration between the plant and the soil surface. Studies have reported higher yields from narrows than wide rows under favorable conditions (Staggenborg et al., 1999). Staggenborg et al. (1999) suggested that when moisture stress limited grain yields, no differences occurred among row-spacing treatments. Increased sorghum yield with increasing plant population has been reported (M'Khaitir and Vanderlip, 1992), usually when soil moisture is not limiting. Grain sorghum has good yield potential and high biomass production, which improves soil properties when residues are returned to the soil. Grain sorghum also has relatively low water and fertilizer requirements, and requires few pesticides inputs (Gallagher et al., 2008).

Planting dates and row configurations need to be optimized in order to maximize benefits and returns. Planting dates should be as early possible to take advantage of favorable growing conditions and accumulate biomass (Kucharic, 2008), but planting too early can expose the crop to adverse environmental conditions. Numerous factors have been suggested as contributing to grain sorghum's response to date of planting. Uniform, regional, early planting has been recommended as the most effective cultural practices to reduce sorghum midge. Castro et al. (2008), however, found that early planting resulted in a longer flowering period and prolonged exposure to insect damage.

Differences have been reported among grain sorghum hybrids in their response to planting date. However, Staggenborg et al. (1999) has suggested that grain yield is not drastically affected by a wide range of plant densities due to its ability to compensate for change in available space and when soil moisture is limiting increasing plant population's result in reduced grain yields. Studies found that the grain yield of a late maturity variety was highest under low seeding rate while yield of an early maturing variety was highest under high seeding rate.

One key to increasing the productivity of field crops is to maximize the amount of radiation they intercept. Interception of solar radiation on leaf surfaces can be maximized by crop husbandry means (Scott et al., 1978). Crop growth can be analyzed in terms of its efficiency to use intercepted radiation. The relationship has been used as a basis for theoretical investigations of crop productivity, modeling climate effects, and the importance of light as a limiting factor in crop performance (Monteith, 1972, 1973, 1981). The variability in yield response to planting practices and environment indicates that additional research is required to develop recommendations for production systems, including specific information on optimum combinations of seeding rate, planting date, hybrid maturity, row spacing, and light interception in semi-arid environments.

We hypothesized that the combination of hybrid maturity, row spacing, and plant population that maximizes yields will differ depending on planting date, latitude, and available moisture. The objective of this study was to optimize sorghum production by determining the effects of planting date, row configuration, hybrid maturity and plant population on growth, light interception and yield in semi-arid environments.

2.3 Materials and Methods

2.3.1 Experiment and treatment Structure

A three year experiment involving planting date, hybrid maturity, row spacing, and different seeding rates was conducted at Kansas State University Research Stations (Manhattan, Ottawa, Hutchinson, and Belleville) in a split-split-plot design during 2009, 2010, and 2011. The experiment was a Randomized Complete Block Design (RCBD) with four replications. Planting date (DATE Late May and Mid-June) was assigned to whole plots, hybrid maturity (MAT (DKS 44-20, Medium Early ME, DKS 54-00, Medium Late ML, Monsanto, St Louis, MO) and row spacing (RS- 25 cm and 75 cm) were assigned in a factorial arrangement to sub plot. Seeding rates (SR- 50000, 80000, 110000, and 140000 seeds ha^{-1}) were assigned to sub-sub-plot. Experiment units consisted of four rows 75 cm row spacing and 12 rows for the 25 cm row spacing. Plots were 12 m long and 3 m wide with four replications.

2.3.2 Experimental Sites and Environmental Conditions

These studies were conducted at four locations: Agronomy North Farm, Manhattan, KS (39^{o}12’44.5824” N lat.; 96^{o}35’40.5486” W long) on a Smolan silt loam soil, East Central Research Station, Ottawa KS (38^{o}53’85.89” N lat.:95^{o}24’46.9” W long) on a Woodson silt loam soil, South Central Experiment Field, Hutchinson (37^{o}55’52.8522” N lat; 98^{o}1’29.5674” N long.) on a Ost loam soil and North Central Experiment Field Belleville, KS (39^{o}49’25” N lat 97^{o}37’49” W long) on a Crete silt loam soil. Weather data during the cropping seasons for Manhattan 2009, 2010 are presented in Fig. 2.1, for Manhattan 2011 in Fig. 2.2, for Ottawa 2010, 2011 in Fig. 2.3, for Hutchinson 2009, 2010 in Fig. 2.4, and for Belleville 2009, 2010 in Fig. 2.5.

2.3.3 Crop Husbandry

Grain sorghum needs a warm, moist soil well supplied with air and fine enough to provide good seed-soil contact for rapid germination. (Grain Sorghum Production Hand Book, KSU). The experiment was no-till planted into corn or soybean stubble depending on locations. Plots were fertilized with 202 kg N per hectare broadcast as Urea Ammonium Nitrate (UAN) before planting. Plots were sprayed with a combination of dimethenamid-P and atrazine herbicides (1440 g ha^{-1}) to control weeds after planting in May. Sorghum was planted using a planter (Hege Cone Drill, Wintersteiger, Inc. Salt Lake City, Utah). Harvest was accomplished by harvesting the two middle rows using a combine modified for experimental plot harvest or by hand harvesting (4.5 m^2). Panicles were bagged, taken to be dried and then threshed and weighed for yield determination.

2.3.4 Data Collection

2.3.4.1 Light Interception

Interception of photosynthetically active radiation (IPAR, 400 to 700 nm wavelengths) was estimated using line quantum sensor (LI-191 LQS Lincoln NE). Readings were collected from 1:00 P.M. three times during the growing season at 45, 60 and 95 days after planting (DAP), by placing the LI-191 LQS on the ground, perpendicular to crop row, with the center of the LQS mid-way between the center two rows and data logger (LI-COR, Biosciences, Lincoln, NE, USA) fixed to it for data recording.

The percent photosynthetically active radiation was computed as follows: IPAR= (1-*eb/ea*) x100 where *eb* is the average signal voltage measured below the canopy and *ea* the average signal above the canopy.

2.3.4.2 Growth Traits

Whole plants were sampled at 45, 60 and 95 DAP. At each harvest, total plant biomass was obtained from 1.5 m of a center row cut at ground level. Leaves, stems and panicles were dried at 60^{o}C for 7 days and weights were recorded.

2.3.4.3 Yield Traits

Grain yields were determined for each plot by hand harvesting an area of 4.5 m^2 or by machine harvesting 9 m^2. Yields were adjusted to 12.5% moisture content using a Dickey John moisture tester (Dickey-John Corporation, Davis, CA. USA). To estimate seed mass, 300 grains from each experimental plot were randomly selected and weighed using a digital scale. Harvest index was calculated as a ratio of grain yield and biological yield.

2.3.5 Data Analyses

Analyses of variance were performed for the dependent variables (plant height, panicle per plant, grain per panicle, 300-grain weight, grain yield, biological yield, total dry weight, light interception, and harvest index) to determine effects of date, maturity, row spacing, populations and their interactions using Proc Mixed (SAS Institute, 2003). Analyses of variance over locations and years indicated significant interactions of treatment variables with locations and years. Therefore, analysis of variance was performed separately for each location-year combination. Blocks within each location were considered as random and other classification variables (date, maturity, row spacing, and population) were considered fixed.

2.4 Results

Precipitation and temperature, which are the two most important climatic factors that affect sorghum growth during the cropping season, varied among locations and years.

In Manhattan, the mean maximum temperatures were 25.4^{o}C, 28.8^{o}C and 29.4^{o}C in 2009, 2010 and 2011, respectively. The minimum temperatures were 13.1^{o}C, 15.8^{o}C and 15.4^{o}C in 2009, 2010 and 2011, respectively. The rainfall was 587.4 mm, 355.4 mm, and 457.1 mm in 2009, 2010 and 2011, respectively (Fig. 2.1, 2.2). The 30 year averages based on 1981-2010 maximum and minimum temperature were 28.10^{o}C and 14.50^{o}C, respectively. The rainfall was 646.44 mm.

In Ottawa, the mean maximum temperatures were 28.8^{o}C and 29.6^{o}C, in 2010 and 2011, respectively. The minimum temperatures were 16.5^{o}C and 15.7^{o}C in 2010 and 2011, respectively. The rainfall was 666.7 mm, and 351.7 mm in 2010 and 2011, respectively (Fig. 2.3). The 30 year averages based on 1981-2010 maximum and minimum temperature were 29.2^{o}C and 13.95^{o}C, respectively. The rainfall was 600.32 mm.

In Hutchinson, the mean maximum temperatures were 26.19^{o}C and 29.4^{o}C in 2009, and 2010 respectively. The minimum temperatures were 13.2^{o}C, and 15.7^{o}C 2009, and 2010 respectively. The rainfall was 558 mm, and 662.0 mm, in 2009, and 2010 respectively (Fig. 2.4). The 30 year averages based on 1981-2010 maximum and minimum temperature were 22.71^{o}C and 14.30^{o}C, respectively. The rainfall was 538.74 mm.

In Belleville, the mean maximum temperatures were 25.4^{o}C and 28.0^{o}C in 2009 and 2010, respectively. The minimum temperatures were 12.4^{o}C and 14.3^{o}C in 2009, and 2010 respectively. The rainfall was 455.0 mm, and 384.3 mm in 2009 and 2010 respectively (Fig. 2.5). The 30 year averages based on 1981-2010 maximum and minimum temperature were 27.9^{o}C and 13.92^{o}C, respectively. The rainfall was 639.99 mm.

2.4.1 Crop Growth and Light Interception

Manhattan

In 2010, based on variance analysis, total dry weight (TDW), leaf area index (LAI) and intercepted phytosynthetically active radiation (IPAR) were affected by planting date, row spacing and seeding rate at the 0.05 probability level (Table 2.1). However, maturity group had no effect on these parameters. A significant interaction was observed between date of planting and row spacing for TDW at 45, 60 and 95 DAP (Table 2.1). None of the other interaction effects were significant. As indicated in Table 2.2, IPAR, LAI and TDW were greater in May planting than in June planting at all three sampling times. LAI increased with reduced row spacing. Narrow row (25 cm) spacing intercepted more light than wider row (75 cm). Total dry weight increased an average of 31% with reduced row spacing (Table 2.2). Higher planting density resulting in increased TDW, IPAR, and LAI (Table 2.2).

In 2011 in Manhattan, variance analysis indicated that IPAR and TDW were affected by planting date, row spacing and seeding rate at the 5% probability level (Table 2.3). Only row spacing effected LAI. There were no treatment interactions for LAI, IPAR or TDW. Total dry weight, LAI, and IPAR were significantly greater with May planting when compared with June planting (Table 2.4). Hybrid maturity group had no effect on TDW, LAI, or IPAR except at 95 days when IPAR was greater for the ME hybrid. Interception of PAR by the canopy was affected by row spacing. The maximum average light interception by the canopy and TDW occurred in 25 cm row compared to 75 cm across among all measurements. Leaf area index was greater in wider row (75 cm) compared with narrow row (25 cm) at 45, 60 and 95 DAP.

Total dry weight increase with narrow rows (25 cm) compared to (75 cm) wider row spacing. Increasing seeding rate from 50000 to 140000 increased TDW and IPAR at 45, 60 and

95 DAP. No significant differences between seeding rates were observed for LAI at all sample dates.

Belleville

In 2010, variance analysis indicated that LAI, IPAR, and TDW were affected by planting date and row spacing at the 5% probability level (Table 2.5). Seeding rate influenced IPAR and TDW but not LAI. Hybrid maturity group had no effect on any parameters measured. A significant interaction was observed between date of planting and row spacing for TDW at 45, 60 and 95 DAP (Table 2.5).

The treatment mean comparisons (Table 2.6) indicated that LAI, IPAR and TDW were greater with May planting compared to June planting at all sample times. Row spacing influenced LAI, IPAR and TDW with the highest value in narrow row (25 cm) compared to wider row (75 cm). Intercepted phytosynthetically active radiation and TDW increased as seeding rate increased from 50000 to 140000 at 45, 60 and 95, DAP. Plant population did not influence LAI (Table 2.6).

Ottawa

In 2010 analysis of variance indicated that IPAR, LAI, and TDW were influenced by date of planting, row spacing and seeding rate at the 5% level of probability at all sample times. Hybrid maturity did not affect any response parameter at any sample dates. A significant interaction was observed between date of planting and row spacing for TDW at all sample date (Table 2.7).

Leaf area index, IPAR and TDW were significantly greater with May planting compared to June planting (Table 2.8). Leaf Area Index, IPAR and TDW were greater in narrow row at all sample times compared to wider row (75 cm) spacing. Intercepted PAR, LAI and TDW also increased with increased seeding rate.

In 2011, variance analysis (Table 2.9) indicated that LAI, IPAR, and TDW were influenced by row spacing at the 5% probability level. Date of planting influenced IPAR at 45 and 60 DAP only. There was no effect of other treatment factors or their interactions. Narrow row (25 cm) had significantly greater TDW, LAI, and IPAR at all sample dates compared to wider rows (75 cm) (Table 2.10).

Hutchinson

In 2010, variance analysis (Table 2.11) indicated that LAI, IPAR, and TDW were affected by planting date, row spacing and seeding rate at the 5% probability level. However, hybrid maturity did not affect any parameters measured. A significant interaction was observed for date of planting and row spacing for TDW.

The means comparisons (Table 2.12) indicated that TDW, LAI, and IPAR were greater with May planting compared to June planting at 45, 60 or 95 DAP. Row spacing influenced TDW, LAI, and IPAR with the greatest values in narrow row (25 cm) at all sampling times. Leaf area index, IPAR and TDW increased with increased seeding rate (Table 2.12).

2.4.2 Yield and Related Traits

Manhattan

In 2009, analysis of variance (Table 2.13) indicated that plant height; panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield and harvest index were affected by planting date, row spacing, and seeding rate at the 5% probability level. Plant height and grains per panicle were influenced also by hybrid maturity group.

Significant interactions were observed for date of planting and maturity on grains per panicle, 300-grain weight, and biological yield. A significant interaction between hybrid maturity and seeding rate was observed on grains per panicle and biological yield. The hybrid maturity and row spacing interaction affected plant height. Similarly, a significant interaction was observed between date of planting and row spacing on panicles per plant, grains per panicle, grain yield and harvest index. Significant interaction existed between date of planting and seed rate for plant height, panicles per plant, grain yield, biological yield, and harvest index. Plant height, panicles per plant, and grains per panicle were influenced significantly by the row spacing and seeding rate interaction.

In 2009, mean comparisons (Table 2.14) indicated that May planting had taller plants, more panicles per plant, more grains per panicle, greater 300-grain weight, grain yield, biological yield, and harvest index values compared to June planting. The ME hybrid had greater plant height and grains per panicle. Plant height, panicle per plant and 300-grain weight did not differ with 25 cm and 75 cm row spacing, but grains per panicle, grain yield, biological yield, and harvest index were greater with narrow rows compared to wider rows. Plant height, grain yield, and biological yield increased with increasing seed rate (Table 2.14). Panicle per plant, grain per panicle, and 300-grain weight decreased with increasing seed rate. Harvest index was maximized at intermediate seeding rates.

In 2010, analysis of variance (Table 2.15) indicated that plant height, panicles per plant and grains per panicle was affected by maturity at the 5% probability level. Plant height, panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield and harvest index also were influenced by planting date, row spacing and seeding rate. Significant interaction was observed between date of planting and row spacing for panicles per plant, grains per panicle, grain yield, biological yield and harvest index and between date of planting and seed rate for grain yield, biological yield, and harvest index.

In 2010, mean comparisons (Table 2.16) indicated that plant height, panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield and harvest index were greater with May planting compared with June planting. Hybrid maturity did not differ except for plant height, panicles per plant, and grains per panicle where the medium early (ME) maturity hybrid was greater compared with the medium late (ML) hybrid.

Narrow row (25 cm) spacing resulted in greater values for all parameters measured compared with wider row (75 cm) spacing. Plant height, grain yield, and biological yield were greater with increasing seed rate, however, panicles per plant, grains per panicle, and harvest index decreased with increasing seed rate. Weight of 300 seeds was greater at 80000 seeds ha^{-1} compared to other seeding rates.

In 2011, based on variance analysis (Table 2.17), plant height, 300- grain weight, grain yield, and harvest index were affected by hybrid maturity group at the 5% probability. Planting date and seeding rate influenced plant height, panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield and harvest index. Seeding rate affected all parameters measured at the 1% probability level. Row spacing influenced 300-grain weight, grain yield, biological yield, and harvest index. Significant interactions were observed between date of planting and hybrid maturity, hybrid maturity and row spacing, hybrid maturity and seeding rate for on 300-grain weight, between hybrid and seed rate for grain per panicle, and between date of planting and seed rate for panicle per plant.

In 2011, mean comparison (Table 2.18) indicated that all parameters measured were greater with May planting compared with June planting. The ME hybrid was greater compared to

ML hybrid for plant height, 300-grain weight, grain yield and harvest index. All the parameters measured performed well in narrow row (25 cm) spacing compared to wider row (75 cm) spacing except for plant height, panicles per plant, and grains per panicle where there were no difference between narrow and wider spacing. Plant height and biological yield increased with increasing seed rate, however, panicles per plant, grains per panicle, 300-grain weight, grain yield and harvest index decreased with increasing seed rate.

Belleville

In 2009, analysis of variance (Table 2.19) indicated that plant height; panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield, and harvest index were affected by planting date, row spacing, and seeding rate. Plant height was also influenced by hybrid maturity. Significant interactions were observed for date of planting and maturity group for plant height, grains per panicle and grain yield, and between hybrid maturity and row spacing for grains per panicle. Similarly, a significant interaction was observed between date of planting and row spacing for plant height, and between date of planting and seeding rate for grains per panicle and for grain yield (Table 2.19).

In 2009, mean comparisons (Table 2.20) indicated that May planting had taller plants, more panicles per plant, more grains per panicle, greater 300-grain weight, grain yield, biological yield, and harvest index values compared with June planting. The medium early hybrid was greater in plant height compared with the ML hybrid, however no differences were observed in panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield, and harvest index.

Row spacings did not differ for plant height or biological yield, but panicles per plant, grains per panicle, 300-grain weight, grain yield, and harvest index were greater when planted in narrow rows (25 cm) compared to wider row (75 cm). Plant height, grain yield, biological yield, and harvest index increased with increasing seed rate, but panicles per plant, grains per panicle, and 300-grain weight decreased with increasing seeding rate (Table 2.20).

In 2010, analysis of variance (Table 2.21) indicated that panicles per plant and grains per panicle were affected by hybrid maturity group at the 5% probability level. Plant height, panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield, and harvest index were influenced by planting date and seeding rate. Panicles per plant, grain yield, biological yield, and harvest index were affected by row spacing. Significant interaction was observed between maturity and row spacing for grains per panicle, between hybrid maturity and seeding rate for plant height, panicles per plant, and grains per panicle. Similarly significant interaction was found between date of planting and seed rate for panicles per plant, grains per panicle, and 300-grain weight.

In 2010, mean comparisons (Table 2.22) indicated that plant height, panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield and harvest were greater in May planting compared with June planting. Hybrid maturity did not differ except for panicles per plant and grains per panicle where the ME maturity hybrid was greater compared with the ML hybrid.

Narrow rows (25 cm) spacing was greater for all parameters except for plant height, grains per panicle and 300-grain weight compared with wider row (75 cm) spacing. Plant height, grain yield, biological yield, and harvest index were greater with increasing seed rate, however, panicles per plant, grains per panicle, and 300-grain weight decreased with increasing seed rate.

Ottawa

In 2010, variance analysis (Table 2.23) indicated that plant height, grain yield, biological yield, and harvest index were significantly influenced by date of planting. Hybrid maturity influenced grain yield at the 5% probability level. Seeding rate significantly influenced plant height, panicles per plant, grain yield, biological yield, and harvest index at the 1% level. Significant interactions existed between hybrid maturity group and row spacing for grain yield and between hybrid maturity group and seed rate for grain yield and harvest index. Also, a significant interaction was observed between date of planting and seed rate for biological yield, and between date of planting and seed rate for plant height and grain yield. A significant interaction was observed also between row spacing and seeding rate for biological yield.

In 2010, mean comparisons (Table 2.24) indicated that plant height, grain yield, biological yield and harvest index were greater for May planting compared with June planting. Panicles per plant were not affected by planting date. Hybrids did not differ except for grain yield where the ME maturity hybrid was superior compared to the ML hybrid.

Narrow row (25 cm) spacing was greater for all parameters except panicles per plant compared with wider row (75 cm) spacing (Table 2.24). Plant height at low seeding rate was shorter compared to the other seeding rate. Panicles per plant, and harvest index decreased with increasing seeding rate, however, grain yield and biological yield increased with increasing seeding rate.

In 2011, analysis of variance (Table 2.25) indicated that 300-grain weight and biological yield were affected by hybrid maturity at the 1% probability. All parameters measured were affected by planting date. Row spacing influenced plant height, grain yield, and biological yield at the 5% probability level. Seeding rates influenced all parameters excepted biological yield. No interactions were observed for any parameters measured except for the effect of row spacing and seeding rate on panicles per plant.

Means comparisons for 2011 (Table 2.26) indicated that plant height, grains per panicle, grain yield, biological yield, and harvest index were greater for June planting compared to May planting. Only panicles per plant and 300-grain weight were greater with May planting. The ME hybrid did not differ from ML hybrid except for 300-graim weight and grain yield where the ME hybrid was superior.

Row spacings did not differ for panicles per plant, grains per panicle, 300-grain weight, and harvest index (Table 2.26). Plants were taller at 75 cm than 25 cm, but the 25 cm row spacing was greater for grain yield and biological yield.

Plants were taller and yielded more with increasing seeding rates. Panicles per plant, grains per panicle, 300-grain weight, and biological yield decreased with increasing seed rates. Harvest index was least at the 80000 seeds ha^{-1} seeding rate.

Hutchinson

In 2009, analysis of variance (Table 2.27) showed that plant height, panicles per plant, grains per panicle, 300-grain weight, grain yield, biological yield, and harvest index were affected by planting date, row spacing and seeding rate at the 5% probability level. Plant height and grains per panicle were influenced also by hybrid maturity group. A significant interaction was observed for harvest index between date of planting and hybrid maturity, maturity and seeding rates for plant height, date of planting and row spacing for grain yield and harvest index. Similarly a significant interaction was observed for date of planting and seed rate for 300-grain weight and harvest index.

In 2009, means comparisons (Table 2.28) indicated that May planting was higher for all parameters measured compared to June planting. Plant height was greater for the ML hybrid maturity, but hybrid maturities did not differ for other parameters.

The narrow rows were greater for all parameters measured compared to wider rows spacing except for plant height (Table 2.28). Increased seeding rate increased plant height, grain yield, biological yield, and harvest index, however, panicles per plant, grains per panicle, and 300-grain weight decreased with increasing seeding rate.

In 2010, analysis of variance (Table 2.29) indicated that plant height, grains per panicle, and grain yield was affected by hybrid maturity at the 5% probability level. Plant height, panicles per plant, grains per panicle, biological yield, and harvest index were influenced by planting date.

The 300-grain weight, biological yield, and harvest index were affected by row spacing (Table 2.29). All parameters measured were affected by seeding rate the 1% probability level. Significant interaction was observed between maturity and seeding rate for plant height, between date of planting and row spacing for harvest index and biological yield, and between date of planting and seeding rate for plant height, biological yield, and harvest index.

In 2010, mean comparisons (Table 2.30) indicated that plant height, panicles per plant, grains per panicle, and biological yield were greater for May planting compared with June planting. Hybrid maturity group did not differ except for grain yield, grains per panicle, and planting rate where the ML hybrid was greater compared to ME hybrid. There was no difference between different row spacing although 300-grain weight and biological yield were greater in 25 cm rows. Plant height, grain yield, biological yield, and harvest index increased with increasing seeding rate, however, panicles per plant, grains per panicle, 300-grain weight decreased with increasing seeding rate.

Interactions Effects

In 2010 dry weight was greatest for May planting in 25 cm row spacing at Hutchinson, Belleville and Manhattan at 60 and 95 DAP (Fig.2.6). A similar biomass production response to row spacing was observed with June planting at Hutchinson and Belleville. The June planting at Manhattan produced more biomass in wide rows initially, but row spacing had no influence on biomass production at 60 and 90 DAP. At Ottawa, 25 cm row spacing produced more biomass in the May planting, but row spacing had no effect on biomass production in the June planting at any sample time.

Interactions effects explained that grain yield significantly increased from the 50000 seeding rate to the 80000 seeding rate and remains relatively constant from the 80000 seeding rate to the 140000 seeding rate when planting in May for all locations (Fig. 2.7, 2.8, 2.9, and 2.10). With June planting 110000 seeding rate was required to maximize yield at all locations.

The 2010 interaction effects indicated that grain yield significantly increased from 50000 seeding rate to 140000 seeding rate planting in the 25 cm row spacing at all locations (Fig. 2.11, 2.12, 2.13, 2.14). However, grain yield did not increase as much in response to increasing seeding rate when planting at 75 cm spacing at all locations.

2.5 Discussion

2.5.1 Environment

The rainfall amount and distribution were not uniform through the three-year period of the study in all locations. The large differences among the parameters observed during the three growing seasons were mainly attributed to variations in seasonal rainfall and high temperature. Weather was characterized by large day and night temperature differentials. The three growing season were similar climatically except in 2011 when drought and high temperature stress was severe during the growing period. Drought was one of the most common environmental stresses that affected growth and development of grain sorghum in Manhattan, Belleville, Ottawa and Hutchinson. Yadav et al. (1999) indicated that drought after flowering of sorghum decreased seed yield through reduction of number of panicles per unit area, seed per head and seed weight. Seed weight decline can be through decreased seed growth rate as well as seed filling period (Naseri et al., 2010). Similarly high temperature stress (>38^{o}C) decreases sorghum grain yield (Prasad et al., 2006). Short periods of high temperature stress also decreased seed-set and seed numbers (Prasad et al., 2008).

2.5.2 Crop Growth

Results from our studies indicated that above-ground dry matter differed for the two sowing dates (May and June) in Manhattan, Belleville, Ottawa and Hutchinson. Results also indicated that early planting produced greater LAI and intercepted more PAR than the late planting. Results also showed that the magnitude of early planting response was greater with higher seeding densities. The results agree with others workers (Khan, 2000; Naeem, 2001).

More dry matter was produced in narrow rows in all locations because plants in wide rows took longer to maximize IPAR by the canopy. This may indicate a higher proportion of evaporation from the soil surface as a fraction of cumulative evapotranspiration in wider rows. High total dry matter thus requires agronomic techniques that produce both a high level of radiation interception and a high rate of conversion of intercepted light to grain.

Narrow rows improve the performance of sorghum through maximizing the capture of incoming solar radiation. In dryland conditions, the management of soil water depletion is more critical than the capture of radiation, which is more abundant than water (Staggenborg et al., 1999). Narrow row spacing increased dry matter production and production of dry matter per unit evapotranspiration, and increased light interception per unit of evapotranspiration (ET), indicating increased partitioning of ET into the transpiration component.

2.5.3 Yield and Related Traits

The taller plants observed with May planting during these experiments can be related to optimum temperature and better moisture regime in May. During this period, plant vegetative growth was slower and longer. In comparison, with June planting, the height of plants decreased. These plants lost the opportunity to produce and store photosynthetically fixed carbon. Hocking and Stapper (2001) and Miralles et al. (2001) consider shortening of vegetative growth as a factor in reduced plant height in later planting. It seems that with early planting more tillers and panicles were produced due to longer vegetative period.

May planting provides the sorghum plant with enough opportunity for vegetative and reproductive growth. In comparison June planting can be influenced by late season drought and temperature stress. In these studies May planting corresponded with more optimum temperatures and better conditions for sorghum to produce a higher number of grains per panicle. Reduced number of grains per panicle with June planting can be attributed to the shortened vegetative growth period and lower amount of carbohydrate available to translocate to grain. Delay in planting also results in shortening the filling period of grain.

The decrease in length of grain filling has a negative effect on grain weight, which is due to less accumulation of fixed carbon and reduction in the amount of carbohydrate delivered to grain. Miralles et al. (2001) found that delayed planting reduces the growth period and as a result the supply of photosynthetically fixed carbon. At Hutchinson, higher grain yield in the latter planting date at wider row spacing is due to higher plant height, weight of grain, the number of panicle in plant, biological performance and its harvest index due to drought and high temperature during the early part of the growing season. In good environmental conditions vegetative growth and plant yield are a function of thermal conditions during different stages of growth, particularly yield which is a function of thermal condition during grain fill, affecting fixed carbon delivered to grain. The optimal conditions associated with May planting date were suitable for vegetative growth. In addition to reduced vegetative growth due to unfavorable environment conditions associated with June planting, grain fill was reduced due to low temperature at the end of growth season. Horn and Burnside (2001) indicated that grain weight decreases with delay in planting date. The reason for this decrease in weight is low moisture during the late part of growing season.

The 300-grain weight depends on the amount of carbohydrate available during grain filling. Studies by other researchers also indicated lower grain yield to delay in planting date (Johnson et al., 1995). Reduction of canopy size and shortened growth periods are among most important reasons for low grain yield in delayed planting dates (Hocking and Stapper., 2001).

High harvest index (HI) for early planting date was due to the plant taking advantage of environment factors and use of resources during key growth periods. Due to longer vegetative period, plants stored more photosynthetic substances and supplied the grains with those substances. Higher HI in narrow row spacing indicates that more consistent distribution of plants allowed plants to allocate more resources to grain.

In most crops, water use efficiency for grain is not due to an improvement in biomass, but, it is due to almost entirely to an improve HI. Yadav et al. (1999) in an experiment with pearl millet under drought stress indicated that a 50% seed yield reduction was related to HI decline. Water stress also had a negative effect on HI.

Increase in height is result of reduced row spacing and increasing length of internodes due to increased gibberellin hormone production in low light conditions. Morrison and Stewart (1995) indicated that plants increased internodes length by stimulating the apical meristem and increasing plant height to reach light.

With increased density, plants have limitations for lateral expansion and as a result, the number of lateral branches decreases. With narrow rows, the spaces between plants within a row were increased. Therefore, in narrow rows, more radiant energy is received. More received light increased the number of lateral tillers and the number of panicles per plant. Increased numbers of panicles per plant in narrow row spacing was reported by Morrison et al. (1997) in wheat. Morrison et al. (1990) reported that simmer rape plants sown at narrow row spacing showed higher grain yield compared to with wide row. Johnson and Hanson (2003) reported that the higher grain yield in narrow row compared to wide row in canola is a result of consistent distribution of plants that results in better distribution of solar radiation into the plant canopy. Consequently it reduces intra-species competition.

In narrow rows (25 cm) due to more heads per plant, plants can utilize sunlight more efficiency to increase grain yield. More consistent distribution of plants in narrower rows causes better distribution of light and lower evaporation. High photosynthesis results in higher yields. Rosenthal et al. (1993) reported that the absorbed radiation per unit increases with plant density.

Narrow row spacing in favorable conditions normally decreased evaporation from the soil surface and inhibited weed growth (Forcella et al., 1998; Teasdale, 1994).

The lower grain yield reported for 75 cm row spacing often was due to fewer panicles and grain number per panicle. These results were consistent with results reported with safflower by Naseri et al. (2010) and Patel et al. (1994) who indicated that narrow row spacing had the maximum grain yield.

It is interesting to note that sorghum seeding rate affected sorghum yield components in our studies. This result is in agreement with the finding of M'Khaitir and Vanderlip (1992). At low populations sorghum plants produce more and larger panicles than at high populations. In the present studies, at all locations sorghum plants produced more panicles at low populations with decreasing intra-row spacing.

In unfavorable conditions like drought and high temperature, at higher population the plants were mutually shaded and tended to elongate, creating a greater competition for photo assimilates between the growing panicle and the elongating stem. This results in smaller panicle forming on the main stem which in turn results in less grain yield per plant and thereafter less grain yield per hectare. In these studies narrow rows had the maximum biological yield due to consistent distribution of plants. The reduced biological yield at 75 cm can be attributed to competition among plants, limitations in available moisture and soil nutrients. Morrison and Stewart (1995) stated that radiation received in wide rows is reduced compared to spacial distribution of plants that allowed more light into plant canopy in narrow rows. As a result more dry matter was produced. Biological yield was influenced by the interaction of planting date and row spacing, but the response depended on location.

