Double crop soybeans management: a review, field studies, and modeling

by

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B.S., Federal University of Santa Maria, 2013
M.S., Federal University of Santa Maria, 2015

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2019

Abstract

Double-crop (DC) soybean (G*lycine max* (L.) Merr.) systems, is an alternative to sustainably intensify production in agricultural land. However, DC system is subject to different environmental conditions relative to the one faced by full-season soybean. To better understand the effect of management practices on DC responses, and to learn how to improve desirable characteristics and minimize non-desirable outcomes, three approaches were chosen for the study of DC soybean. Chapter 1 was a systematic literature review. The objectives were to (i) quantify attainable yield for DC soybean benchmarking against full-season (FS) soybean; (ii) determine and build probabilistic response models on the effect of previous wheat productivity on DC soybean yields; and (iii) detect and rank factors influencing DC soybean yields via a decision inference tree analysis. Analysis showed that the yield gap between FS and DC soybeans increased from -31 to 1160 kg ha^{-1} as FS yield improved from 1500 to 3000 kg ha^{-1}. Even though the proportion of variation accounted for wheat yields in the DC soybean/wheat yield ratio was low (R2 = 0.15), the probability of soybean yield being equal to wheat yield was 0, 20, 30, and 55% for wheat yields of ≥6, ≥4 and < 6, ≥2 and < 4, and < 2 Mg ha^{-1}. Inference tree analysis indicated that the major factors impacting success of the DC system was wheat yield, soybean planting date and maturity group. The second chapter aimed to evaluate the effect of the management practice treatments on seed quality. Seven management practice treatments were tested in each planting date: 1) common practice (no inputs), 2) no seed treatment; 3) non-stay green (without fungicide/insecticide); 4) high plant density (45 m^{-2}); 5) wide rows (75 cm); 6) N effect (without late-season fertilizer N); and 7) kitchen sink, considering all the inputs evaluated in previous treatments. Protein, oil, fatty acids (stearic, palmitic, oleic, linoleic and linolenic), fiber and ash were analyzed. Oil content presented a negative relationship with protein content.

Monounsaturated (oleic) and saturated (stearic and palmitic) fatty as well as total fatty acid yields were increased as inputs and seed yield increased. There were no differences for seed composition and quality for planting times for the majority of the analysis. Lastly, as seed filling duration increases, fatty acids concentrations decrease, increasing final seed content. Chapter 3 aimed to evaluate responses to management practices in field and run simulations for long-term responses of the variables in other environments. Seed yield in DC soybean can vary among years and is dependent on the management practices applied. Greater inputs can have positive influence in yield. However, greatest differences in yield, were observed for planting earlier, right after wheat harvest, beginning of June relative to the late planting date in June. Initial soil moisture had significant effect on yield, being negatively affected as initial soil moisture was 40% in comparison with 90%. Weather greatly affected seed yield for DC soybean. The greatest differences were observed for dry and warm weather, when late planting greatly impaired yield.

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Monounsaturated (18:1) and saturated (18:2 and 18:3) fatty acids as well as total fatty acid yields were increased as inputs and seed yield increased. There were no differences for seed composition and quality for planting times for the majority of the analysis. Lastly, as seed filling duration increases, fatty acids concentrations decrease, increasing final seed content. Chapter 3 aimed to evaluate responses to management practices in field and run simulations for long-term responses of the variables in other environments. Seed yield in DC soybean can vary among years and is dependent on the management practices applied. Greater inputs can have positive influence in yield. However, greatest differences in yield, were observed for planting earlier, right after wheat harvest, beginning of June relative to the late planting date in June. Initial soil moisture had significant effect on yield, being negatively affected as initial soil moisture was 40% in comparison with 90%. Weather greatly affected seed yield for DC soybean. The greatest differences were observed for dry and warm weather, when late planting greatly impaired yield.

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Acknowledgements

First and foremost, I want to thank my God for giving me the desires of my heart and making my plans succeed. He guided my steps and led my way. Without His blessings, this achievement would not have been possible.

To my advisor, that was with no doubt, the best advisor a student could have. His guidance, support, patience, attention and friendship were beyond what I would ever expect from an advisor. To you Dr. Ignacio Ciampitti, my dearest and most sincere admiration and gratitude.

To my beloved husband, Fernando Hansel, for being the best friend and support I could have. Thank you for pausing your dreams in favor of mine.

To my mom, dad and sister, for all the love and teaching that built me to be the person I am today. Thanks to my parents-in-law that are very dear to my heart. Thanks also to all my family that has cheered and prayed for my path.

Thank you to my committee members Dr. Archontoulis, Dr. Prasad, Dr. Durrett that shared their time, knowledge and guidance. Also, thanks to Dr. Shoup for his support.

There are two special guys to whom this dissertation also belongs, Raí and Luiz, my friends and colleagues that helped so much and who were an essential part for the conclusion of this dissertation.

A special appreciation to my fellow graduate students, my dear friends that helped so much in all of the parts that made this day possible, from field to defense. Ana Julia, Guillermo, Osler, Santiago, Sebastian, Luciana, Adrian, Mario, Javier, Rachel and Paula. Thank you to the awesome research scholars, that make so much possible, in the KSU Crops team.

Thanks to my friends in Manhattan, my chosen family, that made the PhD life fun and light, full of laughter and precious moments that I will keep in my heart forever.

To Kansas Soybean Commission for providing the funds for supporting this research. To the Agronomy Department for being always friendly and ready to help. And, my eternal gratitude to Kansas State University that welcomed me and made me feel part of the big K-State family.

Dedication

To my future children, so they can believe in dreams, courage and God. When this is what you bring in your backpack, there is nothing you cannot achieve.

Preface

Because everything we study in agronomy initially comes from and is done for the farmer, this dissertation starts with the basis of any agriculture query, the observation, perceptions and decisions implemented at the field level. There is no better way of finding a solution, than to assessing the real issues, reported by a day-to-day specialist, faced by farmers.

Thus, a survey was conducted with 126 double-crop (DC) soybean (*Glycine max* L.) farmers from 13 states in US, this project was funded by the United Soybean Board (USB), in an initiative for assessing the main issues faced by farmers when growing soybeans as a double crop. The US states included were Kansas, Arkansas, Illinois, Maryland, Kentucky, Missouri, Tennessee, Virginia, Alabama, Pennsylvania, Indiana, Mississippi and New Jersey. The objective of the study was to characterize the status of DC soybean production across the US farming systems.

In US, double-crop soybean was planted after a winter cereal by farmers answering the survey. Wheat (*Triticum aestivum* L.) is usually the crop that is planted before DC soybean. The choice of crop has actually more to do with the subsequent crop to wheat than to the previous crop to soybean. The farmer that chooses to plant DC soybean, is the wheat farmer that is in search of a summer crop that can serve as a cash crop instead of using cover crops or fallow.

Planting soybean in a wheat system, means that or soybean will need to be planted late after wheat harvest, or planted intercropped with wheat, or anticipated planted, via early desiccation of wheat for accelerating the moisture loss process from the wheat plant. In the case of DC crop soybean, planting will depend on time of wheat harvest, soil conditions, weather patterns, calendar date, residue management and availability of quality seed, but with the time of wheat harvest being the most cited (40%) factor by farmers as the main constraint for planting DC soybeans. More than 50% of the farmers, plant DC soybean between June 10th and June 20th, whilst a few farmers plant between July 1st and 10th. This delay causes different management practices responses from the soybean crop. Furthermore, the delay in planting also delays soybean maturity, and because of that there is also the risk of an early frost, interrupting the seed filling process and impacting yields via reducing the final attainable seed weight.

In view of the differences in cycle from full-season (FS) soybean, the typical percentage of FS to DC soybean area in the farm is 66% to 34%, respectively. This shows a significant majority of the field being planted with FS soybean, instead of having two cash crops cultivated in the same area. Management practices commonly change from FS to DC soybean, adapting to the new environment conditioned by the previous crop. Wheat residue can play an important role on the subsequent crop. The majority of DC soybean is planted in a no-till system (80%). Some farmers opt for bailing the straw to remove wheat residue from the field (11%), less farmers burned the residues before DC soybean planting time (9%) and the least execute conventional tillage (1%) before DC soybean planting. Because DC soybean is the subsequent optional crop, the input investment to DC soybean is usually lower than the one applied to wheat or to the FS soybean crop. As reported for farmers, wheat usually receives the majority of the investments, 52% of the farmers, while 37% of the farmers equally distribute input investment between wheat and DC soybean crops and only 11% have the majority of the investments going into DC soybean.

Other management practices divide opinions of DC soybean farmers, such as seed treatment, with 65% of the farmers applying different types of treatment, while 35% do not use any seed treatment. Herbicide application is another practice that divides opinions among farmers, with half of the farmers applying herbicides when there is pressure and the other half implement this practice as their standard.

As the innovative farmers that the DC soybean producers are, they are always looking for improvements in yield and profit. Many different management strategies are cited when the question is about new management tactics to improve DC soybean yields. The management practices cited go from increasing fertilizer rates to choosing a different maturity group for DC soybean. Most of the information comes from experiments tested on-farm by the farmer, testing new options in seeking greater yields.

In view of the information collected from DC soybean farmers, it is important to execute experiments testing different management practices and their combinations. Evaluating different strategies is crucial to meet the goal of increasing the potential yield of DC soybean, as well as investigating seed composition and quality in these different conditions, not only to increase DC soybean yield potential but to improve overall crop quality at harvest time.

The overall dissertation objective was to evaluate the impact of different management practices on DC soybean, reflected on seed yield and seed quality from field, simulations and the scientific literature.

The primary objectives for each chapter are as follows:

1. To conduct a systematic literature review, to better understand the current state of the art for DC soybean systems and the effects of previous crop productivity and the management practices implemented in DC soybean system influencing final seed yield (Chapter 1).
2. To analyze results from field experiments with different management practices applied to DC soybean, and use these results to adjust the Agricultural Production System Simulator (APSIM) for modeling DC soybean yield to evaluate alternative scenarios considering

the impact of long-term weather on main factors such as residue quantity from previous crop, initial soil moisture at planting DC soybeans, selection of soybean maturity group and adjustment on plant density as some of the most relevant management factors for this system (Chapter 2).

3. Evaluate the effect of different management practices applied in field experiments on seed composition and quality of DC soybean and investigate its correlation with yield (Chapter 3).
4. Summary and future research steps (Chapter 4).

Chapter 1 - A Review of Soybean Yield when Double-Cropped after Wheat

Hansel, D. S. S., Schwalbert, R. A., Shoup, D. E., Holshouser, D. L., Parvej, R., Prasad, P. V. V., and Ciampitti, I. A. (2019). A Review of Soybean Yield when Double-cropped after Wheat. Agron. J. 111. doi:10.2134/agronj2018.06.0371

Abstract

Soybean (*Glycine Max* L.) planted after wheat (*Triticum aestivum* L.) harvest in same season (double cropped [DC]) has the potential to increase productivity and sustainability. The objectives of this synthesis review were to (i) quantify attainable yield for DC soybean benchmarking against full-season (FS) soybean; (ii) determine and build probabilistic response models on the effect of previous wheat productivity on DC soybean yields; and (iii) detect and rank factors influencing DC soybean yields via a decision inference tree analysis. A global database on DC soybean studies collected from 1976 to 2017 was divided into three data sets: (i) FS and DC soybean (n = 141 data points); (ii) wheat and DC soybean (n = 463); and (iii) production factors and DC soybean (n = 547). Analysis showed that the yield gap between FS and DC soybeans increased from -31 to 1160 kg ha–1 as FS yield improved from 1500 to 3000 kg ha–1. Even though the proportion of the variation accounted for wheat yields in the DC soybean/wheat yield ratio was low (R2 = 0.15), the probability of soybean yield being equal to wheat yield was 0, 20, 30, and 55% for wheat yields of ≥6, ≥4 and < 6, ≥2 and < 4, and < 2 Mg ha–1. Inference tree analysis indicated that the major factor impacting success of the DC system was wheat yield followed by soybean planting date and maturity group.

Introduction

Soybean and wheat are two important crops that have the potential to produce high protein food. In 2018, wheat and soybean production was 48 and 125 million tons in United States, respectively (USDA–NASS, 2018). These two crops are usually sown separately, followed by a fallow period. Nonetheless, it is possible to produce both crops in immediate succession if the correct management is adopted. Double cropping (DC) soybean immediately after wheat harvest has the potential to increase overall production without expanding land area, potentially increasing net-return for farmers and aiding in sustainably intensifying farming systems (Crabtree et al., 1990; Burton et al., 1996; Kelley, 2003; KyeiBoahen and Zhang, 2006; Browning, 2011). Additionally, DC soybean system allows farmers to transfer the cost of summer weed control to the soybean crop instead of the wheat crop where there is no direct return on their investment.

Ray et al. (2012, 2013) suggested that current rate of increase in agricultural production (0.9 to 1.6% per year) is not meeting the required rate of yield increase of 2.4% per year to reach needed food production for 2050. Furthermore, most of the increase in food production must be derived from land already under cultivation (Hall and Richards, 2013). Crop intensification is defined as the yield improvement per unit of land area and time (Cassman, 1999; Gregory et al., 2002; Sadras and Roget, 2004) with the focus on increasing cropping intensity (more crops per year); this is one strategy to meet the increasing global food demand.

Following this rationale of intensification, DC planted area in the United States increased 28% from 1988 to 2012 (Seifert and Lobell, 2015). In 2018, the total DC planted area was projected to be 1.81 million hectares, roughly representing 5% of total soybean planted area in the United States (USDA–NASS, 2018). Soybean is one of the most frequent crops utilized for

DC systems and in most situations, it is usually planted after wheat harvest. In addition, soybean can generate complementary income to wheat, and can increase potential net-return from the system.

Double-crop soybean is usually planted later than the full- season (FS) soybean due to wheat harvest occurring after optimal soybean planting date. Environmental conditions, such as radiation, temperature and water availability, have a large influence on the establishment and development of the soybean crop, affecting yield (Wesley, 1998; Dillon, 2014). For mid-southern part of US, DC soybean yield declined for planting dates after mid-May, ranging from 0.09 to 1.69% per day, depending on maturity group (Salmerón et al., 2016). In Argentina, late soybean planting date resulted in diminished yields (Caviglia et al., 2011). Full-season soybean has more time to increase biomass and seed yield because of a longer time to capture radiation (Egli, 2011). Moreover, late-planted soybean is more likely exposed to possible freeze events during seed filling (Seifert and Lobell, 2015) leading to lower yields. Wheat residue (quantity and distribution) also represents a challenge for the success of DC soybean systems, potentially reducing growth and lowering yields (Caviness et al., 1986). Wheat may also reduce water availability for soybean, increasing the risk of soil moisture stress (Pearce et al., 1993; Calviño et al., 2003a) and decreasing seedling emergence (Dillon, 2014). The lack of water availability after the wheat crop can reduce time to canopy closure, reducing light interception (Caviglia et al., 2011). In summary, shorter growing cycles, availability of water and nutrients, presence of undecomposed and poorly distributed wheat residue, are among some of the main factors affecting the attainable yields of DC soybean systems.

Therefore, a systematic literature review was conducted to better understand the current state of the art for DC soybean systems pursuing the goals to (i) quantify attainable yield for DC soybean systems benchmarking against the FS soybean both grown in the same location–year; (ii) determine and build probabilistic response models on the effect of previous wheat productivity on subsequent DC soybean yields; and (iii) detect and rank factors, available on the review data, influencing DC soybean yields via a decision inference tree approach.

Materials and methods

Data Collection, Criteria, and Databases

The data were gathered using the following search engines: CABI (www.cabi.org), Web of Science Core Collection (https:// clarivate.com/products/web-of-science/databases), Scopus (www.scopus.com), SpringerLink (https://link.springer.com), Agricola (https://agricola.nal.usda.gov/), and Google Scholar (https://scholar.google.com/). For the literature review, similar procedures as previously developed by Ciampitti and Vyn (2012, 2013, 2014) were followed. Briefly, there was no restriction in the search for years or countries, which resulted in a worldwide data collection. The keywords used for the search were: "doublecrop", "soybean", and "wheat". Using these keywords, the number of publications found were: CABI (475), Web of Science Core Collection (208), Scopus (86), SpringerLink (624), Agricola (69), and Google Scholar (4000). These publications were further evaluated to ensure that the titles and content have the required information about our subject of research. Thereafter, selected publications were reviewed using the abstracts. A total of 126 papers, dissertations, and theses were selected for download and further screened to include information on yield and soybean preceded by a wheat crop. The main criteria for final data inclusion in the database was whether the study presented information on DC soybean yield and reported full season (FS) soybean yield, wheat yield previous to DC soybean and management practices such as planting date, maturity group, among others. Due to this study contemplate worldwide data, we cannot use the term "winter wheat" (applies only to North America) since wheat planted in the Southern hemisphere is not strictly planted during the winter time. Thus, the focus of the study was to evaluate DC soybean when immediately planted after wheat harvest.

Not all studies presented complete information on all these aspects. The studies were analyzed collectively and were used to compile a data table containing results from 16, 31, and 7 studies for Database 1, 2, and 3, respectively (Table 1). The databases were separated based on the yield and management information provided in the studies. Thus, three databases were created with the following objectives: (i) compare DC versus FS soybean on attainable yields when both crops were grown in the same location-year (Database 1); (ii) relate DC soybean and the previous-crop wheat (Database 2), and (iii) when previous wheat yield, and DC soybean yield, maturity group and planting date information were provided to rank factors affecting relative DC soybean (to wheat) yield (Database 3).

A descriptive analysis for yield factor were obtained via implementation of histograms for Databases 1, 2, and 3 (Fig. 1A–D) (GraphPad Prism 6; Motulsky and Christopoulos, 2003). The data for DC soybean and wheat were analyzed relating to older data (1989) to search for possible bias toward yield differences based on when studies were conducted (Supplementary Fig. S2). This showed there was no effect of years on yields of DC soybean and wheat.

Statistical Analysis

For the first database, the comparison between DC versus FS soybean yield, was explored within three different FS soybean yield classes (yield environments): ≤2000 kg ha–1, >2000 to ≤2800 kg ha–1, and ≤2800 kg ha–1 (Fig. 2A). The yield environments were divided using terciles to obtain equal number of observations within each group. To explore the effect of the delay in planting date on the maximum DC soybean yield, a 99% quantile regression was performed using upper boundary regression (Fig. 2B). This regression represents the maximum attainable DC soybean yield that was less limited by other factors, but still affected by planting date. In addition, an overall linear regression (50% quantile regression) was fitted to obtain the average DC soybean yield reduction per day of difference on planting date relative to the FS soybeans. This relationship was described using the “quantreg” package (Koenker, 2017) for R software (R Core Team, 2017). Lastly, planting date difference by FS soybean yield environments was tested to avoid bias on the data collection process (Fig. 2C).