Yield component studies with grain sorghum have indicated that the number of panicles per square meter to be a yield component associated with yield changes from non-uniform stand reductions (Larson and Vanderlip, 1994). Studies have shown the number of panicles per plant to be the yield component most associated with yield changes with plant population but because of profuse tillering the number of panicles per square meter decreased (van Oostrom et al., 2002) or remained nearly constant (M'Khaitir and Vanderlip,1992) with increasing plant population.

2.6 Conclusions

Grain sorghum establishment, plant growth and yield were highly depending on date of planting. The earliest possible planting resulted in better soil moisture levels, less exposure to damaging high temperatures that occur in late summer and less risk of damage and yield loss.

Later plantings can be exposed to warmer temperatures and resulted in lower yields. However this depends on the maturity duration of genotypes. Growth and yield response to row configurations varied between years. Leaf area index seemed to be highest with more equidistant plant spacing. Dry matter production and yield in 2011, the driest year, were greater for the wider row, while in 2010 and 2009 narrower rows produced higher dry matter and yield.

The morphological differences between hybrids selected in the study did not influence the response to variations in the different parameter measured. Plant spacing and plant density had a consistent effect on yield of sorghum. These responses emphasize the importance of intraspecific competition in the expression of yield components of sorghum. Seeding rate can be reduced due to the compensation ability of the grain sorghum crop without yield loss, especially with early planting.

Plants compete for sunlight and water. Increasing seeding rate means fewer resources per plant, decreased number of panicles per plant, and number of grains per panicle. Populations below some minimum will certainly result in yield reductions. In these studies, seeding rate of 80000 to 110000 seeds ha^{-1} were required to maximize yield in nearly and late planting respectively. The minimum population necessary to obtain maximum yields will also probably vary annually with differences in water available due to differences in rainfall.

2.7 Recommendation

- Planting sorghum under good conditions to attain a final plant population of 80000 should be the goal when planting for the highest yields under dry-land farming system in 25 cm apart and in early planting (May).
- If planting is delayed (June) 110000 or more seeds ha^{-1} should be recommended.
- In dry conditions where water will be more limiting than light, planting fewer seeds ha^{-1} in wider rows (75 cm) will maximize yield.

2.8 Tables and Figures

Figure 2.1. Daily maximum and minimum mean air temperatures and rainfall from May to October 2009 and 2010 at Manhattan, KS.

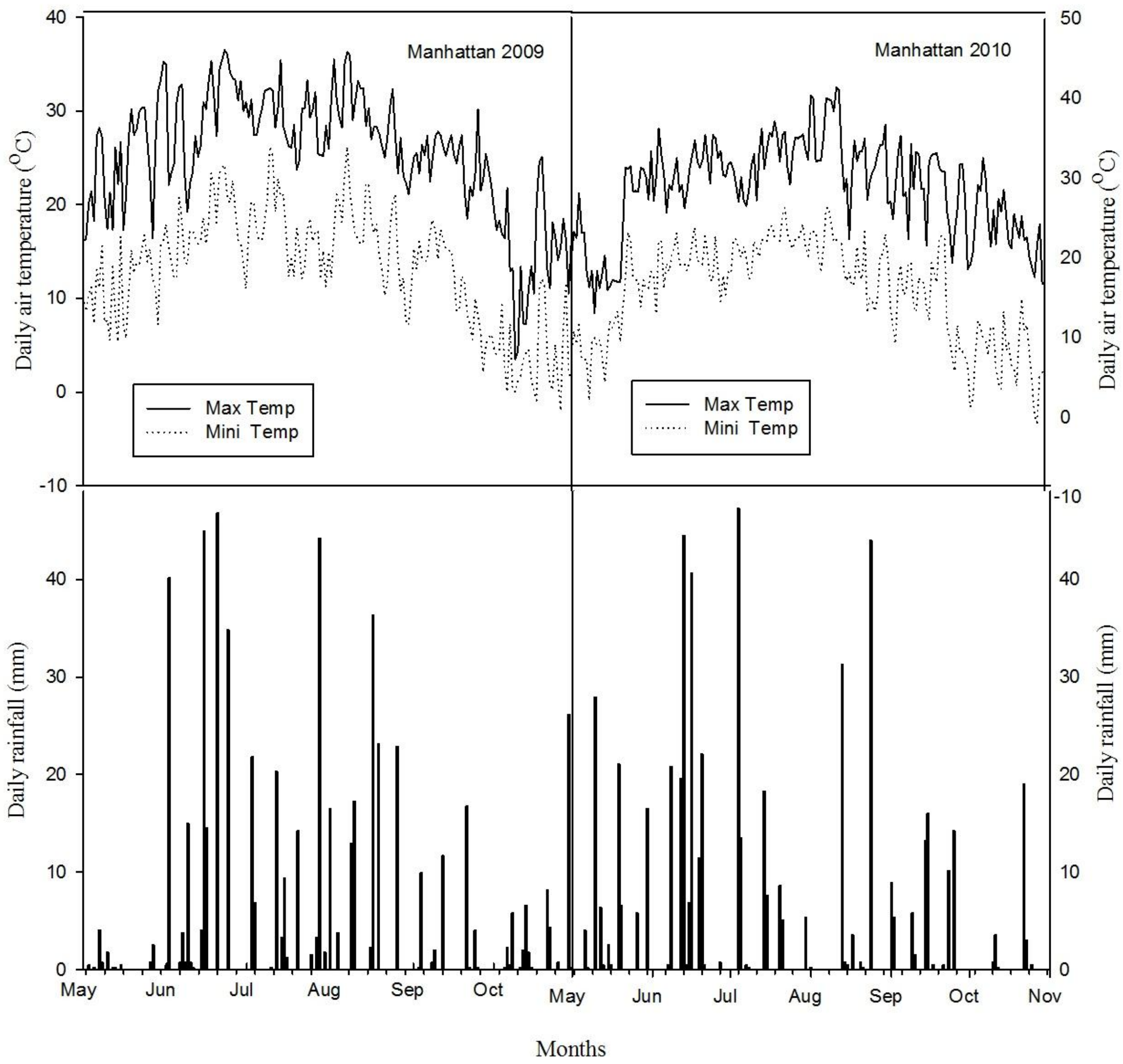

Figure 2.2. Daily maximum and minimum mean air temperatures and rainfall from May to October 2011 at Manhattan, KS.

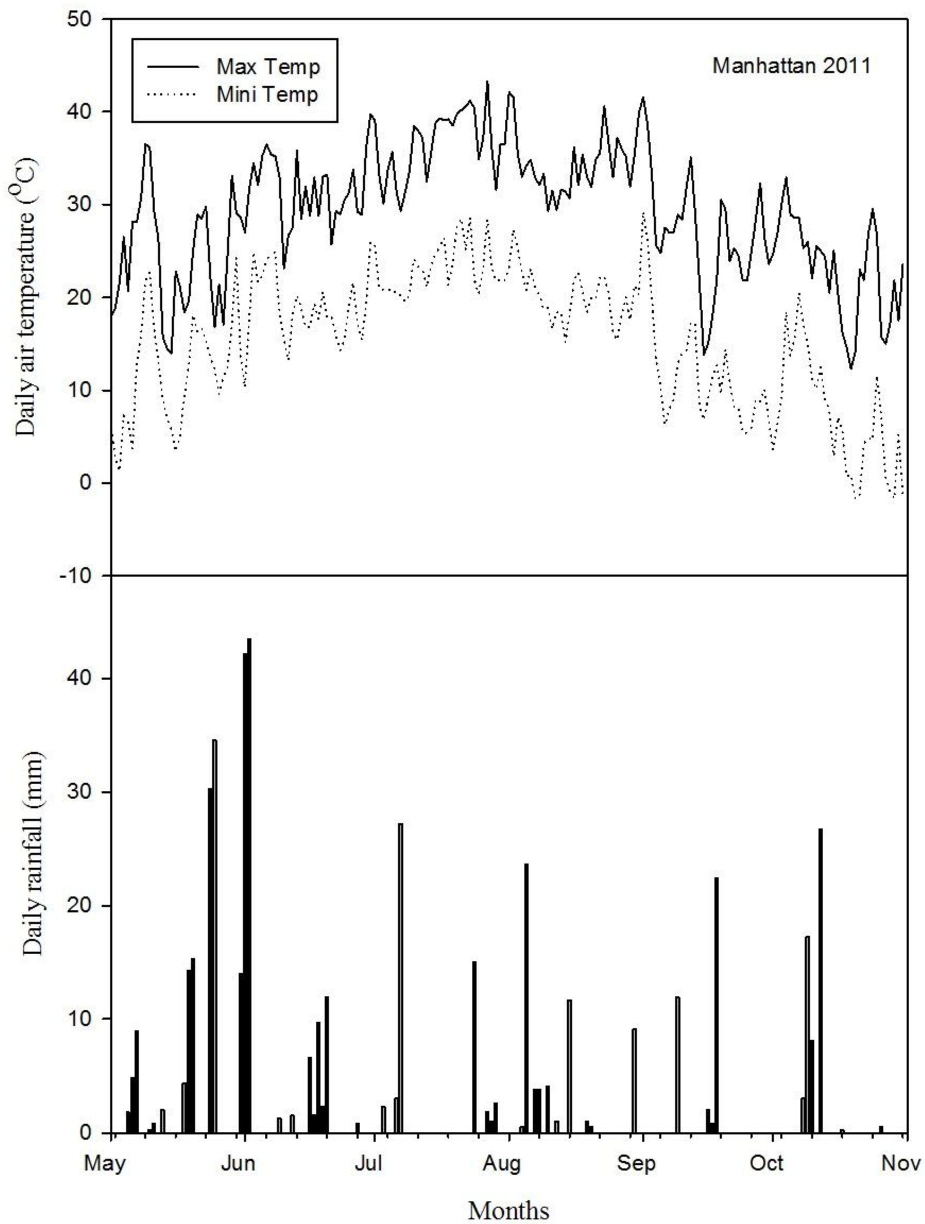

Figure 2.3. Daily maximum and minimum mean air temperatures and rainfall from May to October 2010 and 2011 Ottawa, KS.

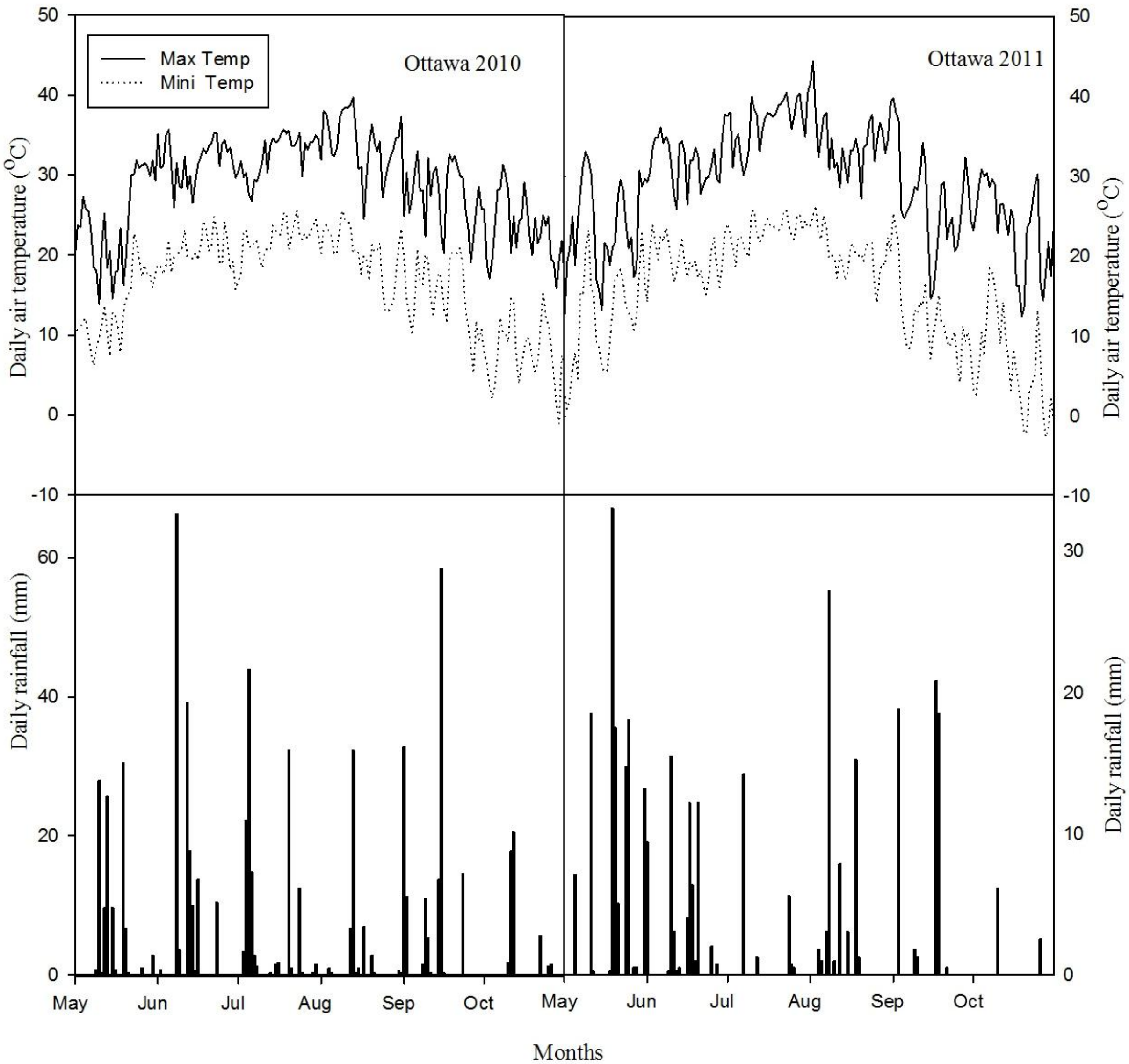

Figure 2.4. Daily maximum and minimum mean air temperatures and rainfall from May to October 2009 and 2010 at Hutchinson, KS.

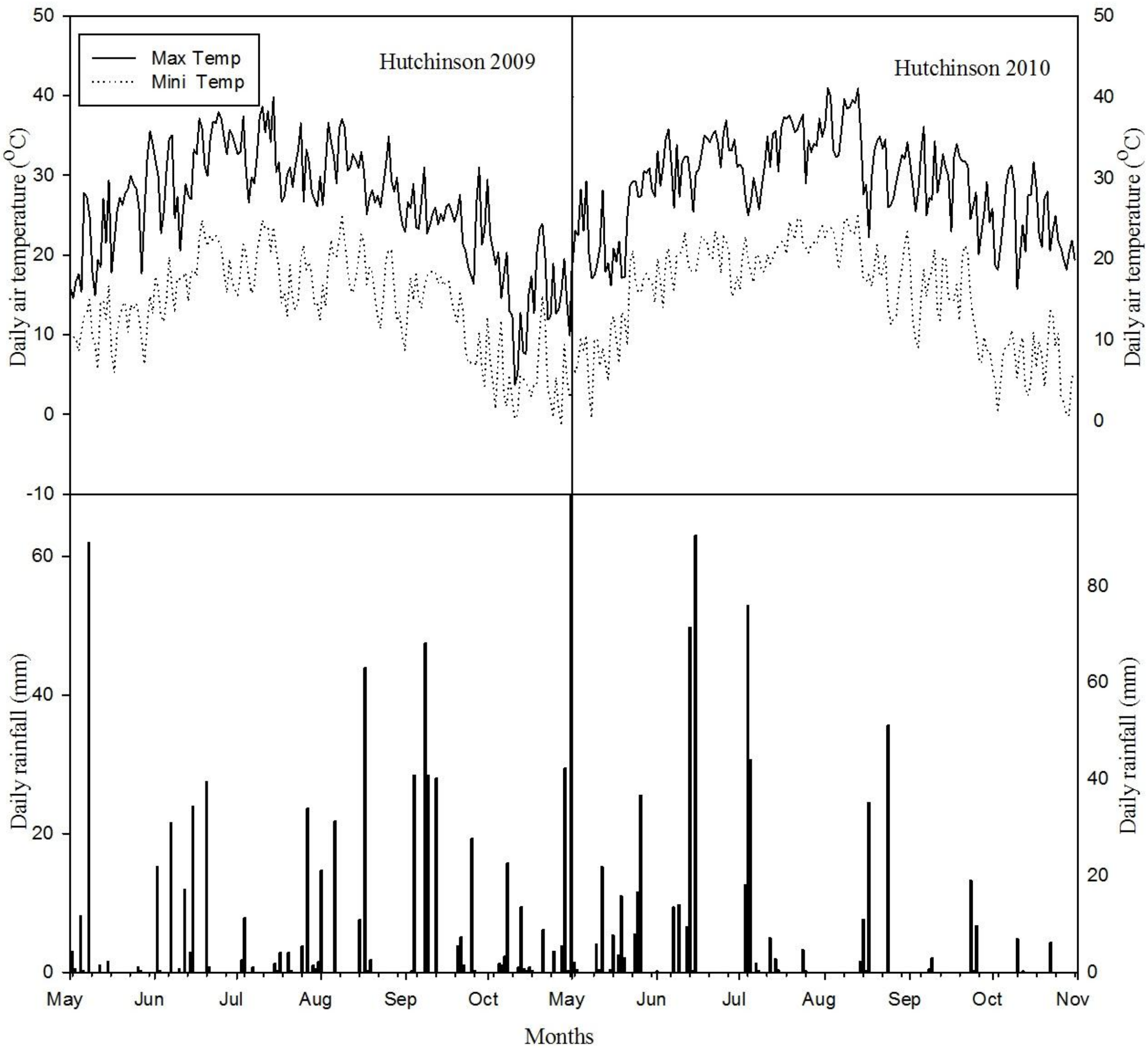

Figure 2.5. Daily maximum and minimum mean air temperatures and rainfall from May to October 2009 and 2010 at Belleville

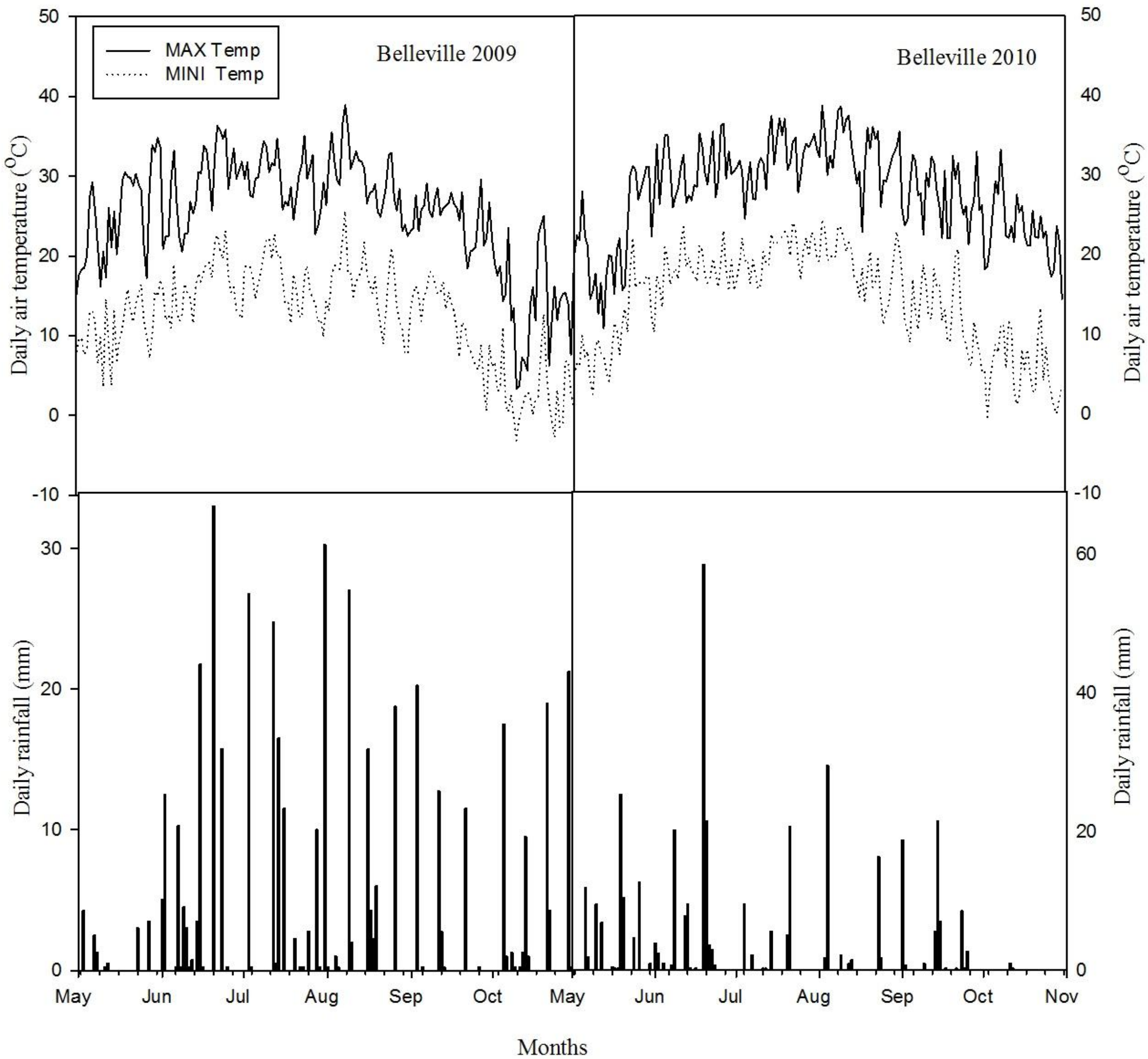

Figure 2.6. Effects of planting date and row spacing on total dry weight of sorghum at different sample date at Manhattan, Hutchinson, Belleville and Ottawa in 2010.

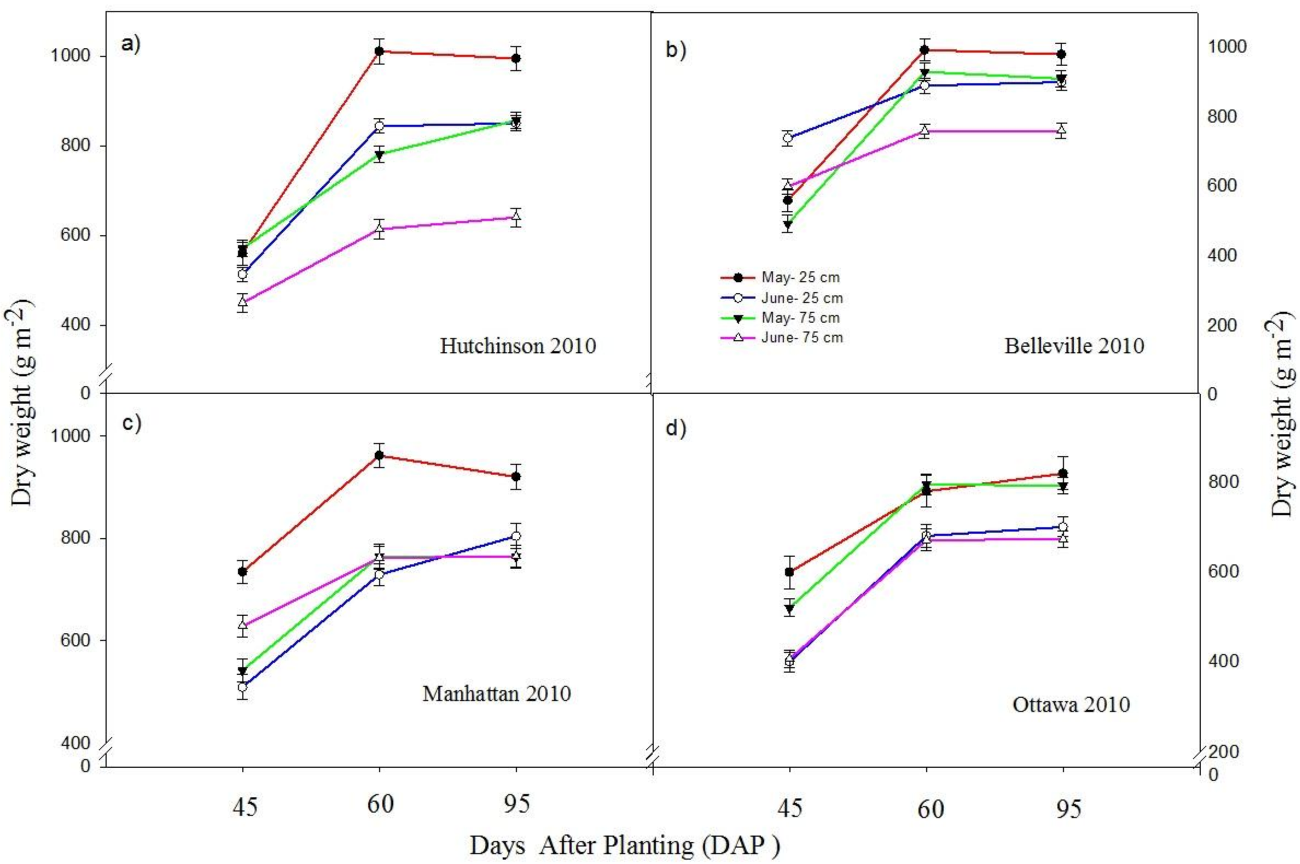

Figure 2.7. Effects of planting date and seeding rate on grain yield at Ottawa in 2010.

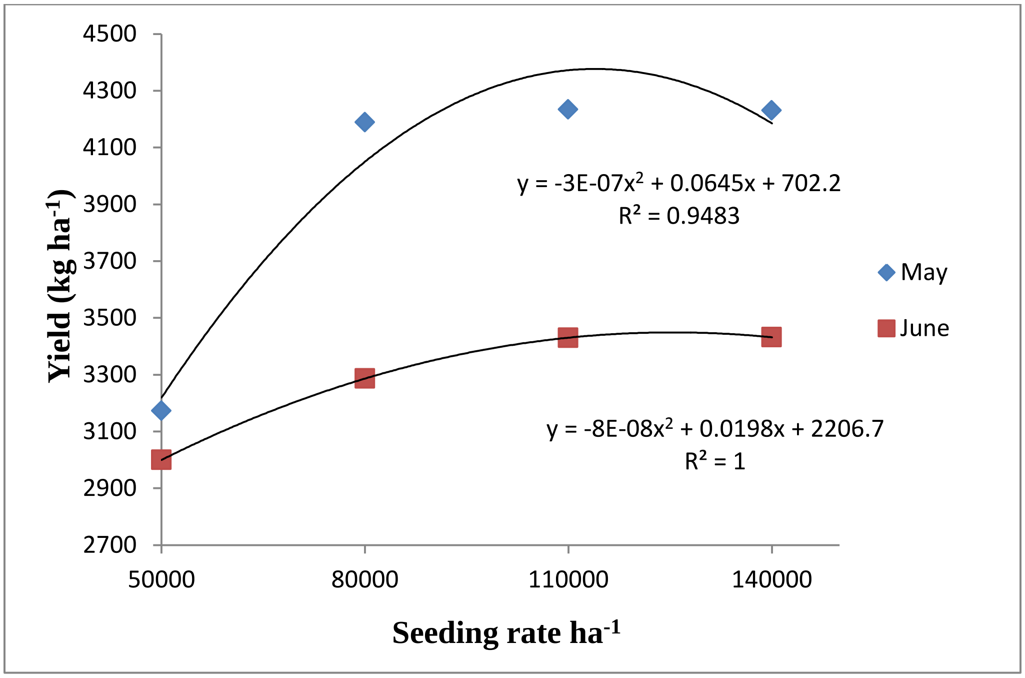

Figure 2.8. Effects of planting date and seeding rate on grain yield at Belleville in 2010.

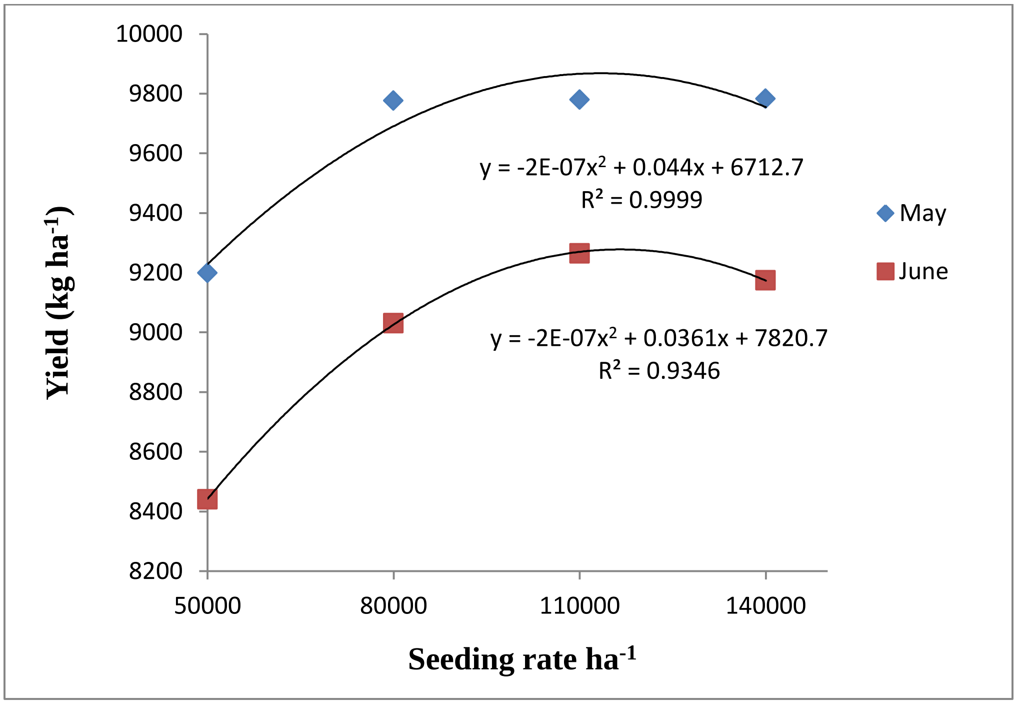

Figure 2.9. Effects of planting date and seeding rate on grain yield at Manhattan in 2010.

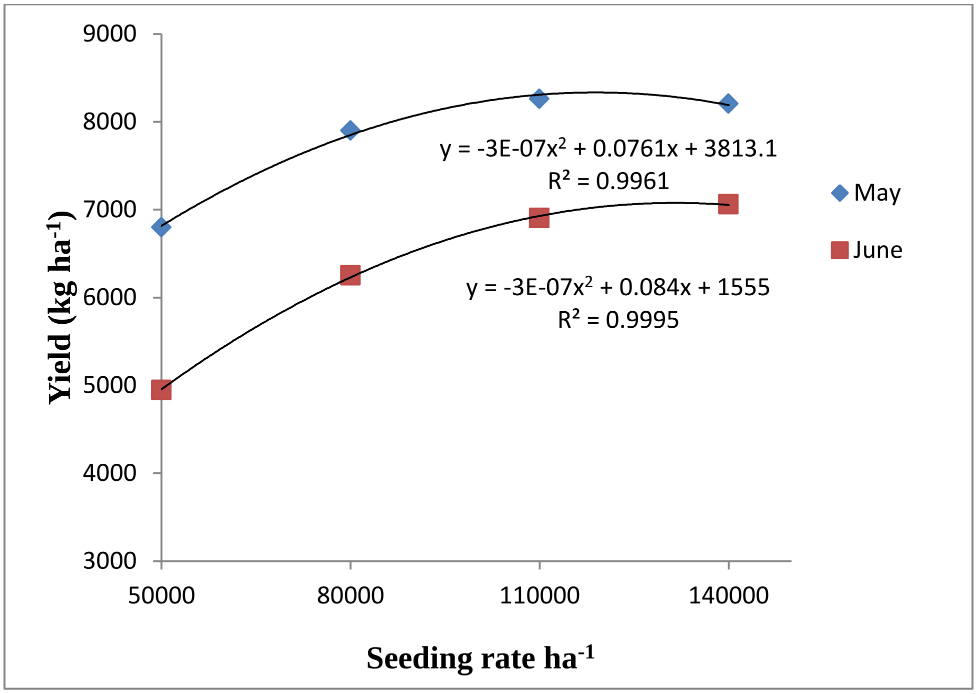

Figure 2.10. Effects of planting date and seeding rate on grain yield at Hutchinson in 2010.

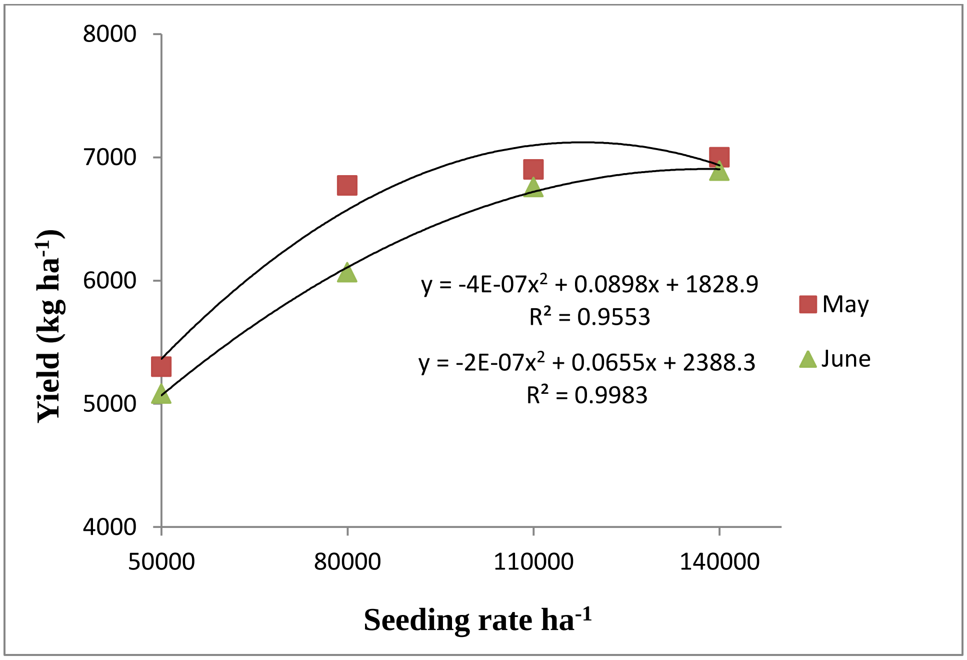

Figure 2.11. Effects of row spacing and plant population on grain yield at Ottawa in 2010.

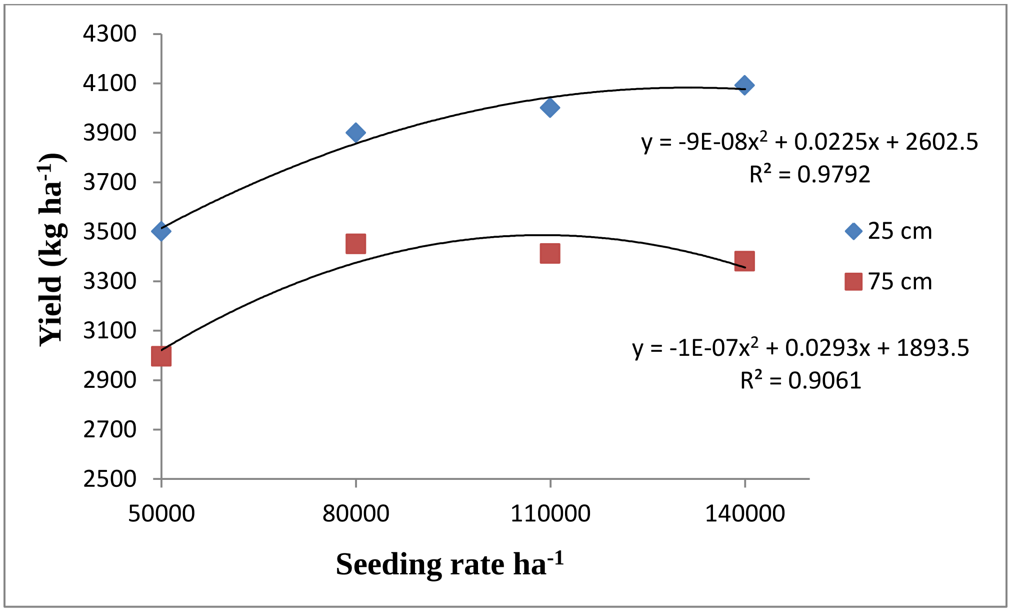

Figure 2.12. Effects of row spacing and plant population on grain yield at Belleville in 2010.

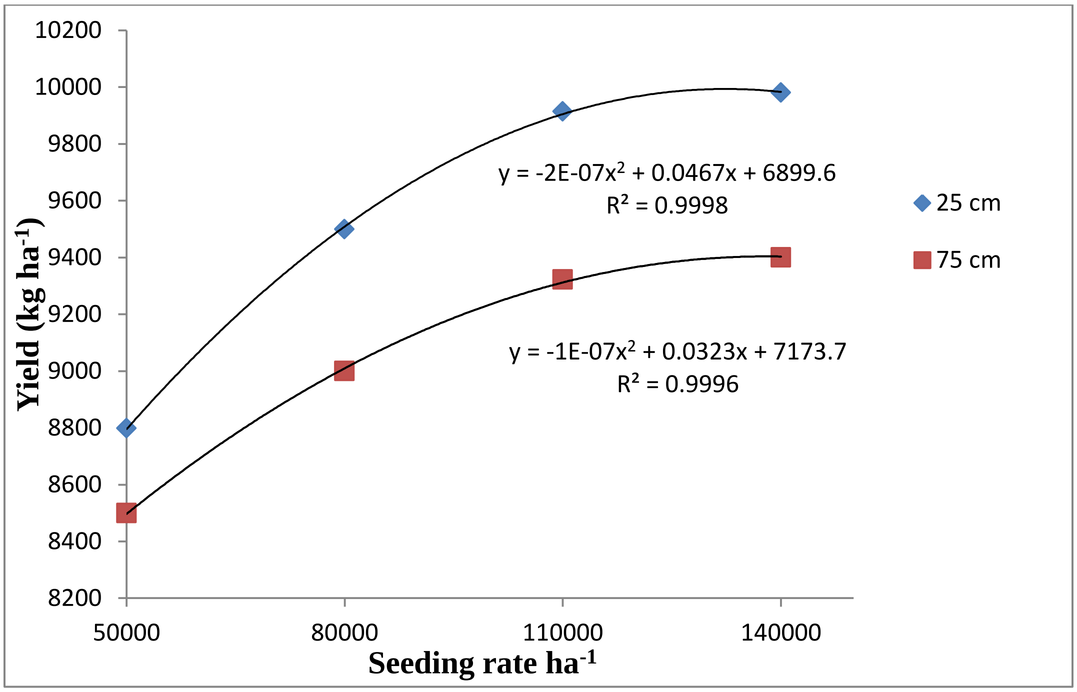

Figure 2.13. Effects of row spacing and plant population on grain yield at Hutchinson in 2010.

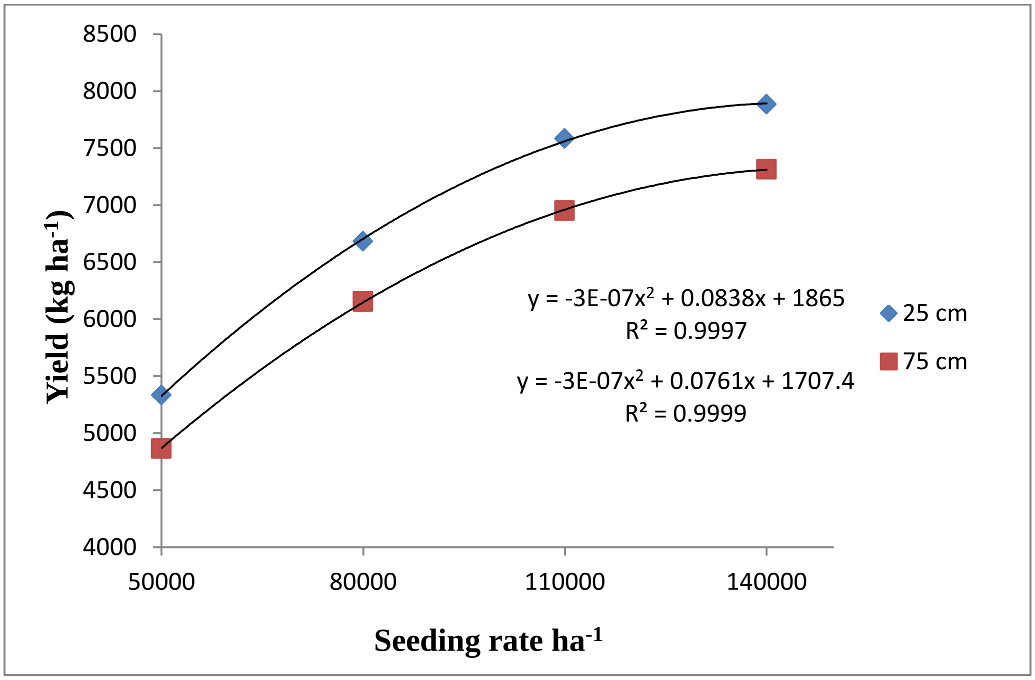

Figure 2.14. Effects of row spacing and plant population on grain yield at Manhattan in 2010.

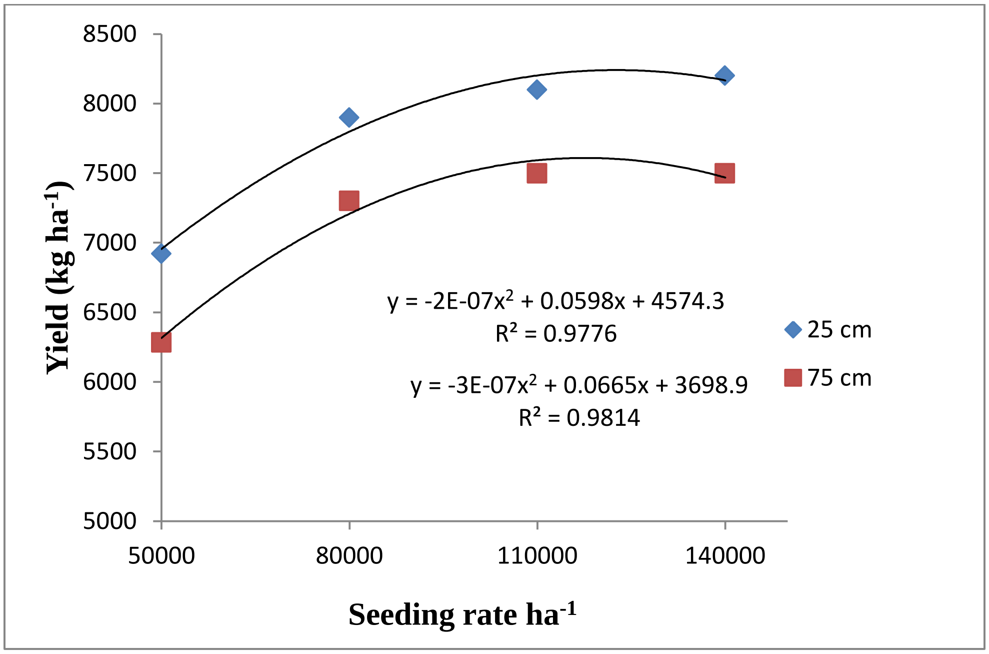

Table 2.1. Analysis of variance for dry weight, light interception and leaf area at Manhattan in 2010.

Treatments	TDW (g m^{-2})			LAI			IPAR (%)		
	45†	60	95	45	60	95	45	60	95
Planting date (DATE)	***	***	***	***	***	***	***	***	***
Maturity group (MAT)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing (RS)	***	***	***	***	***	***	***	***	***
Seeding rate (SR)	*	*	*	*	*	*	*	*	*
DATE*MAT	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS	***	***	***	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS, Non-significant.

†Days after planting (DAP), Total Dry Weight (TDW), Leaf Area Index (LAI), Intercepted Phytosynthetically Active Radiation (IPAR).

Table 2.2. Means comparisons for crop growth and light interception as affected by planting date, maturity, row spacing and plant population at Manhattan in 2010.

	TDW (gm^{-2})			LAI			IPAR (%)		
Treatments	45†	60	95	45	60	95	45	60	95
Planting Date									
May	638.4 a	845.0 a	1048.7 a	3.4 a	3.5 a	3.2 a	88 a	88 a	92 a
June	569.9 b	702.4 b	848.9 b	2.6 b	2.6 b	2.5 b	87 b	86 b	88 b
Maturity Group									
ME-DKS 44-20	607.3 a	780.7 a	960.3 a	2.8a	2.7 a	2.8a	91a	87a	90 a
ML-DKS 54-00	600.1 a	766.8 a	957.3 a	2.6 a	2.8 a	3.0a	90.a	87a	89 a
Row Spacing									
25 cm	682.0 a	802.0 a	991.5 a	3.5 a	3.4 a	3.3 a	88 a	90 a	91 a
75 cm	585.5 b	745.5 b	906.1 b	1.9 b	2.1 b	2.5 b	87 b	84 b	89 b
Seeding Rate									
50000	502.7 c	672.7 c	825.5 d	2.6 b c	2.6 b	2.6 b	82 d	82 d	83 d
80000	607.9 b	777.9 b	930.2 c	2.5 c	2.8 ba	2.7 ba	86 c	83 c	88 c
110000	630.7 a	800.8 ba	979.0 b	3.0 a	2.7 ba	2.8 ba	88 b	88 b	92 b
140000	673.5 a	843.5 a	1060.7 a	2.8 ab	2.9 a	2.9 a	93 a	95 a	96 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

†Days after planting.

Table 2.3. Analysis of variance for dry weight, light interception and leaf area at Manhattan in 2011.

Treatments	TDW (g m^{-2})			LAI			IPAR (%)		
	45[†]	60	95	45	60	95	45	60	95
Planting date (DATE)	***	***	***	NS	NS	NS	***	***	***
Maturity group (MAT)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing (RS)	***	***	***	***	***	***	***	***	***
Seeding rate (SR)	*	*	*	NS	NS	NS	*	*	*
DATE*MAT	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

[†]Days after planting (DAP), Total Dry Weight (TDW), Leaf Area Index (LAI), Intercepted Photosynthetically Active Radiation (IPAR).

Table 2.4. Means comparisons for crop growth and light interception as affected by planting date, maturity, row spacing and plant population at Manhattan in 2011.

	TDW (g m^{-2})			LAI			IPAR (%)		
Treatments	45†	60	95	45	60	95	45	60	95
Planting Date									
May	907.9 a	1360.5 a	2430.9 a	3.5 a	3.0 a	2.5 a	74 a	54 a	70 a
June	640.4 b	918.7 b	2064.2 b	2.9 b	2.4 b	2.4 a	69 b	50 b	66 b
Maturity Group									
ME-DKS 44-20	794.1 a	1176.8 a	2329.4 a	3.1 a	2.5 a	2.5 a	73 a	54 a	70 a
ML-DKS 54-00	754.1 a	1102.5 a	2165.8 a	2.8 a	2.4 a	2.4 a	71 a	51 a	66 b
Row Spacing									
25 cm	826.1 a	1236.4 a	2372.0 a	2.1 b	1.8 b	1.7 b	80 a	56 a	70 a
75 cm	722.2 b	1042.9 b	2123.2 b	3.8 a	3.1 a	3.2 a	72 b	49 b	66 b
Seeding Rate									
50000	547.5 d	802.9 d	1593.9 c	2.9 a	2.4 a	2.6 a	66 c	47 c	60 c
80000	638.0 c	937.0 c	1899.5 b	2.9 a	2.4 a	2.4 a	72 b	53 b	68 b
110000	910.5 b	1332.8 b	2632.0 a	3.0 a	2.5 a	2.4 a	69 cb	49 c	70 b
140000	1000.4 a	1485.8 a	2865.0 a	3.1 a	2.4 a	2.5 a	80 a	61 a	74 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

†Days after planting (DAP).

Table 2.5. Analysis of variance for dry weight, light interception and leaf area at Belleville in 2010.

Treatments	TDW (g m^{-2})			LAI			IPAR (%)		
	45[†]	60	95	45	60	95	45	60	95
Planting date (DATE)	***	***	***	***	***	***	***	***	***
Maturity group (MAT)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing (RS)	***	***	***	***	***	***	***	***	***
Seeding rate (SR)	***	***	***	NS	NS	NS	*	*	*
DATE*MAT	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS	***	***	***	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant. [†]Days after planting (DAP).

Total Dry Weight (TDW), Leaf Area Index (LAI), Intercepted Phytosynthecally Active Radiation (IPAR).

Table 2.6. Means comparisons for crop growth and light interception as affected by planting date, maturity, row spacing and plant population at Belleville in 2010.

Treatments	TDW (g m^{-2})			LAI			IPAR (%)		
	45[†]	60	95	45	60	95	45	60	95
Planting Date									
May	661.0 a	836.8 a	1120.0 a	2.7 a	3.0 a	3.1 a	87 a	89 a	90 a
June	587.3 b	786.3 b	990.8 b	2.4 b	2.8 b	2.5 b	84 b	87 b	89 b
Maturity Group									
ME-DKS 44-20	639.3 a	814.2 a	1013.0 a	2.5 a	2.6 a	2.5a	87 a	87 a	90 a
ML-DKS 54-00	609.0 a	809.0 a	998.8a	2.6 a	2.7 a	2.6a	86 a	86 a	89 a
Row Spacing									
25 cm	679.8 a	833.4 a	1028.3 a	3.5 a	3.5 a	3.3 a	87 a	86 a	90 a
75 cm	568.4 b	689.7 b	983.5 b	1.6 b	1.8 a	1.8 b	85 b	85 b	88 b
Seeding Rate									
50000	462.5 d	847.2 c	918.7 c	2.5 a	2.7 a	2.4 a	77 d	78 d	86 d
80000	607.5 c	725.7 b	993.9 b	2.6 a	2.7 a	2.5 a	85 c	86 c	86 c
110000	673.5 b	847.2 a	985.8 b	2.5 a	2.6 a	2.4 a	88 b	89 b	92 b
140000	735.0 a	905.4 a	1125.2 a	2.5 a	2.7 a	2.5 a	93 a	93 a	93 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level. [†]Days after planting (DAP).

Table 2.7. Analysis of variance for dry weight, light interception and leaf area at Ottawa in 2010**.**

	TDW (g m^{-2})			LAI			IPAR (%)		
Treatments	45[†]	60	95	45	60	95	45	60	95
Planting date (DATE)	***	***	***	*	**	***	***	***	***
Maturity group (MAT)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing (RS)	***	***	***	***	***	***	***	***	***
Seeding rate (SR)	***	***	***	**	***	***	**	**	**
DATE*MAT	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS	***	***	***	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

[†]Days after planting (DAP), Total Dry Weight (TDW), Leaf Area Index (LAI), Intercepted Phytosynthecally Active Radiation (IPAR).

Table 2.8. Means comparisons for crop growth and light interception as affected by planting date, maturity, row spacing and plant population at Ottawa in 2010.

Treatments	TDW(gm^{-2})			LAI			IPAR (%)		
	45[†]	60	95	45	60	95	45	60	95
Planting Date									
May	695.7 a	779.1 a	877.9 a	3.1 a	2.9 a	3.0 a	88 a	89 a	88 a
June	614.5 b	712.5 b	782.3 b	2.7 b	2.7 b	2. b	87 b	88 b	83 b
Maturity Group									
ME-DKS 44-20	667.3 a	748.8 a	837.6 a	2.9 a	3.0 a	2.9 a	88a	89a	86 a
ML-DKS 54-00	657.7 a	741.0 a	822.6 a	2.8 a	2.7 a	2.8 a	87a	88a	85 a
Row Spacing									
25 cm	689.7 a	820.8 a	926.4 a	3.5 a	3.5 a	3.4 a	88 a	90 a	86 a
75 cm	621.2 b	671.7 b	733.8 b	2.3 b	2.3 b	2.2 b	87 b	89 b	85 b
Seeding Rate									
50000	462.0 d	589.0 d	677.8 d	2.8 ab	2.5 c	2.8 b	74 c	67 c	78 d
80000	581.9 c	661.3 c	789.3 c	2.8 b	2.8 b	2.8 b	89 b	90 b	85 c
110000	609.2 b	743.3 b	876.1 b	2.9 ab	2.9 ab	2.9 ab	90 b	91 b	88 b
140000	952.7 a	950.9 a	977.3 a	3.0 a	3.1 a	3.0 a	97 a	98 a	93 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level. [†]Days after planting (DAP).

Table 2.9. Analysis of variance for dry weight, light interception and leaf area at Ottawa in 2011.

	TDW (gm^{-2})			LAI			IPAR (%)		
Treatments	45†	60	95	45	60	95	45	60	95
Planting date (DATE)	NS	NS	NS	NS	NS	NS	***	***	NS
Maturity group (MAT)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing (RS)	***	***	***	***	***	***	***	***	***
Seeding rate (SR)	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*MAT	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

†Days after planting (DAP), Total Dry Weight (TDW), Leaf Area Index (LAI), Intercepted Phytosynthecally Active Radiation (IPAR).

Table 2.10. Means comparisons for crop growth and light interception as affected by planting date, maturity, row spacing and plant population at Ottawa in 2011.

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	TDW (g m^{-2})			LAI			IPAR (%)		
Treatments	45†	60	95	45	60	95	45	60	95
Planting Date									
May	483.6 a	2066.3 a	3265.2 a	2.5 a	2.6 a	2.2 a	63 a	64 a	43 a
June	461.6 a	1646.6 a	2713.6 a	2.4a	2.5 a	2.1 a	50 b	59 b	44 a
Maturity Group									
ME-DKS 44-20	487.6 a	1793.3 a	2816.9 a	2.5 a	2.4 a	2.2 a	58 a	61 a	43 a
ML-DKS 54-00	457.6 a	1919.6 a	3161.9 a	2.4 a	2.5 a	2.1 a	55 a	63 a	44 a
Row Spacing									
25 cm	637.3 a	973.8 a	4449.2 a	3.1 a	3.2 ab	2.6 a	60 a	64 a	44 a
75 cm	308.0 b	273.9 b	1529.6 b	1.8 b	1.8 b	1.7 b	53 b	60 b	43 b
Planting Rate									
50000	469.5 a	1779.2a	3446.5 a	2.3 a	2.4 a	2.2 a	55 a	61 a	42 a
80000	469.6 a	1797.9 a	2969.5 a	2.5 a	2.5 a	2.3 a	58 a	61 a	45 a
110000	499.8 a	2103.0 a	2761.4 a	2.4 a	2.6 a	2.2 a	57 a	61 a	43 a
140000	451.6 a	1745.8 a	2780.1 a	2.5 a	2.5 a	2.2 a	57 a	63 a	43 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level. †Days after planting (DAP).

Table 2.11. Analysis of variance for dry weight, light interception and leaf area at Hutchinson in 2010.

Treatments	TDW (gm^{-2})			LAI			IPAR (%)		
	45[†]	60	95	45	60	95	45	60	95
Planting date (DATE)	***	***	***	***	***	***	***	***	***
Maturity group (MAT)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row spacing (RS)	***	***	***	***	***	***	***	***	***
Seeding rate (SR)	***	***	***	***	***	***	*	*	*
DATE*MAT	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS	***	***	***	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS, Non-significant.

[†]Days after planting (DAP), Total Dry Weight (TDW), Leaf Area Index (LAI), Intercepted Phytosynthecally Active Radiation (IPAR).

Table 2.12. Means comparisons for crop growth and light interception as affected by planting date, maturity, row spacing and plant population at Hutchinson in 2010.

	TDW (gm^{-2})			LAI			IPAR (%)		
Treatments	45†	60	95	45	60	95	45	60	95
Planting Date									
May	609.6 a	877.1 a	966.2 a	2.9 a	2.9 a	2.7 a	87 a	87 a	86 a
June	573.0 b	653.6 b	930.6 b	2.7 b	2.7 b	2.6 b	85 b	86 b	85 b
Maturity Group									
ME-DKS 44-20	666.0 a	768.7 a	1104.4 a	2.8 a	2.7 a	2.6 a	87 a	88 a	87 a
ML-DKS 54-00	659.9 a	762.1 a	1099.4 a	2.8 a	2.8 a	2.6 a	87 a	87 a	87 a
Row Spacing									
25 cm	621.8 a	804.4 a	1028.1 a	3.7 a	3.6 a	3.2 a	87 a	88 a	87 a
75 cm	560.8 b	726.4 b	883.7 b	2.1 b	2.1 b	1.8 b	86 b	86 b	85 b
Seeding Rate									
50000	500.9 d	695.2 c	885.0 a	2.6 b	2.7 c	2.5 b	79 d	81 d	80 d
80000	562.8 c	766.0 b	950.6 b	2.7 b	2.8 ba	2.7 b	84 c	85 c	85 c
110000	620.4 b	769.4 b	978.1 a	2.7 b a	2.9 a	2.7 b	87 b	88 b	88 b
140000	681.2 a	830.9 a	1010.0 a	2.9 a	2.9 a	2.9 a	93 a	93 a	94 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level. †Days after planting (DAP).

Table 2.13. Analysis of variance for measured parameters at Manhattan in 2009.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	***	***	***	***	***	***
Maturity group (MAT)	***	NS	***	NS	NS	NS	NS
Row spacing (RS)	**	***	**	**	**	**	***
Seeding rate (SR)	***	***	***	**	***	***	***
DATE*MAT	NS	NS	*	*	NS	***	NS
MAT*RS	**	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	*	NS	NS	***	NS
DATE*RS	NS	*	**	NS	***	NS	**
DATE*SR	**	*	NS	NS	***	***	**
RS*SR	***	*	**	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

Table 2.14. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and plant population at Manhattan in 2009.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	154 a	1.7 a	2240 a	8.5 a	9922 a	25947 a	40 a
June	151 b	1.3 b	1622 b	8.3 b	8024 b	24872 b	33 b
Maturity Group							
ME-DKS 44-20	157 a	1.4 a	1913 a	8.3 a	8994 a	25379 a	36 a
ML-DKS 54-00	148 b	1.5 a	1869 b	8.3 a	8952 a	2444 a	37 a
Row Spacing							
25cm	152 a	1.5 a	1997 a	8.4 a	9163 a	25559 a	38 a
75 cm	153 a	1.4 a	1866 b	8.5 a	8783 b	24260 b	35 b
Seeding Rate							
50000	145 c	2.4 a	2547 a	8.6 a	8406 b	23358 b	36 b
80000	153b	1.3 b	2002 b	8.4 ab	9265 a	24556 b	38 a
110000	155 b	1.2 c	1770 c	8.4 ab	9295 a	24621 b	39 a
140000	158 a	0.9 c	1406 d	8.3 b	8925 a	27103 a	33 c

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.15. Analysis of variance for measured parameters at Manhattan in 2010.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	**	*	***	***	***	***
Maturity group (MAT)	*	*	**	NS	NS	NS	NS
Row spacing (RS)	*	*	*	**	***	**	*
Seeding rate (SR)	***	***	***	**	*	***	***
DATE*MAT	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS		NS	NS	NS	NS
DATE*RS	NS	*	*	NS	***	***	***
DATE*SR	NS	NS	NS	NS	***	***	***
RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

Table 2.16. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Manhattan in 2010.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	142 a	2.2 a	1983 a	8.6 a	7752 a	23668 a	34 a
June	125 b	1.7 b	1800 b	6.9 b	5910 b	19669 b	31 b
Maturity Group							
ME-DKS 44-20	153 a	2.2 a	2087 a	8.4 a	6833 a	21835 a	32 a
ML-DKS 54-00	133 b	1.7 b	1785 b	8.2 a	6829 a	21503 a	33 a
Row Spacing							
25cm	140 a	2.2 a	1985a	9.1 a	7285 a	22477 a	34 a
75 cm	134 b	1.7 b	1801 b	7.0 b	6377 b	20860 b	31 b
Seeding Rate							
50000	130 c	2.8 a	2269 a	7.4 b	6376 b	16981 d	37 a
80000	133 b	2.3 b	1928 b	9.2 a	6799b a	21393c	32 b
110000	136 a	1.3 c	1813 b	7.4 b	6951 a	22822 b	31 b
140000	137 a	1.3 c	1733 b	7.2 b	7199 a	25478 a	29 b

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.17. Analysis of variance for measured parameters at Manhattan in 2011.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	***	**	*	***	***	***
Maturity group (MAT)	*	NS	NS	***	**	NS	***
Row spacing (RS)	NS	NS	NS	***	**	**	**
Seeding rate (SR)	***	***	***	***	***	***	***
DATE*MAT	NS	NS	NS	***	NS	NS	NS
MAT*RS	NS	NS	NS	***	NS	NS	NS
MAT*SR	**	NS	NS	**	NS	NS	NS
DATE*RS	NS	NS	NS	NS	NS	NS	NS
DATE*SR	NS	***	NS	NS	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

Table 2.18. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Manhattan in 2011.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	121 a	2.0 a	702 a	9.0 a	3955 a	24309 a	23 a
June	118 b	1.3 b	671 b	8.4 b	3674 b	20642 b	16 b
Maturity Group							
ME-DKS 44-20	120 a	1.7 a	706 a	8.8 a	4056 a	23294 a	21 a
ML-DKS 54-00	119 b	1.6 a	667 a	8.7 b	3573 b	21658 a	18 b
Row Spacing							
25cm	120 a	1.6 a	687 a	8.9 a	3916 a	23720 a	21 a
75 cm	119 a	1.7 a	686 a	8.6b	3713 b	21293 b	18 b
Seeding Rate							
50000	117 b	2.5 a	940 a	9.3 a	4234 a	15939 c	28 a
80000	120 a	1.6 b	791 b	8.7 b	3949 b	18995 b	22 b
110000	121 a	1.3 c	550 c	8.5 cb	3621 c	26320 a	15 c
140000	120 a	1.3 c	465 d	8.4 c	3455 c	28650 a	13 c

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.19. Analysis of variance for measured parameters at Belleville in 2009.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	***	*	**	***	***	***
Maturity group (MAT)	***	NS	NS	NS	NS	NS	NS
Row spacing (RS)	**	*	***	**	***	NS	*
Seeding rate (SR)	***	***	***	***	**	***	**
DATE*Mat	*	NS	***	NS	*	NS	NS
MAT*RS	NS	NS	*	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS	***	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	*	NS	**	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * significant at 0.05, NS Non-significant.

Table 2.20. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Belleville in 2009.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	140 a	1.5 a	2582 a	7.6 a	11545 a	40221 a	41 a
June	127 b	1.4 b	2142 b	7.4 b	9821 b	29778 b	26 b
Maturity Group							
ME-DKS 44-20	136 a	1.5 a	2277 a	7.5 a	10750 a	36387 a	33 a
ML-DKS 54-00	134 b	1.4 a	2247 a	7.4 a	10616 a	33612 a	34 a
Row Spacing							
25cm	134 a	1.5 a	2526 a	7.5 a	11606 a	35598 a	35 a
75 cm	132 a	1.3 b	2198 b	7.3 b	9760 b	34402 a	32 b
Seeding Rate							
50000	129 c	2.7 a	2827 a	7.9 a	10209 b	35110 b	30 b
80000	133 b	1.1 b	2774 a	7.7 b	10989 a	36037 a	34 a
110000	135 ba	1.0 bc	2144 b	7.4 c	10921 a	36783 a	34 a
140000	137 a	0.9 c	1703 c	7.0 d	10613a	37100 a	35 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.21. Analysis of variance for measured parameters at Belleville in 2010.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	**	**	***	***	**	**	**
Maturity group (MAT)	NS	**	***	NS	NS	NS	NS
Row spacing (RS)	NS	**	NS	NS	***	***	***
Seeding rate (SR)	***	***	***	**	*	***	**
DATE*MAT	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	*	NS	NS	NS	NS
MAT*SR	**	**	**	NS	NS	NS	NS
DATE*RS	NS	NS	NS	NS	NS	NS	NS
DATE*SR	NS	*	***	**	NS	NS	NS
RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

Table 2.22. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Belleville in 2010.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	133 a	1.4 a	2424 a	8.1 a	9747 a	29967 a	35 a
June	131 b	1.27 b	2088 b	7.5 b	8951 b	28217 b	31 b
Maturity Group							
ME-DKS 44-20	133 a	1.4 a	2407 a	7.8 a	9604 a	28891a	32 a
ML-DKS 54-00	131 a	1.2 b	2106 b	7.8 a	9594 a	29293a	34 a
Row Spacing							
25cm	132 a	1.4 a	2290 a	7.8 a	9584 a	31402 a	34 a
75 cm	132 a	1.2 b	2222 a	7.8 a	9113 b	26782 b	31 b
Seeding Rate							
50000	127 c	2.1 a	3083 a	8.0 a	9069 b	22735 c	25 c
80000	130 b	1.2 b	2434 b	7.9 a	9147 b	28819 b	33 b
110000	135 a	1.1 cb	1978 c	7.7 b	9404 ba	29944 b	33 b
140000	136 a	1.0 c	1529 d	7.6 b	9775 a	34870 a	40 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.23. Analysis of variance for measured parameters at Ottawa in 2010.