For the second database, the relationship between the maximum relative soybean-to-wheat yield (expressed in ratios) versus wheat yield (expressed in absolute values) was explored using the 99% quantile regression fitting a linear plateau model (Fig. 3A). This relationship was analyzed with the objective of understanding how the previous wheat yield affects the subsequent soybean yield. Relative soybean DC/wheat yield ratio was given by DC soybean yield divided by the previous wheat yield from the same area. This ratio was related to absolute values of wheat yield; thus, allowing the observation on the change of DC soybean depending on previous wheat yields. The relation has the objective of helping on decision making toward the next crop (DC soybean) based on a value that is easily available to the wheat grower. The comparison of wheat and DC soybean yields, as well as the ratio between them, does not have the intention of showing when DC soybean is outyielding wheat. The objective is to give the grower an estimated yield to expect from the DC soybean if planting after specific wheat yield levels. This analysis was previously performed by Rondanini et al. (2012), on rapeseed (Brassica napus L.)/wheat yield ratio. Additionally, wheat yield was divided into four yield classes: were obtained using Markov-Chain Monte Carlo (MCMC) simulation (Gelman et al., 2004) and Metropolis–Hastings algorithm with 10,000 random draws from each posterior after a suitable burn-in period of about 200 iterations. Posteriors cumulative density functions were built for each yield class to facilitate interpretation.

For the third database, the influence of additional sources of variation (such as planting date and maturity group) in DC soybean relative to wheat yield variability was evaluated. This analysis used a conditional inference using the partykit package in R (Hothorn and Zeileis, 2015) (Fig. 4). This analysis is based on hierarchically ordered and recursively repeated binary splits, where the strength of each association is measured by a P-value. To avoid overfitting and enhance interpretability, the maximum tree depth was set to 10 nodes. The data used for the conditional tree analysis contained only field research studies conducted in North America. However, only one study was conducted in South America (Caviglia et al., 2011) and excluded from the analysis to avoid a confounding effect on the planting date evaluation.

Lastly, a yield deviation calculation (yield value of each observation – average yield of the entire experiment) for each study was implemented and plotted against year of the experimentation to check if there was any historical trend related to yield gain and to quantify if the effect of a particular study was influencing the database (Supplementary Fig. S1). Similarly, DC soybean and wheat historical trends (relative yield to an initial point) were compared to avoid a bias toward differential yield gain for one crop relative to the other (Supplementary Fig. S2).

Results and discussion

For the entire database, yield showed similar dispersion from the mean throughout the evaluated years (1976–2017) (Supplementary Fig. S1).

The overall distribution of the data points permitted to visually demonstrate lack of a temporal trend. Therefore, it can be concluded that the year of experimentation did not influence the analyses of Databases 1 and 2 (Supplementary Fig. S2).

The histograms of Database 1 and 2 (Fig. 1) portrayed different distributions for DC and FS soybean yields as well as for DC soybean and wheat yields. In Database 1, DC (Fig. 1A) and FS soybean yields (Fig. 1B) displayed similar normal distribution ($p > 0.05$; Shapiro-Wilk test), differing on the mean for DC soybean of 2000 kg ha–1 and for FS soybean of 2500 kg ha–1. As for Database 2, both DC soybean (Fig. 1C), and wheat (Fig. 1D) yields portrayed normal distributions ($p > 0.05$– Shapiro-Wilk test). The peaks in yield occur in different yield levels for both crops. The highest frequency occurs for DC soybeans between 1500 and 2000 kg ha–1, while for wheat it occurs between 3000 and 3500 kg ha–1. As expected, yield distribution was generally toward high values for FS soybean related to DC soybean, and similar observation was reported for the wheat yield relative to DC soybean comparison.

Double-Crop versus Full Season Soybean (Database 1)

Full-season soybean out-yielded DC soybean in yield environments where yields were ≥2000 kg ha–1; however, the yield gap between FS and DC soybean increased in higher yielding environments (Fig. 2A). The difference between DC soybean yield and FS soybean yields were 31 ($p > 0.05$), 430 ($p > 0.01$) and 1119 ($p > 0.01$) kg ha–1 for yield environment ≤2000 kg ha–1, >2000 to ≤2800 kg ha–1, and >2800 kg ha–1, respectively.

Double-crop soybean was usually planted later than FS soybean due to wheat harvest time (Fig. 2B). Due to late planting, DC soybean had shortened growth cycle and higher risk of an early fall freeze (Egli and Bruening, 2000; Calviño et al., 2002). These, among other reasons, are likely responsible for the drastic DC yield reduction in potential DC soybean yields, observed when the difference in sowing time between FS and DC soybean increased (Fig. 2B). Yet, the average decline in yield to difference in planting date was not statistically significant ($p > 0.01$, $R2 = 0.04$) (Fig. 2B). Thus, attainable yield decreased as DC soybean was planted later in the season. Planting date showed a similar difference among all the yield environments (Fig. 2C), indicating that response in the yield gap between FS and DC soybean was primarily due to the yield environment and not confounded with potential differences in planting dates (Fig. 2A).

Wheat versus Double Crop Soybean Yields (Database 2)

Relative DC soybean (to wheat) yield was analyzed with the purpose of predicting DC soybean yields, using previous crop information for a probability analysis (Fig. 3A, B). The ratio for DC soybean/wheat yield was greater as wheat yield decreased. When wheat yield was 2000 kg ha–1, the average DC soybean yield is 86% of the previous wheat yield.

In contrast, when wheat yields are above 4000 kg ha–1, DC soybean will yield an average 65% of the previous wheat, and when above 6000 kg ha–1, DC soybean will yield 45% of the previous wheat yield (Fig. 3A). Also, DC soybean yields decreased after this threshold. Based on the average percentage of DC soybean in relation to wheat, the farmer can have an estimate of the expected yield level for the upcoming DC soybean crop. The linear regression (50% quartile) showed an average of 13 kg ha–1 decrease in DC soybean for each 100 kg ha–1 increase in wheat yield (slope –0.014% kg ha–1). The upper bilinear regression (99% quartile–upper boundary regression) shows the potential DC soybean yields, in relation to wheat. This relationship between the maximum soybean/wheat yield ratio, reaches 170% until wheat yield increases to 2900 kg ha–1. After this, the DC soybean/wheat yield ratio decreased 0.054% kg ha–1, resulting in 54 kg ha–1 decrease of potential yield for DC soybean for each 100 kg ha–1 of increase in wheat yield. Although wheat is an excellent choice to pair with DC soybean (Evans et al., 1993), it may negatively affect the soybean crop (Pearce et al., 1993; Calviño et al., 2003a). Superior wheat yields will demand use of more resources (e.g., water, nutrients) (Daniels and Scott, 1991; Caviglia et al., 2004; Andrade et al., 2015), depleting those resources for the following soybean crop. Thus, previous studies concluded that soybean yields were affected by wheat yield and its residue, reducing soybean yield as wheat yield increases (Caviness et al., 1986; Kyei-Boahen and Zhang, 2006; Nelson et al., 2010). Due to that, many researchers have studied the effect of quantity of wheat residue on soybean yield, although conclusions vary on how to manage wheat stubble (Pearce, 2005; Cordell et al., 2007; Amuri et al., 2010). Still, no-tillage of the DC soybean presented greater net return relative to conventional tillage combinations (Amuri, 2008). In addition, the effect of greater wheat residue on DC soybean yields can be due to the effect of the residue itself, per se residue effect, or due to the greater wheat yield that utilized more resources (water and nutrients), directly affecting the ability of the DC soybean crop to grow early in the season and indirectly impacting yields. Double-crop soybean yields are likely a direct consequence of the interaction between environmental conditions experienced by the crop and effects of the previous wheat yield. However, the decline in the ratio DC soybean/wheat can be due to greater wheat yields, with soybean yields remaining constant. Regardless, for the upper boundary function (Fig. 3A), maximum DC soybean/wheat yield ratio reached 100%, at a wheat yield of approximately 5500 kg ha–1.

Thereby, there are many factors interacting on the final DC soybean yield response, increasing the complexity and challenges for providing science-based management decisions.

To help in the decision-making process toward DC soybean and, a posterior predictive probability analysis was performed (Fig. 3B). Thus, when wheat yield environment was greater than 6000 kg ha–1, there is zero probability of DC soybean to yield more than the wheat yields (ratio >100%). In this high yielding wheat environment, the probability shows that the maximum DC soybean yield, would be 50% of the previous wheat yield (ratio <50%). As wheat yield decreased, the likelihood of DC soybean yielding more than the yield observed for wheat increased, reaching 20, 30, and 55% of probability of greater DC soybean yield than wheat, when wheat yield ranged from 4000 to 6000, 2000 to 4000, and <2000 kg ha–1, respectively (Fig. 3B). There was a 75% probability that DC soybean would yield 25, 50, 70, and 75% of the previous wheat yield, when wheat yield ranged from ≥4000 to <6000 kg ha–1, ≥2000 to <4000 kg ha–1, and <2000 kg ha–1, respectively. Likewise, Porter et al. (1997) showed increased benefits for DC soybean yields in lower wheat yield environments.

Although DC soybean yields can be predicted in relation to the previous wheat yields, there are many factors that influence both responses. Wheat yields can predict only 15% confidence on the decline in DC soybean yields. The effects from DC soybean itself and its interactions with the environment can be accountable with 51% of the response from yields (Fig. 3C). Even though the proportion of the variation accounted for wheat yields in the DC soybean/wheat yield ratio was low (R2 = 0.15), several factors influence the final attainable soybean yields (e.g., weather, genotype, and management) (Pearce, 2005; Navarro, 2010; Nelson et al., 2010; Andrade and Satorre, 2015; Liu et al., 2015; Norman et al., 2016).

Relevance of Management Decisions on Double Crop Soybean Yield (Database 3)

Based on the management data gathered for this review, including seven studies from North America, the most important factor influencing DC soybean was the previous wheat yield, with a different response when wheat yield values >2800 and ≤2800 kg ha–1 (Fig. 4).

In wheat yield environments ≤2800 kg ha–1, neither soybean maturity group (MG) nor DC sowing time (expressed as day of the year [DOY]) were relevant factors; 80% of all data points (n = 47) presented greater DC soybean yields relative to wheat yield (Node 2 in Fig. 4). For this wheat yield level (≤2800 kg ha–1), the average ratio for relative DC soybean to wheat, was 146%. However, for wheat yields >2800 kg ha–1, DOY followed by MG influenced DC soybean yields. Many studies have found that later sowing date reduced yields (Egli and Bruening, 2000; Calviño et al., 2003b; Salmeron et al., 2014). Rattalino Edreira et al. (2017), conducted in the North-Central US region, utilizing a large self-reported farmer database found that yield potential was reduced for each day planted later than 1 April (DOY 91). According to our analysis (Fig. 4), when soybean was planted after DOY 180 (“late” planted), corresponding to the end of June, there was no difference in DC yield ratio for early or late MGs (Node 9 in Fig. 4). The average DC soybean/wheat yield ratio was 67%. Soybean yielded less than the previous wheat, for an overwhelming majority (>90% of all observations, n = 73) of the observed data analyzed (Node 9 in Fig. 4). If soybean planting date was earlier than DOY 180 (“early” planted), there was a different response for wheat yields that ranged from >2800 to 4500 kg ha–1 and with yields above 4500 kg ha–1. Regarding the latter group, more than 80% of all data points (n = 55) presented lower ratio for relative DC soybean/wheat (2088 and ≤4500 kg ha–1, and MG was above 4.5, 70% from all the data points (n = 17) portrayed DC soybean yields lower than wheat, at the average of 57% relative DC soybean to wheat yield (Node 7 in Fig. 4).

When soybean MG was ≤4.5, 60% of the data points (n = 22) presented DC soybean yields greater than the observed wheat yield, with average of 115% relative DC soybean to wheat yield (Node 6 in Fig. 4). Agreeing to the observed in this study, mid-MG 3 was observed as the ideal to maximize yields for DC in Missouri (Minor and Wiebold, 1998). Holshouser (2015) observed that late MGs allow more time for plant growth, although the plant has to reach maturity before the first frost.

Main Limiting Factors in a Double Crop Soybean System

There are many limiting factors related to DC soybean systems. To better understand the yield-limiting factors in the DC soybean system, 19 studies were reviewed. The main factors impacting yield were late planting date or short crop cycle, lack of water, low temperature, radiation/photoperiod, residue, limitation of soil nutrients, and early frost and machinery requirements. From the 19 studies, yields in 15 were limited by water (Crabtree et al., 1990; Ritter and Scarborough, 1992; Lehrsch et al., 1994; Duncan and Schapaugh, 1997; Calviño et al., 2002; Pearce, 2005; Behera et al., 2007; Bruinsma, 2009; Nelson et al., 2010; Smith, 2013; Dillon, 2014; Qin et al., 2015; Gesch and Johnson, 2015; Liu et al., 2015; Norman et al., 2016). Of these, only five reported soil water status (Lehrsch et al., 1994; Gesch and Johnson, 2015; Liu et al., 2015; Qin et al., 2015; Norman et al., 2016). Therefore, it is evident that soil water status should be investigated further.

The second most reported limiting factors were late planting (Lehrsch et al., 1994; Calviño et al., 2003b; Caviglia et al., 2004; Dillon, 2014; Salmeron et al., 2014) and soil nutrient availability (Behera et al., 2007; Nelson et al., 2010; Andrade and Satorre, 2015; Qin et al., 2015). Other factors, were temperature, radiation/photoperiod, residue and early frost (Pearce, 2005; Bruinsma, 2009; Navarro, 2010; Nelson et al., 2010; Holshouser, 2015; Andrade and

Satorre, 2015; Liu et al., 2015; Norman et al., 2016). Lastly, machinery requirements were also cited as a limiting factor (Navarro, 2010).

Identification of the major limiting factors affecting DC soybean yields and then determination of the best management practices should be further investigated with the goal of not only increasing attainable DC soybean yields but for improving the overall productivity of the wheat–DC soybean farming system.

Conclusions

The most striking outcomes from this review paper were (i) as yield environments are greater (from 1500 to 3000 kg ha–1), yield gap of DC soybean compared to FS soybean widens from –31 to 1162 kg ha–1; (ii) even though the proportion of the variation accounted for wheat yields in the DC soybean/ wheat yield ratio was low (R2 = 0.15), the probability of DC soybean yield being equal to wheat yield was 0, 20, 30, and 55% for wheat yields of ≥6, ≥4 and < 6, ≥2 and < 4, and < 2 Mg ha–1; thus, more than 50% probability to obtain similar DC soybean and wheat yields was obtained with low wheat yields (<2 Mg ha–1); and (iii) the inference tree analysis ranked wheat yield as the main factor, followed by planting date and maturity group as secondary factors influencing DC soybean yields. In summary, the probability of obtaining greater DC soybean yields (relative to wheat) is reduced as the wheat yield improves and planting date for soybeans after wheat is delayed.

There is still the need to critically evaluate and identify best management practices to produce greater and stable DC soybean yields. Deployment of comprehensive field studies investigating multi-factors under different soil and environment conditions are needed to identify factors influencing DC soybean farming systems around the globe. In addition, consideration of using crop simulation models to evaluate different scenarios (soil, water, environment, and management and their interactions) and improved knowledge on site-specific best management practices recommendations (including sowing time, variety selection, seeding rate, and row spacing, among other factors) are potential avenues to be explored for increasing attainable soybean yields under the complex genotype × environment × management interaction.

Acknowledgments

Support for Mrs. Damaris Hansel for implementation of this review was provided by the Kansas Soybean Commission. This is a contribution 18-890-J from Kansas Agricultural Experiment Station.

References

Amuri, N. 2008. Evaluation of the impact of alternative wheat residue and water management on soil properties and soybean yield in a wheat soybean double-crop system, eastern Arkansas. Ph.D. diss., University of Arkansas, Fayetteville.

Amuri, N., K.R. Brye, E.E. Gbur, D. Oliver, J. Kelley, N. Amuri, K.R. Brye, E.E. Gbur, D. Oliver, and J. Kelley. 2010. Weed populations as affected by residue management practices in a wheat– soybean double-crop production system weed populations as affected by residue management practices in a wheat– soybean double-crop production system. Weed Sci. 58:234–243. doi:10.1614/WS-09-088.1

Andrade, J.F., S.L. Poggio, M. Ermácora, and E.H. Satorre. 2015. Productivity and resource use in intensified cropping systems in the rolling pampa, Argentina. Eur. J. Agron. 67:37–51. doi:10.1016/j. eja.2015.03.001

Andrade, J.F., and E.H. Satorre. 2015. Single and double crop systems in the Argentine Pampas: Environmental determinants of annual grain yield. F. Crop. Res. 177:137–147. doi:10.1016/j.fcr.2015.03.008

Bauer, P.J., J.R. Frederick, and W.J. Busscher. 2002. Tillage effect on nutrient stratification in narrow- and wide-row cropping systems. Soil Tillage Res. 66:175–182. doi:10.1016/S0167-1987(02)00025-9

Behera, U.K., A.R. Sharma, and H.N. Pandey. 2007. Sustaining productivity of wheat– soybean cropping system through integrated nutrient management practices on the Vertisols of central India. Plant Soil 297:185–199. doi:10.1007/s11104-007-9332-3

Browning, P.W. 2011. Agronomic and economic comparison of full-season and double-cropped small grain and soybean systems in the mid-Atlantic USA. Ph.D. diss., Virginia Tech, Blacksburg.

Bruinsma, J. 2009. The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050 In: Expert on how to feed the world. Food and Agriculture Organization of the United Nations, Rome. p. 24–26. Burton, R.O., M.F. Crisostomo, P.T. Berends, W. Kenneth, R.O.

Burton, M.F. Crisostomo, P.T. Berends, K.W. Kelley, and O.H. Buller. 1996. Risk/return analysis of double-cropping and alternative crop rotations with and without government programs. Rev. Agric. Econ. 18:681–696.

Calviño, P.A., V.O. Sadras, and F.H. Andrade. 2003a. Quantification of environmental and management effects on the yield of late-sown soybean. F. Crop. Res. 83:67–77. doi:10.1016/S0378-4290(03)00062-5

Calviño, P.A., V.O. Sadras, and F.H. Andrade. 2003b. Development, growth and yield of late-sown soybean in the southern Pampas. Eur. J. Agron. 19:265–275. doi:10.1016/S1161-0301(02)00050-3

Calviño, P.A., G.A. Studdert, P.E. Abbate, F.H. Andrade, and M. Redolatti. 2002. Use of non-selective herbicides for wheat physiological and harvest maturity acceleration. F. Crop. Res. 77:191–199. doi:10.1016/ S0378-4290(02)00072-2

Cassman, K.G. 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proc. Natl. Acad. Sci. USA 96:5952–5959.

Caviglia, O.P., V.O. Sadras, and F.H. Andrade. 2004. Intensification of agriculture in the south-eastern Pampas I. Capture and efficiency in the use of water and radiation in double-cropped wheat–soybean. F. Crop. Res. 87:117–129. doi:10.1016/j.fcr.2003.10.002

Caviglia, O.P., V.O. Sadras, and F.H. Andrade. 2011. Yield and quality of wheat and soybean in sole- and double-cropping. Agron. J. 103:1081–1089. doi:10.2134/agronj2011.0019

Caviness, C.E., F.C. Collins, and M. Sullivan. 1986. Effect of wheat residue on early growth of soybean. Arkansas Farm Res. 35:8.