Source	Plant Height (cm)	Panicles per Plant	Grains Yield (k –ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	NS	***	**	***
Maturity group (MAT)	NS	NS	*	NS	NS
Row spacing (RS)	*	NS	***	***	NS
Seeding rate (SR)	***	***	***	***	**
DATE*MAT	NS	NS	NS	NS	NS
MAT*RS	NS	NS	*	NS	NS
MAT*SR	NS	NS	**	NS	*
DATE*RS	NS	NS	NS	***	NS
DATE*SR	***	NS	**	NS	NS
RS*SR	NS	NS	NS	**	NS
DATE*RS*SR	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

Table 2.24. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Ottawa in 2010.

Treatments	Plant Height (cm)	Panicles per Plant	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date					
May	145 a	1.0 a	3992 a	11234 a	39 a
June	129 b	1.1 a	2947 b	10301 b	28 b
Maturity Group					
ME-DKS 44-20	137 a	1.1 a	3585 a	10706 a	35 a
ML-DKS 54-00	137 a	1.1 a	3354 b	10829 a	32 a
Row Spacing					
25cm	138 a	1.1 a	3646 a	12000 a	35 a
75 cm	136 b	1.1 a	3293 b	9535 b	32 b
Seeding Rate					
50000	132 b	1.7 a	3010 b	8195 d	37 a
80000	138 a	0.9 b	3591 a	10466 c	35 a
110000	138 a	0.8 b	3702 a	11440 b	33 a
140000	139 a	0.9 b	3575 a	12968 a	28 b

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.25. Analysis of variance for measured parameters at Ottawa in 2011.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	***	***	***	***	***	**
Maturity group (MAT)	NS	NS	NS	**	NS	***	NS
Row spacing (RS)	*	NS	NS	NS	**	***	NS
Seeding rate (SR)	*	***	***	**	**	NS	*
DATE*MAT	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS	NS	NS	NS	NS	NS	NS	NS
DATE*SR	NS	NS	NS	NS	NS	NS	NS
RS*SR	NS	**	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, ** Significant at 0.01, * Significant at 0.05, NS Non-significant.

Table 2.26. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Ottawa in 2011.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	103 b	1.9 a	910 b	7.8 a	2215b	7410 b	32 b
June	118 a	1.4 b	1960 a	7.4 b	7249 a	20159 a	38 a
Maturity Group							
ME-DKS 44-20	111 a	1.7 a	1546 a	7.7 a	4917 a	14090 a	33 a
ML-DKS 54-00	110 a	1.6 a	1325 a	7.5 b	4547 b	13479 a	36 a
Row Spacing							
25cm	110 b	1.6 a	1325 a	7.6 a	4954 a	14730 a	34 a
75 cm	111 a	1.7 a	1546 a	7.7 a	4510 b	12839 b	36 a
Seeding Rate							
50000	109 b	2.2 a	2121 a	8.0 a	4687 c	13810 b a	34 ba
80000	110 ba	1.6 b	1504 b	7.7 b	4704 ba	14799 a	32 b
110000	112 a	1.4 cb	1136 cb	7.5 cb	4697 b	13691 ba	35 ba
140000	112 a	1.4 c	980.0 c	7.3 c	4840 a	12838 b	38 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.27. Analysis of variance for measured parameters at Hutchinson in 2009.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	**	**	***	***	***	**
Maturity group (MAT)	***	NS	*	NS	NS	NS	NS
Row spacing (RS)	**	**	**	**	**	**	*
Seeding rate (SR)	**	***	***	**	***	*	***
DATE*MAT	NS	NS	NS	NS	NS	NS	**
MAT*RS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	**	NS	NS	NS	NS	NS	NS
DATE*RS	NS	NS	NS	NS	*	NS	***
DATE*SR	NS	NS	NS	**	NS	NS	**
RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, **Significant at 0.01, * Significant at 0.05, NS, Non-significant.

Table 2.28. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Hutchinson in 2009.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	137 a	1.5 a	1933 a	9.1 a	8074 a	33629 a	29 a
June	120 b	1.2 b	1642 b	7.4 b	5960 b	25017 b	26 b
Maturity Group							
ME-DKS 44-20	122 b	1.3 a	1694 a	8.3 a	7168 a	30236 a	27 a
ML-DKS 54-00	136 a	1.4 a	1882 a	8.2 a	6867 a	27772 a	28 a
Row Spacing							
25cm	127 b	1.4 a	1879 a	8.3 a	7025 a	30236 a	30 a
75 cm	130 a	1.3 b	1696 b	8.1 b	7019 b	28410 b	28 a
Seeding Rate							
50000	126 b	2.1 a	2341 a	8.6 a	5699 b	26606 b	24 c
80000	130 a	1.2 b	1829 b	8.2 b	7189 a	32464 a	25 c
110000	129 a	1.0 b	1565b c	8.1 b	7573 a	29988 ba	29 b
140000	130 a	1.0 b	1416 c	8.1 b	7608 a	28234 ba	33 a

Means in each column followed by similar letters are not significantly different at the 5 % probability level.

Table 2.29. Analysis of variance for measured parameters at Hutchinson in 2010.

Source	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300-Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting date (DATE)	***	*	*	NS	NS	***	***
Maturity group (MAT)	**	NS	**	NS	***	NS	NS
Row spacing (RS)	NS	NS	NS	*	NS	***	***
Seeding rate (SR)	***	***	***	**	***	***	***
DATE*MAT	NS	NS	NS	NS	NS	NS	NS
MAT*RS	NS	NS	NS	NS	NS	NS	NS
MAT*SR	*	NS	NS	NS	NS	NS	NS
DATE*RS	NS	NS	NS	NS	NS	***	**
DATE*SR	**	NS	NS	NS	NS	***	**
RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*RS*SR	NS	NS	NS	NS	NS	NS	NS
DATE*MAT*RS*SR	NS	NS	NS	NS	NS	NS	NS

*** Significant at 0.0001, **Significant at 0.01, * Significant at 0.05, NS Non-significant.

Table 2.30. Means comparisons of parameters measured as affected by planting date, maturity, row spacing and seeding rate at Hutchinson in 2010.

Treatments	Plant Height (cm)	Panicles per Plant	Grains per Panicle	300 Grain Weight (g)	Grain Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest Index (%)
Planting Date							
May	136 a	1.4 a	1765 a	7.7a	6397a	24800 a	26 b
June	120 b	1.3 b	1599 b	7.5a	6143a	17900 b	34 a
Maturity Group							
DKS 44-20	127 b	1.2 a	1556 b	7.6a	5613 b	21675 a	27 a
DKS 54-00	130 a	1.4 a	1808 a	7.6a	6928 a	21025 a	28 a
Row Spacing							
25cm	129 a	1.3 a	1631 a	7.7 a	6399 a	22393 a	36 a
75 cm	127 a	1.3 a	1733 a	7.5 b	6141 a	20307 b	30 b
Planting Rate							
50000	122 c	2.1 a	2097 a	8.0 a	4836 c	17381 d	28 b
80000	128 b	1.2 b	1698 b	7.6 b	6209 b	20760 c	31 ba
110000	129 b	1.1 b	1541 cb	7.6 b	6975 a	22205 b	32 a
140000	133 a	0.9 b	1391 c	7.3 c	7061 a	25053 a	30 ba

Means in each column followed by similar letters are not significantly differently at the 5 % probability level.

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Chapter 3 - Use of Nitrogen Management Tools to Estimate Leaf Nitrogen Status and Yield of Grain Sorghum

3.1 Abstract

Improving N management would eventually depend on the accuracy with which the N status of plant can be assessed. Producers need simple, inexpensive tools which can help them to access the N status of the plant throughout the growing season, and if additional nitrogen applications need to be made, how much N should be applied. The usefulness of chlorophyll meter readings (SPAD) for plant N assessment is based on the direct proportionality between leaf chlorophyll and leaf N concentration. Other tools such as leaf color chart (LCC), counting of number green leaves were tested. Field experiments were in 2010 to determine the response of grain sorghum yield and leaf nitrogen status to N fertilizer application rate and to determine if there were a strong relationship between SPAD, LCC, and number of green leaves with N and grain yield. Leaf chlorophyll was measured by using SPAD on the youngest fully developed leaves, the greenness of leaves by using LCC. Another method of counting the number of green leaves at growth stages was developed with the hope of potentially using this information to help producers make informed management decisions quickly with little or no cost. The average of SPAD values was higher with the increasing of N fertilizer application at all growth stages. The LCC scores increased with increasing N rate, and the number of green leaves was greater with increased N rate. Positive correlation was observed with SPAD, LCC and green leaf with N rate and grain yield in all locations. In conclusion, SPAD, LCC, and number of green leaves can be used to estimate leaf chlorophyll content which is an indicator of leaf N status, and therefore can predict grain yield.

3.2 Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] plays an important role as a staple food grain in many developing countries. In many smallholder farms in developing countries little or no agricultural input is added to the soil. This leads to a decline in soil nitrogen (N) and phosphorus (P) which frequently results in low crop yields or soil productivity. In the past, long fallow periods of 5-10 years allowed for natural restoration of soil fertility. The fallow period has decreased in length or is almost nonexistent in many farming communities because of pressure on land to increase food production and other socioeconomic activities. Nutrient inputs from chemical fertilizers are needed to replace nutrients which are exported and lost during cropping, to maintain a positive nutrient balance. However, because of scarcity and high cost of fertilizer, most smallholder farmers in Africa rarely use inorganic fertilizers on food crops including sorghum. Subsistence farming in sub-Saharan Africa is thus characterized by low external input, low crop yield, food insecurity, nutrient mining and environmental degradation (Stoorvogel et al., 1993; Rhodes, 1995; Mafongoya et al., 2006). Strategies must therefore be developed to restore soil fertility, to reduce erosion and environmental degradation in order to increase food production and alleviate chronic hunger in the zone (Vagen et al., 2005). The limited amounts of fertilizer available need to be used judiciously for maximum benefit, since, a majority of these farmers have low income; technical packages to increase and sustain agricultural production must be affordable, profitable and applicable to ensure their acceptability. Grain sorghum is an important part of the cropping system and farm economy in Kansas. Nitrogen is often considered to be the most important limiting factor, after water deficit, for sorghum production. In cropping system, N fertilization practices can provide sufficient N supply for sorghum to achieve the potential yield. But because of climate variability, and in consequence of potential yield, farmers need to ensure that this potential yield is reached each year, applied often more quantities of N fertilizers larger than the quantity strictly required for achieving maximum yield. Another uncertainty leading farmers to apply large quantity of N is the unpredictable soil N supply according to soil type, previous crop management and climate of the year. This great uncertainty in both sorghum and N demand in relation to its growth potential and soil N supply incited farmers to adopt secure fertilization strategies that led to an increased risk of N leaching in most of the intensive cropping systems.

Nowadays, protection of soil water and air quality becomes a necessary for agriculture, and the secure fertilization strategy cannot be longer used. In the hypothesis of a continuous increase of the energy price, N fertilizers will be more and more expensive. Moreover, considering climate change, the cost of N fertilizers should be evaluated in term of CO_2 equivalent released in atmosphere by fertilizer factories, and the emission of N_2O from cropping systems should be also included. With the new agricultural policy, maximum profitability of farmers does not always correspond to maximum yield and the target yield of farmers can become significantly lower than the potential. Instead of applying too much N to be sure to cover always potential crop N demand, should be to determine corresponding N application rate and timing. To achieve this objective, it is necessary to develop practical tools for N status diagnostic and N fertilization management. The leaf color chart (LCC), SPAD and counting green leaves are tools that could be used for assessing leaf N status and the crop's need for N. The LCC had been used for monitoring the relative greenness of a rice leaf as an indicator of the plant N status (Alam et al., 1996; Witt et al., 2005). Leaf N status is closely related to photosynthesis rate and biomass production and it is a sensitive indicator of the plant N status (Alam et al., 1996; Witt et al., 2005). The SPAD allows the measurement of chlorophyll content of leaves based on leal transmittance or leaf reflectance in specific wave's bands. Peng et al. (1996) showed that chlorophyll meter measurements were correlated with leaf color chart estimations.

The objective is to develop tools that can be utilized to estimate N status, and to help farmers optimize nitrogen management in sorghum.

3.3 Materials and Methods

3.3.1 Plant Material

Hybrid DSK44-20 (Monsanto, St Louis, MO) was used for this study.

3.3.2 Experimental Site

Field experiments were conducted at the Kansas State University Experiment Research Station at Agronomy North Farm in Manhattan, KS (39^{o}12'44.5824" N lat.; 96^{o}35'40.5486"W long.), Ottawa East Central Research Station, KS (38^{o}53'85.89" N lat.:95^{o}24'46.9" W long), Salina (38^{o}49'27" N lat.; 97^{o}36'26" W long.) and Randolph (39^{o}25'48"N lat.; 96^{o}45'34"W long.) The daily weather conditions during the cropping seasons and the daily maximum and minimum air temperature for each location are presented (Fig. 2.4).

3.3.3 Crop Husbandry

The experiments were conducted in a randomized complete block design with four replications. Each location was planted in no till conditions into existing residue. At Randolph, sorghum was planted in wheat stubble, at Ottawa on wheat double cropping bean stubble, at

Salina on wheat double crop sorghum stubble and at Manhattan soybean stubble. Weed control was performed by using Dual/harness or Lumax plus hand weeding. The experiment plots were 15.2 meters long and 3.04 meters (4 rows) wide. The N treatments were applied after planting when sorghum was at three-to four-leaf stage of growth at each location and six N rate 0, 35, 70, 105, 140, and 175 kg N $ha^{-1.}$ The N response curve was established using broadcast urea at rate 0, 35, 70, 105, 140, and 175 kg N ha^{-1}, to determine the N response function at each location. Starter fertilizer was applied to all treatments at a rate of 22 kg N ha^{-1} as UAN.

3.3.4 Data Collection

3.3.4.1 Soil and Plant Sampling and Analyses

At each location, a composite soil sample was taken from each replication at a depth of 15 cm for pH, available phosphorus (P), exchangeable potassium (K), soil organic matter (SOM) and a depth of 60 cm for profile ammonium and nitrate. Sampling was done using a hand probe, and samples consisted of 12 to 15 individual cores composited to form an individual composite sample. Analysis was done by the KSU Soil Testing Laboratory using procedures described in Recommended Chemical Soil Testing Procedures for the North Central Region NCRR Publication no. 221 (1998). Measurements of plant N were made to document the relative effectiveness of each treatment. Flag leaves were collected at half bloom to determine plant N content. All samples were dried at 60°C and ground to pass a 0.5 mm stainless steel sieve. Concentrations of N were digested using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed by a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology N0. A303-S072.

3.3.4.2 Chlorophyll Meter (SPAD)

Chlorophyll meter readings were taken with Minolta SPAD 502 (Minolta Camera Co., Ltd., Japan) chlorophyll meter, starting 45 days after planting. Five plants were chosen at random in each treatment and tagged. Five reading were taken from the tagged plant from the uppermost fully expanded leaf at three growth stages vegetative (V), panicle initiation (PI) and flowering (FL).

3.3.4.3 Leaf Color Chart (LCC)

The LCC developed by Munsell Color Chart (North Brunswick, NJ, USA) for plant tissues consisted of six green strips showing increasing greenness with increasing numbers was used. As with the chlorophyll meter, the chart was used to take reading starting at vegetative, panicle initiation and flowering along with SPAD readings from the same tagged plants. The color of the youngest fully expanded leaf was compared by placing its middle part on the top of the color strip in the chart and its intensity and color determined.

3.3.4.4 Rating of Leaf Firing

Leaf ratings for sorghum are defined as the average number of green leaves remained at different growth stage. Average number of green leaves measurements was taken approximately 10 days after flowering. When counting the number of green leaves on a plant, each leaf was assigned a value of 0 or 1 based on visual firing present. For example, a leaf that was completely green was assigned a value of 6, while a leaf that had any N deficiency symptoms (firing) was assigned a value of 2. Mean leaf ratings for individual plots were determined by counting green leaves on 5 randomly selected plants in the two center rows of the plot. Leaf ratings were based on the number of green leaves, rather than the number of dead leaves, because leaves that die early in the season often fall from the plant and cannot be detected later in the season.

3.3.4.5 Grain Yield

Plots were hand harvested by marking 5.3-m of plot and collecting all of the panicles in both rows. The hand harvested sorghum was thrashed using an Almaco mechanical thrasher; a grain sample was collected for each plot to determine grain N content and grain moisture. Yield data were recorded at harvest.

3.4 Data Analyses

Data were analyzed using SAS version 9.1 with proc GLM using an alpha level of 0.05. Correlations (PROC CORR) and regression (PROC REG) analysis were used to quantify the relationship between SPAD, LCC, green leaves and N and grain yield using SAS version 9.1. Experimental design was a randomized complete block design with four replications.

3.5 Results

3.5.1 Salina

By increasing rates of N fertilizer, SPAD readings were significantly increased at all growth stages (Fig. 3.1). Higher correlation coefficients were observed for the relation between SPAD readings and N fertilizer at all growth stages. The regression analyses indicated a significant quadratic equation for SPAD values versus different level of N fertilizer (Fig. 3.1).

Similarly leaf color scores increased with increasing N applications rates. A positive relationship was observed between leaf color and N application (Fig. 3.2) at all growth stages. It was higher at 7-8 leaf stage (R^2=0.88) than flag leaf (R^2=0.55) and flowering (R^2=0.78). There was a strong relationship between number of green leaves and N rate at all growth stages (Fig. 3.3).

The SPAD values reflecting crop N status is positively related to sorghum grain yield (Fig. 3.4). The correlation coefficients between sorghum grain yield and SPAD values in different growth stages is presented in Table 3.5. The SPAD readings at all growth stages were positively related to sorghum grain yield (Fig. 3.4). Relationship between SPAD and grain yield was higher at flag leaf stage (R^2= 0.85) of sorghum development compared to growth stage (GS) 6 (R^2=0.66).

The leaf color chart scores are positively related to sorghum grain yield (Fig. 3.5). The number of green leaves was positively related to sorghum grain yield (Fig. 3.6). The numbers of green leaves at all growth stages were positively related with grain yield at 7-8 leaf stage (R^2= 0.47) flag leaf (R^2= 0.61) and flowering stage (R^2= 0.72). At early growth stage low correlation observed, but correlation between number of green leaves and grain yield was higher during later stages of sorghum development at flag leaf and flowering.

Grain yield was increased with increasing N rate (Fig. 3.7). A positive significant quadratic equation (R^2= 0.74) was obtained between sorghum grain yield and applied N. Grain yield ranged from 2365 to 6155 kg ha^{-1} depending on N rate (Table 3.4). The crop responds to the higher rate of N, 175 kg N ha^{-1} applied at both four leaf and eight leaf growth stages.

3.5.2 Randolph.

SPAD readings were significantly increased with increasing N rate application at all growth stages (Fig. 3.8). Strong relationship were observed between SPAD readings and N fertilizer at 7-8 leaf stage (R^2= 0.95), flag leaf (R^2=0.91) and flowering (R^2=0.90). The regression analyses indicated a significant quadratic equation for SPAD values versus different level of N fertilizer (Fig. 3.8). At early growth stage high relationship was observed at 7-8 leaf and decreased at later growth stage (flag and flowering) (Fig. 3.8).

Leaf color scores were greater with increasing N rates (Fig. 3.9). The leaf color scores were correlated to N rates at all growth stages (Table 3.6). The leaf color scores had a strong relationship with N applications at 7-8 leaf (R^2=0.98), flag leaf (R^2=0.92) and at flowering stages (R^2=0.9) (Fig. 3.9). At the early growth stage higher relationship observed, but relationship between leaf color scores and N rate was higher during later stages (flag leaf) of sorghum development. The signs of N deficiency always appear first as yellow discoloration with lower leaf color scores, and withering of the older parts of plant, whilst the younger parts remain green longer. However, the younger parts were sometimes paler than usual.

The number of green leaves was positively related to sorghum N rate (Table 3.6). A significant quadratic regression equation (Fig. 3.10) was obtained between leaf color scores and N rate. The numbers of green leaves had a strong relationship with N rate at 7-8 leaf (R^2=0.93), flag leaf (R^2=0.85) and flowering (R^2=0.99). At the early growth stage 7-8 leaf and at flowering low relationship was observed with N, but correlated was higher during later stage (Table 3.6).

The SPAD values were positively related to sorghum grain yield (Fig. 3.11). The correlation coefficients between sorghum grain yield and SPAD values in different growth stages is presented in Table 3.5. The SPAD readings at all growth stages were positively related with sorghum grain yield. At the early growth stages 7-8 leaf good relationship was observed

(R^2=0.75), but relationship between SPAD and grain yield was good during later stages flag leaf (R^2= 0.77) and flowering (R^2=0.78) of sorghum development. Regression analysis of the data showed that nitrogen concentration based on SPAD values was positively related to sorghum grain yield at all growth stages (Fig. 3.11).

The leaf color chart scores at all growth stages were correlated to grain yield (Table 3.5).

The results showed that at Randolph there was a weak relationship (R^2=0.39 to 0.63) between number of green leaves and grain yield at all growth stages (Fig. 3.13). Randolph location had wet conditions early but late season heat and drought stress. At early growth stages 7-8 leaf and flag leaf low correlation observed, but correlation between number of green leaves and grain yield was higher during later stage flowering of sorghum development (Table 3.5).

Grain yield increased with increasing N rate (Table 3.4). A positive significant quadratic equation R^2= 0.61 was obtained between sorghum grain yield and applied N (Fig. 3.14). Grain yield ranged from 4025.2 to 7085 kg ha^{-1} depending on N rate (Table 3.4). The crop responds to the higher rate of 140 kg N ha^{-1} applied. Even at these high N rates, symptoms of N deficiency were observed due to water and heat stress.

3.5.3 Ottawa

By increasing rates of N fertilizer, SPAD readings significantly increased at all growth stages (Table 3.1). Strong correlation coefficients were observed between SPAD readings and N fertilizer at all growth stages (Table 3.6). The regression analyses indicated a significant quadratic equation for SPAD values versus different level of N fertilizer (Fig. 3.15). At early growth stage 7-8 leaf (R^2=96) strong relationship was observed and slowly decreased at flag leaf (R^2=0.85) and at flowering (R^2=0.77).

Leaf color chart scores increased with increasing N applications rates (Table 3.2). A positive relationship was observed between leaf color and N application (Fig. 3.16) at all growth stages. It was higher at 7-8 leaf stage (R^2=0.90) than flag leaf (R^2=0.83) and at flowering (R^2=055).

The results showed that at Ottawa there was a strong relationship between number of green leaves and N at 7-8 leaf stage (R^2=0.82) at flag leaf (R^2=0.98) and flowering (R^2=0.97) (Fig. 3.17). The SPAD values reflecting crop N status was correlated to sorghum grain yield (Table 3.5). The correlation coefficients between sorghum grain yield and SPAD values in different growth stages is presented in Table 3.5. The SPAD readings at all growth stages were positively related to sorghum grain yield (Fig 3.18). At the early growth stages 7-8 leaf strong relation was observed (R^2=0.91), but relatively lower during at flag leaf (R^2= 0.88) and at flowering (R^2=0.72) of sorghum development.

The leaf color chart scores are related to sorghum grain yield at all stages of development (Fig. 3.19). The leaf color chart scores at all growth stages were correlated to grain yield (Table 3.5).

The number of green leaves was related to sorghum grain yield (Fig. 3.20). The numbers of green leaves at all growth stages were positively related to grain yield 7-8 leaf (R^2= 0.81) flag leaf (R^2= 0.91) flowering (R^2= 0.93). At early growth stage low relationship was observed, but relationship between number of green leaves and grain yield was strong during later stages of sorghum development at flag leaf and flowering.

Grain yield increased with increasing N rate (Table 3.4). A positive significant quadratic relation (R^2= 0.96) was obtained between sorghum grain yield and applied N (Fig. 3.21). Grain yield ranged from 1927 to 7289 kg ha^{-1} depending on N rate (Table 3.4). The crop responds to the higher rate of N, 175 kg N ha^{-1} applied.

3.6 Discussion

The site of Salina experienced several sequential periods of high rainfall, which together with the poor drainage of the Crete silt loam soil created exceptionally favorable conditions for denitrification. Randolph and Ottawa locations had wet conditions early but suffered from late season heat and drought stress. Leaf N concentration greatly influences both the development of sorghum canopies and their photosynthesis as showed by leaf color scores. The linear regression of leaf N concentration and leaf color scores was significant at each growth stages. The signs of nitrogen deficiency always appear with lower leaf color scores because the remobilized nitrogen obtained from intrinsic sources was far from adequate for normal growth or optimal chlorophyll synthesis (Bergann et al., 1992). Schepers et al. (1992) found that at flag leaf, leaf color scores was correlated with leaf N concentration for a given genotypes, but the calibration of the color chart was not practical due to unique greenness characteristics of hybrids. Asian farmers generally apply fertilizer N in several split applications, but the number of splits, amounts of N applied per split, and the time of application vary substantially. Although the LCC differs, strong correlations existed among their scores. Relation between LCC scores and N varied depending on the growth stage of plant. Adjusting LCC scores by improving estimates of N. Peng et al. (1993) reported that SPAD reading adjusted for improved the prediction of N of rice leaves, because SPAD indirectly measured chlorophyll content of a leaf based on the amount of absorption of red light, a thick leaf, which usually has a larger specific leaf weight and likely greater chlorophyll content on area basis, should absorb more light than a thin leaf. In contrast to measurements of light absorption, the LCC method visually matches the color of light reflected by the LCC and leaf surface. Apparently, a thick leaf tends to match with higher LCC scores a thin leaf when the two leaves have the same chlorophyll and N contents on a dry weight basis.

Grain yield increased with increasing N rate at all locations. Varvel et al. (1997) demonstrated N fertilizer significantly increased both grain yield and SPAD readings. At Randolph (Fig. 3.14) sorghum yield decreased with increasing of N fertilizer. Results showed that with increasing N fertilizer application response of yield decreased, this indicated that high N rates increased N loss, so nitrogen use efficiency decreased with increasing N rates. Arregui et al. (2006) showed that the response of crop yield in relation to N fertilizer application followed two models of behavior. In general there was a response to N applications, but once the optimal dose was reached, a maximum yield was obtained and did not improve with additional increase of N fertilizer. The coefficient of correlation decreased with advancement in crop growth stage at locations. It suggests that during early stages of sorghum there was sufficient N supply from the soil as well as from basal N application (Blackmer et al., 1993). The SPAD value reflecting crop N status was correlated to sorghum grain yield at all growth stages and all locations. Many studies Varvel et al. (1997), Vetsch et al. (2004) and Fox et al. (2001) using the SPAD to assess maize nitrogen status have shown reliable indications of N stress and relationship to yield, especially in later season.

3.7 Conclusion

The simultaneous optimization of grain yield and N use in sorghum is possible by matching N supply with crop N demand. In many field situations, more than 60% of applied N is lost due in part to the lack of synchrony of plant N demand with N supply (Arvind et al., 2004). Results presented in this study provide evidence that current fertilizer N recommendation fixed time N are not adequate for maintaining the yields and efficient use of N in sorghum.

SPAD readings are closely related to leaf nitrogen concentration, the SPAD meter can be used to monitor the N status of sorghum and thereby to adjust the rates of N fertilization in order to increase nitrogen use efficiency (Hussain et al., 2000 and Varvel et al., 2007). Analyses of data collected at different growth stages and at all locations were used to determine how early in the season SPAD data could be used to predict future sorghum N need. The proposed method allows the fertilization in sorghum to be managed by dynamically adjusting the N recommendations to the crop N requirements during the growing season. SPAD readings taken at early stages offered better relationship with grain yield and leaf N concentration than those taken later. However, there are some limitations to the use of SPAD. SPAD values did not indicate how much N should be added but, only indicated the need for additional N. Plant chlorophyll is affected by many factors, it is impossible to identify a meter reading that indicates sufficient N for all varieties of a specific crop.

The LCC based N management assure high yields consistent with efficient N use in sorghum and can enhances total productivity and farmer's profit. The LCC is a simple and easy to use tool that can help farmers manage N judiciously. Future studies can compare the efficiency, labor use, cost, and profit of improved N management strategies. Improved split N can be experienced using LCC allowing the farmers to apply N as needed by the plant.

The leaf ratings have potential to serve as a quick, inexpensive means of assessing the N status and potentially could be used to guide late season N application. This study also suggests that green leaves numbers or firing rating may actually be better tools to guide late season application than the traditional leaf N content, commonly used to assess mid-season N status. However, additional work need to be done to determine if visually firing rating can be both correlated to N status over a broad range of soils and genetic families, and calibrated to provide N rate guidance.