Ciampitti, I.A., and T.J. Vyn. 2012. Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: A review. F. Crop. Res. 133:48–67. doi:10.1016/j.fcr.2012.03.008

Ciampitti, I.A., and T.J. Vyn. 2013. Grain nitrogen source changes over time in maize: A review. Crop Sci. 53:366–377. doi:10.2135/ cropsci2012.07.0439

Ciampitti, I.A., and T.J. Vyn. 2014. Understanding global and historical nutrient use efficiencies for closing maize yield gaps. Agron. J. 106:2107–2117. doi:10.2134/agronj14.0025

Cordell, M.L., K.R. Brye, D.E. Longer, and E.E. Gbur. 2007. Residue management practice effects on soybean establishment and growth in a young wheat soybean double-cropping system. J. Sustain. Agric. 29:97–120. doi:10.1300/J064v29n02_08

Crabtree, R.J., J.D. Prater, and P. Mbolda. 1990. Long-term wheat, soybean, and grain sorghum double-cropping under rainfed conditions. Agron. J. 82:683–686. doi:10.2134/agronj1990.00021962008200 040007x

Daniels, M.B., and H.D. Scott. 1991. Water use efficiency of double cropped wheat and soybean. Agron. J. 83:564–570. doi:10.2134/agr onj1991.00021962008300030009x

Dillon, K.A. 2014. Double-crop soybean vegetative growth, seed yield, and yield component response to agronomic inputs in the mid-Atlantic, USA. Ph.D. diss., Virginia Tech, Blacksburg.

Dıaz-Zorita, M., J.H. Grove, L. Murdock, J. Herbeck, and E. Perfect. 2004. Soil structural disturbance effects on crop yields and soil properties in a no-till production system. Agron. J. 96:1651–1659. doi:10.2134/agronj2004.1651

Duncan, S.R., and J.W.T. Schapaugh. 1997. Relay-intercropping soybean in different water regimes, planting patterns, and winter wheat cultivars. J. Prod. Agric. 10:123–129. doi:10.2134/jpa1997.0123

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean and wheat. Agron. J. 80:76– 80. doi:10.2134/agronj1988.00021962008000010018x

Egli, D.B. 2011. Time and the productivity of agronomic crops and cropping systems. Agron. J. 103:743–750. doi:10.2134/agronj2010.0508

Egli, D.B., and W.P. Bruening. 2000. Potential of early-maturing soybean cultivars in late plantings. Agron. J. 92:532–537. doi:10.2134/ agronj2000.923532x

Evans, E.E., T.C. Keisling, L.R. Oliver, F.L. Baldwin, L.O. Ashlock, and C.R. Dillon. 1993. Stubble management, preplant tillage, and row spacing for double-cropped soybeans. 1993 South. Conserv. Tillage Conf. Sustain. Agric., Monroe, LA.

Gelman, A., J.B. Carlin, H.S. Stern, and D.B. Rubin. 2004. Bayesian data analysis. CRC Press, Boca Raton, FL.

Gesch, R.W., and D.W. Archer. 2013. Double-cropping with winter camelina in the northern Corn Belt to produce fuel and food. Ind. Crops Prod. 44:718–725. doi:10.1016/j.indcrop.2012.05.023

Gesch, R.W., and J.M.F. Johnson. 2015. Water use in camelina–soybean dual cropping systems. Agron. J. 107:1098–1104. doi:10.2134/ agronj14.0626

Gregory, P.J., J.S.I. Ingram, R. Andersson, R.A. Betts, V. Brovkin, et al. 2002. Environmental consequences of alternative practices for intensifying crop production. Agric. Ecosyst. Environ. 88:279–290.

Grey, T.L., L.B. Braxton, and J.S. Richburg. 2012. Effect of wheat herbicide carryover on double-crop cotton and soybean. Weed Technol. 26:207–212. doi:10.1614/WT-D-11-00143.1

Grove, F.J., and J.H. Coale. 1987. Root distribution and shoot development in no-till full-season and double-crop soybean. Agron. J. 82:606–612. doi:10.2134/agronj1990.00021962008200030034x

Hairston, J.E., J.O. Sanford, J. Hayes, and L.L. Reinschmiedt. 1984. Crop yield, soil erosion, and net returns from five tillage systems in the Mississippi Blackland Prairie. J. Soil Water Conserv. 39:391–395.

Hall, A.J., and R.A. Richards. 2013. Field Crops Research Prognosis for genetic improvement of yield potential and water-limited yield of major grain crops. F. Crop. Res. 143:18–33. doi:10.1016/j. fcr.2012.05.014

Holshouser, D. 2015. Double cropping soybean in Virginia. Virginia Coop. Ext. Pub. CSES-102NP, Blacksburg.

Hothorn, T., and A. Zeileis. 2015. Partykit: A modular toolkit for recursive partitioning in R. Journal of Machine Learning Research 16:3905–3909.

Kelley, K.W. 2003. Double-cropping winter wheat and soybean improves net returns in the eastern great plains. Crop Manag. 2:0–0. doi:10.1094/CM-2003-1112-01-RS

Khalilian, A., C.E. Hood, J.H. Palmer, T.H. Garner, and G.R. Bathke. 1991. Soil compaction and crop response to wheat. Trans. ASAE. 34:2299–2303.

Koenker, R. 2017. Quantile regression: 40 years on. Annual Review of Economics 9:155–176.

Kruschke, J. 2013. Bayesian estimation Supersedes the t-test. J. Exp. Psychol. Gen. 142:573–603. doi:10.1037/a0029146

Kumar, M., T.K. Das, and N.T. Yaduraju. 2012. An integrated approach for management of Cyperus rotundus (purple nutsedge) in soybean-wheat cropping system. Crop Prot. 33:74–81. doi:10.1016/j. cropro.2011.11.016

Kyei-Boahen, S., and L. Zhang. 2006. Early-maturing soybean in a wheat–soybean double-crop system: Yield and net returns. Agron. J. 98:295–301. doi:10.2134/agronj2005.0198

Lehrsch, G.A., F.D. Whisler, and N.W. Buehring. 1994. Cropping system influences on extractable water for mono- and double-cropped soybean. Agric. Water Manage. 26:13–25. doi:10.1016/0378-3774(94)90021-3

Lewis, W.M., and J.A. Philips. 1976. Double cropping in the Eastern United States. In: Multiple cropping: Proceedings of a symposium. ASA, Madison, WI. p. 41–50.

Liu, L., C. Hu, P. Yang, Z. Ju, J.E. Olesen, and J. Tang. 2015. Effects of experimental warming and nitrogen addition on soil respiration and CH4 fluxes from crop rotations of winter wheat–soybean/fallow. Agric. For. Meteorol. 207:38–47. doi:10.1016/j.agrformet.2015.03.013

Meadors, T.C. 2015. The suitability of energy beets for double-cropping with soybeans in the Arkansas Delta. Ph.D. diss., Arkansas State University, Jonesboro.

Minor, H.C., and W.J. Wiebold. 1998. Wheat–soybean double-crop management in Missouri. https://extensiondata.missouri.edu/pub/pdf/agg uides/crops/g 04953. pdf?_ ga=2 .14 4255989.156917354 4.154 49734 49- 2064604830.1515877414

Moomaw, R.S., and T.L. Mader. 1991. Double cropping seed and forage crops with small grains in the Upper Midwest. J. Prod. Agric. 4:385– 390. doi:10.2134/jpa1991.0385

Motulsky, H.J., and A. Christopoulos. 2003. GraphPad Software Inc. GraphPad, San Diego CA.

Nash, P.R., K.A. Nelson, P.P. Motavalli, and C.G. Meinhardt. 2012. Effects of polymer-coated urea application ratios and dates on wheat and subsequent double-crop soybean. Agron. J. 104:1074–1084. doi:10.2134/agronj2011.0235

Navarro, J.I. 2010. Economic analysis of double cropping systems in central Indiana: Winter wheat, corn, sorghum, sweet sorghum and soybeans. M.S. thesis, Purdue Univ., West Lafayette, IN.

Nelson, K.A., C.G. Meinhardt, and R.L. Smoot. 2010. Wheat (Triticum aestivum L.) cultivar selection affects double-crop and relay-intercrop soybean (Glycine max L.) response on claypan soils. Int. J. Agron. 2010:1–8. doi:10.1155/2010/543261

Norman, C.R., K.R. Brye, E.E. Gbur, P. Chen, and J. Rupe. 2016. Long-term management effects on soil properties and yields in a wheat soybean double-crop system in Eastern Arkansas. Soil Sci. 181:1–12. doi:10.1097/SS.0000000000000131

O'Kelley, R.K. 1989. Growth characteristics and selection criteria for soybean genotypes adapted for double cropping with wheat. Ph.D. diss., University of Arkansas, Fayetteville.

Pearce, J.T. 2005. Double-cropped soybean response to various wheat stubble managements. Ph.D. diss., University of Maryland, College Park.

Pearce, R.C., L.J. Grabau, J.H. Grove, and H. Lin. 1993. Development of double-crop soybean under different soil water regimes. Agron. J. 85:576–583. doi:10.2134/agronj1993.00021962008500030011x

Popp, M.P., P.M. Manning, L.R. Oliver, T.C. Keisling, E.C. Gordon, and P.C. Counce. 2003. Analysis of a novel bedded planting system for dry clay soil management of full-season and double-crop soybean. Commun. Soil Sci. Plant Anal. 34:2925–2950. doi:10.1081/ CSS-120025217

Porter, P.M. 1995. Double cropping soybean after canola and wheat. J. Prod. Agric. 8:222–226. doi:10.2134/jpa1995.0222

Porter, P.M., J.G. Lauer, W.E. Lueschen, J.H. Ford, T.R. Hoverstad, E.S. Oplinger, and R.K. Crookston. 1997. Environment affects the corn and soybean rotation effect. Agron. J. 89:442–448. doi:10.2134/agr onj1997.00021962008900030012x

Pullins, E.E., and R.L. Myers. 1998. Agronomic and economic performance of wheat and canola-based double-crop systems. Am. J. Altern. Agric. 13:124–131. doi:10.1017/S0889189300007803

Qin, W., D. Wang, X. Guo, T. Yang, and O. Oenema. 2015. Productivity and sustainability of rainfed wheat-soybean system in the North China Plain: Results from a long-term experiment and crop modelling. Sci. Rep. 5:17514. doi:10.1038/srep17514

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rattalino Edreira, J.I., S. Mourtzinis, S.P. Conley, A.C. Roth, I.A. Ciampitti, M.A. Licht, H. Kandel, P.M. Kyveryga, L.E. Lindsey, D.S. Mueller, S.L. Naeve, E. Nafziger, J.E. Specht, J. Stanley, M.J. Staton, and P. Grassini. 2017. Assessing causes of yield gaps in agricultural areas with diversity in climate and soils. Agric. For. Meteorol. 247:170–180. doi:10.1016/j.agrformet.2017.07.010

Ray, D.K., N.D. Mueller, P.C. West, and J.A. Foley. 2013. Yield trends are insufficient to double global crop production by 2050. PLoS One 8. doi:10.1371/journal.pone.0066428

Ray, D.K., N. Ramankutty, N.D. Mueller, P.C. West, and J.A. Foley. 2012. Recent patterns of crop yield growth and stagnation. Nat. Commun. 3:1293. doi:10.1038/ncomms2296

Ritter, W.F., and R.W. Scarborough. 1992. Response of double cropped soybeans to irrigation. Appl. Eng. Agric. 8:17–22. doi:10.13031/2013.26027

Rondanini, D.P., N.V. Gomez, M.B. Agosti, and D.J. Miralles. 2012. Global trends of rapeseed grain yield stability and rapeseed-to-wheat yield ratio in the last four decades. Eur. J. Agron. 37:56–65. doi:10.1016/j.eja.2011.10.005

Sadras, V. O., and D.K. Roget. 2004. Production and environmental aspects of cropping intensification in a semiarid environment of southeastern Australia. Agron. J. 96:236–246.

Salmerón, M., E.E. Gbur, F.M. Bourland, N.W. Buehring, L. Earnest, F.B. Fritschi, B.R. Golden, D. Hathcoat, J. Lofton, A.T. McClure, T.D. Miller, C. Neely, G. Shannon, T.K. Udeigwe, D.A. Verbree, E.D. Vories, W.J. Wiebold, and L.C. Purcell. 2016. Yield response to planting date among soybean maturity groups for irrigated production in the US Midsouth. Crop Sci. 56:747–759. doi:10.2135/ cropsci2015.07.0466

Salmerón, M., E.E. Gbur, F.M. Bourland, N.W. Buehring, L. Earnest, F.B. Fritschi, B.R. Golden, D. Hathcoat, J. Lofton, T.D. Miller, C. Neely, G. Shannon, T.K. Udeigwe, D.A. Verbree, E.D. Vories, W.J. Wiebold, and L.C. Purcell. 2014. Soybean maturity group choices for early and late plantings in the midsouth. Agron. J. 106:1893– 1901. doi:10.2134/agronj14.0222

Sandler, L., K.A. Nelson, and C. Dudenhoeffer. 2015. Winter wheat row spacing and alternative crop effects on relay-intercrop, double-crop, and wheat yields. Int. J. Agron. 2015:1–8. doi:10.1155/2015/369243

Sanford, J.O. 1982. Straw and tillage management practices in soybean– wheat double-cropping. Agron. J. 74:1032–1035. doi:10.2134/agron j1982.00021962007400060023x

Sanford, J.O., B.R. Eddleman, S.R. Spurlock, and J.E. Hairston. 1986. Evaluating ten cropping alternatives for the Midsouth. Agron. J. 78:875–880. doi:10.2134/agronj1986.00021962007800050026x

Seifert, C.A., and D.B. Lobell. 2015. Response of double cropping suitability to climate change in the United States. Environ. Res. Lett. 10:024002. doi:10.1088/1748-9326/10/2/024002

Senigagliesi, C., and M. Ferrari. 1993. Soil and crop responses to alternative tillage practices. Int. Crop Sci. 1:27–35.

Smith, S.F. 2013. Long-term residue and water management effects on soil respiration and soil aggregate stability in a wheat-soybean, doublecrop system in Eastern Arkansas. M.S. thesis, University of Arkansas, Fayetteville.

Trusler, C.S., T.F. Peeper, and A.E. Stone. 2007. Italian ryegrass (Lolium multiflorum) management options in winter wheat in Oklahoma. Weed Technol. 21:151–158. doi:10.1614/WT-06-038.1

USDA–NASS. 2018. USDA–NASS – quick stats. https://www.nass. usda.gov.

Wagger, M.G., and H.P. Denton. 1988. Tillage effects on grain yields in a wheat double-crop soybean, and corn rotation. Agron. J. 81:493– 498. doi:10.2134/agronj1989.00021962008100030020x

Wesley, R.A. 1998. Double cropping wheat and soybeans. In: L.G. Heatherly and H.F. Hodges, editors, Soybean production in the Midsouth. p. 146–156.

Wesley, R.A., and F.T. Cooke. 1986. Wheat–soybean double-crop systems on clay soil in the Mississippi Valley Area. J. Prod. Agric. 1:166–171. doi:10.2134/jpa1988.0166

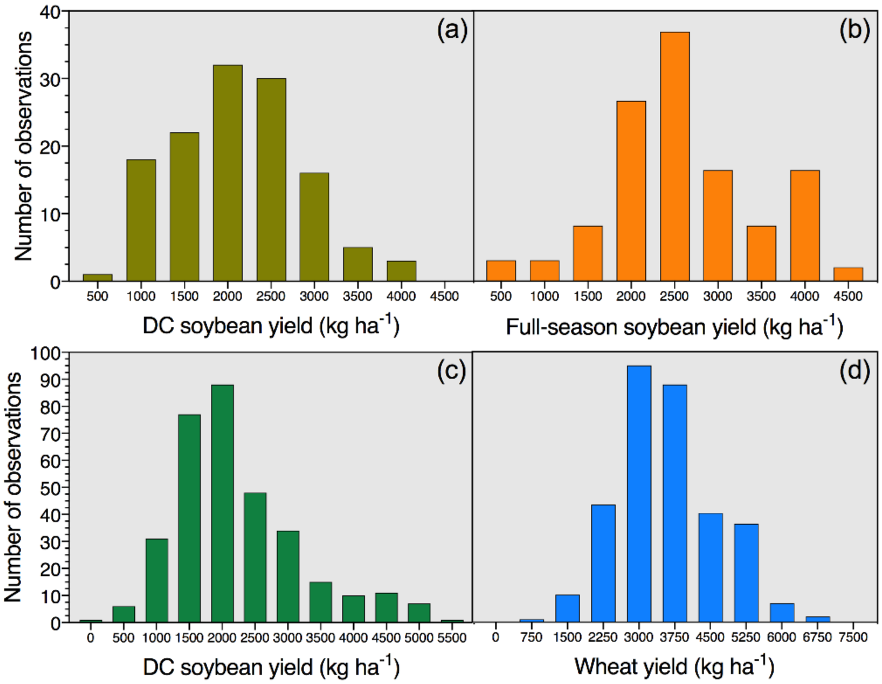


Figure 1. Descriptive analysis of the dispersion of number of observations for yield data in databases 1 (a and b) and 2 (c and d). Database 3 is included in database 1 and 2 in addition to the unpublished data that also follows the same trend of distribution.

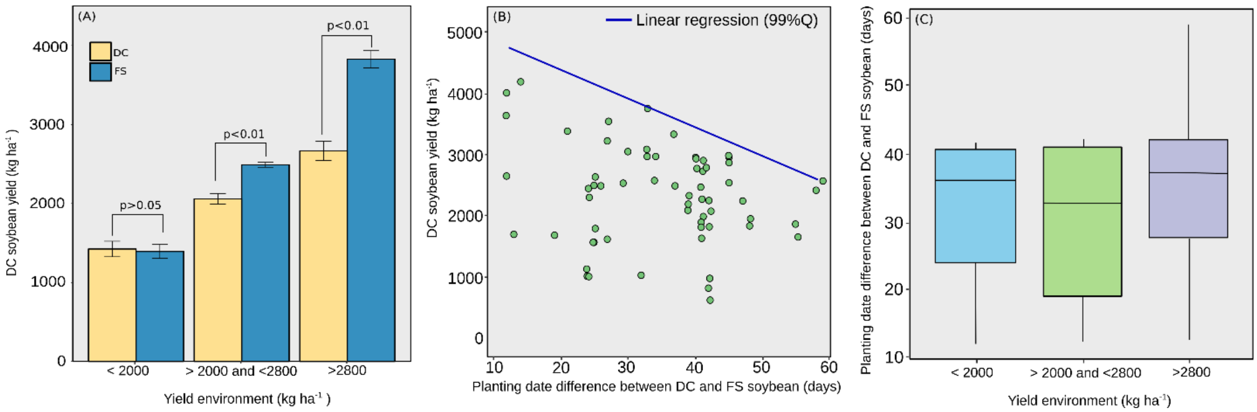


Figure 2. Double-crop (DC) soybean yields compared to full-season (FS) soybean yield. Yield environments were divided in three yield environments <2000 kg ha^{-1}, 2000 to <2800 kg ha^{-1}, ≥2800 kg ha^{-1}. (B) Effect of different planting dates between DC and FS soybean in DC soybean yields. Upper boundary regression (99% Q) showing the potential yield decline for DC soybean. (C) Planting date difference in days between DC and FS soybean for each yield environment.

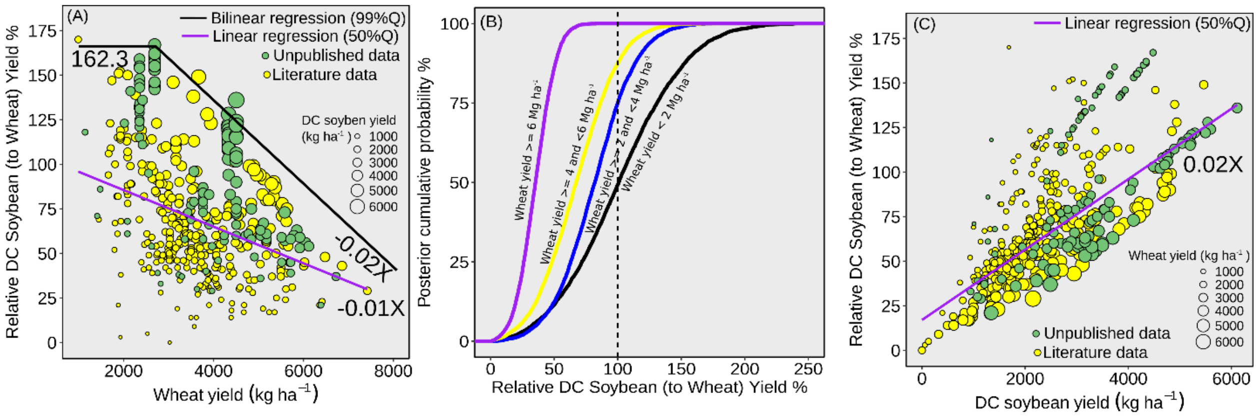


Figure 3. Relative soybean (to wheat) yield response to previous wheat yield. The potential yield is given by the bilinear regression- upper border line (99% quartile). The mean response is given by the 50% quartile line (R^2= 0.15) (A). Posterior predictive probability for DC soybean (to wheat) yields for four yield environments of previous wheat yield <2000 kg ha^{-1}, >=2000 to <4000 kg ha^{-1}, >=4000 to <6000 kg ha^{-1} and >=6000 kg ha^{-1}(B). Influence of DC soybean yields on the ratio of relative soybean (to wheat) yield response. Mean response is given by a 50% quartile line (R^2= 0.52) (C). Green circles are unpublished data, and yellow circles are for literature data. Size of circles represent soybean yield absolute values.

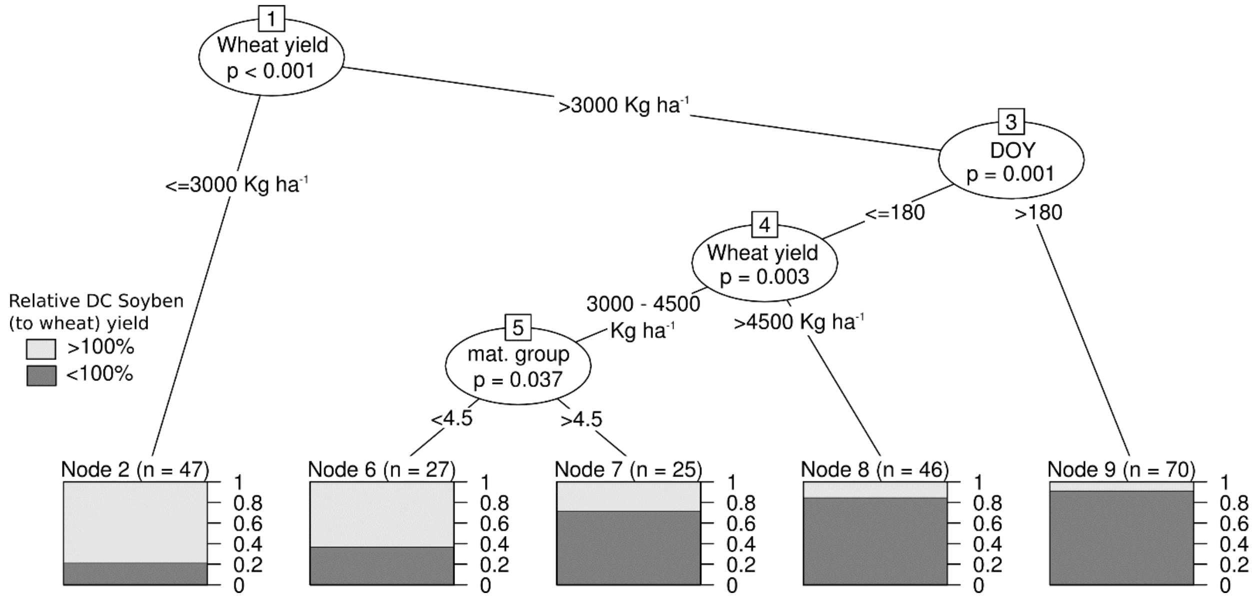
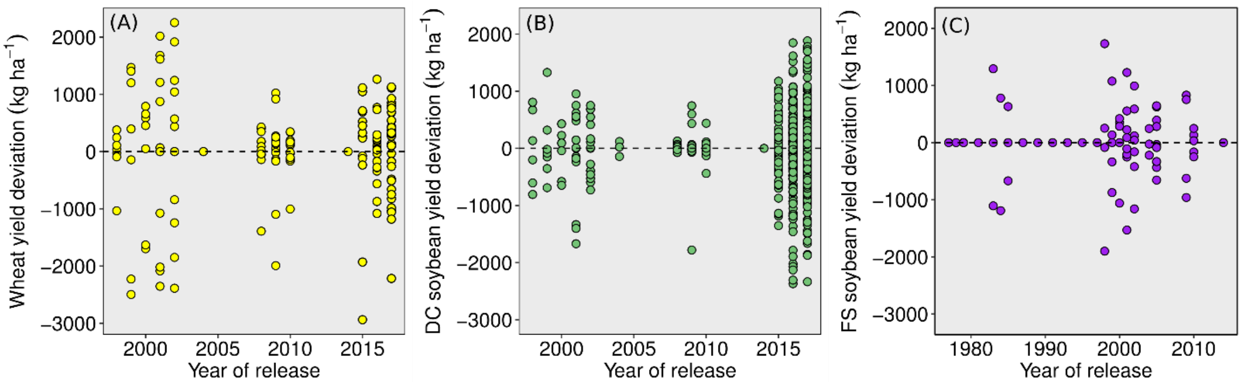
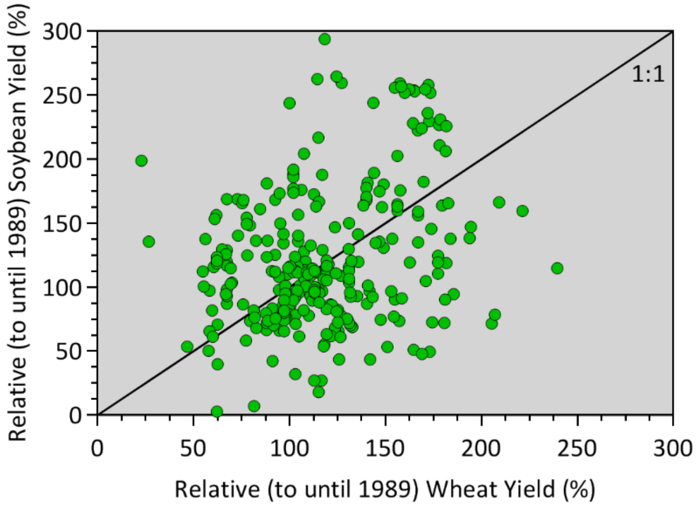


Figure 4. Inference tree showing the hierarchical order of importance in the response of relative soybean (to wheat) yields to main management factors (wheat yield, day of the year – DOY and maturity group – MG). Being 1 higher and 10 lower hierarchical order. at least significant difference p< 0.05.



Supplementary figure 1. Yield dispersion from the mean throughout the evaluated years of release for database 1, 2 and 3. Wheat yield deviation in kg ha^{-1}(a), double-crop soybean yield deviation in kg ha^{-1} (b), and full-season soybean yield deviation in kg ha^{-1} (C).



Supplementary figure 2. Relative (to until 1989) soybean yield (%) to relative (to until 1989) wheat yield. Effect of year the study was conducted of DC soybean yields to older studies and wheat yields to older studies for database 2.

Table 1. Authors, publication year, type of publication, region of study, crop year, main characteristics, number of observations per study for databases 1, 2 and 3.

	Authors	Publication year	Type of publication	Region	Crop year	Main characteristics	Databases 1	2	3
Database 1	Gesch and Archer	2013	paper	North America	2008 - 2009	DC for fuel and food	12		
	O'Kelley	1989	thesis	North America	1986 - 1987	Soybean genotypes adapted to DC	12		
	Edwards et al.	1988	paper	North America	1981 - 1984	Tillage and crop rotation	12		
	Coale and Grove	1987	paper	North America	1984 - 1985	Root and shoot development	2		
	Hairston et al.	1984	paper	North America	1981 - 1982	Tillage systems	4		
	Sanford	1982	paper	North America	1974 - 1976	Straw and tillage management	3		
Database 1 and 2	Andrade and Satorre	2015	paper	South America	2003 - 2008	Environ. effects on single and DC soybean	11	11	
	Andrade et al.	2015	paper	South America	2010 - 2011	Intensification of resources	3	3	
	Kelley et al.	2003	paper	North America	1979 - 1997	Long-term crop rotations	10	10	
	Popp et al.	2003	paper	North America	1999 - 2000	Novel bedded system	10	10	
	Sanford et al.	1986	paper	North America	1978 - 1979	Cropping alternatives	3	2	
	Wesley et al.	1986	paper	North America	1983 - 1985	DC systems	18	18	
1,2 and 3	Meadors et al.	2015	thesis	North America	2014	Suitability of energy beets for DC	1	1	1
	Browning et al.	2011	thesis	North America	2009 - 2010	Agronomic and economic comparison	10	6	6
	Kyei-Boahen et al.	2006	paper	North America	2001 - 2004	Yield and net returns	10	10	10
Database 2 and 3	Sandler et al.	2015	paper	North America	2012 - 2013	Row spacing in wheat and crop effects		2	
	Grey et al.	2012	paper	North America	2008 - 2009	Herbicide study		34	

	Kumar et al.	2012	paper	South Asia	2006 - 2007	Integrated weed management		9	
	Nash et al.	2012	paper	North America	2008 - 2010	Polymer coated urea		33	33
	Caviglia et al.	2011	paper	South America	2000 - 2002	Wheat yield and quality		2	
	Nelson et al.	2010	paper	North America	2005	Cultivar selection		6	
	Behera et al.	2007	paper	South Asia	1996 - 2000	Integrated nutrient management practices		18	
	Trusler et al.	2007	paper	North America	1999	Weed management in winter wheat		4	
	Pierce et al.	2005	thesis	North America	2003 - 2004	Wheat stubble managements		16	
	Diaz-Zorita et al.	2004	paper	North America	1994 - 2000	Soil structural disturbance		14	
	Bauer et al.	2002	paper	North America	1996	Tillage effect and row spacing		12	
	Pullin and Myers	1998	paper	North America	1993 - 1994	Agronomic and economic performance		4	
	Wesley et al.	1998	chapter	North America	1984 - 1991	Doublecropping		30	
	Porter et al.	1995	paper	North America	1992	Doublecropping		2	
	Senigaglies i et al.	1993	paper	South America	1991 - 1992	Alternative tillage practices		4	
	Daniels et al.	1991	paper	North America	1986	Water use efficiency		18	
	Khalilian et al.	1991	paper	North America	1988 - 1990	Soil compaction		36	
	Moomaw et al.	1990	paper	North America	1987 - 1989	Doublecropping		1	
	Wagger et al.	1988	paper	North America	1985 - 1987	Tillage effects on a rotation		16	
	Lewis and Philips	1976	paper	North America	1971 - 1974	Doublecropping		4	
Database 3	Hansel	2017	unpublished	North America	2016 - 2017	Management practices for double-cropping			67
	Parvej	2017	unpublished	North America	2015 - 2016	Maturity groups, planting dates and cultivars		67	380*
	Holshouser	2017	unpublished	North America			20	60	48
*bootstrapped						Total	141	463	545

Chapter 2 - Field and simulated management strategies for double-crop soybean planted after wheat

Abstract

Double-cropping is an intensification management practice with the potential to increase productivity and land diversity to satisfy the food security and soil health. Double cropped (DC) soybeans after winter wheat (*Triticum aestivum* L.) harvest, is such a system. The challenge is that the soybean planted after winter wheat is usually delayed more than one month, relative to a full-season soybean cycle, which creates a yield penalty. Thus, identification of management practices that can increase double cropping soybeans yields is needed. To this end, field experiments (Ashland Bottoms and Ottawa, in Kansas, in 2016 and 2017) were conducted aiming to test different management practices for improving productivity of this crop. Two planting dates in each site and seven management treatments were tested within each planting date as follows: 1) common practice (no inputs added), 2) no seed treatment; 3) non-stay green (without fungicide/insecticide application); 4) high plant density (45 seeds m^{-2}); 5) wide rows (75 cm); 6) N effect (without late-season fertilizer N); and 7) kitchen sink, considering all the inputs evaluated in previous treatments. At the Ashland Bottoms location, the late plating in 2016 for the common practice treatment resulted in lower yield while treatment with wide-rows presented greater yield. At the Ottawa location, the early planting in 2017 presented greater yield for treatments high plant density, N effect and kitchen sink relative to the rest of the treatments. Late planting also presented differences in treatments, where common practice showed lower yields and treatments non-stay green, N effect and kitchen sink presented greater yields. In all sites, where there were significant differences, common practice yielded less than the treatments with greater inputs. To expand DC soybean responses to other environment conditions, crop simulations were executed using APSIM (Agricultural Production Systems Simulator) software. Crop growth simulations were run for twenty years (1998 to 2017), with selected management practices. The management practices evaluated were planting date (May 15, June 5, and June 25), initial soil moisture (40 and 90%), plant density (30 and 40 plants m^{-1}), previous wheat residue (1250 and 4500 kg ha^{-1}), and maturity group (3, 4 and 5). The output data from the model, was grouped by weather conditions (warm wet, warm dry, cold wet, and cold dry). There were no differences among plant densities, wheat residue or maturity groups. Yet, warm and wet weather presented greater yield, while warm and dry weather presented a yield reduction by 1292 kg ha^{-1}. Initial moisture affected yield loss, reducing by 1075 kg ha^{-1} when initial soil moisture decreased from 90% to 40%. As planting date was delayed, yield was reduced by 1296 kg ha^{-1}, presented the greatest impact from the factors evaluated in this study. Future research studies should focus on exploring how soil moisture at planting can impact DC soybean emergence, as well as how to increase water availability for the DC soybean crop. It is also necessary to understand more deeply how management practices affect the seed filling period through a deeper analysis of how this process occurs for DC soybean systems.

Keywords: simulation, yield prediction, intensification.

Abbreviations: double-crop (DC), initial soil moisture (IM), maturity group (MG).

Introduction

Sustainable intensification of agricultural systems need to be better studied and practiced, with the objective of increasing food production in order to meet the increasing global human demand. Single crop centered systems do not make full use of inputs, such as radiation and rainfall (Caviglia et al., 2004). The soybean production intensification challenge for soybean, is to increase in 36% by 2025, requiring an extra 1000 kg per hectare using the currently available land area in the United States (United Soybean Board). Although very difficult, the goal is possible with new and innovative technologies and cropping systems, improved production methods and effective educational/technology transfer programs.

Double-crop (DC) is defined by harvesting two crops or commodities in the same calendar year, such as winter wheat (*Triticum aestivum* L.) harvested in the spring and soybean (G*lycine max* (L.) Merr.) in the fall (Borchers et al., 2014). Double-cropping soybean after small grains addresses world food demand by growing two crops in one year and simultaneously addresses environmental concerns by growing a harvestable "cover crop" and minimizing the cost of summer weed control where there is no direct return on their investment. DC soybean is cultivated in many regions of United States and around the world. In most DC systems, soybean is planted immediately after wheat harvest, which increases potential profit where there would probably be a non-cash cover crop or even fallow (Crabtree et al., 1990; Moomaw and Mader, 1991; Burton et al., 1996; Kelley, 2003; Kyei-Boahen and Zhang, 2006; Browning, 2011; Thomason et al., 2017). Additionally, with declining commodity prices of wheat, producers are seeking other avenues to increase the productivity of their land and increase net-return from their own farm. Double-crop soybean after wheat is a very viable option.

Soybean can be managed in no-till systems, reducing costs due to less machinery, fuel and labor expenses after the wheat harvest (Bolliger et al., 2006). Furthermore, no-till maintains wheat residue on soil surface which prevents excessive runoff of nutrients and other chemicals, and enhancing good soil properties (Triplett and Dick, 2008). Double-crop soybean area increased 28% from 1988 to 2012 in US (Seifert and Lobell, 2015). The total DC area was projected to be 1.81 million hectares, representing 5% of the soybean planted area in the US by 2019 (USDA – NASS, 2018). While the double cropping wheat-soybean system is not uncommon, double-cropping have increased costs and therefore economic barriers, and although two crops can provide additional revenue from the same land, it also has the potential to shorten one or both of the crops cycle (Egli and Bruening, 2000).

Farmers desire to increase yields and diversify the rotations, while limiting risk, and hold back on investing in inputs (Dillon, 2014). The yield gap between full-season and DC soybeans exists and is larger when environments are higher yielding (>2800 kg ha^{-1}), although in lower yielding environments (<2000 kg ha^{-1}) the gap between full season and double-crop soybean is close to null (Hansel et al., 2019). To improve yields for DC soybean there are some management practices that should be further investigated: 1) fertilizer application, promoting stronger plant growth and earlier canopy closure to overcome stresses due to a late planting season; 2) ideal row spacing and seeding rate, allowing more plants in the same unit area, potentially suppressing weed establishment and increasing yield; 3) integrated pest management, due to the late planting, the risk of late summer soil and foliar disease and insects could decrease yield; and 4) earlier planting time to lengthen growing season and allow more time for soybean plants to set pods and seed before the first killing frost.