3.8 Tables and Figures

Figure 3.1 Relationship between SPAD readings and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Salina in 2010

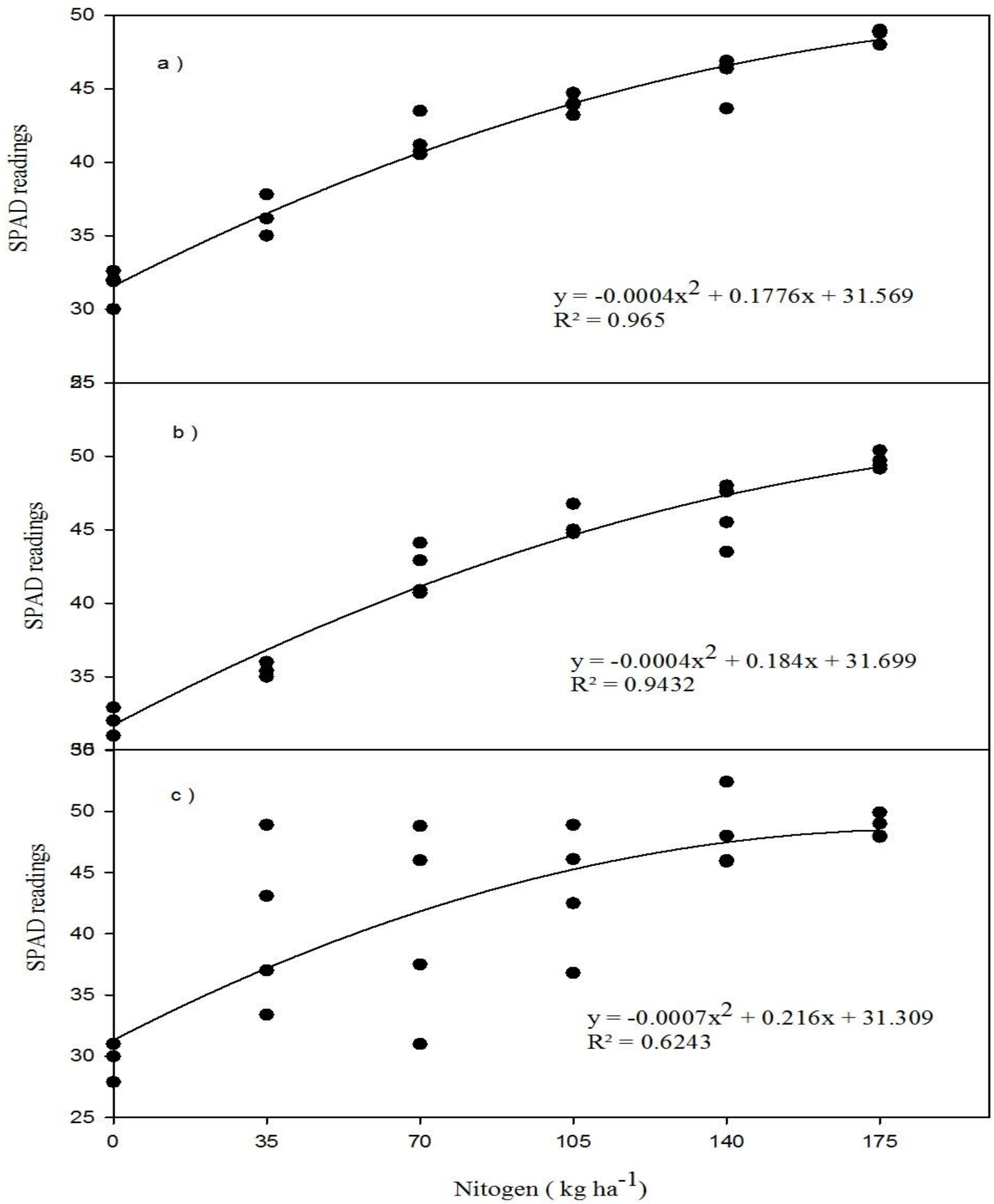


Figure 3.2 Relationship between leaf color chart scores and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Salina in 2010

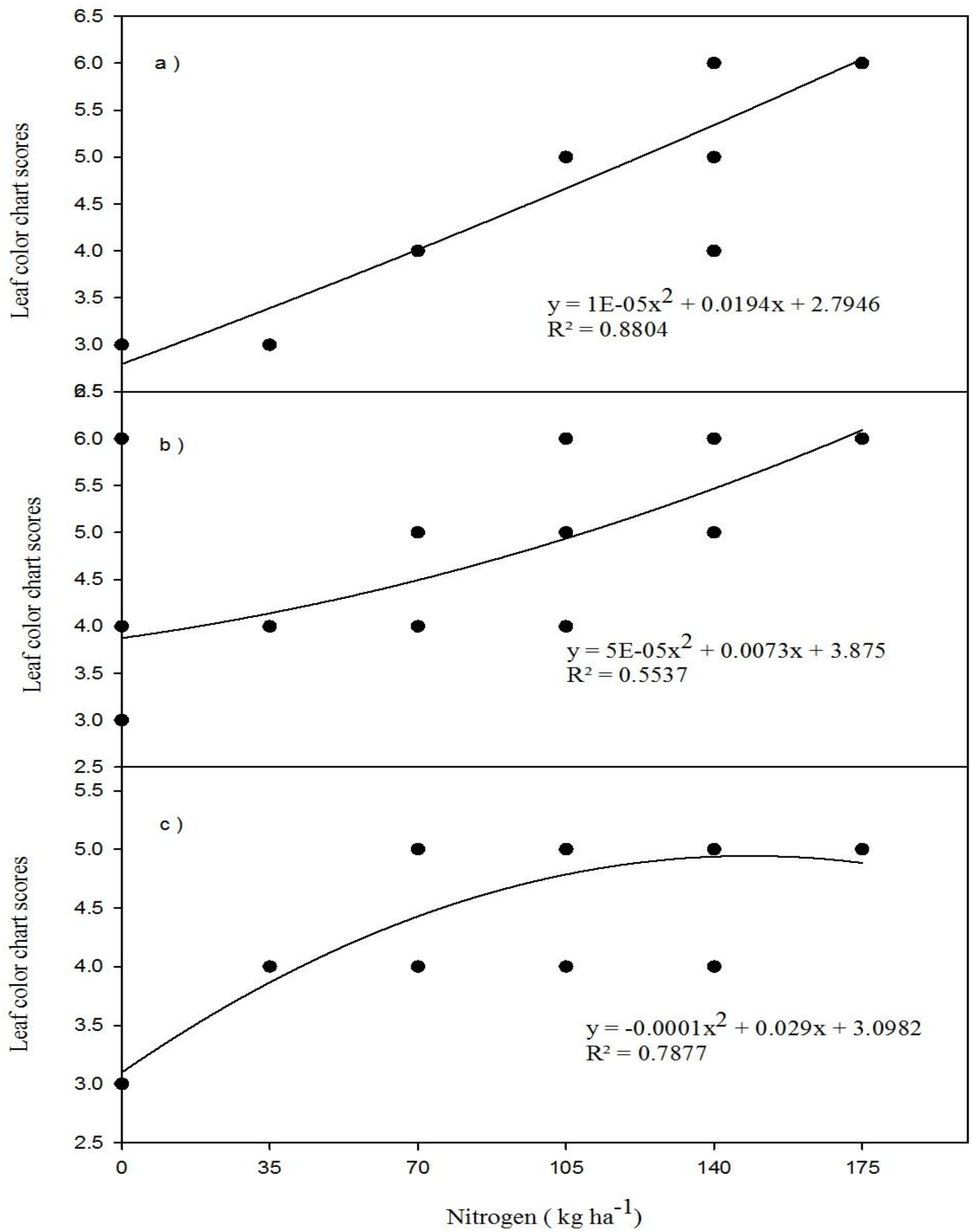
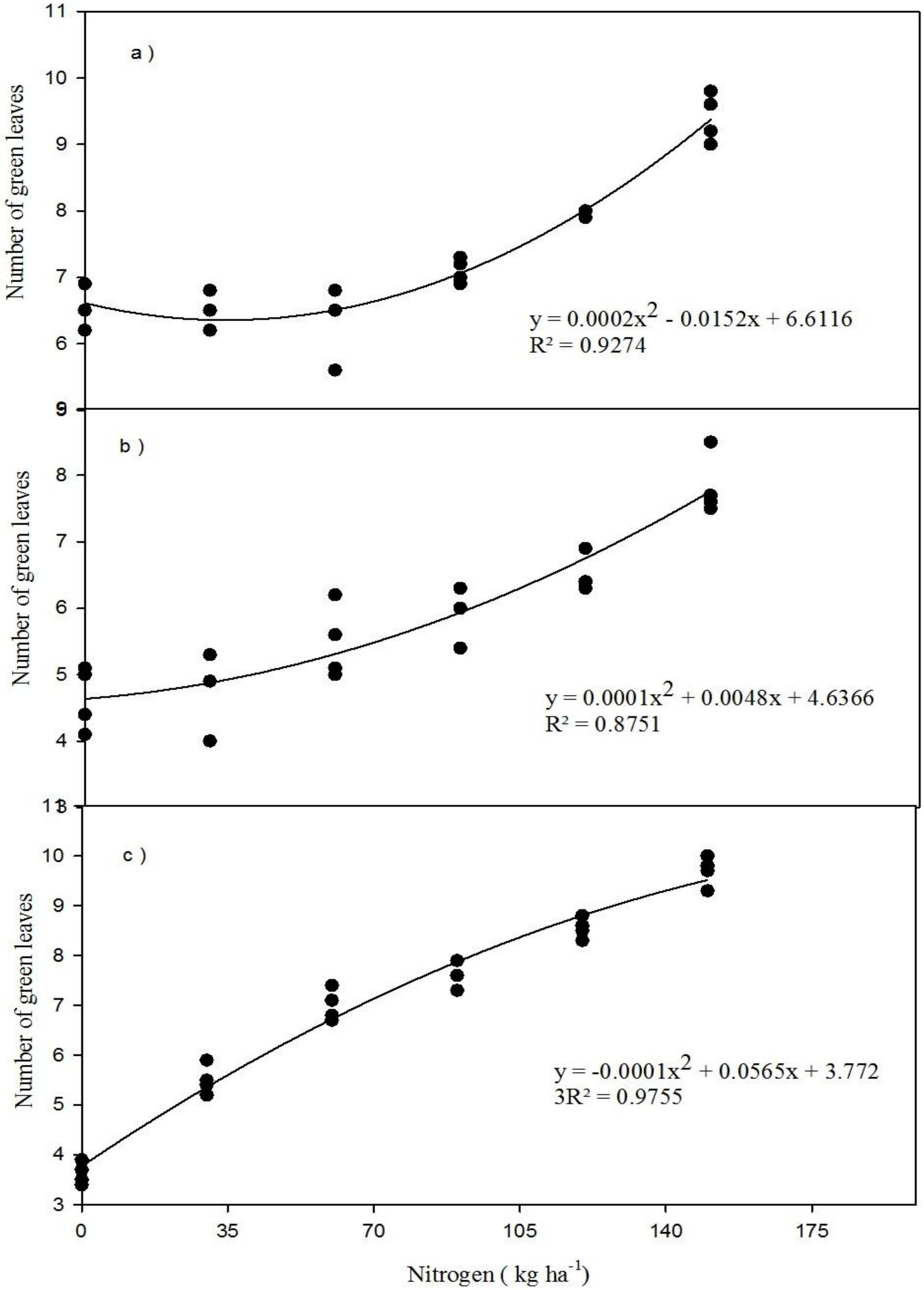


Figure 3.3 Relationship between number of green leaves and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Salina in 2010



igure 3.4 Relationship between SPAD and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Salina in 2010

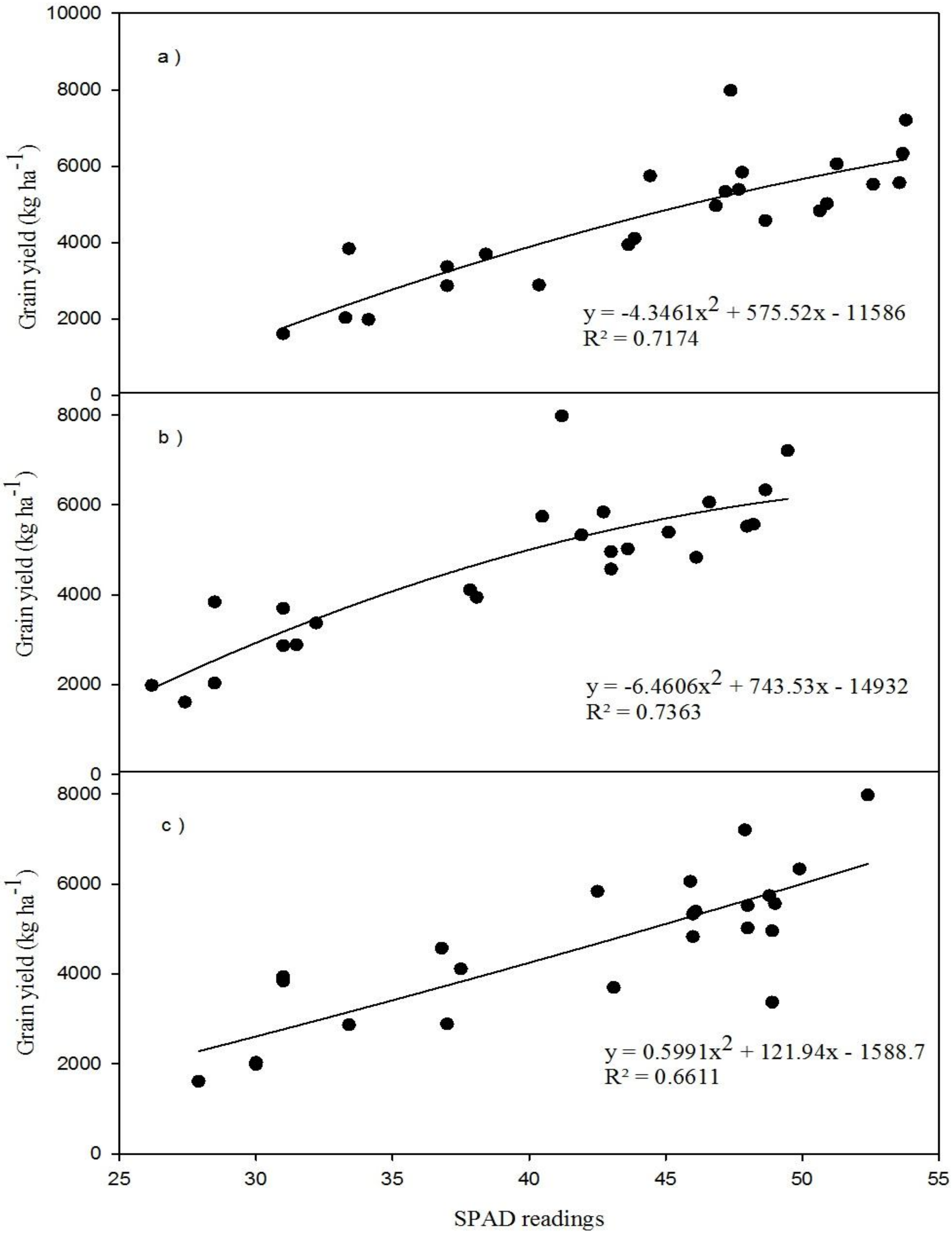


Figure 3.5 Relationship between leaf color chart scores and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Salina in 2010

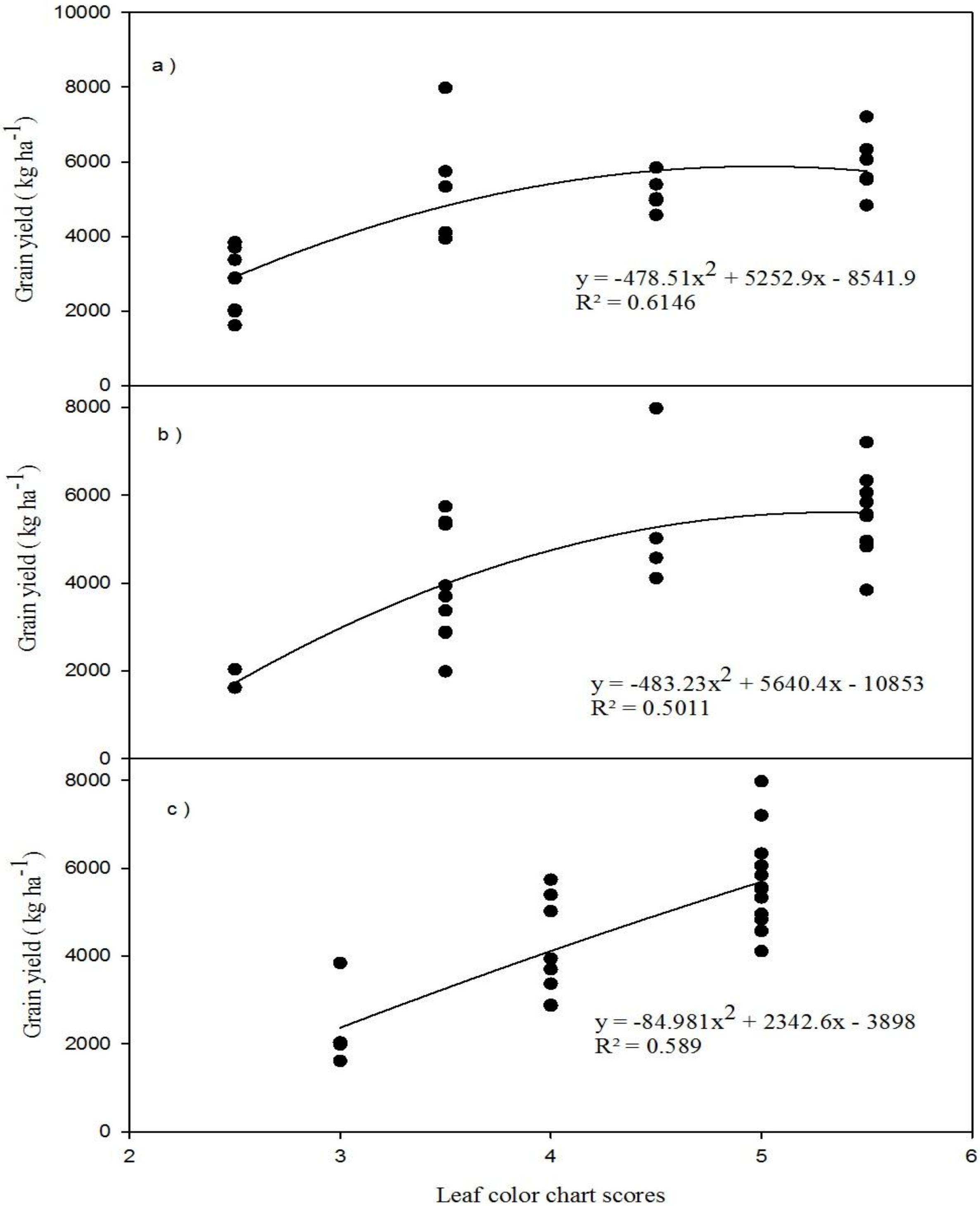


Figure 3.6 Relationship between number of green leaves and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Salina in 2010

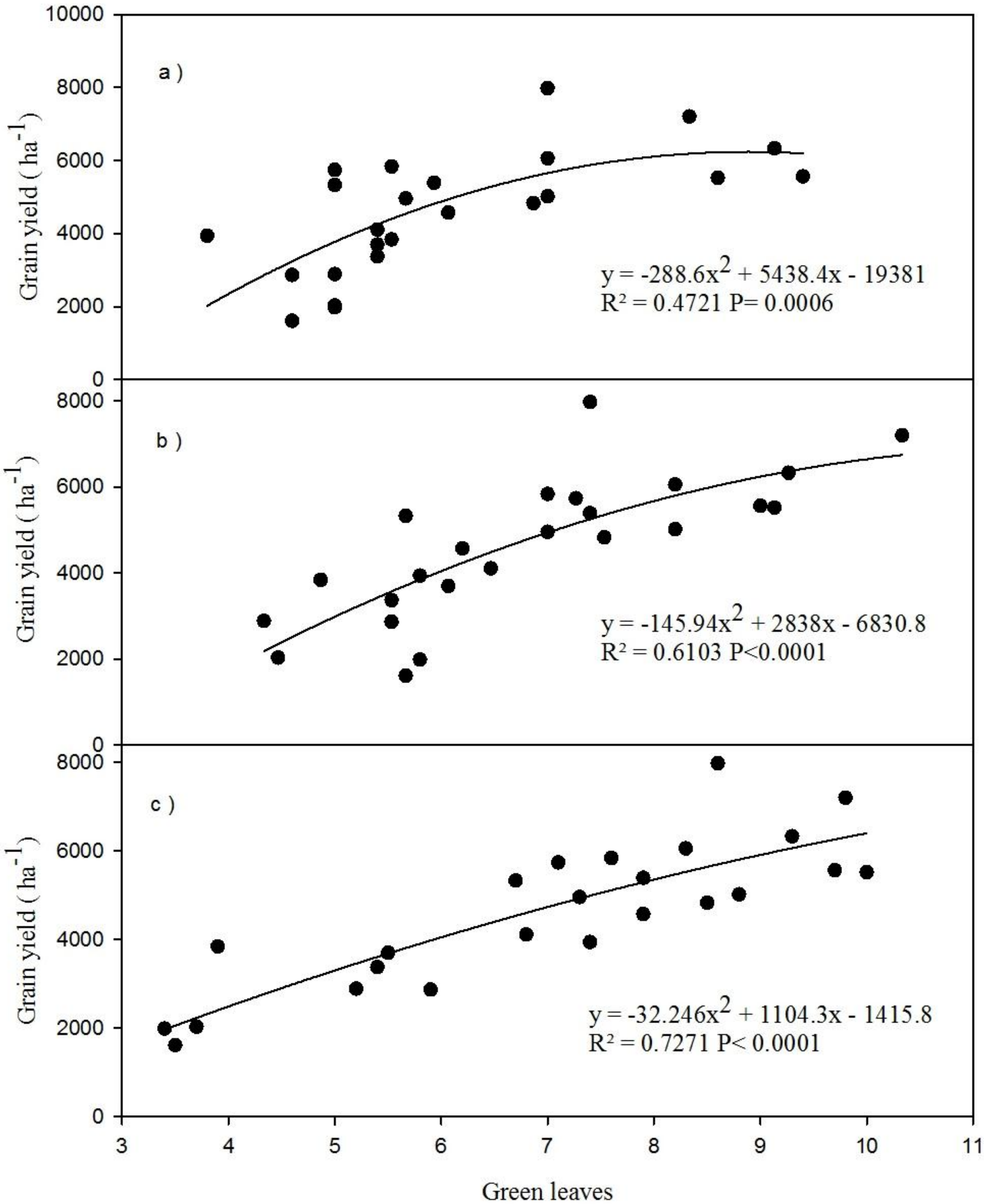


Figure 3.7 Relationship between nitrogen applied and grain yield at Salina in 2010

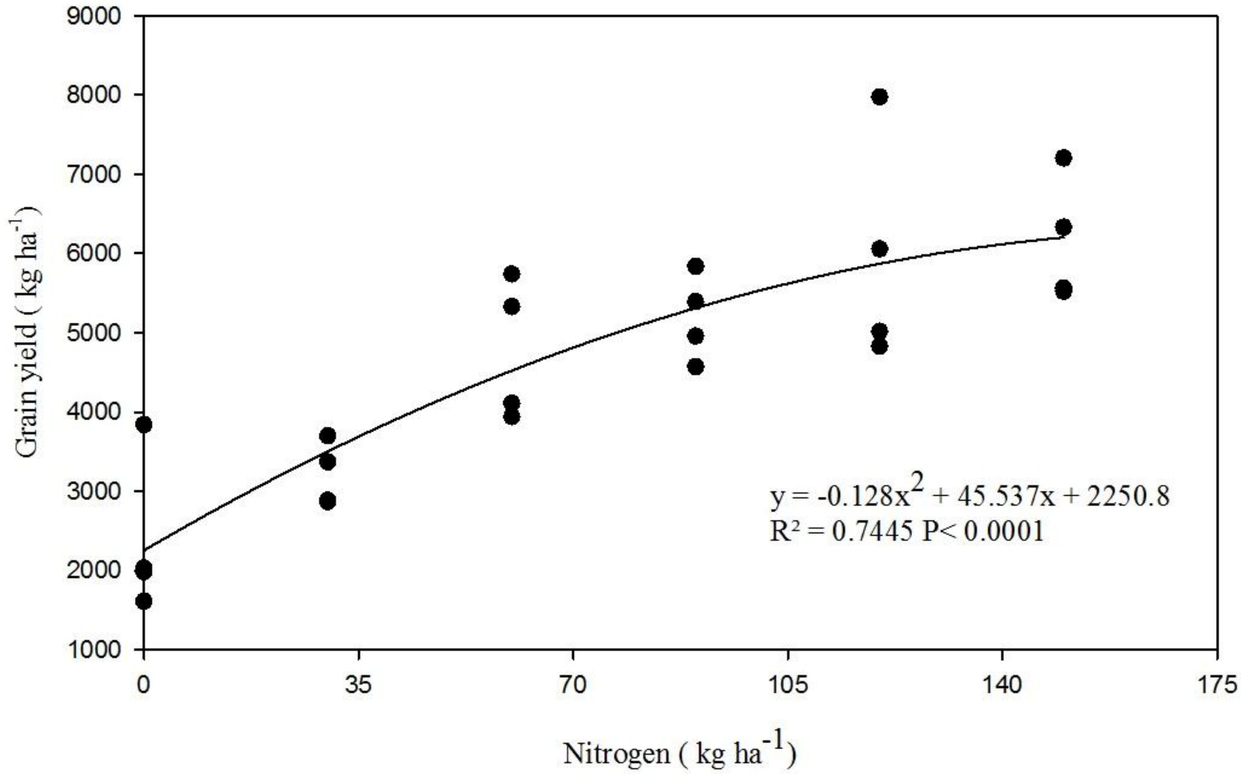


Figure 3.8 Relationship between SPAD readings and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Randolph in 2010

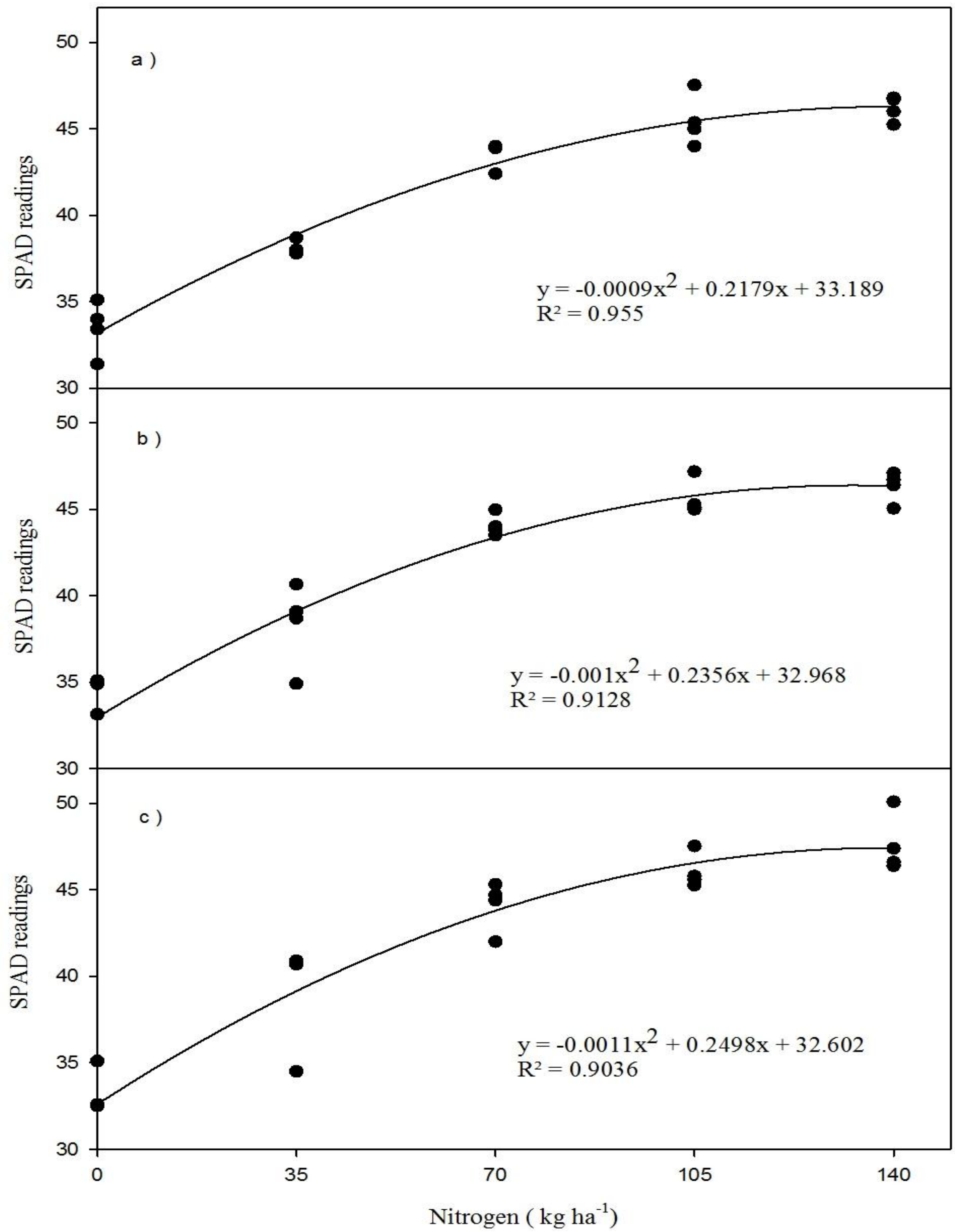


Figure 3.9 Relationship between leaf color chart scores and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Randolph in 2010

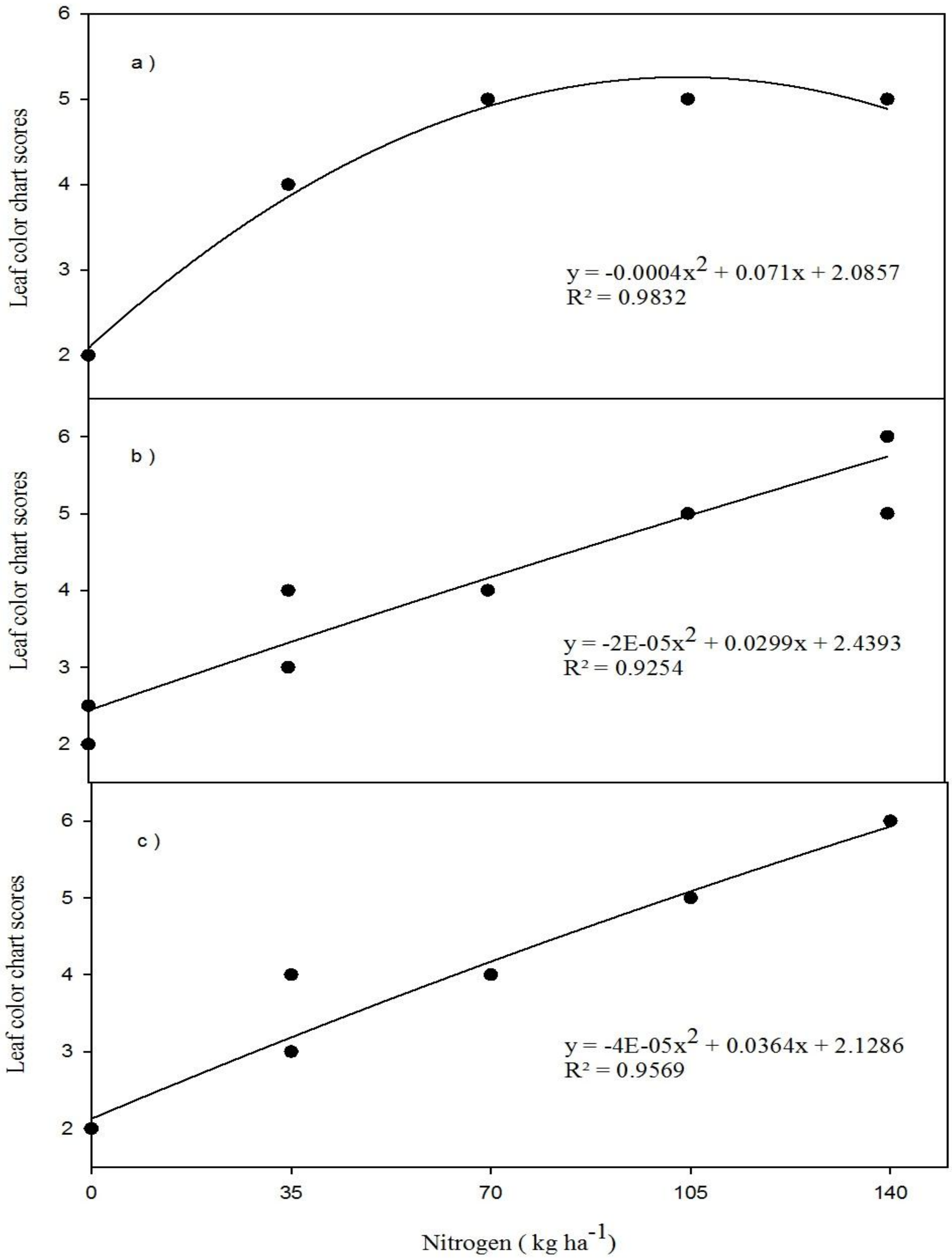


Figure 3.10 Relationship between number of green leaves and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Randolph in 2010