The goal of this study was to identify practices or combination of practices that can improve yields of soybeans grown in double crop systems without sacrificing wheat yield and identify the main yield-limiting factors affecting DC soybean productivity from a perspective of environment (E) and management practices (M) interaction (E x M). To do so, we combined field experiments and simulation modeling. The specific objectives of this study were to: i) evaluate field responses to different management practices x weather combinations of DC soybean; ii) calibrate the APSIM model to simulate DC soybean responses to management practices observed from field experiments; iii) use the simulation model to extrapolate results from 2 years to 20 years to develop data that can better help with development of probabilities for decision making and to identify management practices that have greater impact on DC soybean system as reference for further studies.

Materials and methods

Field experiments

Two field experiments were established. The soil type at the Ottawa location was a Woodson silt loam (Mollisols) and at Ashland Bottoms location it was a Belvue silt loam. Soil samples were taken prior to planting at a depth of 0 to 15 cm in. Soil chemical parameters analyzed were pH (1:2.5) (Thomas, 1996), Mehlich P (Frank et al., 1998), organic matter (OM) (Walkley and Black, 1934), calcium, magnesium, and potassium (K) availability (Warncke and Brown, 1998). Cation exchange capacity (CEC) was determined by summing the exchangeable cations (in cmolc kg-1) (Table 1).

The field experiments were arranged in a randomized complete block design with 4 replications. Plot size was 3m wide × 18m long. The soybean variety utilized was Asgrow 4232 (Monsanto Co.), maturity group 4.2. Soybean was planted immediately after wheat harvest of the cultivar WB Cedar (Monsanto Co.). Study 1 (early wheat harvest) was planted on June 10, 2016, and June 13, 2017, and for Study 2 (conventional wheat harvest) on June 23, 2016, and June 22, 2017. Seven treatments were evaluated in 2016 and 2017: 1) common practice (no inputs added), 2) no seed treatment; 3) non-stay green (without fungicide/insecticide application); 4) high plant density (45 seeds m^{-2}); 5) wide rows (75 cm); 6) N effect (without late-season fertilizer N); and 7) kitchen sink, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization. The specific management practices composing each treatment are listed in Table 2.

The seed treatment was Acceleron Standard (Monsanto Company, St. Louis, US) which contains a fungicide + insecticide. For the foliar fungicide + insecticide application, the chemicals used were Aproach Prima + Prevathon (6 + 17 fl oz/a) (Dupont Co.) and applied to soybean at the R3-R4 growth stage (Fehr and Caviness, 1977). Herbicides and hand weeding were used to maintain no weed interference for the entire season. Fertilizer application was performed on treatments 2 to 7 using the formulation 7-7-7-7S-7Cl (chloride). The application rate was 12 kg ha^{-1} of N, P, K, S and Cl. In treatment 2 to 6, late N was applied at a rate of 57 kg ha^{-1}, in the formulation of 32-0-0 (N-P-K). Biomass was collected in a 1.16 m^2 area, sampled outside the area collected for yield.

For evaluating how treatments responded in each environment, in relation to biomass and yield dependence, relative values were calculated for each treatment in each environment (Figure 4). All the mean values from a treatment in each experiment were combined in a graph. The relative values were calculated by the difference of each treatment's mean, of biomass and yield, to the mean value of biomass and yield for all treatments in all environments. As values were greater than zero, the treatment responded better in that specific environment in relation to the mean of all treatments, while if it was lower than zero, the treatment responded worse than the mean for that environment. The inclination of the data points towards the x or y axes presented greater influence of biomass or yield on the final value.

APSIM Crop growth model

The Agricultural Production Systems Simulator (APSIM) software version 7.9 was used in this study. The software is a free and public internationally utilized simulator for modeling agricultural systems at field level, and can be downloaded from the software's webpage (www.apsim.info). The software evaluates production and environmental performance of cropping systems, while operating on a daily time step, or even hourly, for some processes. APSIM integrates knowledge from field and laboratory research in the form of mathematical equations in attempt to represent a real world system, combining process-based model into a new model corrected to a featured target of study.

The field measurements from two locations in Kansas, two years and two planting dates, were used for the calibration of the model. Based on the responses measured from the field experiments, questions arose about the probability of finding the similar responses in other years, under different management (e.g., maturity group and plant density) and environments, or what would be the response in these other contexts.

Simulations

To enable a better understanding of how management practices effect yield, simulations were generated using the APSIM software. The simulations were based on the weather, soil characteristics from the Ashland Bottoms location. Twenty years of weather data (1998 to 2017) were sued to drive the model, with the objective of simulating different environments and observe a broader spectrum of responses from double-crop soybean. The management practices evaluated were planting date (May 15, June 5, and June 25), initial soil moisture (40 and 90%), plant density (30 and 40 plants m^{-1}), previous wheat residue (1250 and 4500 kg ha^{-1}), and maturity group (3, 4 and 5). Three graphs were created with the output data from the APSIM software. Initial moisture and planting dates were presented for 20 years, for evaluating yield responses.

For the first simulations (Figure 5), the plant densities of 30 and 40 plants m^{-2} were tested, added to the initial moisture and planting dates. For this graph the cultivar used was from maturity group 4 and previous wheat residue was of 4500 kg ha^{-1}. The second graph (Figure 6), tested previous wheat residues (1250 and 4500 kg ha^{-1}) and the plant density used was 40 plants m^{-2}. Maturity groups 3, 4 and 5 were tested (Figure 7), plant density was 40 plants m^{-2}, and wheat residue was 4500 kg ha^{-1}. For analyzing the data from the simulations statistically, the years were grouped by weather (Figure 1). The weather groups were determined by the average of each year in relation to the average values of precipitation and temperature from the mean of the 20 years, for the months of August and September. This period was chosen for the group classification due to the great influence this period being the most important to seed filling in soybeans (Hou et al. 2006)

Statistical analysis

Data analysis was performed for each database, considering the data 1) from field experiments; and 2) from APSIM simulations. For the first database, linear mixed models were fitted for each site × year × planting date combination (total of 2 sites x 2 years x 2 planting dates), accounting for treatment as fixed effect and block as the random component. For the second database, fixed effect models were adjusted for each set of tested factors, considering all the possible interactions. In both cases, Tukey test was performed for means comparison (at 5% significance) when significant differences were detected by the analysis of variance (ANOVA). All the analyses were performed with the *R software* (R Core Team, 2018) and mixed model effects were adjusted using the “lme4” package (Bates et al., 2015).

Results

Field experiments, Seed yield

Yield only differed for treatments at Ashland Bottoms in 2016, when planted late. The common practices presented lower yield and treatment 5 (wide-rows) presented greater yields. At the Ottawa location treatments differed only in 2017. For the early planting, common practice yielded less and treatments 4, 6 and 7 presented greater yield. For late planting in 2017, the Ottawa location presented greater yield for treatments 3, 6 and 7, and lower yields for the common practice (Figure 2). In Ottawa, yields were similar in both years. The differences in yield were not consistent for a specific input treatment. However, in the trials where yield presented statistical differences, common practice always showed lower yields.

Total biomass

There were no differences between treatments for total biomass. Biomass for treatments were averaged and presented by site (Figure 3). In year 2016, both locations and planting dates presented high biomass in relation to 2017.

When evaluating relative values for biomass and yield (Figure 4), treatment 1, the common practice treatment was lower than the mean of the treatments for yield and biomass, going from 80 to 100% of the mean of all treatments. Treatment seven, kitchen sink, showed more values above the mean for all treatments, with most of the values at 100 to more than 120% of the mean for biomass and yield. The other treatments had distribution among all sections of the graphs, showing a greater variance between environments. Overall the increase in both parameters show that seed yield and biomass were directly related.

Crop growth simulations

The simulations for yield, considering planting date, initial soil moisture, and their combination with plant density, residue, and maturity group are very variable among years (Figures 5, 6, and 7). When analyzing data from APSIM simulations, comparing plant densities 30 and 40 plants m^{-2}, there was no difference for levels of plant density (Figure 5).

Thus, there was interaction between weather and planting dates (Table 3). In all the weather combinations, seed yield was affected as planting date was later on timing. When comparing the weather for each planting date, dry and warm weather resulted in lower yields for all planting dates relative to the other weather combinations. Wet and warm weather presented greatest yields across planting dates. Wet and cold weather and dry and warm weather presented lower yields, in relation to the other weather conditions for the later planting date.

Previous wheat residue simulations did not show significant differences for residue levels (Table 4). Although a trend can be observed, of greater yield for wheat residue of 4500kg ha^{-1} for planting date 1 (Figure 6).

Planting date significantly affected yield in all weather conditions, decreasing as planting was later and as weather was drier and colder (Table 4). When both residue levels were considered together, wet and cold weather was not as greatly affected by planting date, in the comparison between weather conditions. When observing all weather conditions, planting date affected yields negatively only for dry and warm weather.

Yields were not statistically different for maturity groups when analyzing the years by the pre-defined weather groups (Figure 7). Yet, as planting date is later in the season, there is a tendency of greater yields for maturity group 3 relative to the yields documented for maturity groups 4 and 5.

Weather groups, planting date and initial soil moisture, were significantly different with single effects (Table 5). Dry and warm weather presented lower yield. Planting date showed a significant effect in yield only for the last planting date (Jun 25^{th}), when comparing all three maturity groups. Initial moisture affected yield when it was 40% at the beginning of the season.

Considering the lack of difference observed from the simulations for plant densities, previous wheat residue, and maturity groups, an analysis was done for comparing only weather planting date and initial water, without considering differences only one planting density (40 plants m^{-2}), wheat residue (4500 kg ha^{-1}) and maturity group (4) (Table 6). The result of the analysis was single effects for weather, planting date and initial water. Dry and warm weather affected yield negatively, with a decrease of 959.1 kg ha^{-1}. The later planting date, June 25^{th}, showed significantly lower yields. The decrease in yield observed from planting date 1 to planting date 3 was of 1292.8 kg ha^{-1}. Also, 40 % initial soil moisture implied a decrease of 1029.5 kg ha^{-1}on yields, and was significantly lower than when initial soil moisture was 90%.

A comparison of yield differences from the second planting date (June 5^{th}) to the first planting date (May 15^{th}), and from the third planting date (June 25^{th}) to the first is presented in Figure 8 a. The greatest difference in yield occurred in dry and cold weather, in which yield decreased 2168 kg ha^{-1}, between the first and last planting date tested. The weather conditions that had less effect on yield when planting later in the season, was wet and warm. Rate of yield decrease was calculated dividing total yield loss in the planting delay period by the number of days in the period (Figure 8 b). The results showed a greater rate of yield decline for dry and cold weather for 41 days delayed planting with a loss of 53 kg ha^{-1} per day. When delaying 20 days (planting in June 5^{th} in comparison with May 15^{th}, the loss was less per day was still 34 kg ha^{-1}. In the other weather environments, great losses from 777 to 2168 kg ha^{-1} were observed for 41 days, but relatively small losses, from 39 to 714 kg ha^{-1}, for when planting was delayed for 20 days. However, for the dry and warm environment, even when delaying only 20 days the losses were up to 19-fold as much as for the wet and warm environment.

Discussion

Field experiments were conducted in years with no severe stresses in drought or in flooding. Weather is one of the most important modulators of yield responses (Rondanini et al., 2012), and climate differences can help explain differences in DC farming systems (Shapiro et al., 1992). This condition helps the plant to uptake nutrients present in the soil, increase resistance to attacks from pests and diseases, and overcome small down points in the season.

Thereunto, when observing the simulations (Figures 5, 6 and 7) for the years studied in field (2016 and 2017), it can be observed that they present standard to high response on yields when compared to other 18 simulated years, for the variables tested. This can help understand how the years observed, had support for DC soybean productivity observed from the field. Even so, treatments did present impact on yield responses in 3 out of the 8 site-years tested. The differences observed in yield, always showed lower response from the treatments with common practice, as expected since this treatment had a very low input level. The treatments that presented greater yield, were higher input treatments, and varied by location. At the Ashland Bottoms location, yield was lower for the year of 2017, when comparing it when 2016. Precipitation was 585 mm for 2016 while in 2017, it was only 360 mm (Kansas Mesonet). The difference in precipitation was probably a reason for lower yields in 2017. Ottawa yields were more stable, when comparing 2016 and 2017, as also was the precipitation for the season. Common practice treatment had yields at the locations were there was significant differences among treatments. The treatments that had greater yield were different for each year. Thus different characteristics of each environment imposed different responses from the soybean crop. Biomass did not show differences for treatments, which relates well with the few or no responses in yield. The distribution of relative yield and biomass show that there was dependence among the two traits, which is expected (Wallace, 1985).

Yield simulations showed there was no difference for the tested plant densities, previous wheat residue, or maturity groups. This is maybe due to a great variation among years and the conditions experienced by the soybean plant during that year. However, weather conditions, planting dates and initial soil moisture inflicted differences in yield from the double-crop soybean.

Weather and planting dates interacted for the group of simulations from Figures 5 and 6, and showed single response on Figure 7. Drier environments had more negative influence in yield as planting dates were later. Late sowing in DC can generate dry soils in planting, causing poor crop establishment (Egli, 1998), as well as water deficit during the crop season (Board and Harville, 1996). When weather was also dry and warm, transpiration presented a demand that the dry soil could not support. Dry soil enhances the negative effect for not being able to sustain the high water demand of a plant in warm weather, that transpires more. Stomata controls transpiration and has a role of maintaining leaf temperature within an optimal range (Burke et al 1988). Though, soybean has the ability to maintain turgor as a result of slow decline in leaf water potential generated by low transpiration rate and continued uptake in nutrient (Tanguilig et al. 1987).

Initial water influenced a significant decline in yield due to the importance of initial moisture for seed emergence, since seed imbibition is a critical stage for the soybean success in the germination (McDonald et al., 2010). Double-crop soybean is planted in sequence to wheat harvest. Due to that, when soybean is planted, there is less water in the soil profile than when succeeding winter fallow (Knott et al., 2018).

Planting dates affected yield, as planting was performed later in the season. Other studies have also observed that double-crop soybeans are negatively affected by late planting (Coale and Grove, 1987; De Bruin and Pedersen, 2008; Chen and Wiatrak, 2010; Hansel et al., 2019). Environment conditions are modified with late planting dates, and affect capture of radiation and partitioning of crop resources (Calviño et al., 2003). These affects can include less vegetative growth, shorter stems, less reproductive nodes, and shortening of the seed filling period (Board et al. 1992, Boquet et al 1990, Board et al. 1999, Kantolic and Slafer 2001). The decrease in yield for planting dates in these simulations, was significantly lower for the last planting date tested. Thus, the planting in early June was not significantly lower than planting in mid-May, which shows that DC can be planted without a significant loss in yield, right after winter wheat harvest, if wheat is harvested as wheat reaches maturity.

Conclusion

Seed yield in DC soybean can vary among years and is dependent on the management practices applied. Greater inputs can have positive influence in yield. However, the greatest differences in yield, were observed for planting earlier, right after wheat harvest, beginning of June relative to the late planting date in June. Initial soil moisture was crucial and had significant effect on yield, being negatively affected as initial soil moisture was 40% in comparison with 90%. Weather played an important role in affecting seed yield for DC soybean. The greatest differences in the effect of weather in DC soybean yield was for the dry and warm weather, when late planting greatly impaired yield.

Future research studies should focus on exploring how soil moisture at planting can impact DC soybean emergence, as well as how to increase water availability for the DC soybean crop. It is also necessary to understand more deeply how management practices affect the seed filling period through a deeper analysis of how this process occurs for DC soybean systems.

References

Board, J. E., Kamal, M., and Harville, B. G. 1992. Temporal importance of greater light interception to increased yield in narrow-row soybean. Agronomy Journal, 84(4), 575-579.

Board, J.E., and B.G. Harville. 1996. Growth dynamics during the vegetative period affects yield of narrow- row, late-planted soybean. Agron. J. 88(4): 567–572. doi: 10.2134/agronj1996.00021962008800040012x.

Board, J. E., Kang, M. S., and Harville, B. G. 1999. Path analyses of the yield formation process for late-planted soybean. Agronomy Journal, 91(1), 128-135.

Boquet, D. J. (1990). Plant population density and row spacing effects on soybean at post-optimal planting dates. Agronomy Journal, 82(1), 59-64.

Bolliger, A., J. Magid, J.C.T. Amado, F. Skóra Neto, M. de F. dos S. Ribeiro, A. Calegari, R. Ralisch, and A. de Neergaard. 2006. Taking Stock of the Brazilian "Zero-Till Revolution": A Review of Landmark Research and Farmers' Practice. Adv. Agron. 91(06): 47–110. doi: 10.1016/S0065-2113(06)91002-5.

Borchers, A., E. Truex-powell, and C. Nickerson. 2014. Multi-Cropping Practices: Recent Trends in Double Cropping. Economic Information Bull. (125).
Browning, P.W. 2011. Agronomic and Economic Comparison of Full-Season and Double-Cropped Small Grain and Soybean Systems in the Mid-Atlantic USA.

De Bruin, J.L., and P. Pedersen. 2008. Effect of row spacing and seeding rate on soybean yield. Agron. J. 100(3): 704–710. doi: 10.2134/agronj2007.0106.

Burke, J. J., Mahan, J. R., and Hatfield, J. L. 1988. Crop-specific thermal kinetic windows in relation to wheat and cotton biomass production. Agronomy Journal, 80(4), 553-556.

Burton, R.O., M.F. Crisostomo, P.T. Berends, W. Kenneth, R.O. Burton, M.F. Crisostomo, P.T. Berends, K.W. Kelley, and O.H. Buller. 1996. Agricultural & Applied Economics Association Risk / Return Analysis of Double-Cropping and Alternative Crop Rotations with and without Government Programs Kelley and Orlan H . Buller Source: Review of Agricultural Economics, Vol. 18, No . 4 Oct ., 1.

Calviño, P.A., V.O. Sadras, and F.H. Andrade. 2003. Quantification of environmental and management effects on the yield of late-sown soybean. F. Crop. Res. 83(1): 67–77. doi: 10.1016/S0378-4290(03)00062-5.

Caviglia, O.P., V.O. Sadras, and F.H. Andrade. 2004. Intensification of agriculture in the south-eastern Pampas I. Capture and efficiency in the use of water and radiation in double-cropped wheat – soybean. F. Crop. Res. 87: 117–129. doi: 10.1016/j.fcr.2003.10.002.

Chen, G., and P. Wiatrak. 2010. Soybean development and yield are influenced by planting date and environmental conditions in the southeastern coastal plain, United States. Agron. J. 102(6): 1731–1737. doi: 10.2134/agronj2010.0219.

Coale, J.H., and F.J. Grove. 1987. Root Distribution and Shoot Development in No-Till Full-Season and Double-Crop Soybean. Agron. J. 82(3): 606–612.

Crabtree, R.J., J.D. Prater, and P. Mbolda. 1990. Long-term wheat, soybean, and grain sorghum double-cropping under rainfed conditions. Agron. J. 82: 683–686.

Dillon, K.A. 2014. Double-crop soybean vegetative growth, seed yield, and yield component response to agronomic inputs in the mid-altlantic, USA.

Egli, D. B. 1998. Seed biology and the yield of grain crops. CAB international.

Egli, D.B., and W.P. Bruening. 2000. Potential of early-maturing soybean cultivars in late plantings. Agron. J. 92(3): 532–537. doi: 10.2134/agronj2000.923532x.

Frank, K., Beegle, D., Denning, J., 1998. Phosphorus. In: J.R. Brown (Eds.), Recommended chemical soil test procedures for the North Central Region. North Central Region. Missouri Agric. Exp. Stn., Columbia.

Hansel, D.S.S., R.A. Schwalbert, D.E. Shoup, D.L. Holshouser, R. Parvej, P. V. Vara Prasad, and I.A. Ciampitti. 2019. A review of soybean yield when double-cropped after wheat. Agron. J. 111(2): 677–685. doi: 10.2134/agronj2018.06.0371.

Hou, G., Ablett, G. R., Pauls, K. P., & Rajcan, I. (2006). Environmental effects on fatty acid levels in soybean seed oil. Journal of the American Oil Chemists' Society, 83(9), 759-763.

Kantolic, A. G., and Slafer, G. A. 2001. Photoperiod sensitivity after flowering and seed number determination in indeterminate soybean cultivars. Field Crops Research, 72(2), 109-118.

Kelley, K.W. 2003. Double-cropping Winter Wheat and Soybean Improves Net Returns in the Eastern Great Plains. Crop Manag. 2(1): 0–0. doi: 10.1094/CM-2003-1112-01-RS.

Knott, C.A., E.M. Swiggart, J.H. Grove, and E.R. Haramoto. 2018. Double-crop soybean germination, seedling growth, and seed yield differences when preceded by different winter annuals. Agron. J. 110(4): 1430–1438. doi: 10.2134/agronj2017.11.0639.

Kyei-Boahen, S., and L. Zhang. 2006. Early-maturing soybean in a wheat-soybean double-crop system: Yield and net returns. Agron. J. 98(2): 295–301. doi: 10.2134/agronj2005.0198.

McDonald, M.B., C.W. Vertucci, and E.E. Roos. 2010. Soybean Seed Imbibition: Water Absorption by Seed Parts. Crop Sci. 28(6): 993. doi: 10.2135/cropsci1988.0011183x002800060026x.

Moomaw, R.S., and T.L. Mader. 1991. Doublecropping seed and forage crops with small grains in the upper Midwest. J. Prod. Agric. 4(3): 385–390.

Rondanini, D.P., N. V. Gomez, M.B. Agosti, and D.J. Miralles. 2012. Global trends of rapeseed grain yield stability and rapeseed-to-wheat yield ratio in the last four decades. Eur. J. Agron. 37(1): 56–65. doi: 10.1016/j.eja.2011.10.005.

Seifert, C.A., and D.B. Lobell. 2015. Response of double cropping suitability to climate change in the United States. Environ. Res. Lett. 10(2): 024002. doi: 10.1088/1748-9326/10/2/024002.

Shapiro, B.I., B.W. Brorsen, and D.H. Doster. 1992. Adoption of Double-Cropping Soybeans and Wheat. J. Agric. Appl. Econ. 24(2): 33–40. doi: 10.1017/s0081305200018355.

Thomas, G.W. (1996) Soil pH and Soil Acidity. In: Sparks, D.L., Ed., Methods of Soil Analysis: Part 3—Chemical Methods, Book Series No. 5, SSSA and ASA, Madison, WI, 475-489.

Thomason, W., B.K. Chim, D. Holshouser, H. Behl, M. Balota, K. Xia, W. Frame, and T. Black. 2017. Comparison of full-season and double-crop soybean and grain sorghum systems in central and southeastern Virginia. Agron. J. 109(4): 1532–1539. doi: 10.2134/agronj2016.10.0577.

Triplett, G.B., and W.A. Dick. 2008. No-tillage crop production: A revolution in agriculture! Agron. J. 100(3 SUPPL.). doi: 10.2134/agronj2007.0005c.

Walkley, A., and I.A. Black. 1934. An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37(1): 29–38. doi: 10.1097/00010694-193401000-00003.

Warncke, D., Brown, J.R., 1998. Potassium and other cations. In: J.R. Brown (Eds.), Recommended chemical soil test procedures for the North Central Region. North Central Region. Missouri Agric. Exp. Stn., Columbia.

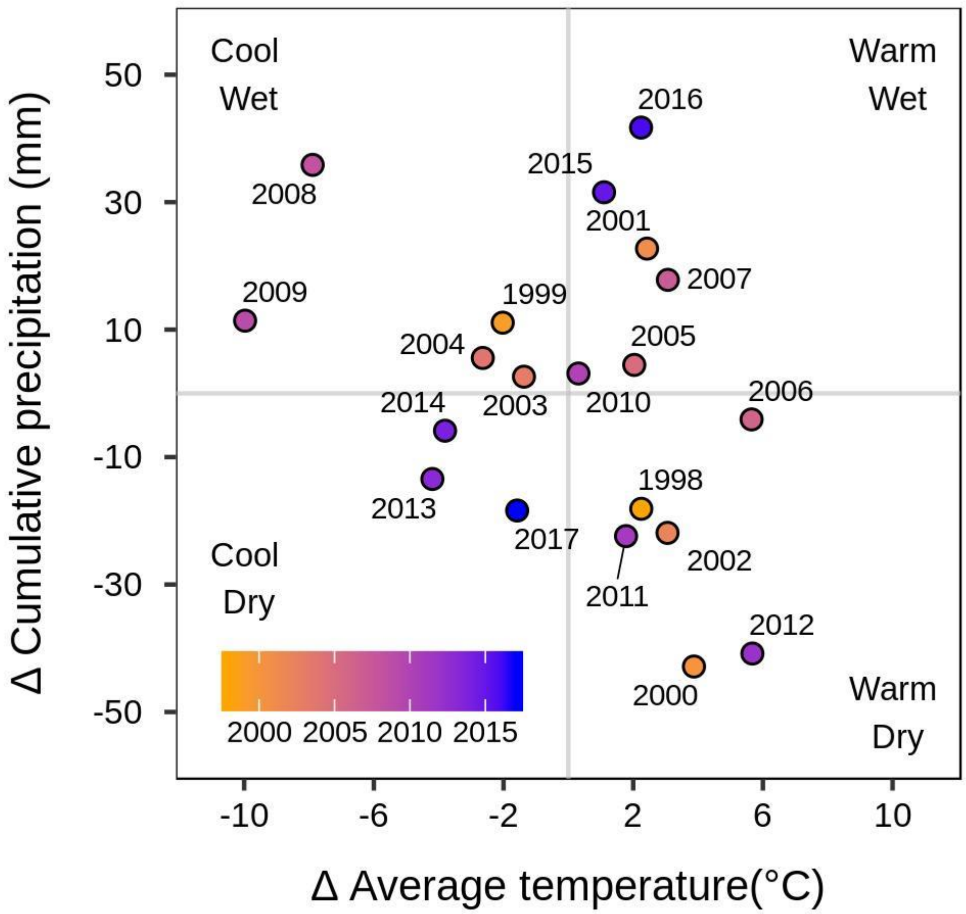


Figure 1. Weather classification of the years 1989 to 2017 based on the mean temperature and cumulative precipitation for August and September, compared to the mean temperature and precipitation from the 20 years.

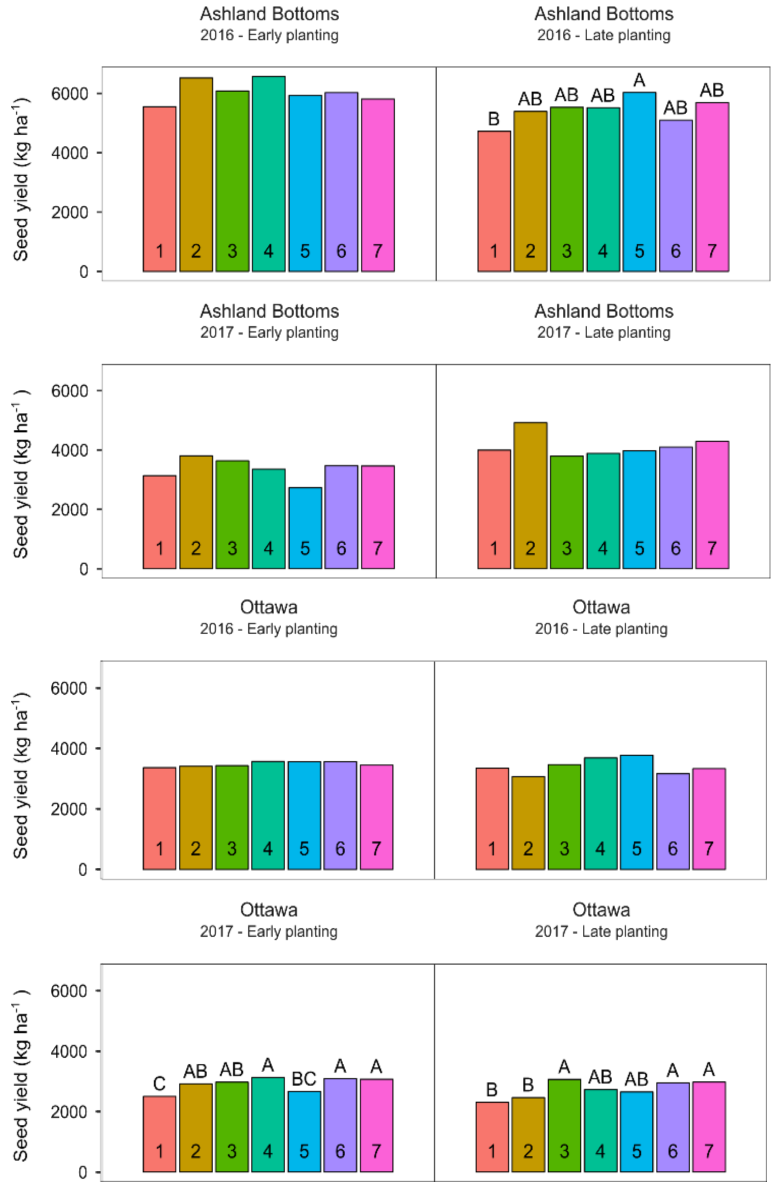


Figure 2. Seed yield for Ashland Bottoms and Ottawa, in 2016 and 2017, for early and late planting. Treatments: 1) common practice (no inputs added), 2) no seed treatment; 3) non-stay green (without fungicide/insecticide application); 4) high plant density (45 seeds m^{-2}); 5) wide rows (75 cm); 6) N effect (without late-season fertilizer N); and 7) kitchen sink, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization. Letters refer to the statistical significance ($p< 0.05$) between treatment for each location.

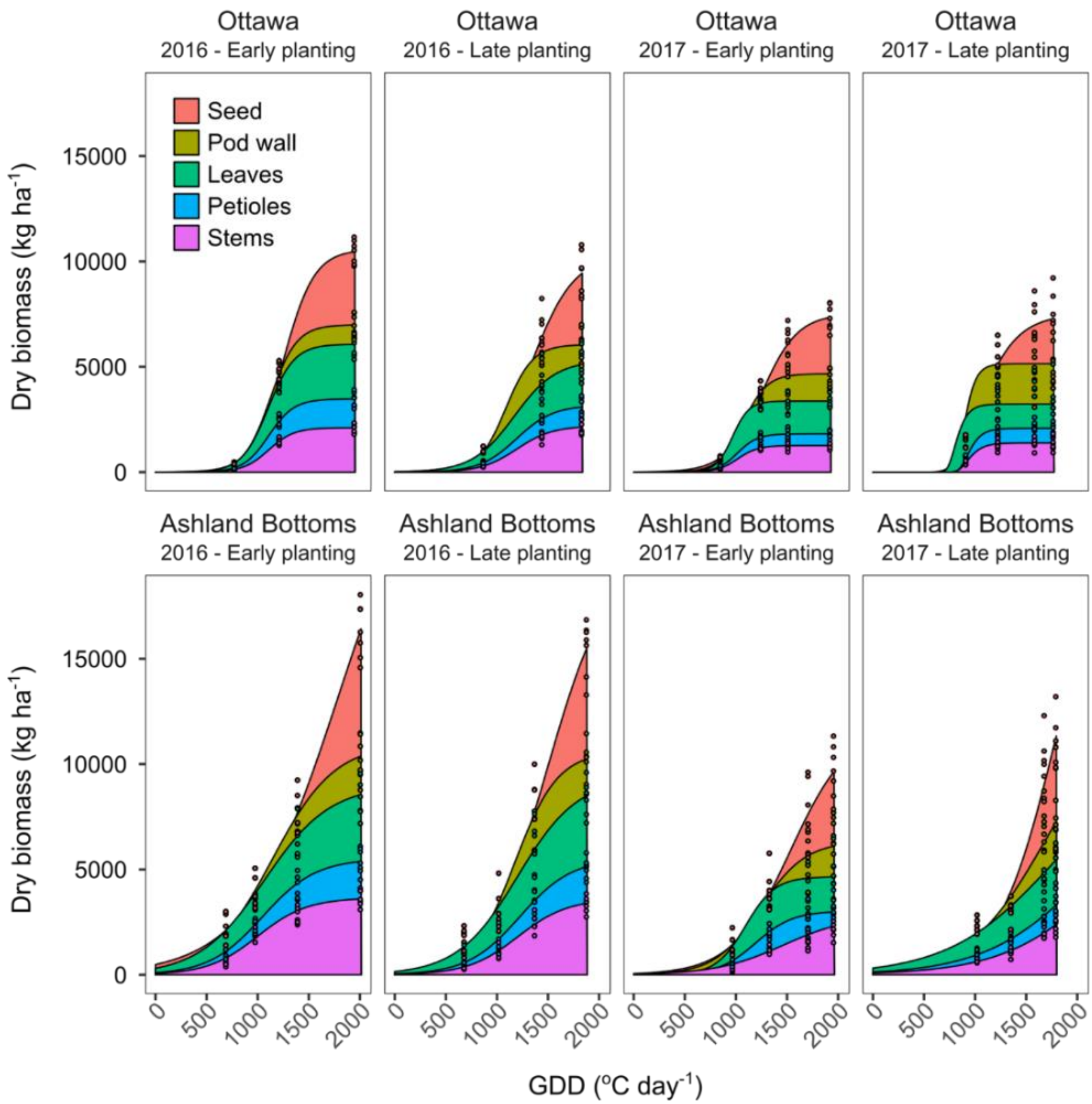


Figure 3. Total dry biomass and biomass partitioning for Ashland Bottoms and Ottawa, in 2016 and 2017, for early and late planting. Treatments are averaged for each location. Partitions were seeds, pod wall, leaves, petioles and stems. Growing degree days (GDD).

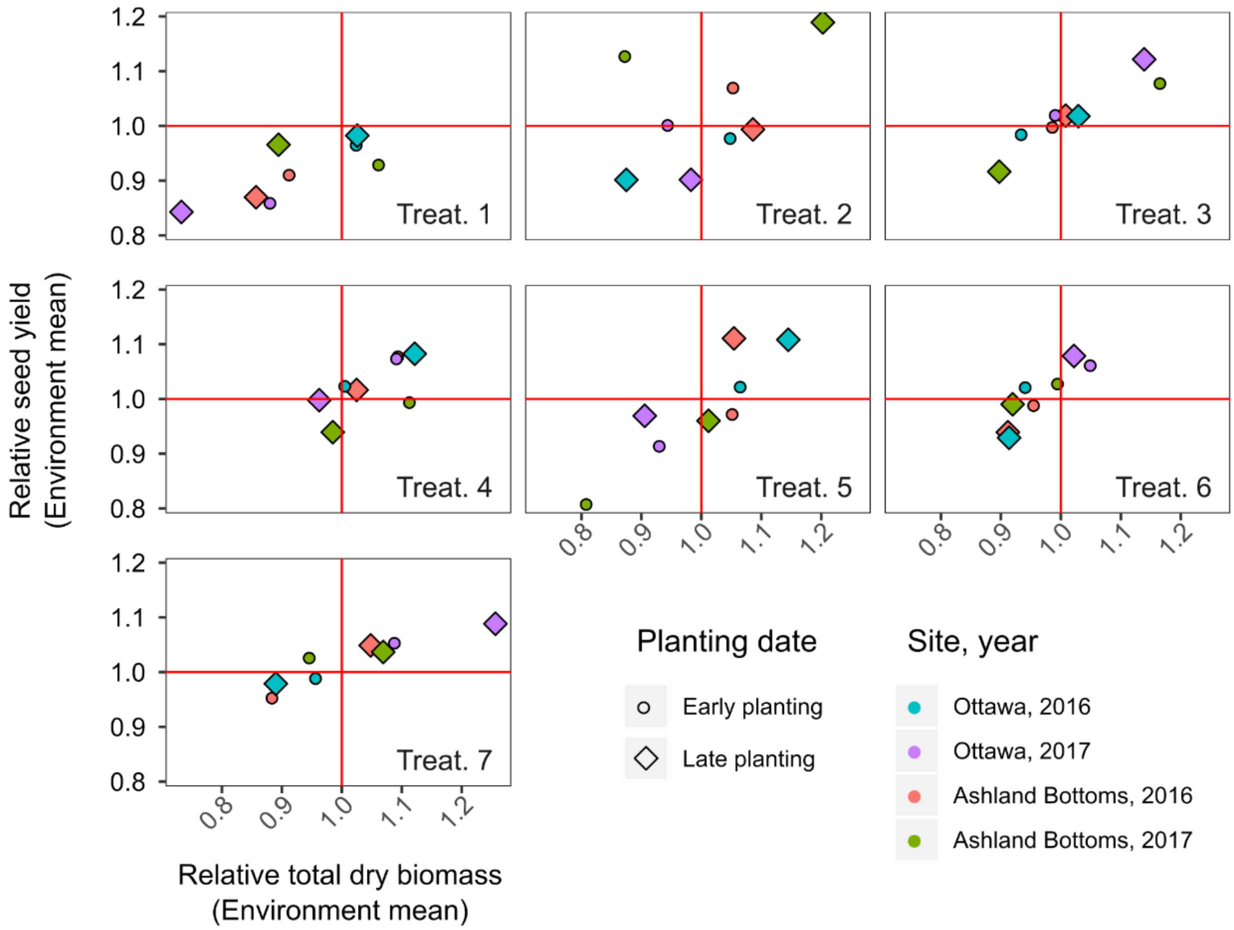


Figure 4. Relative values for seed yield and biomass for each environment. Treatments: 1) common practice (no inputs added), 2) no seed treatment; 3) non-stay green (without fungicide/insecticide application); 4) high plant density (45 seeds m^{-2}); 5) wide rows (75 cm); 6) N effect (without late-season fertilizer N); and 7) kitchen sink, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization.