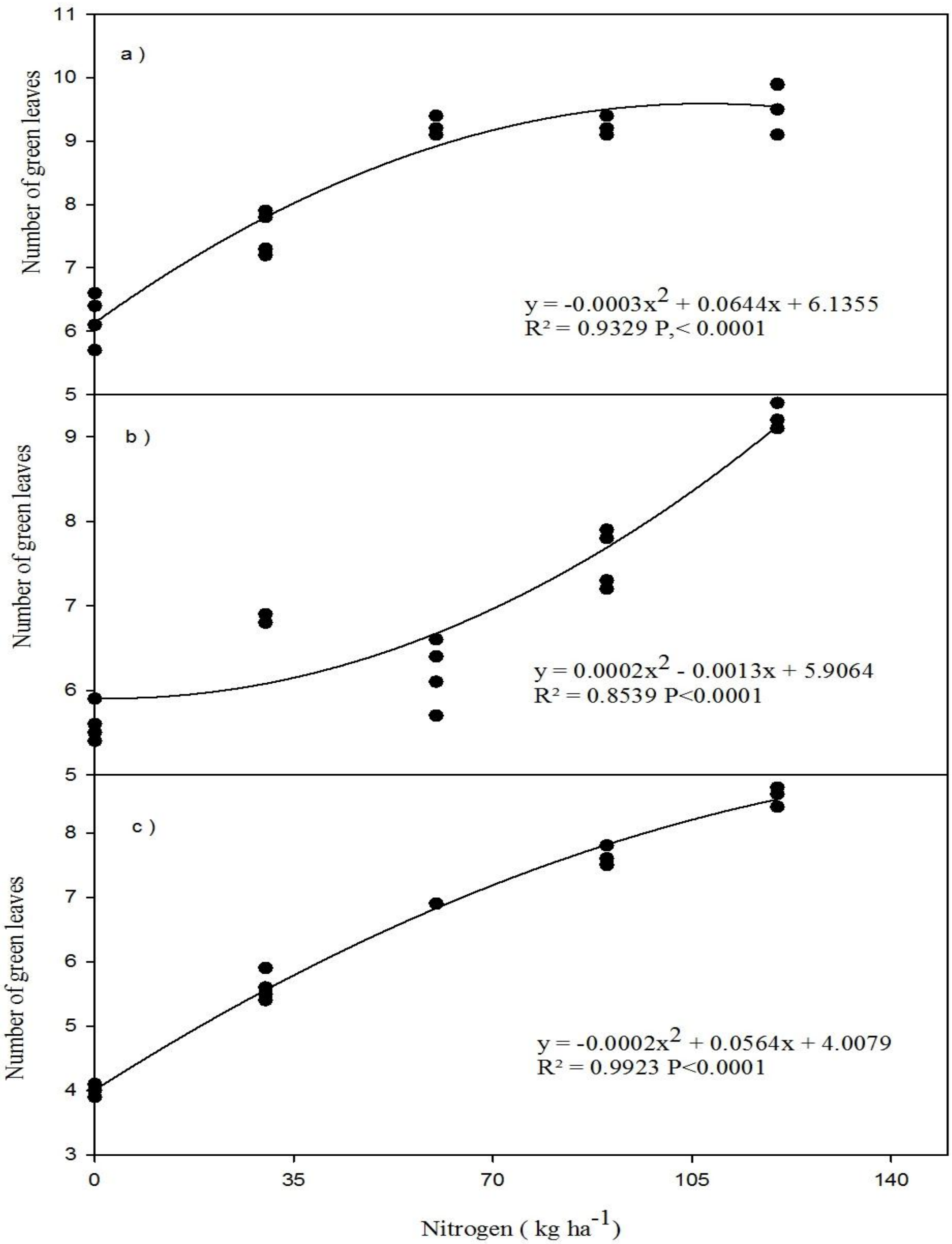


Figure 3.11 Relationship between SPAD readings and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Randolph in 2010

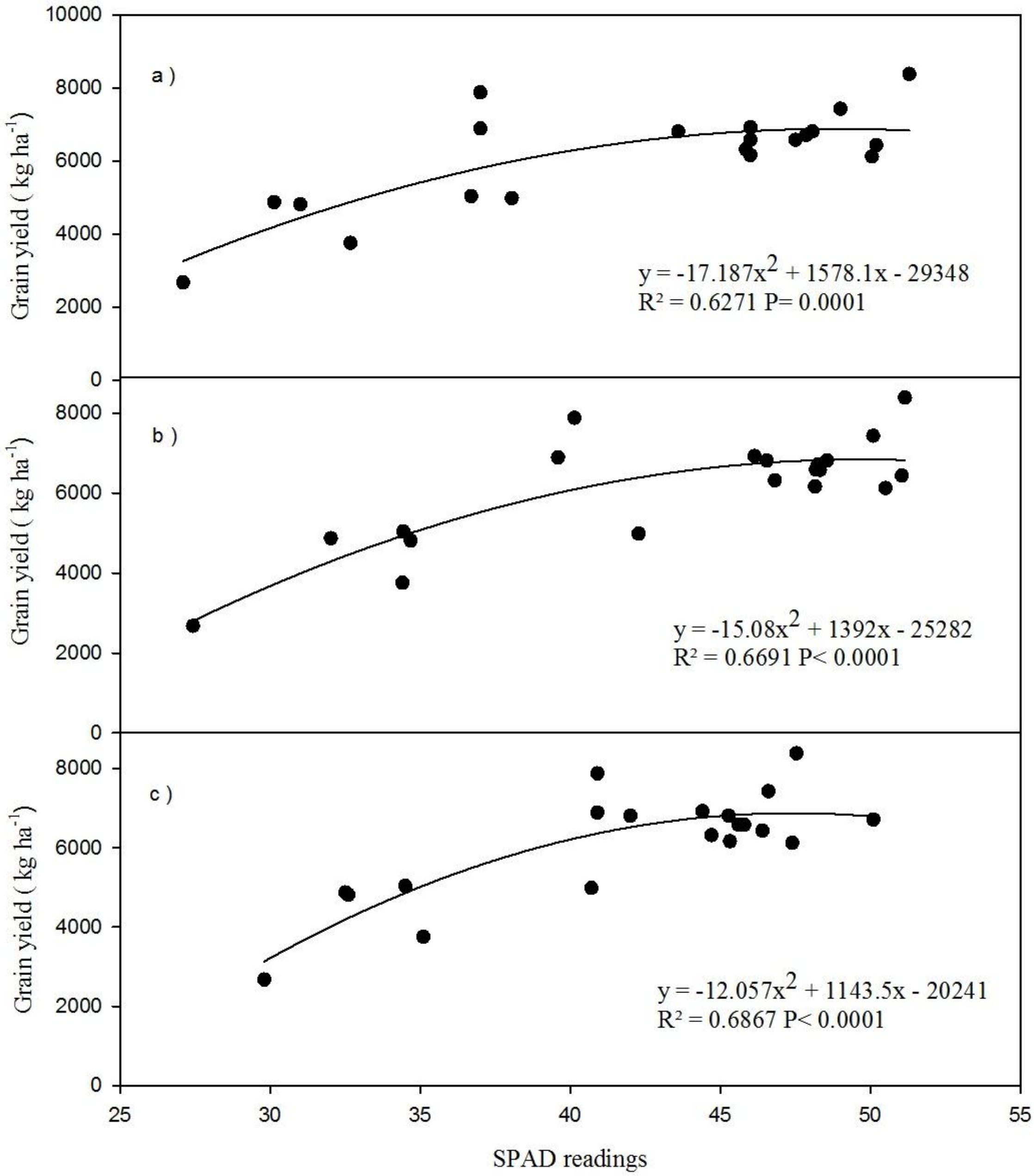


Figure 3.12 Relationship between leaf color chart scores and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Randolph in 2010

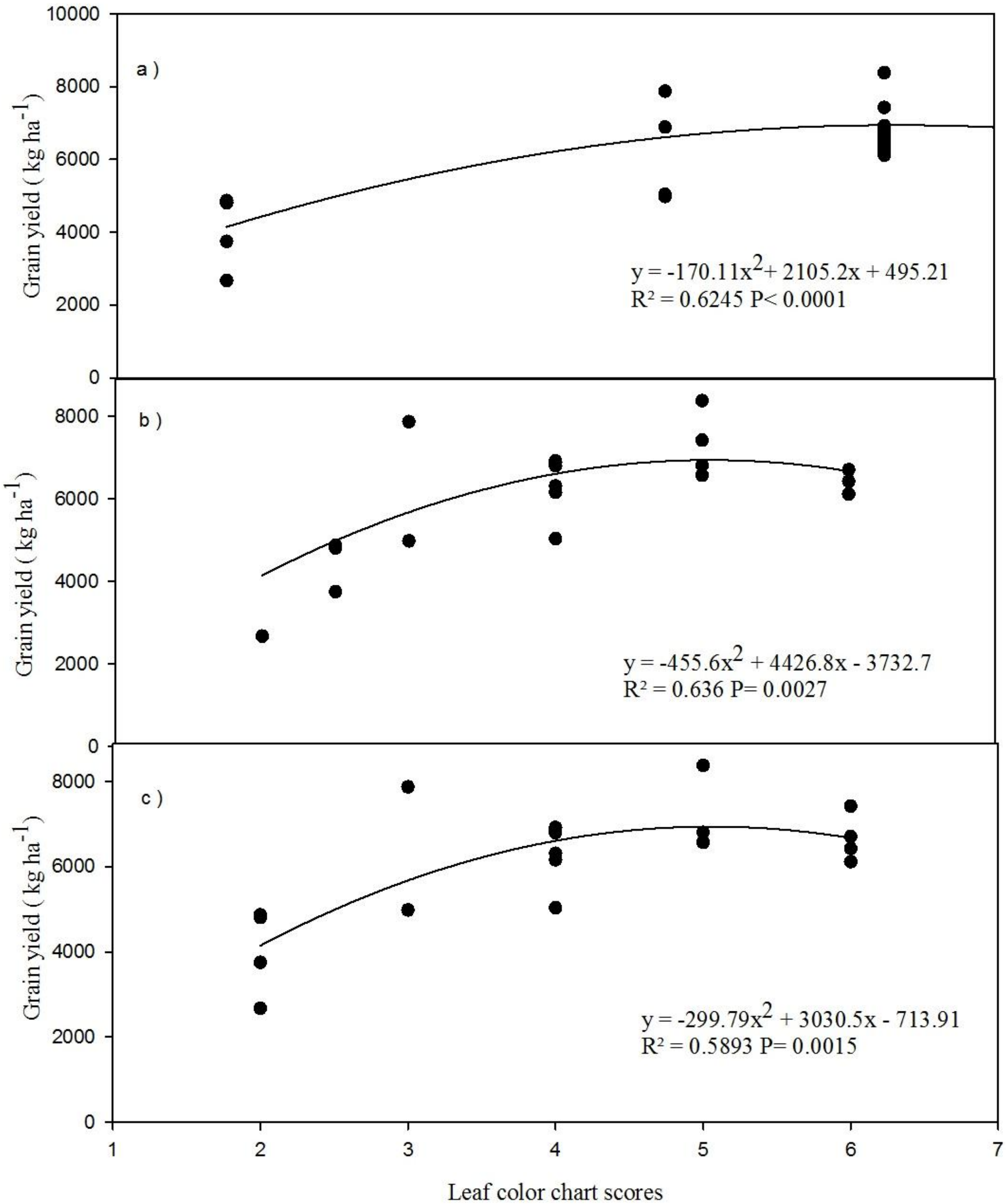


Figure 3.13 Relationship between number of green leaves and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Randolph in 2010

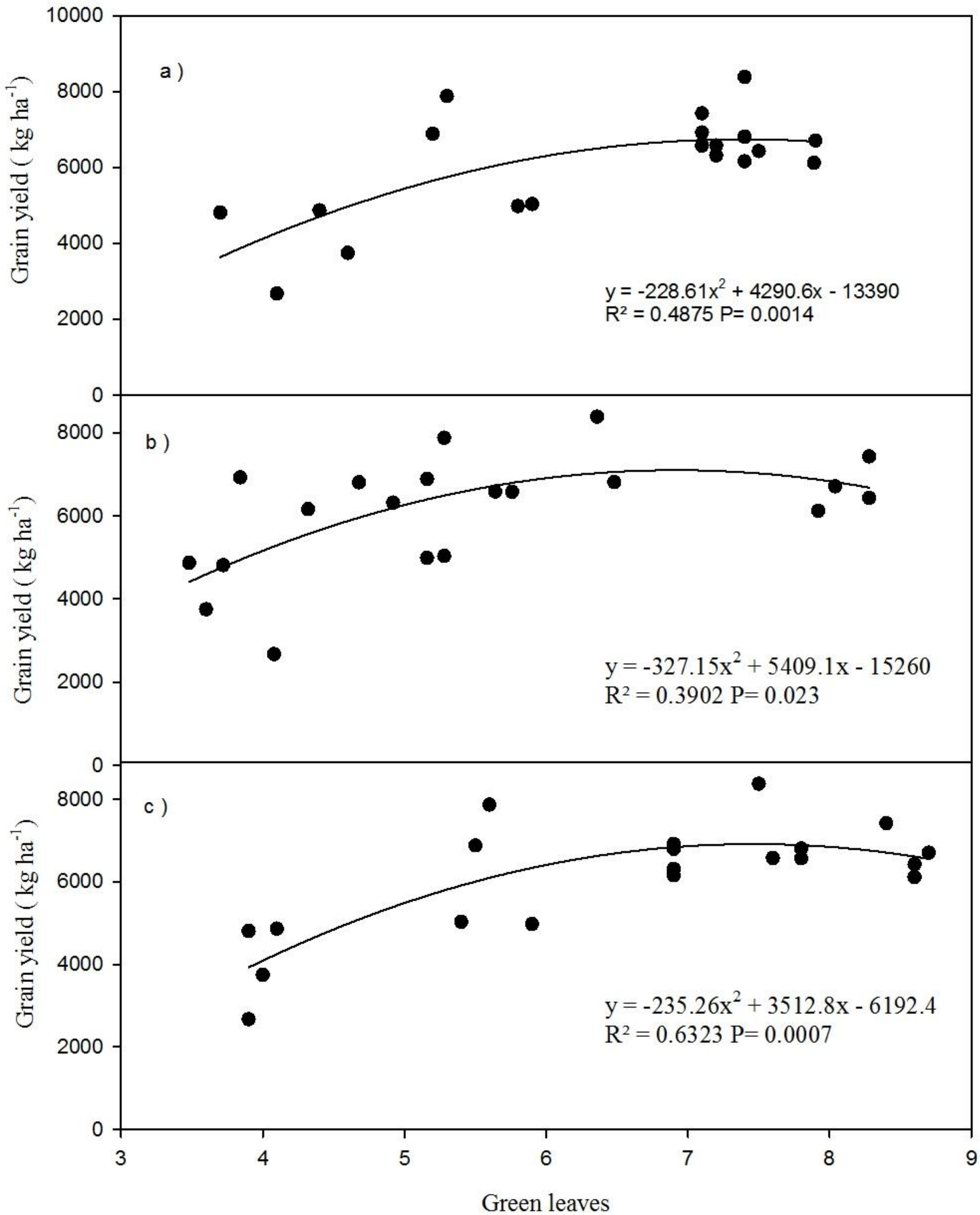


Figure 3.14 Relationship between nitrogen applied and grain yield at Randolph in 2010

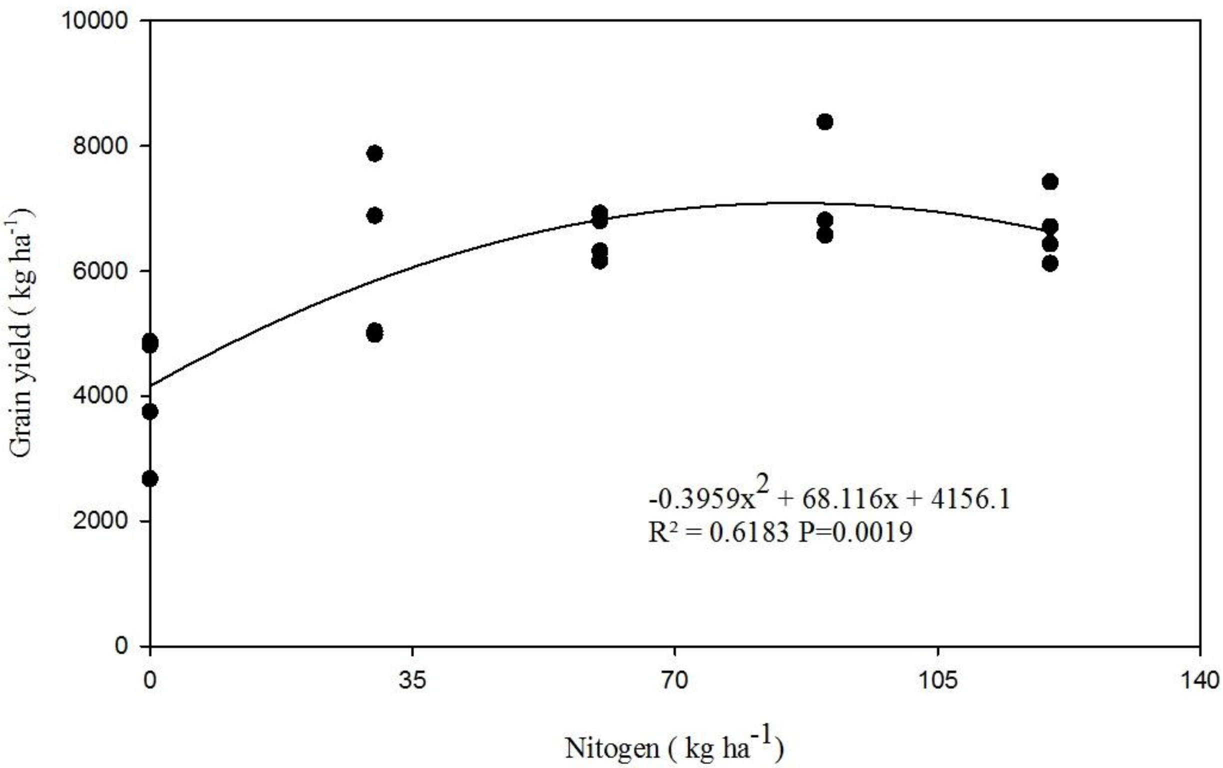


Figure 3.15 Relationship between SPAD readings and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Ottawa in 2010

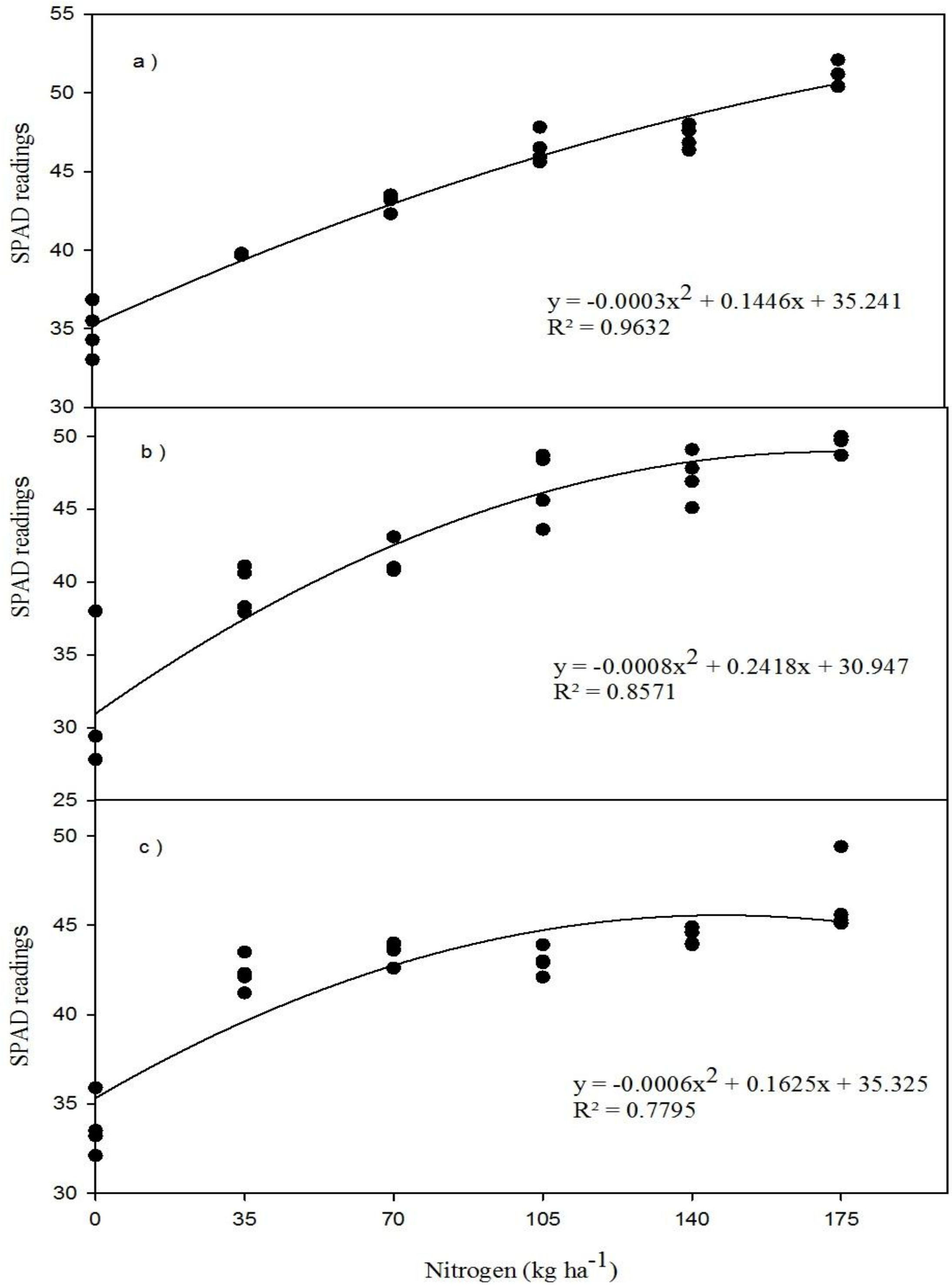


Figure 3.16 Relationship between leaf color chart scores and nitrogen at (a) growing point differentiation (b) flag leaf and (c) flowering at Ottawa in 2010

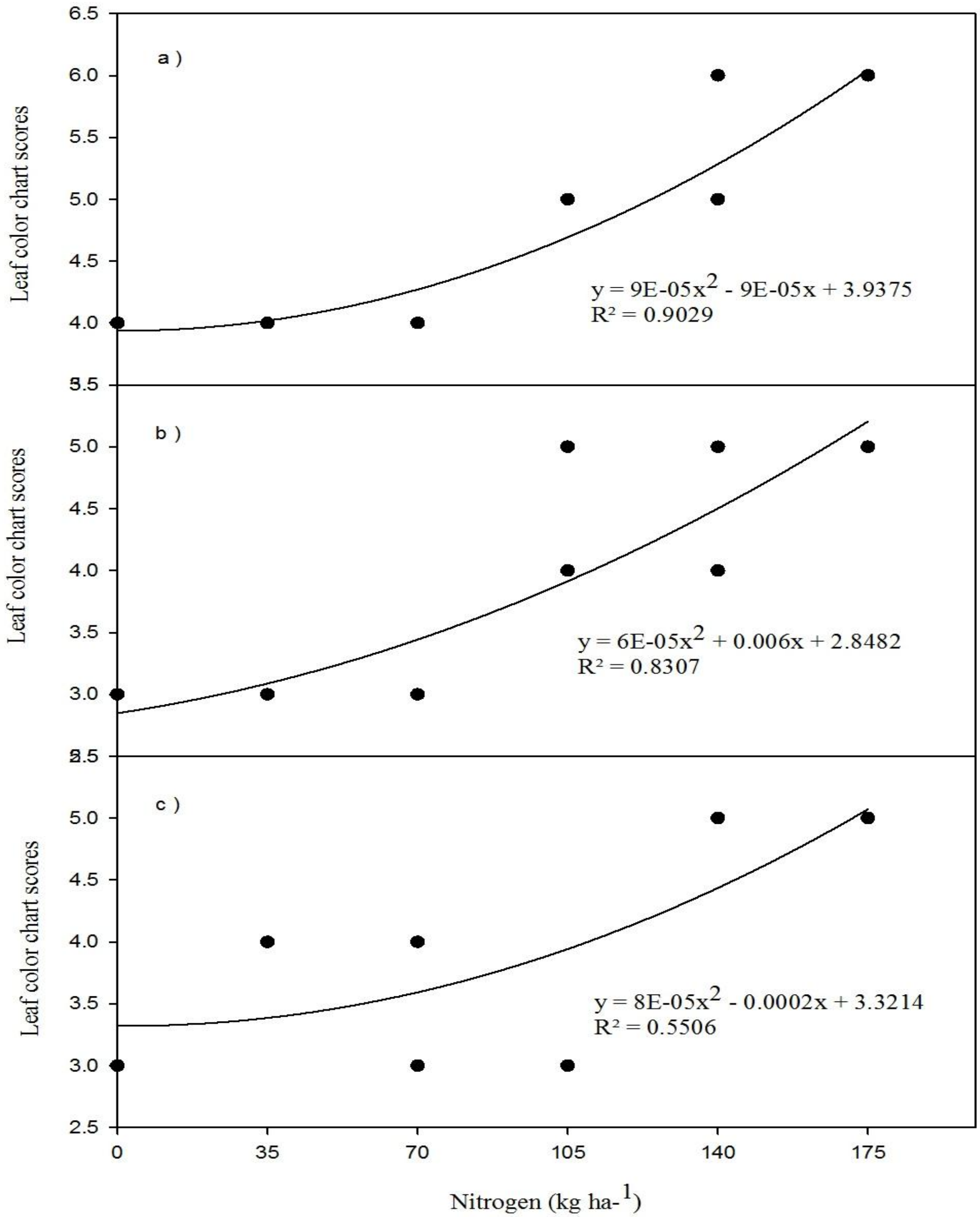


Figure 3.17 Relationship between number of green leaves and nitrogen applied at (a) growing point differentiation (b) flag leaf and (c) flowering at Ottawa in 2010

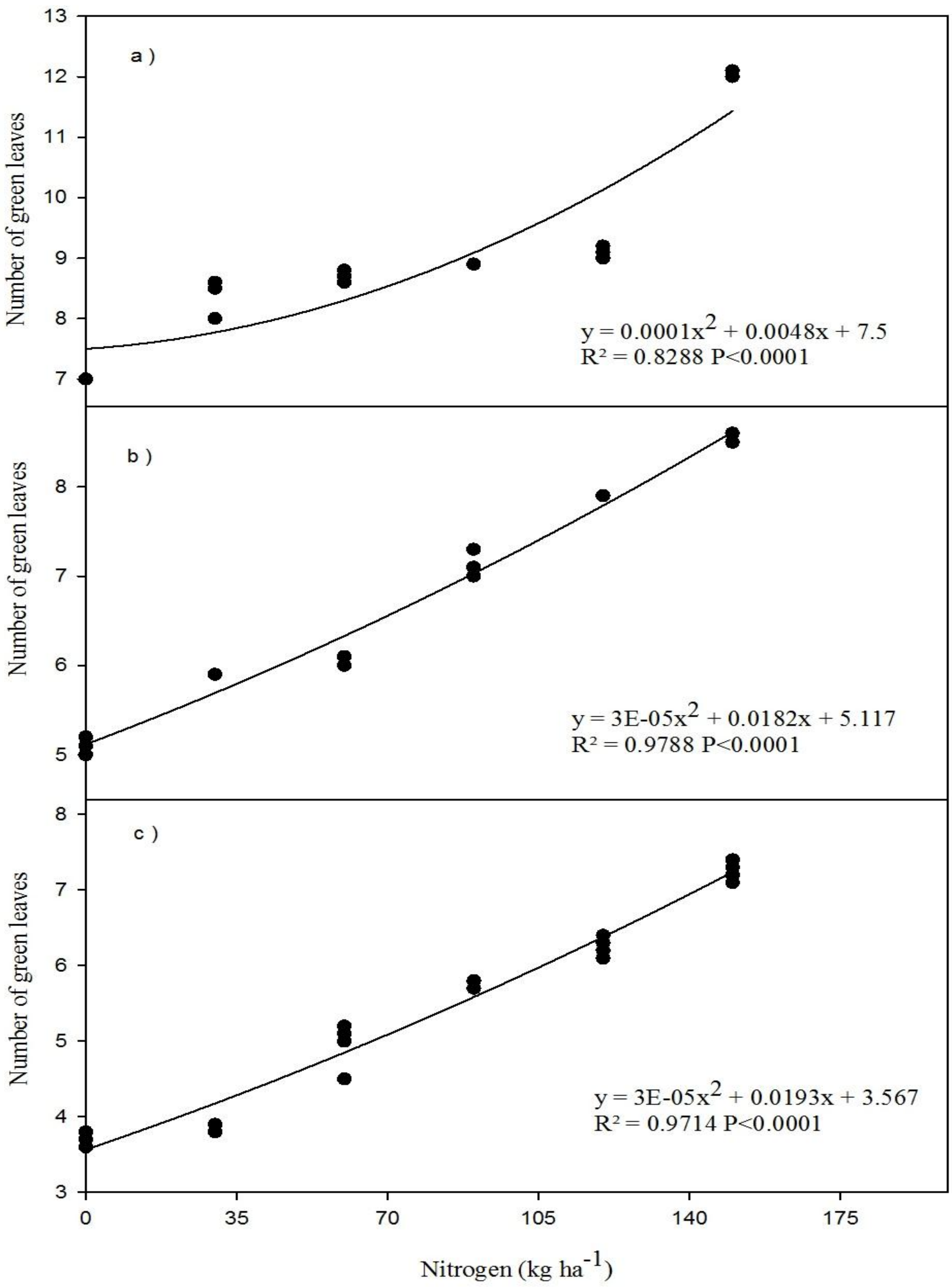


Figure 3.18 Relationship between SPAD readings and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Ottawa in 2010

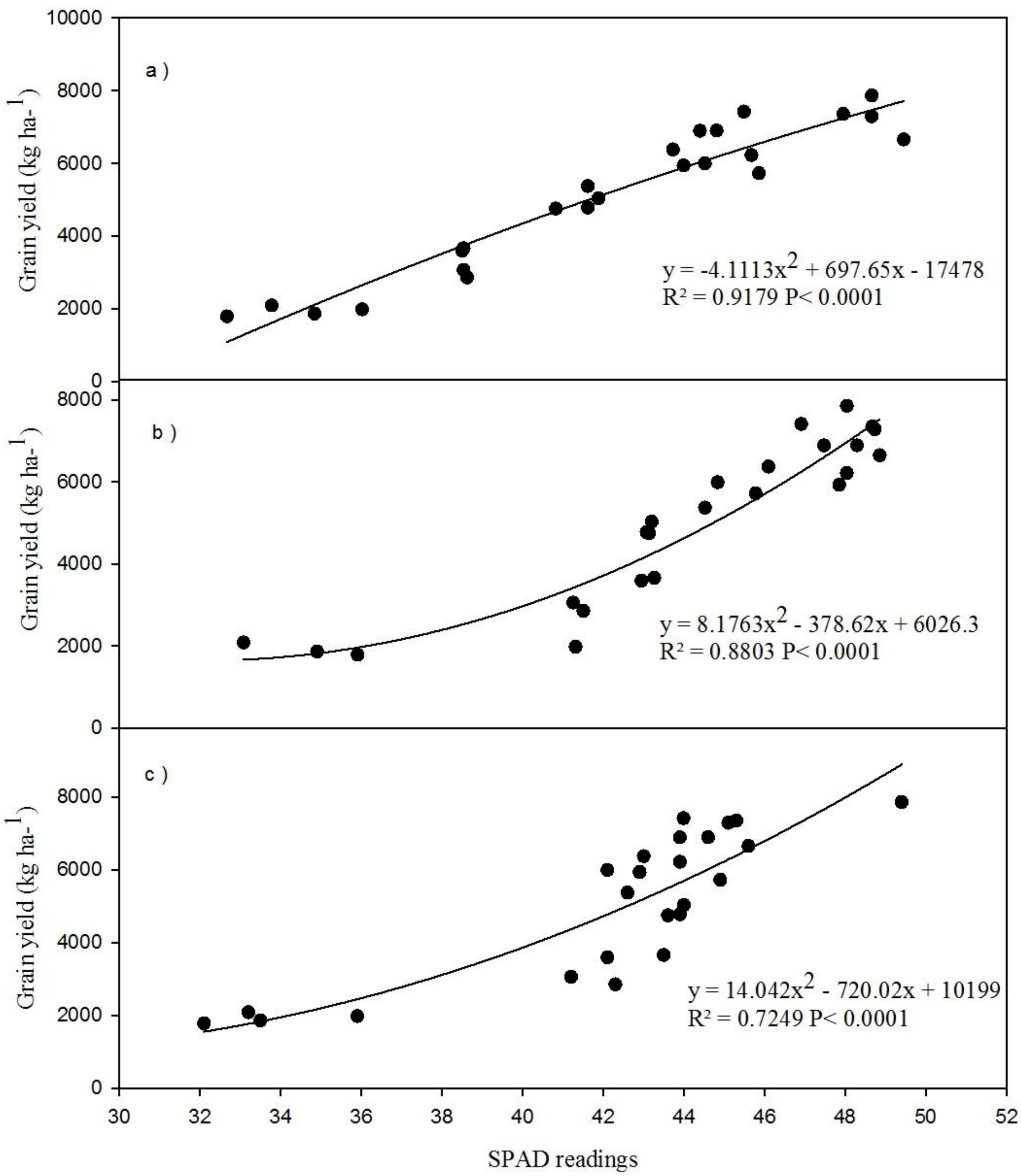


Figure 3.19 Relationship between leaf color chart scores and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Ottawa in 2010