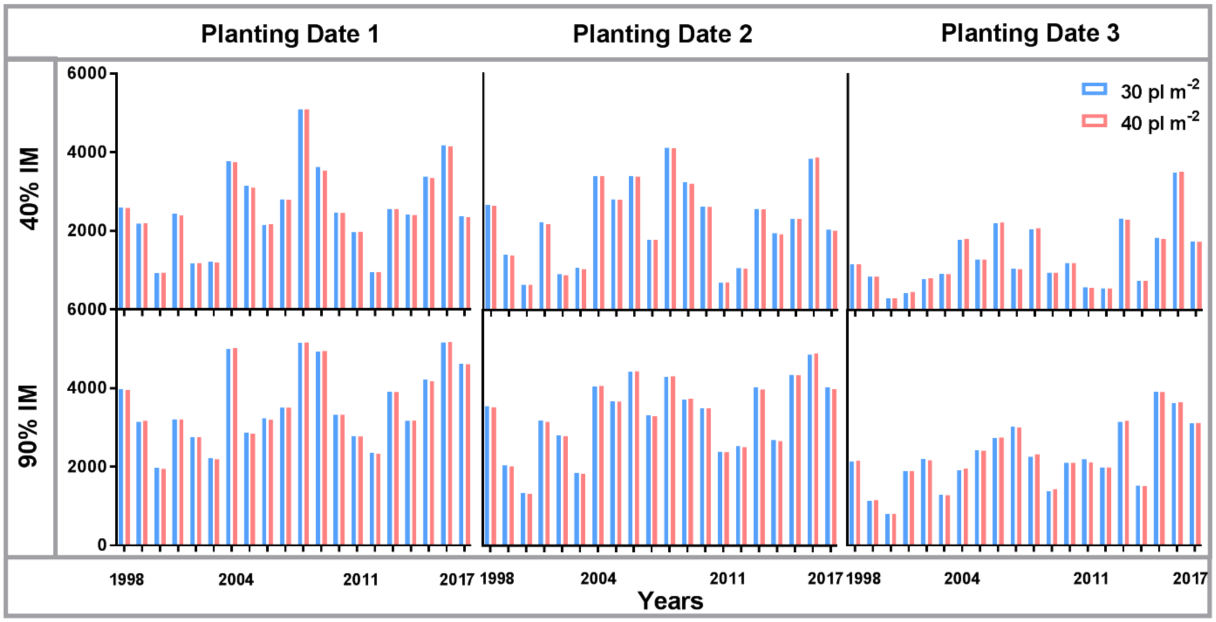


Figure 5. Simulations from 1998 to 2017 for seed yield for plant densities (30 and 40 plants m^{-2}), initial soil moisture (40% and 90%) and planting dates (May15, June 5 and June 25). Initial soil moisture – IM.

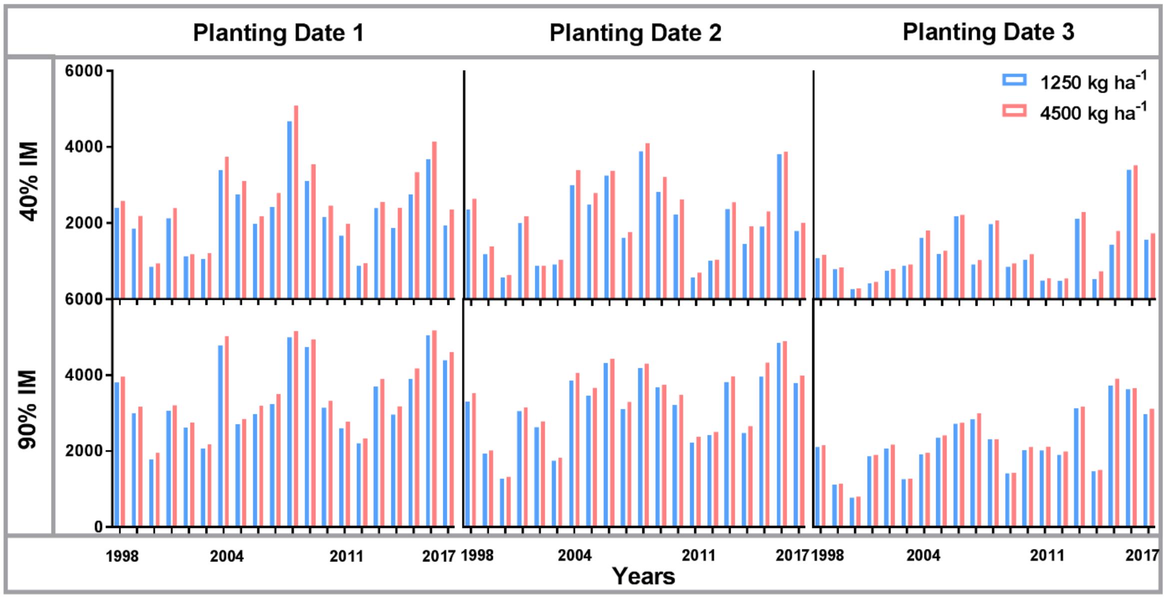


Figure 6. Simulations from 1998 to 2017 for seed yield for previous wheat residue (1250 and 4500 kg ha^{-1}), initial soil moisture (40% and 90%) and planting dates (May15, June 5 and June 25). Initial soil moisture – IM.

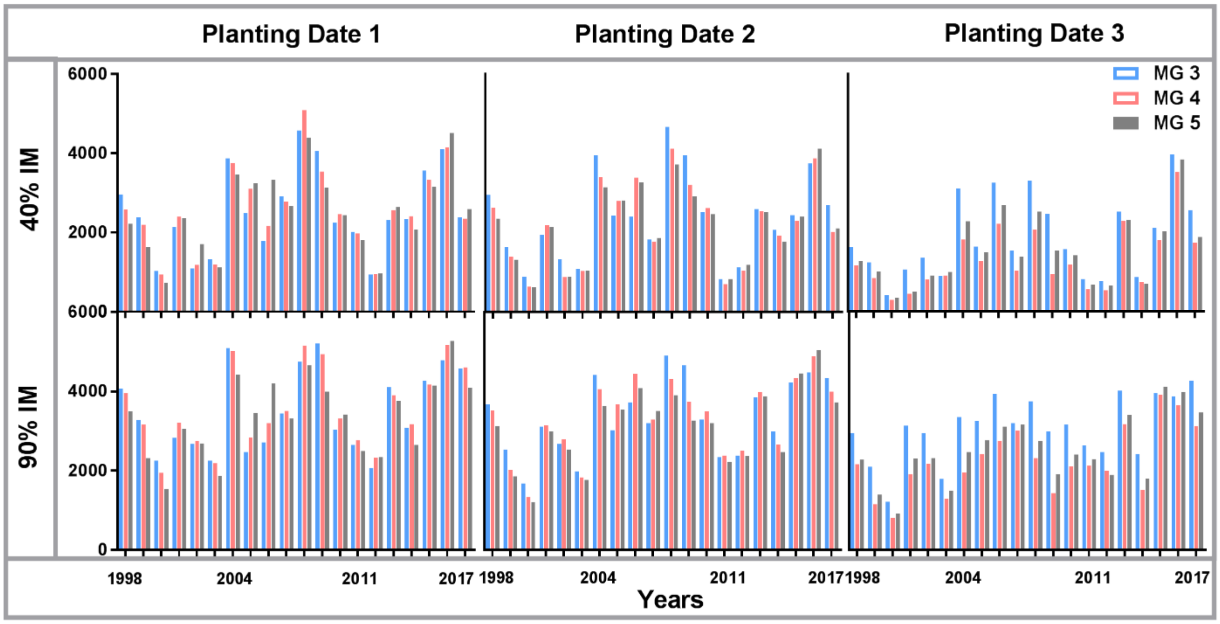


Figure 7. Simulations from 1998 to 2017 for seed yield for maturity groups (3, 4 and 5), initial soil moisture (40% and 90%) and planting dates (May15, June 5 and June 25). Initial soil moisture – IM, maturity group –MG.

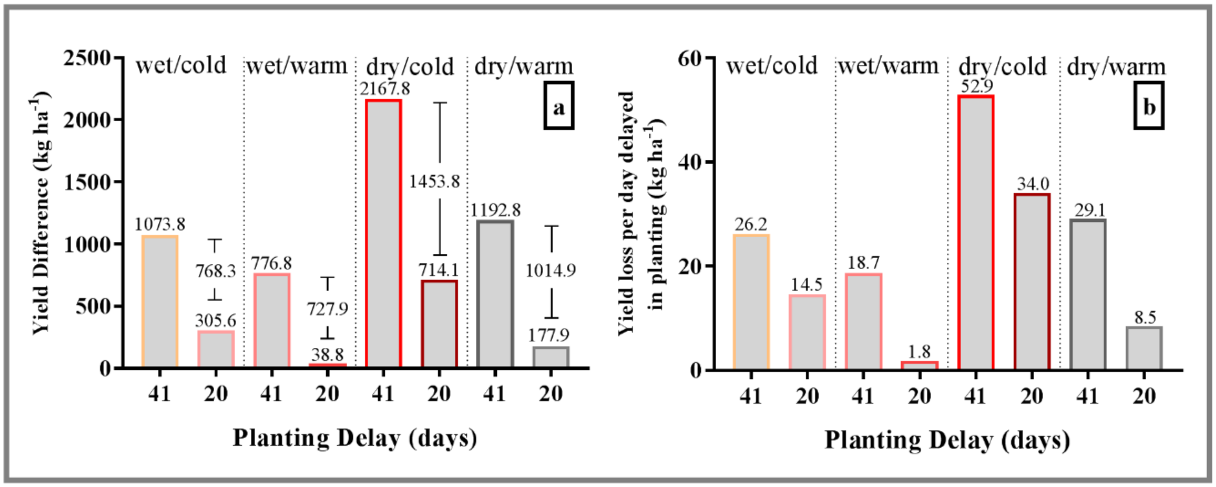


Figure 8. Yield decrease for weather environments (kg ha^{-1}), depending on planting delay of double-crop soybean (a). Rate of yield decrease per day (kg ha^{-1} day^{-1}) for delay in planting date compared to the first tested planting date (b).

Table 1. Pre-plant soil characterization at 0-15 cm at Ottawa and Ashland Bottoms, Kansas, in 2016 and 2017.

Soil parameters	**Ottawa**		**Ashland**	
	2016	**2017**	**2016**	**2017**
pH	5.8	5.7	5.9	6.1
Mehlich P (ppm)	14.5	19.6	57.7	62.5
CEC (meq/100 g)	15.4	23.6	7	9.4
Organic matter (%)	2.8	3	1.1	1.5
Potassium (ppm)	79.3	122.9	223.0	206.3
Calcium (ppm)	2248.7	2447.4	1028.8	1061.1
Magnesium (ppm)	303.5	348.7	105.8	118.3

Table 2. Management practices for treatments imposed on double-crop soybean planted after wheat for the early- and late-planting studies at Ottawa and Ashland, KS, in 2016 and 2017.

Trt	Description	Seed treatment	Fungicide / insecticide	Fertility	Density (seeds m^{-2})	Rows (cm)	Late nitrogen
1	Common practice	No	No	No	35	75	No
2	No seed treatment	No	Yes	Yes	35	38	Yes
3	Non-stay green	Yes	No	Yes	35	38	Yes
4	High plant density	Yes	Yes	Yes	45	38	Yes
5	Wide rows	Yes	Yes	Yes	35	75	Yes
6	Nitrogen fixation	Yes	Yes	Yes	35	38	No
7	Kitchen sink	Yes	Yes	Yes	35	38	Yes

Table 3. Statistical analysis of planting date and initial water when simulation values were grouped by weather classification. Uppercase letters compare significance among columns, and lowercase letters compares significance in the rows.

	Weather							
Planting date	**Dry/Cold**		**Dry/Warm**		**Wet/Cold**		**Wet/Warm**	
15-May	3173	Aa	2233	Ab	3629	Aa	3381	Aa
5-Jun	2867	ABab	2194	Ab	2915	Ba	3203	Aa
25-Jun	2099	Bab	1466	Bb	1461	Cb	2189	Ba

Initial soil moisture	**Yield**	
90%	3081	a
40%	2054	b

Table 4. Statistical analysis of previous wheat residue and initial water when simulation values were grouped by weather classification. Uppercase letters compare significance among columns, and lowercase letters compares significance in the rows.

	Weather							
Planting date	**Dry/Cold**		**Dry/Warm**		**Wet/Cold**		**Wet/Warm**	
15-May	3024	Aa	2153	Ab	3497	Aa	3227	Aa
5-Jun	2738	ABab	2129	Ab	2816	Bab	3089	Aa
25-Jun	2034	Bab	1433	Bb	1442	Cab	2131	Ba

Initial soil moisture	**Yield**	
90%	3013	a
40%	1939	b

Table 5. Statistical analysis of maturity groups, and initial water when simulation values were grouped by weather classification. Uppercase letters compare significance among columns, and lowercase letters compares significance in the rows.

Weather			Planting date			Initial soil moisture		
Dry/Cold	2789	a	**15-May**	3030	a	**90%**	3157	a
Dry/Warm	2025	b	**5-Jun**	2789	a	**40%**	2133	b
Wet/Cold	2795	a	**25-Jun**	2116	b			
Wet/Warm	2972	a						

Table 6. Statistical analysis of maturity groups, and initial water when simulation values were grouped by weather classification. Uppercase letters compare significance among columns, and lowercase letters compares significance in the rows.

Weather			**Planting date**			**Initial Water**		
Dry/Cold	2707	a	**15-May**	3098	a	**90%**	3079	a
Dry/Warm	1960	b	**5-Jun**	2788	a	**40%**	2049	b
Wet/Cold	2669	a	**25-Jun**	1805	b			
Wet/Warm	2919	a						

Chapter 3 - Seed Quality Response to Field Management Practices in Double-Cropped Soybeans

Abstract

Double-crop (DC) soybean [G*lycine max* (L.) Merr.] is usually planted after winter wheat (*Triticum aestivum* L.) harvest in North America. A double-cropped soybean system is subject to different environmental conditions relative to the one faced by full-season soybean. Therefore, DC soybean may not only experience a differential seed yield response to management practices, but also changes in seed composition and quality. This study was conducted with the goal of evaluating the responses of DC soybean seed composition and quality to different management practices and planting times. Two sites were tested in Kansas during two growing seasons, 2016 and 2017 years. In each site-year, two planting dates were tested, one planted before the anticipated winter wheat harvest (greater wheat grain moisture content, 18-22%) and one planted right after the conventional wheat harvest time, with these planting times differing between 5-10 days. A total of seven management practice treatments were tested in each planting date: 1) common practice (no inputs added), 2) no seed treatment; 3) non-stay green (without fungicide/insecticide application); 4) high plant density (45 seeds m^{-2}); 5) wide rows (75 cm); 6) N effect (without late-season fertilizer N); and 7) kitchen sink, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization. Protein, oil, fatty acids (stearic, palmitic, oleic, linoleic and linolenic), fiber and ash were analyzed for seed composition. Oil content presented a negative relationship with protein content. Monounsaturated (oleic) and saturated (stearic and palmitic) fatty acids, as well as total fatty acid yields were increased as inputs and seed yield increased. There were no differences for seed

composition and quality for planting times for the majority of the analysis. Seed filling duration can be affected by management practices, promoting differences in seed composition. Lastly, as seed filling duration increases, fatty acids concentrations decrease, but improving their final seed content.

Introduction

Double-crop soybean [G*lycine max* (L.) Merr.] is usually planted after winter wheat (*Triticum aestivum* L.) harvest in North America. Because wheat is harvested later than the ideal time for planting soybean, the crop growth cycle is delayed and management practices may differ in response to the delay on planting time. Management practices such as fertilizer application rate, row spacing, plant density and seed treatment can influence the crops in different ways, when they are subject to other environments. In the case of soybean double-cropped (DC) after winter wheat, a different environment is given by the late season and the effect of the previous crop (its productivity and residue level).

Seed composition is an inherited trait in soybean (Burton, 1985; Wilcox, 1985). However, studies have shown that management practices can affect seed composition (Bellaloui, 2015; Ray, 2006; Singer and Kohler, 2005). Soybean is known for having high protein and oil concentration in its composition. Protein composes about 40% of the soybean seed and can be classified in three groups: metabolic enzymes, structural membrane and storage proteins (Krishnan, 2001; Nielsen, 1997). Oil composes 12 to 23% of the soybean seed (Gao, 2009). Besides the composition quantities of protein and oil, there is the quality aspect that needs to be taken in consideration when evaluating seed composition. The oil composition is obtained from five fatty acids: palmitic, stearic, oleic, linoleic and linolenic. The fatty acid composition and distribution determine oil quality, nutritional value, flavor, oxidative stability, melting point, crystallization form, among other relevant traits (Yadav, 1996).

The development of soybean seeds with high oleic acid content has been sought due to a great part of soybean production being directed to the food industry. However, poor oxidative and frying stability, due to high polyunsaturated fatty acids in soybean oil, limits industry uses.

In addition, industry refining process also decreases oxidative stability during the neutralization step (Farhoosh et al., 2009). Linolenic acid (polyunsaturated, 18:3) derives from linoleic acid (polyunsaturated, 18:2), which derives from oleic acid (monounsaturated, 18:1). When values of linoleic and linolenic acids are high, it means that oleic acid was lost in the conversion. Decreasing levels of linoleic and linolenic acids improves soybean oil quality by lowering the amount of polyunsaturated fatty acids while increasing oleic acid, improving oxidative and frying stability (Demorest et al., 2016).

Soybean oil in connected to biofuel, which can be used as an alternative for petroleum based fuels (Fargione et al., 2008). Soybean oil is biodegradable, it has increased flashpoint, emits less pollutants to the atmosphere, has a reduced toxicity and increased lubricity. But there are important characteristics that have limited the use of soybean oil for this purpose. The main limitation to the use of soybean oil for biofuel is the cold flow, in colder climates (Boshui et al., 2010). High oleic, and low linoleic and linolenic contents need to be prioritized for increased use of soybean oil in biofuel mixes (Kinney and Clemente, 2005). Soybean oil can be also used as a lubricant for hydraulic systems (Honary, 1996), but low oxidative stability hinders its use.

There are many factors that affect the concentration of oil and its components, such as soil moisture (Carrera, 2009; Rotundo and Westgate, 2009; Kumar, 2006), temperature (Caviglia, 2011; Gibson and Mullen, 1996; Wolf, 1982), biomass and yield (Assefa et al., 2018), among many other factors.

Despite that, there is not much information in the literature on how field management practices affect these factors in relation to soybean seed composition quality. Different factors affect seed quality, environmental conditions, planting times and management practices. Understanding how management practices effect seed quality characteristics can help when opting for different management strategies for different purposes related to seed composition. When soybean is planted later in the season as in a DC system, the reproductive stages are postponed closer to later in the fall. The decrease in temperature and radiation can also shorten the season and affect seed composition. Thus, this study was conducted with the goal of evaluating the effect of different management practices and two planting times (early and late during wheat harvest time) for DC soybean farming systems in response to seeds composition and quality.