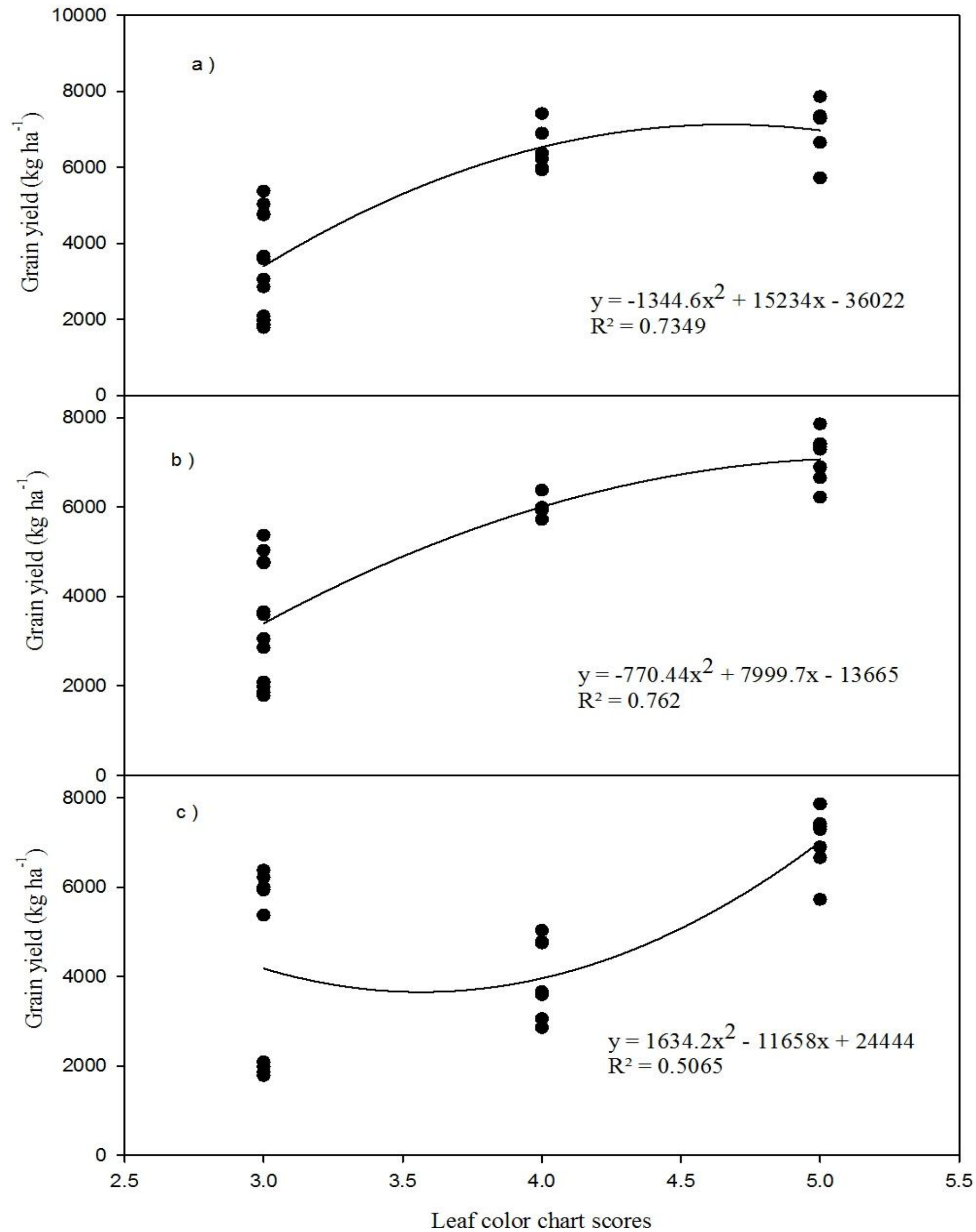


Figure 3.20 Relationship between number of green leaves and grain yield at (a) growing point differentiation (b) flag leaf and (c) flowering at Ottawa in 2010

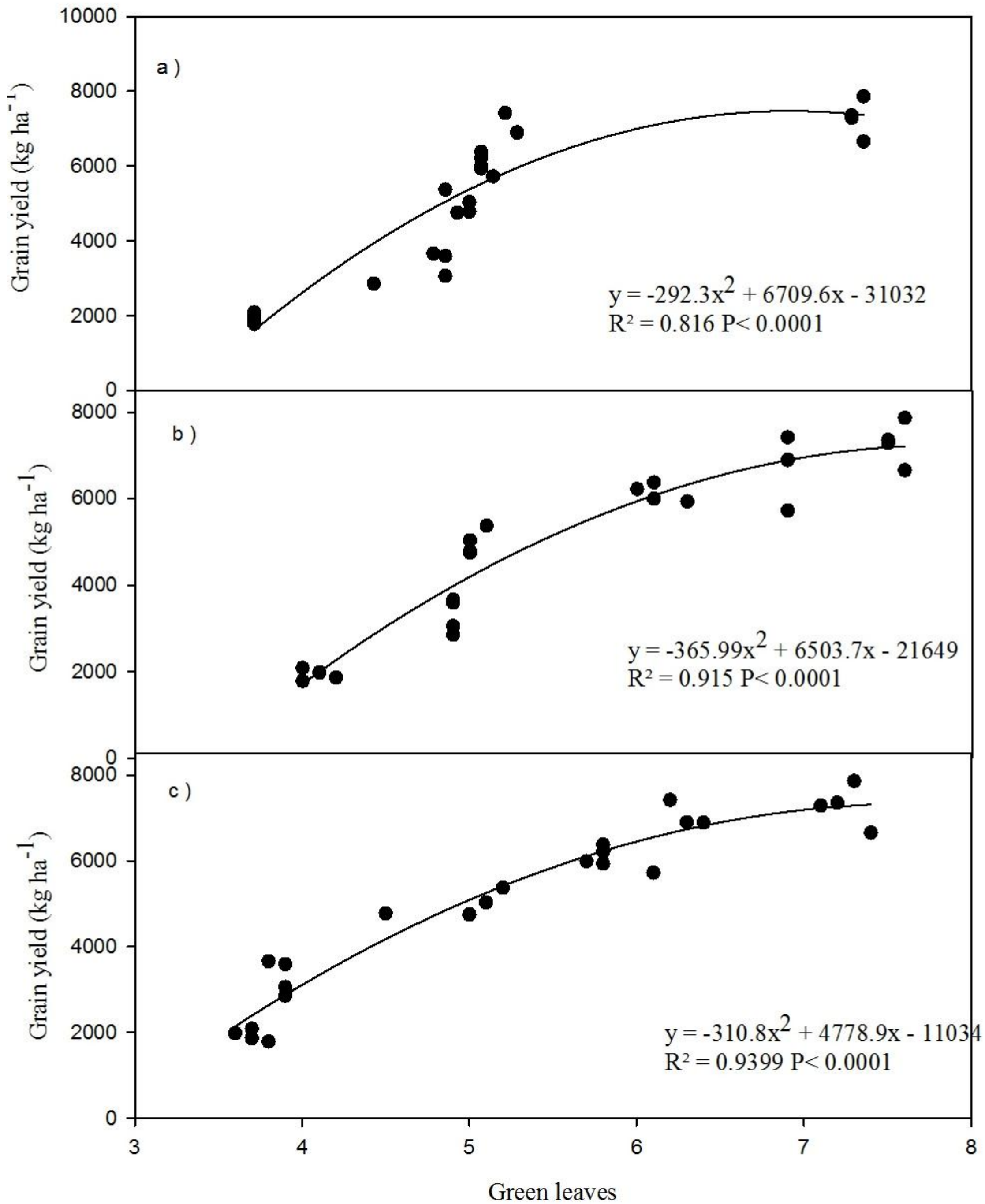


Figure 3.21 Relationship between nitrogen applied and grain yield at Ottawa in 2010

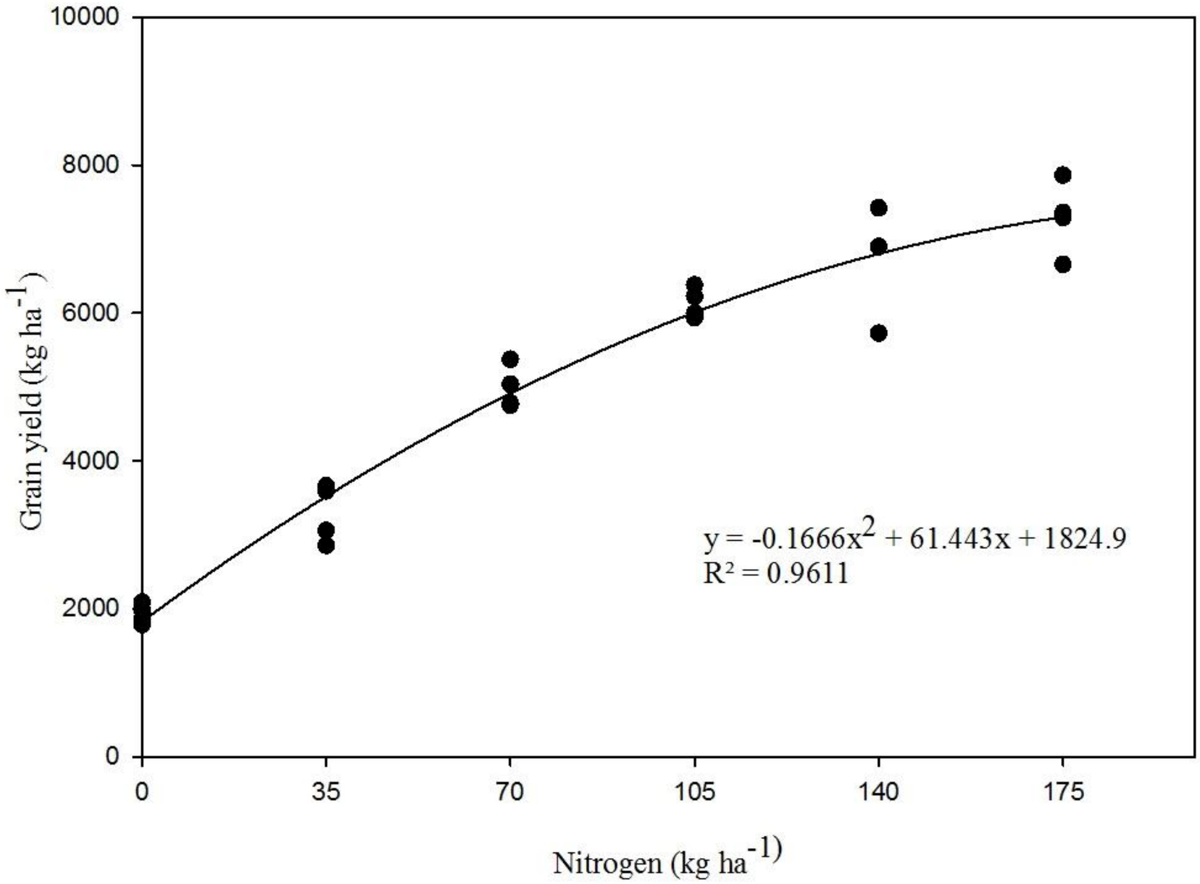


Table 3.1 Means comparisons of SPAD reading as affected by N application at Salina, Randolph and Ottawa in 2010.

N (kg ha^{-1})		Salina		Randolph			Ottawa		
	GS3†	GS4	GS6	GS3	GS4	GS6	GS3	GS4	GS6
0	31.6 f	32.1 f	29.7 b	32.5 a	33.4 d	33.2 c	34.9 e	30.0 c	29.8 b
35	35.9 e	35.3 e	40.6 a	39.2 c	38.1 c	38.3 b	39.7 d	39.4 b	40.7 a
70	41.9 d	42.4 d	42.7 a	44.1 b	43.5 b	44.1 a	43.1 c	41.4 b	42.8 a
105	43.9 c	44.9 c	43.1 a	46.0 ba	45.4 a	45.6 a	46.4 b	46.5 a	43.6 a
140	46.6 b	47.3 b	46.6 a	47.6 a	46.1 a	46.3 a	47.2 b	47.2 a	46.5 a
175	48.6 a	49.6 a	48.7 a	-	-	-	51.2 a	49.5 a	48.8 a

Means, in each column, followed by similar letters are not significant different at the 5 % probability level.

† GS3: Growing point differentiation, GS4: flag leaf, GS6: flowering

- No data recorded

Table 3.2 Means comparisons of LCC scores as affected by N application at Salina, Randolph, and Ottawa in 2010.

N (kg ha^{-1})	Salina			Randolph			Ottawa		
	GS3†	GS4	GS6	GS3	GS4	GS6	GS3	GS4	GS6
0	3.0 e	4.0 b	3.0 c	3.2 c	3.0 e	3.2 d	3.0 d	3.0 c	3.0 b
35	3.0 e	4.0 b	4.0 b	3.5 c	3.5 d	3.2 d	3.0 d	3.0 c	3.2 ba
70	4.0 d	4.4 b	4.6 a	3.7 c	4.0 c	4.0 c	4.0 c	3.0 c	3.5 ba
105	5.0 c	5.6 a	4.6 a	5.0 b	5.0 b	5.0 b	5.0 b	4.2 b	3.7 ba
140	5.6 b	5.6 a	5.0 a	5.7 a	6.0 a	5.7 a	5.2 b	4.7 a	3.8 ba
175	6.0 a	6.0 a	5.0 a	-	-	-	6.0 a	5.0 a	4.0 a

Means, in each column, followed by similar letters are not significant different at the 5 % probability level.

† GS3: Growing point differentiation, GS4: flag leaf, GS6: flowering

- No data recorded

Table 3.3 Means comparisons of number of green leaves as affected by N application at Salina, Randolph, and Ottawa in 2010

N (kg ha^{-1})	Salina			Randolph			Ottawa		
	GS3†	GS4	GS6	GS3	GS4	GS6	GS3	GS4	GS6
0	7.1 c	4.6 d	3.0 d	5.2 d	5.0 d	5.8 a	7.3 b	4.8 c	2.8 c
35	7.8 b	4.7 d	3.1 d	6.3 c	6.2 c	5.9 a	8.2 ba	5.2 c	2.9 c
70	8.1 a	5.8 c	4.2 c	6.8 b	6.3 b	6.1 a	8.2 ba	6.1 b	4.5 b
105	8.2 a	5.9 c	4.1 c	6.9 b	6.4 b	6.2 a	8.3 ba	6.6 b	5.1 ba
140	8.5 a	6.7 b	5.0 b	8.5 a	7.1 a	6.3 a	9.0 a	7.4 a	5.1 ba
175	9.2 a	7.8 a	6.0 a	-	-	-	9.1 a	7.7 a	5.5 a

Means, in each column, followed by similar letters are not significant different at the 5 % probability level.

† GS3: Growing point differentiation, GS4: flag leaf, GS6: flowering

- No data recorded

Table 3.4 Means comparisons of sorghum grain yield as affected by N application at Salina, Randolph, and Ottawa in 2010

N (kg ha^{-1})	Salina	Randolph	Ottawa
0	2365 c	4025 b	1927 e
35	3204 bc	6194 a	3290 d
70	4353 bac	6549 a	4983 c
105	5123 ba	7085 a	6131 b
140	5301 ba	6670 a	6732 ba
175	6155 a	-	7289 a

Means, in each column, followed by similar letters are not significant different at the 5 % probability level.

- No data recorded

Table 3.5. Pearson correlation between sorghum grain yield and SPAD, LCC, number of green leaves (GL) at different growth stages at Salina, Randolph, Ottawa in 2010

	Salina			Randolph			Ottawa		
	GS3†	GS4	GS6	GS3	GS4	GS6	GS3	GS4	GS6
SPAD	0.84**	0.85**	0.81**	0.75*	0.77**	0.78**	0.95**	0.91**	0.83**
LCC	0.72**	0.66*	0.76**	0.78**	0.63*	0.66*	0.80**	0.86**	0.60*
GL	0.64*	0.76**	0.84**	0.66*	0.50*	0.69*	0.76**	0.86**	0.89**

* Significance at 5%, ** Significance at 1%, GL: Number of green leaves
† GS3: Growing point differentiation, GS4: flag leaf, GS6: flowering

Table 3.6. Pearson correlation between N applied and SPAD, LCC, number of green leaves (GL) at different growth stages at Salina, Randolph, Ottawa in 2010.

	Salina			Randolph			Ottawa		
	GS3†	GS4	GS6	GS3	GS4	GS6	GS3	GS4	GS6
SPAD	0.96**	0.95**	0.76**	0.93**	0.90**	0.90**	0.63*	0.57*	0.81**
LCC	0.93**	0.73**	0.81**	0.84**	0.96**	0.97**	0.91**	0.89**	0.71**
GL	0.84**	0.91**	0.97**	0.90**	0.88**	0.98**	0.85**	0.90**	0.91**

* Significance at 5%, ** Significance at 1%, GL: Number of green leaves

† GS3: Growing point differentiation, GS4: flag leaf, GS6: flowering

Table 3.7 . Pearson correlation between sorghum grain yield and N applied at Salina, Randolph, and Ottawa in 2010

	Salina	Randolph	Ottawa
Nitrogen	0.84**	0.64*	0.96**

* Significance at 5%, ** Significance at 1%

3.9 References

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Chapter 4 - Response of Sorghum Hybrids to Nitrogen Fertilizer

4.1 Abstract

Little information is available on the response of grain sorghum genotypes to N response. Such knowledge is important for reducing the reliance upon fertilizer N. Field experiments were conducted in 2010 at Manhattan and Hays, KSU Experiment Stations evaluating the agronomic responsiveness of six sorghum hybrids to three N rates (0, 45 and 90 kg N ha^{-1}). Grain and yield was determined in all hybrids, and hybrids were differed significantly for all variables, but N rate interaction by hybrids was no significant. Nitrogen fertilizer enhanced grain yield. The results suggested that the selected sorghum hybrid did not respond differently to N.

4.2 Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is often considered the third most important cereal crop of the Great Plains region of the U.S. Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are planted on greater land area and often occupy land with greater production potential than grain sorghum. This, coupled with decreased availability and increased cost of irrigation water and nitrogen fertilizer, enhances the importance of identifying grain sorghum genotypes adapted to dryland soils with low nitrogen fertility.

It is widely accepted that differences exist both between and within species to use mineral elements efficiently for growth. Some cultivars grow well where others perform poorly or even die when subjected to mineral stresses. This differential response may be an important component of the adaptation complex that could be exploited in breeding programs to increase nutrient use efficiency, thereby, making attempts at raising agricultural productivity more specific for designated areas of the world with their unique associated problems. Our understanding of genotype by soil fertility interactions however, is rather limited especially with regard to grain sorghum and nitrogen fertility regimes. Plant growth and reproduction are not only controlled by inherent genetic mechanisms, but also by environmental factors that permit the degree of expression of these genetic capabilities. Therefore, this understanding becomes elusive as year to year; soil type to soil type, geographic region, and other variables presents themselves in the experimental data. With these environmental factors not easily controllable, the understanding of physiological and morphological parameters associated with uptake, assimilation, translocation, and deposition of N and dry matter in grain sorghum may prove valuable in selecting for genotypes more efficient in extraction and utilization of N where this nutrient would ordinarily become limiting. Because of its transitory nature in the soil, it susceptibility to leaching, its potential for becoming a pollutant, and its ever increasing cost as a production input, the efficient use of applied and residual N should receive more attention in overall management than any other plant nutrient.

Nitrogen fertility is becoming an increasingly important component in gauging the economic and environmental viability of agro ecosystems. Leaching losses of N fertilizer are an economical problem for farmers and pose environmental concerns for the general public. There is, therefore, the need to have crop plants that will use fertilizer and soil N more efficienly for grain production. Nitrogen deficiency can result in reduced dry matter, crude protein and grain yield (Jarvis, 1996; Ashiono et al., 2005). Soil nutrients become depleted due to leaching of nitrogen, soil erosion and removal by crops (Zobeck et al., 2000).

Landrace cultivars that have adapted to low N environments may possess different stress-coping mechanisms than do domesticated cultivars developed in contemporary breeding programs (Pearson, 1985). Higher rates of N fertilizer have been found to increase grain N content and grain yield in grain sorghum. Genotypes with differences in grain yield potential may have differences in N accumulation and NUE (Sinclair and de Wit, 1995).

Further comparisons are needed among sorghum cultivars from diverse selection environments to determine their mechanisms of coping with limited supplies of N. The objective was to evaluate the agronomic responsiveness of grain sorghum hybrids to N fertilizer under dryland conditions, and if selection for high N responsiveness alters responsiveness to applied N.

4.3 Materials and Methods

4.3.1 Plant Material

Six grain sorghum hybrids (23012, 26056, CSR1114R45, Tx3042Tx2737, 99480, 95207) were evaluated in 2010 at Kansas State University Experiment Stations (Ashland Bottoms and Hays, KS)

4.3.2 Experimental Site

The experiments sites were located in Unit 7 at Ashland Bottoms (37^{o}11'12"N lat.; 99^{o}46'9"W long) during 2010-2011 and Hays (38^{o}52'46" N lat.; 99^{o}19'20" W long). Total average rainfall at Manhattan was 83.3 mm and 48.4 mm at Hays. The monthly maximum temperature average during the crop growing season (May to October) was 26.6^{o}C at Manhattan and 26.3^{o}C at Hays.

4.3.3 Crop Husbandry

The experiments were conducted in a randomized complete block design with four replications. The experiments were a split plot arrangement of a randomized complete block design with four replications. Whole plot treatments were three N rates of 0, 45 and 90 kg N ha^{-1} applied as granular urea (46 % N) in a broadcast application approximately at emergence. Split plots were six hybrids. Each sub plot consisted of four rows, spaced 0.75 cm apart and 6.0 m long. Plants were thinned by hand after emergence, approximate plant population of 140000 plants ha^{-1}. Weeds were controlled with pre-emergence herbicide, at Manhattan (Callisto at 0.37 L ha^{-1} and Bicep at 2.75 L ha^{-1}) and at Hays (Atrazine at the rate of 2.9 L ha^{-1} and Bicep at the rate of 3.3 L ha^{-1}).

Maximum day and minimum night time air temperatures during the same growing season were 28.9 and 12^oC, respectively. The normal (1971-2000) daily maximum and minimum air temperature for the period was 26.1^oC and 11.8^oC.

4.3.4. Data Collection

4.3.4.1 Soil and Plant Sampling and Analyses

At each location a composite soil sample was taken from each replication to a depth of 15 cm for pH, available phosphorus (P), exchangeable potassium (K), soil organic matter (SOM) and a depth of 60 cm for profile ammonium and nitrate. Sampling was done using a hand probe, and samples consisted of 12 to 15 individual cores composited to form an individual composite sample. Analysis was done at the KSU Soil Testing lab using procedures described in Recommended Chemical Soil Testing Procedures for the North Central Region NCRR Publication no. 221 (1998). The soil at Manhattan (Unit 7) was a silty clay loam having a pH of 6.2, nitrate-N (NO_3-N) of 2.0 mg kg^{-1}, NH_4-N of 3.0 mg kg $^{-1}$, Bray P of 81 mg kg^{-1},organic matter content of 2.6%, Cl^- of 6.2 mg kg^{-1} and S of 5.8 mg kg^{-1}. The soil at Hays was a silty loam having a pH of 6, nitrate-N (NO_3-N) of 7.6 $mgkg^{-1}$, NH_4-N of 2.3 mg kg $^{-1}$, Bray P of 61.4 mg kg^{-1}, Organic matter content of 1.8%, Cl^- of 3.4 mg $^{-1}$ and S of 3.9 mg kg^{-1}. Measurements of plant nitrogen were made to document the relative effectiveness of each treatment. To determine the concentrations of N, the samples were digested using a sulfuric acid-hydrogen peroxide digest. The extract containing ammonia was analyzed by a colorimetric procedure (nitropruside-sodium hypochlorite) using RFA Methodology No. A303-S072.

4.3.4.2 Grain Yield

Plots were hand harvested by marking 5.3-m of plot and collecting all of the panicle in both rows of this area. The hand harvested sorghum was thrashed using an Almaco mechanical thrasher; a grain sample was collected for each plot to determine grain and grain moisture. Yield data were recorded at harvest and grain samples were collected to measure grain N content. Nitrogen in the grain was determined by collecting a representative sub sample from each plot, drying, grinding, and analyzing for total N. All soil analysis was done by the KSU Soil Testing Laboratory.

4.4. Data Analyses

Data were analyzed using SAS version 9.1 with proc GLM using an alpha level of 0.05 using LSD test, genotypes were compared within group as response to N applied.

4.5 Results

Ashland (Unit 7)

Nitrogen fertilizer rate and sorghum hybrids effect for various yield and N content parameter are presented in Table 4.1. Genotypes differences were found for all variables, no N rates by genotype interaction effects were significant (Table 4.4).

The hybrid 99480 had the highest grain yield (7914 kg ha^{-1}) followed by CSR1114R (7278 kg ha^{-1}) (Table 4.1). The lowest yield was obtained by hybrid 95207 (5505 kg ha^{-1}). There was no response of sorghum genotypes to N application for grain yield (Table 4.2). Grain yield increase was a numerical increase from 0 to 90 kg ha^{-1} applied N. The 90 kg ha^{-1} N rate generally produced significantly higher grain yields than the other rates (Table 4.2). The highest yield was obtained with 90 kg N ha^{-1}.

Hays

Tests of significance for N fertilizer rate and sorghum hybrids effect for various yield and N content parameter are presented in Table 4.1. Genotypes differences were found for all variables, no N rates by genotype interaction effects were significant (Table 4.4).

The effect of sorghum genotypes averaged across N rates on grain yield is presented in Table 4.1. The hybrid 99480 had the highest grain yield (5250 kg ha^{-1}) followed by hybrid 26056 (5230 kg ha^{-1}) (Table 4.1). The lowest yield was obtained by hybrid 95207 (3750 kg ha^{-1}). There was no response of sorghum genotypes to N application for grain yield (Table 4.2). Grain yield increase was a numerical increase from 0 to 90 kg ha^{-1} applied N. The 90 kg ha^{-1} N rate generally produced significantly higher grain yields than the other rates (Table 4.2). The highest yield was obtained with 90 kg N ha^{-1} (4586 kg ha^{-1}) and the lowest with 0 kg N ha^{-1} (4276 kg ha^{-1}).

4.6 Discussion

Seasonal variation rainfall and distribution of rain at both locations was partly responsible during the growing season for differences in many parameters measured (Fig. 4.1).

Sorghum genotypes responded positively to N fertilizer application even though N rate did not influence sorghum yield at both locations. The depletion of inorganic NO_3^- by previous crop at Manhattan and leaching at Hays without N was sufficient to lower total soil N enough that sorghums did not respond to N additions but maximum sorghum yields were attained. In general the 90 kg ha^{-1} of N rate was superior to the lower rates. The higher N rates increased N contents in the genotypes. Eghball and Maranville (1993) found that the mean N influx of maize increased with increasing soil N supply. Dhugga and Waines (1989) showed that genotypes with high yield potential accumulated more N than genotypes with less yield potential. Nitrogen accumulation influences NUE values.

4.7 Conclusions

In general, application of N fertilizer will be effective in term of crop utilization and sustainable productivity. Raising the N rates from 0 to 90 kg ha^{-1} did not result in corresponding increase in grain yield to merit the extra production in the group of hybrid and site locations. The results from these studies indicated that genotypes 99480, CRS1114R, 23012 and 26506 can be selected for response to N. Further testing of these hybrids at different locations and fields for multiple years is necessary to draw any strong conclusions.

4.8 Tables and Figures

Figure 4.1 Daily maximum and minimum mean air temperatures and rainfall from May to October at Hays, KS in 2010

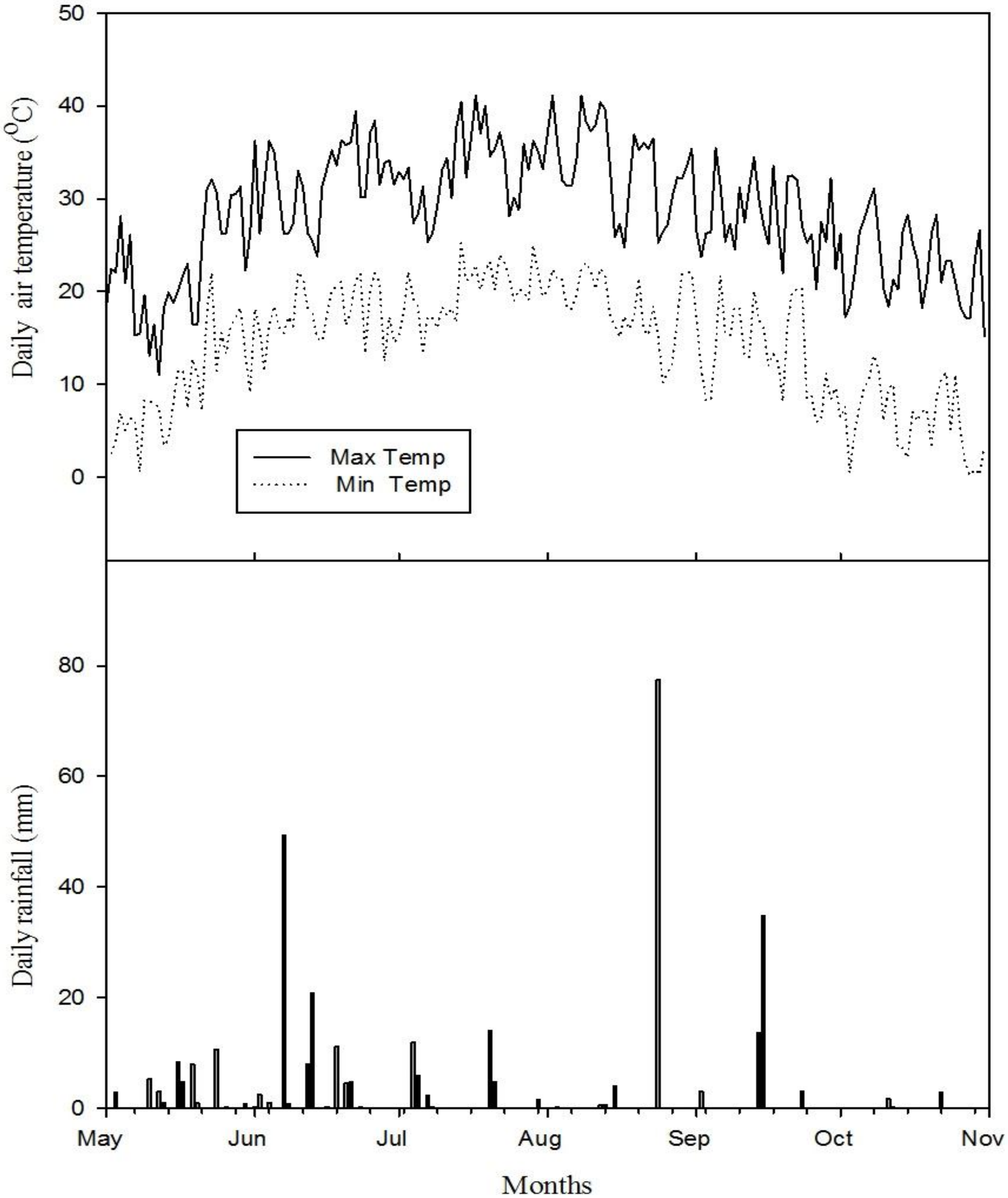

Figure 4.2 Daily maximum and minimum mean air temperatures and rainfall from May to October at Manhattan, KS in 2011

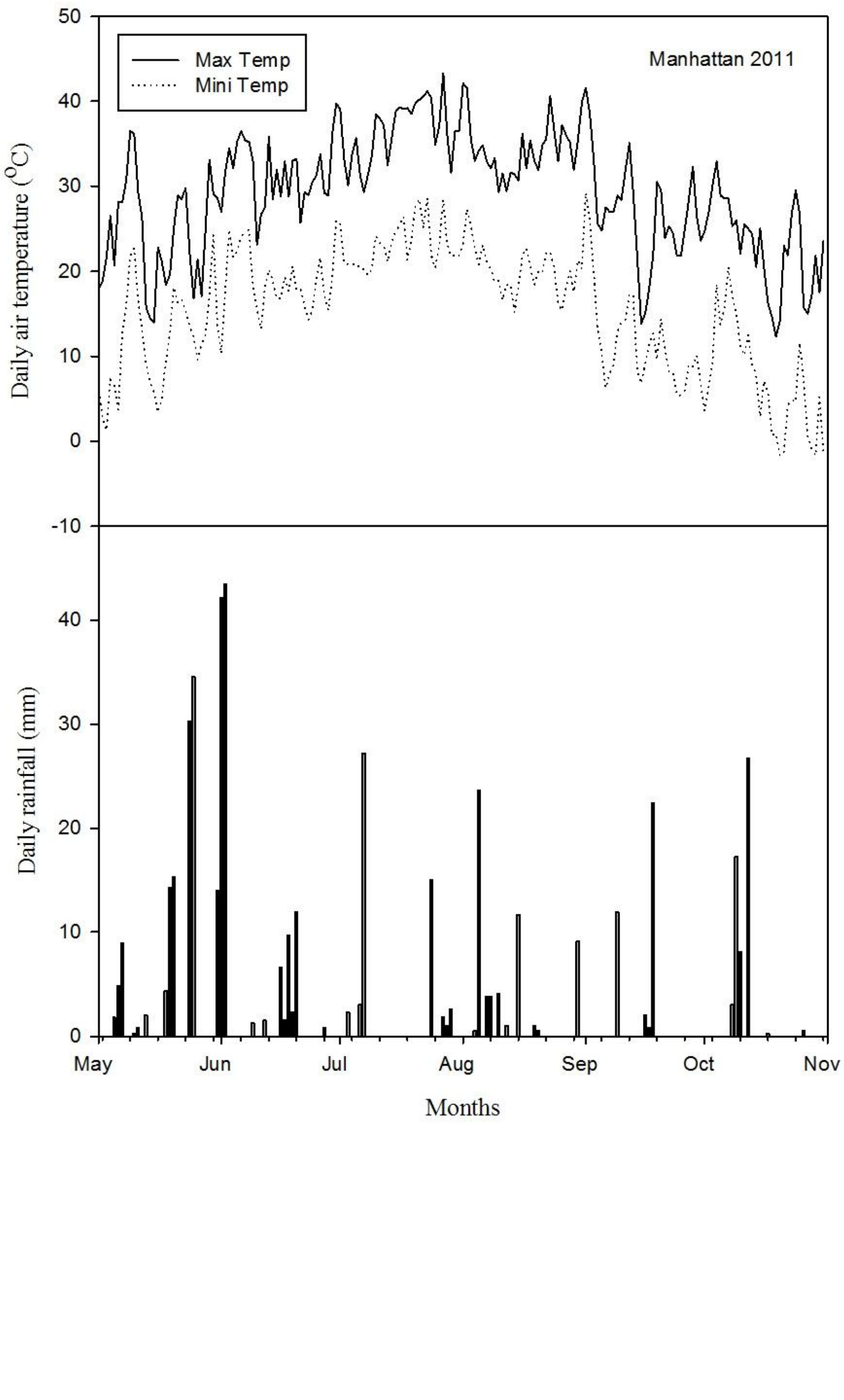

Table 4.1 Genotype comparisons for grain yield averaged across N rates at Ashland and Hays in 2010

	Yield (kg ha^{-1})	
Hybrids	**Manhattan**	**Hays**
99480	7913a	5250 a
CSR1114R	7277 ba	4469 b
23012	7033 ab	4054bc
26056	6718 bc	5230 a
Tx 3042/Tx2737	6389 c	4033 bc
95207	5505 d	3750 c

Means in the same column followed by the same letter are not significantly different P=0.05.

Table 4.2 Analysis of variance of grain yield as affected by N rate at Ashland and Hays in 2010

Source	**Manhattan**	**Hays**
Genotypes (G)	**	**
Nitrogen (N)	NS	NS
GxN	NS	NS

** Significant at 0.01   NS Non-significant

Table 4.3 Means comparisons of sorghum grain yield as affected by N fertilizer application at Ashland and Hays in 2010

	Yield (kg ha^{-1})	
N rates (kg ha^{-1})	Ashland	Hays
0	6710 a	4275a
45	6792 a	4532 a
90	6916 a	4585 a

Means in the same column followed by the same letter are not significantly different P=0.05.

4.8 References

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Chapter 5 - Yield Response and Economic Analyses of Variables - Rate Nitrogen Applications

5.1 Introduction

Nutrient input from chemical fertilizers is needed to replace nutrients which are exported and lost during cropping to maintain a positive nutrient balance. However, because of scarcity and high cost, many smallholder farmers in developing countries rarely use inorganic fertilizers on food crop including sorghum. Subsistence farming in these countries is thus characterized by low external input, low crop yield, food insecurity (Stoorvogel et al., 1993; Rhodes, 1995; Mafongoya et al., 2006). The limited amounts of fertilizer available need to be used judiciously for maximum benefit. Since a majority of these farmers have low income, the technical package to increase and sustain agricultural production must be affordable, profitable and applicable to ensure their acceptability.

Getting maximum profitability lies not only in reducing use of N per unit area but also in lowering costs per unit crop production through higher yields. Therefore, economic analysis is required for making recommendations to farmers from agronomic experiments. Farmers in developing areas are profit-oriented, and therefore, they are interested in net returns rather than the gross returns. In practice, not all farmers, however, can aim for the largest net returns because of the generally larger costs involved to other risks associated with farming.

Good management is a crucial factor in the success for any farmers. Farms are no exceptions. To be successful farmers today need to spend more time making management decisions and developing management skills. This is because production agriculture in the USA and other countries is changing along the following lines: more mechanization, increasing farm size, continued adoption of new technologies, growing capital investment per worker. Many of the day-to-day management decisions made by farmers are really adjustments to, or fine-tuning of, an existing farm plan. These adjustment decisions often affect revenue and expenses.

A convenient and practical method for analyzing the profit potential of these partial changes in the overall farm plan is the use of a partial budget (Ronald et al., 2004). A partial budget provides a formal and consistent method for calculating the expected change in profit from a proposed change in the farm.

Many studies have shown that leaf color scores were strongly correlated to nitrogen application. The statistical significant treatments of this experiment were subjected to economic analysis using the partial budget procedure to determine the N level that is the most profitable to farmers. Therefore the objectives (1) to develop several version of the partial budget (2) to compare profit (3) to develop a visual tool in relation to leaf color in order to indicate whether to increase fertilizer or not, and how much.

5.2 Materials and Methods

The sorghum yields from previous study at Salina, Randolph and Ottawa were used for economic analyses. The nitrogen curves had shown that the optimum yield were obtained with 70 kg N ha^{-1} at Randolph and 175 kg N ha^{-1} at Salina and Ottawa. Economic analyses were done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested. All cost and benefits were calculated based on Kansas State Research and Extension Service Common Rates.

5.2.1 Revenues

- Means grain yield is the average predicted yield (kg ha^{-1}) of each treatment.

- The Gross Return (GR) per hectare or Revenue is the product of field price of sorghum:

  Q x P

  Q = yield in kg sorghum, and P = market sorghum price

  The average price that is the national (US) price was used for all calculation, however each location had different price called local prices.

5.2.2 Cost

- The Cost Variable (VC) of cultivation of sorghum was calculated on the basis of different operations performed and materials used for raising the crops, including (land preparation, plowing, weeding, fertilization, harvest, transport, seeds).
- Like sorghum price, the standard national was used to calculate fertilizer prices, even though each location had it had a local price and these alternative prices would affect le gross return by localities (Tables 5.1, and 5.2).

  Source: (Department of Agricultural Economics: Kansas State University Agricultural Experimental Station and Cooperative Extension Service, December 2011).

5.2.3 Net Returns

- Profitability

The profitability or net return per hectare for each treatment is the difference between the gross return and the variable costs.

Net Return = GR-VC, where GR= gross return, and VC = variable cost

- Marginal rate of return

For each pair of treatments, a percent marginal rate return (MRR) was calculated. The % MRR between any pair of treatments denotes the return per unit of investment in fertilizer expressed as a percentage. To obtain an estimate of these returns calculated the MRR, which was given by the following formulas:

MRR = Change in net return (NR_2-NR_1) / Change in VC_2-VC_1

5.2.4 Sensitivity Analyses

In sensitivity analyses local market prices are important so we need to take those into consideration. It is often difficult to estimate the average prices and yields needed in a partial budget. Estimation is particularly difficult if the budget projects well into the future. Sensitivity analyses consisted of doing the budget computations several times and also using low, average, and high prices for sorghum and fertilizer in a different partial budget (e.g., Tables 5.9, 5.10, 5.11) for each location.

5.2.5 Development of the Chart Tool

A visual chart was developed based on price of sorghum, prices of fertilizer and the percent rate of return by location. That visual tool will assist farmers by making decision whether to add or fertilizer based on market price.

5.3 Results

5.3.1 Environmental Factors

Weather in 2010 had a significant effect on sorghum production at all locations. The site of Salina experienced several sequential periods of high rainfall, which together with the poor drainage of the Crete silt loam created exceptionally favorable conditions for denitrification. The economic optimum was reached at 140 N kg ha^{-1}. At Randolph and Ottawa experienced wet conditions early but suffered from late season heat and drought stress. The economic optimum were reached at 70 kg N ha^{-1} at Randolph and 140 kg N ha^{-1} at Ottawa.

5.3.2 Net Return

Salina

The results of the partial budgets of fertlizer N levels are presented in Table 5.3. In increasing order of total costs that vary, the fertilizer N levels could be ranked as 0, 35, 70, 105, 140 and 175 N kg ha^{-1}. All treatments had positive benefits across N level. Fertilzer N levels 35,70, 105, 140, and 175 N kg ha^{-1} gave gross benefits that were greater than those of control (0 N). The net benefits (or returns) ranged from 299.65 (0 kg N ha^{-1}) to 880.65 \$/ha (175 kg N ha^{-1}). The marginal rate of return between no fertilizer treatment (farmer' practice) and 35 N kg ha^{-1} was positive and greater than that of 70, 105, 140 kg N ha^{-1} and negative at 175 N kg ha^{-1} treaments.

Randolph

The results of partial budgets of fertlizer N levels are presented in Table 5.4. In increasing order of total costs that vary, the fertilizer N levels could be ranked as 0, 35, 70, 105 and 140 N kg ha^{-1}. All treatments had positive benefits up to 70 kg N ha^{-1} and negative benefit at 105 , 140 N kg ha^{-1}. Fertilzer N levels 35, 70, 105, 140 N kg ha^{-1} gave gross benefits that were greater than those of control (0 N). The net benefits ranged from 716.91(0 kg N ha^{-1}) to 857.98 \$/ha (140 kg N ha^{-1}). The marginal rate of return between no fertilizer treatment (farmer' practice) and 35 N kg ha^{-1} was higher (47%) than that of 70 kg ha^{-1} (13%) where for N rate of 105, 140 kg N ha^{-1} the marginal return was negative (-5 and -24%; respectively).

Ottawa

The results of the partial budgets of fertlizer N levels are presented in Table 5.5. In increasing order of total costs that vary, the fertilizer N levels could be ranked as 0, 35, 70, 105, 140, and 175 N kg ha^{-1}. All treatments had positive benefits across N level. Fertilzer N levels 35,70, 105, 140, and 175 N kg ha^{-1} gave gross benefits that were greater than those of control (0 N). The net benefits ranged from 206.39 (0 kg N ha^{-1}) to 1138.1 $/ ha (175 kg N ha^{-1}). The marginal rate of return between no fertilizer treatment (farmer' practice) and 35 N kg ha^{-1} was higher (169%) than that of 70 (49%) 105 (22%) 140 (9%) and 175 (1%) kg N ha^{-1}.

5.3.23 Sensitivity Analyses

At Salina by increasing the prices of sorghum by 10% from 0.219 $ kg^{-1} to 0.251 $ kg^{-1} and also the prices of fertilizer the maximum return was obtained with 140 kg N ha^{-1} and remained negative for any increased of fertilizer prices with changes of sorghum prices (Table 5.7). At Randolph the maximum return was obtained with 70 kg N ha^{-1} for all combinations and were negative with changes of sorghum prices and fertilizer prices (Table 5.8). At Ottawa the maximum return was obtained with 175 kg N ha^{-1} but became negative if the prices of fertilizer increased with lower prices of sorghum (Table 5.9).

5.3.4 Development of The Chart Tool

The objective is to develop a simple tool to help farmers to determine the most profitable fertilizer level by combining the information's from the partial budget with the color chart. We summarize the profitability depending on location (Fig.5.2). At Salina and Ottawa the profitability can be achieved by adding fertilizer in second application up to 175 kg N ha^{-1} and can still be profitable. By contrast farmers at Randolph would lose profit by adding more N. Beyond this information has been translated in fertilizer recommendation for each location (Tables 5.6, 5.7, 5.8). These tools provide farmers a simple decisions aid to determine whether it is profitable to add additional fertilizer. These steps involved are: (1) farmers compared leaf color to the chart; (2) determine the price of sorghum; and (3) farmers compare fertilizer price to market price to determine optimum fertilizer application. This tool can also help farmers prevent over use of fertilizer or under use and help maximize profits and also protect environment impacts of excess N.

5.4 Conclusion

Crop production costs per unit and net returns are highly depending on yields. Partial budgets are easy to use, require minimal data, and are readily adaptable to many types of management decisions. However, partial budgeting does have some limitations. It can only compare the present management plan with one alternative at a time. This requires many budgets when there are many alternatives to consider. Partial budget can still be used in this situation but it is time cosuming. The data in partial budgets are expected average annual changes in economic revenue and expenses. While an alternative may increase profit based on average changes there are other factors to consider when the changes are not constant from year to year. A partial budget should include appropriate opportunity costs to account for all economic costs. The expected change in net profit must be adjusted for any opportunity cost include in its calculation to find the expected change in accounting profit. The following estimated budget which are intended to represented expected yield from land of varying quality for a given level of management. Comparing alternative expected yields can help producers analyze the profitability of crop on farmland with varying yield potential. In customizing a budget to your farm, attention should be given also to using land values representative of your farm's productive capacity as well farm-specific cost.

5.5 Figures and Tables

Figure 5.1. Nitrogen curve at Salina, Randolph and Ottawa in 2010.

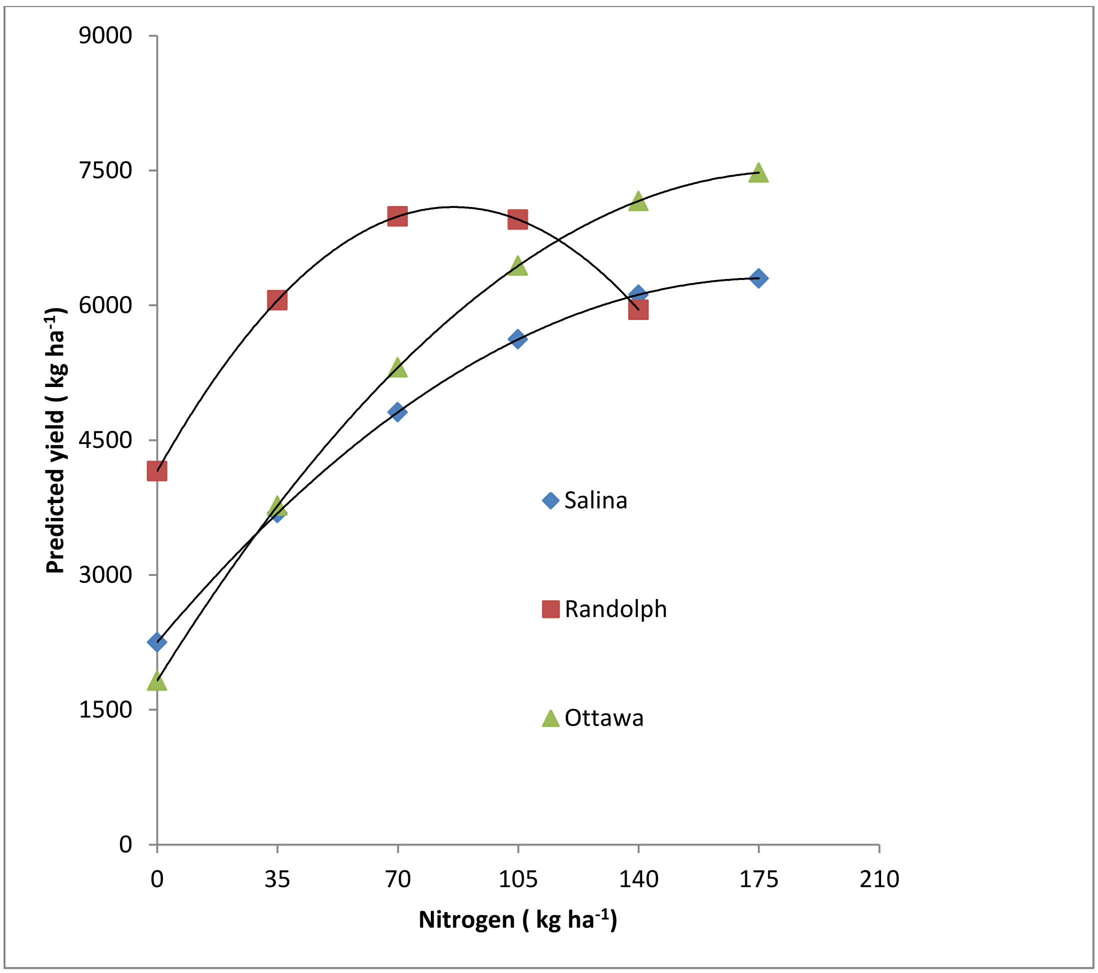

Table 5.1 Production inputs - grain sorghum.

Item	Units	Custom Price
Sorghum price	$ / kg	0.219
Seeds	$/ kg	19.80
Herbicides	$/ ha	45.74
N (Urea)	$/kg	1.5
Field cultivation	$/ha	23.49
Ploughing	$/ha	34.18
Fertilization	$/ha	13.26
Harvest	$/ha	53.41
Transport	$/kg	0.0074

Source: KSU Agricultural Experiment Station and Cooperative Extension Service MF-574

Table 5.2 Economic Analyses at Salina in 2010.

Items	Nitrogen level (kg ha^{-1})					
	0	35	70	105	140	175
Yield (kg ha^{-1})	2250.80	3687.80	4811.2	5620.19	6117.18	6299.78
Price of sorghum	0.22	0.22	0.22	0.22	0.22	0.22
Revenue (US$)	**492.92**	**807.62**	**1053.65**	**1230.99**	**1339.66**	**1379.64**
Cost Per Hectare						
Seed	19.80	19.80	19.80	19.80	19.80	19.80
Herbicide/Fungicide	45.74	45.74	45.74	45.74	45.74	45.74
N (Urea) cost	0.00	52.50	105.00	157.50	210.00	262.50
Land preparation	23.49	23.49	23.49	23.49	23.49	23.49
Plowing	34.18	34.18	34.18	34.18	34.18	34.18
Fertilization	0.00	13.26	13.26	13.26	13.26	13.26
Harvest	53.41	53.41	53.41	53.41	53.41	53.41
Transport	16.65	27.36	35.60	41.59	45.26	46.61
Total Cost	**193.27**	**269.74**	**330.48**	**388.97**	**445.14**	**498.99**
Net Return	299.65	537.88	723.17	842.02	894.52	880.65
Marginal Rate Return (%)		**79%**	**34%**	**16%**	**6%**	**-2%**

Table 5.3 Economic Analyses at Randolph in 2010.

Items	Nitrogen levels (kg ha^{-1})				
	0	35	70	105	140
Yield (kg ha^{-1})	4156.10	6056.28	6988.72	6953.40	5950.34
Price of sorghum	0.22	0.22	0.22	0.22	0.22
Revenue (US$)	**910.18**	**1326.32**	**1530.52**	**1522.79**	**1303.12**
Cost Per Hectare					
Seed	19.80	19.80	19.80	19.80	19.80
Herbicide/Fungicide	45.74	45.74	45.74	45.74	45.74
N (Urea) cost	0.00	52.50	105.00	157.50	210.00
Land preparation	23.49	23.49	23.49	23.49	23.49
Plowing	34.18	34.18	34.18	34.18	34.18
Fertilization	0.00	13.26	13.26	13.26	13.26
Harvest	53.41	53.41	53.41	53.41	53.41
Transport	16.65	27.36	35.60	41.59	45.26
Total Cost	193.27	269.74	330.48	388.97	445.14
Net Return	**716.91**	**1056.58**	**1200.04**	**1133.82**	**857.98**
Marginal Rate Return (%)		**47%**	**13%**	**-5%**	**-24%**

Table 5.4 Economic Analyses at Ottawa in 2010.

Items	Nitrogen levels (kg ha^{-1})					
	0	35	70	105	140	**175**
Yield (kg ha^{-1})	1824.90	3771.31	5309.57	6439.34	7161.14	7475.30
Price of sorghum	0.219	0.219	0.219	0.219	0.219	0.219
Revenue (US$)	**399.65**	**825.91**	**1162.79**	**1410.21**	**1568.28**	**1637.09**
Cost Per Hectare						
Seed	19.80	19.80	19.80	19.80	19.80	19.80
Herbicide/Fungicide	45.74	45.74	45.74	45.74	45.74	45.74
N (Urea) cost	0.00	52.50	105.00	157.50	210.00	262.50
Land preparation	23.49	23.49	23.49	23.49	23.49	23.49
Plowing	34.18	34.18	34.18	34.18	34.18	34.18
Fertilization	0.00	13.26	13.26	13.26	13.26	13.26
Harvest	53.41	53.41	53.41	53.41	53.41	53.41
Transport	16.65	27.36	35.60	41.59	45.26	46.61
Total Cost	**193.27**	**269.74**	**330.48**	**388.97**	**445.14**	**498.99**
Net Return	**206.39**	**556.17**	**832.31**	**1021.24**	**1123.14**	**1138.10**
Marginal Rate Return (%)		**169%**	**49%**	**22%**	**9%**	**1%**

Table 5.5 Rate of nitrogen to be added based on visual score, sorghum price and nitrogen price at Salina, Ottawa and Randolph in 2010.

Salina

Sorghum price = $ 0.219 kg^{-1}

N price	Dark Yellow	Yellow	Yellowish Green	Light Green	Green	Dark Green
			(kg N ha^{-1})			
1.5	140	105	70	35	0	0
1.65	140	105	70	35	0	0
1.80	140	105	70	35	0	0
1.95	140	105	70	35	0	0

Ottawa

N price	Dark Yellow	Yellow	Yellowish Green	Light Green	Green	Dark Green
			(kg N ha^{-1})			
1.5	175	140	105	70	35	0
1.65	175	140	105	70	35	0
1.80	175	140	105	70	35	0
1.95	175	140	105	70	35	0

Randolph

N price	Yellow	Yellowish Green	Light Green	Green	Dark Green
			(kg N ha^{-1})		
1.5	70	35	0	0	0
1.65	70	35	0	0	0
1.80	70	35	0	0	0
1.95	70	35	0	0	0

Table 5.6 Sensibility analyses of marginal rate percent of return based on visual score at Salina. Y=Yellow; Y-G = Yellowish Green; L-G = Light Green; G = Green; and D-G: Dark Green

Sorghum price : 0.219 $/ kg

Color Chart	Y	Y-G	L-G	G	D-G
N prices (US$)	Marginal rate of return (%)				
1.5	77	36	17	6	**-2**
1.65	73	34	15	4	**-5**
1.80	67	32	13	2	**-7**
1.95	62	30	12	0	**-10**

Sorghum price: 0.230 $/ kg

Color Chart	Y	Y-G	L-G	G	D-G
N prices (US$)	Marginal rate of return (%)				
1.5	73	35	17	6	**-2**
1.65	69	33	15	5	**-3**
1.80	65	32	14	3	**-5**
1.95	61	30	13	2	**-7**

Sorghum price : 0.251 $/ kg

Color Chart	Y	Y-G	L-G	G	D-G
N prices (US$)	Marginal rate of return (%)				
1.5	71	34	17	6	**-1**
1.65	67	33	15	5	**-2**
1.80	63	32	14	4	**-4**
1.95	60	30	13	3	**-6**

Table 5.7 Sensibility analyses of marginal rate percent of return based on visual score at Randolph. Y=Yellow; Y-G = Yellowish Green; L-G = Light Green; G = Green; and D-G: Dark Green

Sorghum price: 0.219 $/ kg

Color Chart	Y	Y-G	L-G	G
N prices (US$)		Marginal rate of return (%)		
1.5	52	13	**-7**	**-2**
1.65	50	12	**-8**	**-29**
1.80	48	11	**-9**	**-32**
1.95	46	10	**-11**	**-35**

Sorghum price: 0.230 $/ kg

Color Chart	Y	Y-G	L-G	G
N prices (US$)		Marginal rate of return (%)		
1.5	51	14	**-6**	**-25**
1.65	49	13	**-7**	**-27**
1.80	47	11	**-8**	**-29**
1.95	45	10	**-10**	**-32**

Sorghum price: 0.251 $/ kg

Color Chart	Y	Y-G	L-G	G
N prices (US$)		Marginal rate of return (%)		
1.5	50	14	**-5**	**-24**
1.65	49	13	**-6**	**-25**
1.80	47	12	**-7**	**-27**

1.95	46	11	**-8**	**-29**

Table 5.8 Sensibility analyses of marginal rate percent of return based on visual score at Ottawa. Y=Yellow; Y-G = Yellowish Green; L-G = Light Green; G = Green; and D-G: Dark Green

Sorghum price: 0.219 $/ kg

Color Chart	Y	Y-G	L-G	G	D-G
N prices (US$)			Marginal rate of return (%)		
1.5	231	52	23	10	1
1.65	222	51	22	9	**-1**
1.80	212	50	21	7	**-2**
1.95	203	48	20	6	**-4**

Sorghum price: 0.230 $/ kg

Color Chart	Y	Y-G	L-G	G	D-G
N prices (US$)			Marginal rate of return (%)		
1.5	202	51	23	10	1
1.65	195	49	22	9	0
1.80	188	48	21	8	**-1**
1.95	179	47	20	7	**-3**

Sorghum price: 0.251 $/ kg

Color Chart	Y	Y-G	L-G	G	D-G
N prices (US$)			Marginal rate of return (%)		
1.5	184	49	23	10	2
1.65	178	48	22	9	1
1.80	173	47	21	8	0
1.95	167	46	20	8	**-2**

Chapter 6 - General Summary and Future Direction

The objectives of this present study were to (i) optimize sorghum production by determining the best management practices (planting date, row spacing, seeding rate, hybrid maturity) for growth and yield and (ii) to evaluate the agronomic responsiveness of grain sorghum genotypes to N fertilizer and to develop a partial financial budget return to N fertilizer application based on best management practices. These results were presented in five chapters (Chapters 2 through 5). The summary points from each of those chapters are listed below:

Chapter 2:

- Sorghum establishment, plant growth and yield are highly depending on date of planting.
- The early planting (May) resulted in greater yield across all locations when compared to later planting (June).
- Higher yields for early planting may be due to avoidance of stress events (drought and/high temperatures) that occur in late summer and minimize the risk associated with crop damage and yield losses.
- Later planting can lead to exposed to warmer temperatures and longer periods of drought during reproductive stages of crop development, thus resulting in lower yield. In addition, later planted crop may also be exposed to cooler temperature during maturity and cause problems with crop drying.
- Dry matter production and yield in the dryer year were greater for the wider rows, while in the other years 2009 and 2010 narrower (25 cm) rows planted produced higher dry matter and yield.

- Leaf area index was generally higher with equidistant narrow row spacing (25 cm) when compared to wider rows (75 cm).
- Light intercepted was greater in narrower rows (25 cm) than in wider rows (75 cm) at all locations.
- Plants compete for light, water and nutrients. Increasing seeding rate means fewer resources per plant, decreased panicles per plant, number of grains per panicle.
- Seeding rates of 80000 plant ha^{-1} came close to maximizing yield with May planting, but 110000 or more seeds ha^{-1} were required with June planting.
- Planting sorghum under good conditions to attain a final plant population of 80000 to 110000 plants ha^{-1} should be the goal when planting for the highest yields under dry-land farming system (rows 25 cm apart and possibly early planting in May).
- Grain sorghum response to planting date, hybrid maturity, row spacing, and seeding rate depended on year and location, indicating that recommendations should be specific to each definable environment.

Chapter 3:

- The simultaneous optimization of grain sorghum yield and N use is possible by matching N supply with crop N demand. In many field situations, more than 60% of applied N is lost, due in part to the lack of synchrony of plant N demand with N supply. Results presented in this study provide the evidence that current fertilizer N recommendation at fixed time N (mostly before or at the time of planting) are not adequate for maintaining the yields and efficient use of N in sorghum. Thus, in season N application methods should be identified, tested and used.

- Since SPAD readings are closely related to leaf N concentration, the SPAD meter can be used to monitor the N status of sorghum and thereby to adjust the rates of N fertilization in order to increase NUE.
- The LCC based N management assure high yields consistent with efficient N use in sorghum and can enhances total productivity and farmer's profit. Simple and easy to use tools that can help farmers manage N judiciously.
- The leaf ratings have potential to serve as a quick, inexpensive means of assessing the N status and potentially could be used to guide late season N application.
- The leaf ratings may actually be better tools to guide late season application than the traditional leaf N content, commonly used to access mid-season N status.
- However, additional work need to be done to determine if visually leaf ratings can be both correlated to N status over a broad range of soil and genetic families, and calibrated to provide N rates guidance.
- Future studies can compare the efficiency; labor use, cost, and profit of improve N management strategies. Improved split N can be experienced using LCC allowing the farmers to apply N as needed by the plant.

Chapter 4:

- Increasing N rates from 0 to 90 kg ha^{-1} did not result in significant increase in grain yield. This lack of response could be due to residual N in the fields, and environmental conditions that increases N losses (such as leaching, de-nitrification).

- All hybrids did not respond to N application as there was no N by hybrid interaction. However, there were large differences among sorghum hybrids for grain yield.
- Greater grain yields were generally observed in hybrids 99480 and CSR1114R. As there was no response of hybrids to N, further studies on these hybrids at different locations and fields and environments for multiple years is necessary to draw any strong conclusions.

Chapter 5:

- Crop production costs per unit and net returns are highly depending on yield. Partial budgets are easy to use, require minimal data, and are readily adaptable to many types of management decisions.
- Partial budgeting does have some limitations. It can only compare the present management plan with one alternative at a time.
- Comparing alternative expected yields can help producers analyze the profitability of crop on farmland.
- The leaf color chart (LCC) can help farmers to determine whether is profitable to add additional fertilizer. These step involved comparing the LCC, the price of sorghum, and the fertilizer price from the market to determine optimum fertilizer application.
- These tools can also help farmers prevent over use or under use of fertilizer thus providing optimum economic yield.

Future Directions

- Response of selected sorghum hybrids need to be tested in low soil N conditions, different locations (environments) and multiple years.
- Testing hybrids with known traits need to be tested at multiple locations and years to determine if different hybrids vary in their response to N fertilizer.
- Research on management tools should be continued to confirm the results obtained and make a final calibration for use under field conditions.
- Similarly, protocol needs to be tested for conditions with low soil fertility and genotypes that are commonly used in West Africa (particularly in Mali) for multiple crops (rice, maize, cotton and sorghum).