Materials and Methods

Field settings

The soil type at Ottawa, Kansas, was a Woodson silt loam (Mollisols) and at Ashland Bottoms, Kansas, was a Belvue Silt Loam. Soil samples were taken prior to planting at a depth of 0 to 15 cm. Soil chemical parameters analyzed were pH, Mehlich P, cation exchange capacity (CEC), organic matter (OM), calcium, magnesium, and potassium (K) availability (Table 1).

The studies were arranged in a randomized complete block design with four replications. Plot size was 3m wide × 18m long. The soybean variety used was Asgrow 4232 (Monsanto Co.), maturity group 4.2. Soybean was planted immediately after winter wheat harvest of the cultivar WB Cedar – WestBred, (Monsanto Co.). The studies were conducted in four site-years in northeast Kansas. In each study there were two planting dates, planted after early winter wheat harvest and planted after conventional wheat harvest (Table 2).

Seven treatments were evaluated in each site-year: 1) common practice (no inputs added), CP, 2) no seed treatment, NST; 3) non-stay green (without fungicide/insecticide application), NSG; 4) high plant density (45 seeds m^{-2}), HP; 5) wide rows, WR (75 cm); 6) N effect (without late-season fertilizer N); and 7) kitchen sink, KS, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization. The seed treatment was Acceleron standard (Monsanto Company) which contains a fungicide plus an insecticide. For the foliar fungicide plus insecticide application, the chemicals used were Aproach Prima + Prevathon (0.45 + 1.24 L ha^{-1}) (DuPont Company) and applied to soybean at the R3-R4 growth stage (Fehr and Caviness, 1977). Herbicides and hand weeding were used to maintain no weed interference for the entire season. Fertilizer application was performed on treatments 2 to 7 using the formulation 7N-

$7P_2O_5$-$7K_2O$-7S-7Cl (chloride). The application rate was 12 kg ha^{-1} of N, P, K, S and Cl. In treatment 2 to 6, late N was applied at a rate of 57 kg ha^{-1}, in the formulation of 32-0-0 (N-P_2O_5-K_2O). Biomass was collected in a 1.16 m^2 area, sampled outside the area collected for yield in R7. The specific management practices composing each treatment are listed in Table 3.

Seed samples were collected at harvest from a subsection of 1m^2 within the plot of 55 m^2. Seeds were dried to 13% moisture. Seed yield was collected from an area of 55 m^2. Seed weight was calculated from a 1000 seed weight base, dividing the total weight by the number of seeds, for the final individual seed weight. Biomass was collected from a 1 m^2 area and calculated to a hectare. Harvest index (HI) was calculated dividing seed yield by total biomass (shoot and grain). For the laboratory analysis 3 seeds were used for each of the fatty acid determinations.

Lab analysis

Protein and oil concentrations (expressed in dry basis) were tested using the near infrared (NIR) spectroscopy technique on seed samples collected at harvest with a Perten DA 7200 (Perten Instruments, Springfield III, US).

Analysis of fatty acid methyl esters (FAMEs) was carried out as previously described (Li et al., 2006) with minor modifications. Pre-weighed crushed dry seeds were transmethylated with 2ml of 5% (v/v) sulfuric acid in methanol for 1 h at 90 ^oC. Before transmethylation, 200 µg of tripentadecanoin was added as an internal standard and 50 µg of butylated hydroxytoluene was added to prevent oxidation. The FAMEs were then extracted with 1.5 mL of 0.9% (v/v) potassium chloride and 2 mL of hexane. The organic phase was analyzed with a Shimadzu GC-2010 plus gas chromatograph equipped with a DB-23 column (30.0 m x 0.25 mm; Agilent Technologies) coupled with flame ionization detector (GC-FID) as described previously (Aznar Moreno and Durrett, 2017). Content was calculated by the multiplication of the concentration of protein, oil and fatty acids by seed dry mass at harvest. Concentration is independent of the sample size; while content, extensive property, is size dependent (Farhoomand and Peterson, 1968).

Fatty acid yield was calculated by multiplying concentration by seed yield. Relative fatty acids were calculated using the proportions of each fatty acid to the total amount of fatty acids, generating a percentage of each fatty acid to the total.

Statistical analysis

The R software (R Core Team, 2018) was used for statistical analyses. Mixed model were fitted for each variable using the "lme4" package (Bates et al., 2015). The fixed effects corresponded to the treatment, planting date, and its interaction, while the random components were the site-years (four), and block within site-year. Before running the ANOVA, normality of the residuals and homogeneity of the variances were tested using Shapiro-Wilk and Levene's test, respectively. Tukey test (5% significance) was performed for comparison of the means with the "multicomp" package (Hothorn et al., 2008). Soybean crop and seed composition parameters were placed together in a correlation matrix (Pearson correlation), using the "PerformanceAnalytics" package (Peterson et al., 2018) in R software. The values used for the correlation matrix were the relative values, calculated from the deviations from the mean of each experiment.

Results

Crop evaluations

There were no differences in yield, biomass, or seed number for treatments (Table 4). Planting dates were compared across locations, using each location as a repetition. However, there were no differences observed in relation to crop evaluations. On the other hand, seed weight and harvest index showed interaction between treatments and planting dates. The common practice (treatment 1) and the wide row spacing (treatment 5) presented significantly lower seed weight in the early planting date. The kitchen sink treatment (treatment 7) presented greater seed weight, while the no seed treatment (treatment 2) resulted in the greater HI. There were no significant differences for the latest planting date.

Protein and oil

There were no differences in concentration for ash and fiber (Table 5). Yet, oil and protein concentration significantly differ among treatments, as well as protein content. Oil presented greater concentration for treatments 1 and 3, while there was lower concentration for treatment 5. On the other hand, there was greater protein concentration for treatments 4 and 5, while treatment 1 showed lower protein concentration. There were no significant differences for oil and protein concentrations for different planting dates.

Ash, fiber and protein content were significantly lower for CP. The kitchen sink treatment had greater content of protein, fiber and ash. Wide rows treatment also had greater content of protein. Despite there were no differences in treatments for ash concentration, ash content had similar responses to treatments as protein content, with greater content for treatments with higher inputs, except for treatment 3.

Biomass and seed yield showed significant positive correlation ($p < 0.001$, $r = 0.75$) (Figure 1). The same relation occurred for biomass and seed number ($p < 0.001$, $r = 0.68$), but in a very slight positive relationship with seed weight ($p < 0.05$, $r = 1.13$). Naturally, as biomass and seed yield had a positive relationship, but biomass showed a negative relation with harvest index ($p < 0.001$, $r = -0.55$). Seed yield and number were highly positively related ($p < 0.001$, $r = 0.93$), while seed weight and number showed a slightly negative relation ($p < 0.001$, $r = -0.24$).

Oil and protein portrayed an expected strong negative correlation among them ($p < 0.001$, $r = -0.80$). As seed weight increased, oil concentration decreased slightly ($p < 0.05$, $r = -0.17$) while protein increased slightly ($p < 0.05$, $r = 0.14$).

Fatty acids

Concentration of fatty acids (μg FAMEs mg^{-1}) did not differ among them (Table 6). Nonetheless, stearic acids content (mg $seed^{-1}$), showed statistical differences among treatments, being greater for treatment 2 and lower for treatment 3. Fatty acid yields (kg ha^{-1}) showed increase in oleic, stearic, palmitic and total fatty acids for intensified management practices (Table 6). The CP treatment presented less monounsaturated and saturated fatty acid yield. Relative concentration (%mol FAMEs) showed significant differences for palmitic acid for treatments with greater inputs and lower values for CP treatment (Table 6). There were no interactions or differences in early and late planting dates for fatty acid concentration, content, fatty acid yield or relative concentration, when testing among planting dates across all locations.

All fatty acids concentrations were averaged across treatments due to lack of significance among them. There was a highly negative relationship between oleic acid (18:1) and linoleic acid (18:2) relative values, as well as for oleic and linolenic (18:3) acids (Figure 2). There was a positive relation between linoleic (18:2) and linolenic acid (18:3) relative values. Other correlations showed in Figure 2, showed low correlations.

Discussion

Crop evaluations

Both years evaluated had good precipitation during the season. There was no drought or flooding stresses. The cumulative precipitation was from was 540 and 508 mm during the seasons, for planting dates early and late, respectively (Kansas Mesonet). There were no early freeze events, or pest and disease strong attacks at the sites studied. Therefore, in the specific conditions of these experiments, the soybean plants did not have a significant response to the treatments tested on yield, biomass and seed number. However, seed weight showed lower values for common practices, in the early planting date, presenting an effect from the treatments with more inputs.

Protein and oil

Protein and oil showed inverse relationship between oil and protein concentration. The treatments that presented greater protein, had less oil and vice-versa (Table 5). This correlation tested in Figure 1, was also observed in other studies, when one component increasing in detriment of the other (Krober and Cartter, 1962, Hymnowitz et al., 1972, Marega Filho et al., 2001).

Protein and seed yield were not correlated significantly (Figure 1). The flat or even negative relationship of protein and yield is due to the high expense of the plant on oil and carbohydrates (Wilcox and Shibles, 2001). In agreement with Pedersen and Lauer (2003), there were no differences for protein and oil concentrations for different planting dates (early and late May). However, other studies found that protein concentration increased as planting was delayed (Helms 1990, Beatty et al. 1982). The different responses may be due to differences among environments, which can be caused by late planting, locations or yet, different year to year weather patterns.

Fatty acids

There was greater availability of oleic, stearic and palmitic acids per area, represented by fatty acid yield. The greater quantity of unsaturated fatty acids denotes higher production of higher quality oil yield. Oils that are rich in unsaturated fats are considered healthier for human and animal consumption, in addition to having a longer shelf life and better oxidative stability (Clemente and Cahoon, 2009). The fact of having greater unsaturated and saturated oil yields in the treatments with greater inputs, implies that these treatments are affecting higher quality oil total productivity, increasing the total production of unsaturated and saturated fatty acids per area. Relative values of fatty acids explain the effect of the treatment on the proportion of the specific fatty acids to a unit of oil. In this study, oil quality was slightly increased by the difference in palmitic acid depending on treatments, where common practices and seed treatment showed lower proportions of palmitic acid.

Positive correlation between oleic (18:1) and linoleic acid (18:2), show that oleic acid and saturated fatty acids had a trade-off balance. The lack of transformation of 18:1 into 18:2, suggests that the biochemical steps affected by in the evaluated field conditions were primarily at the level of 18:2 biosynthesis. Increases in oleic acid with a decrease in linoleic and linolenic acids were also observed in other studies (Dornbos and Mullen 1992, Kane et al. 1997, Rennie and Tanner 1989). These studies suggest that oleic acid increases due to high temperatures, as linoleic and linolenic acids decrease.

Despite there being no statistical differences in fatty acids for planting date in this study, in other conditions, planting earlier resulted in greater oil and oleic acid, as well as lower protein and linolenic acid (Bellaloui, 2015). In the latter study changes in seed constituents were attributed mainly to temperature changes and drought, indicating that shifts in planting dates forced the crop to be exposed to different environmental conditions. In the present study, differences between environments, experienced by the minimum changes on planting dates, were not enough to change responses due to weather.

Box 1. Relevance of seed filling duration and the effect of management practices
The analysis of seed composition and quality in the context of management effect can be improved by investigating the effect of seed filling duration and its rate on the effect in the concentration of the fatty acids and oil seed components. Below is an example of contrasting effective filling period (EFP) and its results on oil composition.

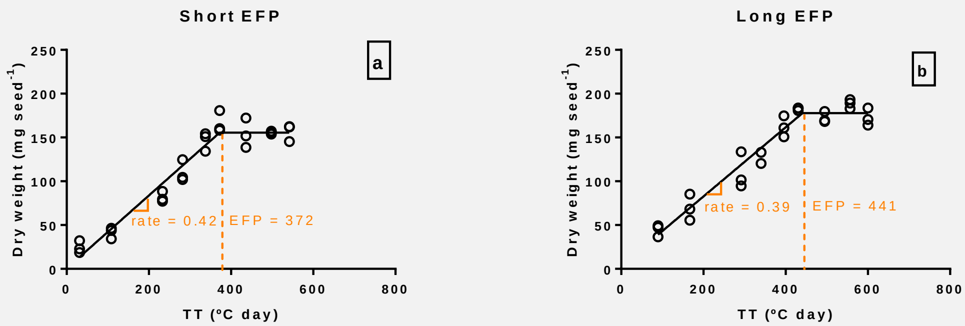


Figure 1. Effective filling period (EFP) and dry weight of soybean seeds, affected by contrasting management treatments. Graph "a" shows fatty acids concentration for a short EFP accumulation, graph "b" presents the values for a longer EFP. Thermal time (TT).

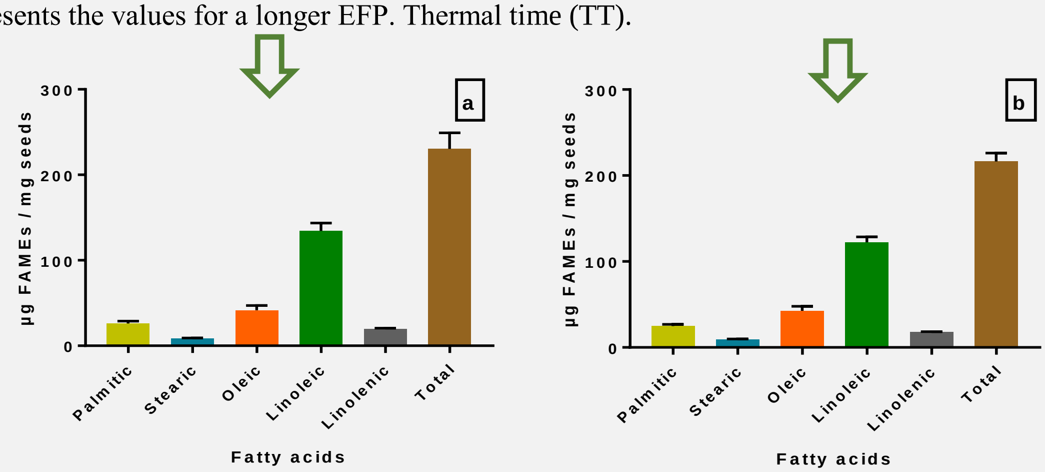


Figure 2. Palmitic, stearic, oleic, linoleic and linolenic fatty acids concentration for contrasting management treatments. Graph "a" shows fatty acids concentration for a short effective filling period (EFP) accumulation, graph "b" presents the values for a longer EFP.
The EFP reflects the actual duration of the seed filling period and the rate also influences on the final seed weight. In this example, the two treatments influenced the duration in 69 extra thermal time (TT) units (ºC) (Figure 1). Depending on the weather, this can represent an additional week in seed filling. The scenario with the shorter EFP duration showed greater concentration of fatty acids in relation to the scenario with a shorter EFP (Figure 2). This result can mean that fatty acids were accumulated in the beginning of the seed filling, and other components of the seed continued to compose the total weight of the seed during the extra period. Privett et al. (1973) found that the percentage of saturated fatty acids decreased rapidly in early seed development stages, and gradually decreased as seed matured. Oil concentration decreases, while protein increases concentration with the progression of seed filling period. Although oil content increases when seed weight is enhanced, which occurs when seed filling period is longer (Ghassemi-Golezani and Farhangi-Abriz, 2016). Temperature could also affect the relationship between oil and protein, as this factor impact seed filling. It was suggested that daily day time temperatures should be under 28ºC (Dornbos and Mullen, 1992) or even 25ºC daily (day plus night) temperature (Gibson and Mullen, 1996) for improving seed filling duration.

Conclusion

Protein and oil have strong inverse concentration correlation. Protein concentration was lower when no inputs were applied, whilst oil presented greater concentration. There were no differences in concentration for fatty acids. However, for fatty acid yield, there were more monounsaturated and saturated fatty acids for treatments with more inputs, generating more high quality oil per area. Relative palmitic acid was lower when less inputs were applied. Fatty acids were all positively correlated among them. Seed filling duration can be affected by management practices, generating differences in seed composition at the end of the period. As the seed filling duration is longer, there is lower concentration of fatty acids.

Reference

Aznar-Moreno, J. A., & Durrett, T. P. (2017). Simultaneous targeting of multiple gene homeologs to alter seed oil production in Camelina sativa. Plant and Cell Physiology, 58(7), 1260-1267.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48.

Beatty, K. D., Eldridge, I. L., & Simpson, A. M. (1982). Soybean Response to Different Planting Patterns and Dates 1. Agronomy Journal, 74(5), 859-862.

Bellaloui, N., Bruns, H. A., Abbas, H. K., Mengistu, A., Fisher, D. K., & Reddy, K. N. (2015). Agricultural practices altered soybean seed protein, oil, fatty acids, sugars, and minerals in the Midsouth USA. Frontiers in plant science, 6, 31.

Boshui, C., Yuqiu, S., Jianhua, F., Jiu, W., & Jiang, W. (2010). Effect of cold flow improvers on flow properties of soybean biodiesel. Biomass and bioenergy, 34(9), 1309-1313.

Burton JW (1985) Breeding soybeans for improved protein quantity and quality. In: Shibles R (ed) Proc 3rd World Soybean Res. Conf. Westview Press, Boulder/CO, pp 361- 367.

Clemente, T. E., & Cahoon, E. B. (2009). Soybean oil: genetic approaches for modification of functionality and total content. Plant physiology, 151(3), 1030-1040.

Demorest, Z. L., Coffman, A., Baltes, N. J., Stoddard, T. J., Clasen, B. M., Luo, S., ... & Mathis, L. (2016). Direct stacking of sequence-specific nuclease-induced mutations to produce high oleic and low linolenic soybean oil. BMC plant biology, 16(1), 225.

Dornbos, D. L., & Mullen, R. E. (1992). Soybean seed protein and oil contents and fatty acid composition adjustments by drought and temperature. Journal of the American Oil Chemists Society, 69(3), 228-231.

Fargione, J., Hill, J., Tilman, D., Polasky, S., & Hawthorne, P. (2008). Land clearing and the biofuel carbon debt. Science, 319(5867), 1235-1238.

Farhoomand, M. B., & Peterson, L. A. (1968). Concentration and Content 1. Agronomy Journal, 60(6), 708-709.

Farhoosh, R., Einafshar, S., & Sharayei, P. (2009). The effect of commercial refining steps on the rancidity measures of soybean and canola oils. Food Chemistry, 115(3), 933-938.
Fehr, W. R., & Caviness, C. E. (1977). Stages of soybean development.

Gao, J., Hao, X., Thelen, K. D., & Robertson, G. P. (2009). Agronomic management system and precipitation effects on soybean oil and fatty acid profiles. Crop science, 49(3), 1049-1057.

Ghassemi-Golezani, K., & Farhangi-Abriz, S. (2018). Changes in oil accumulation and fatty acid composition of soybean seeds under salt stress in response to salicylic acid and jasmonic acid. Russian journal of plant physiology, 65(2), 229-236.

Gibson, L. R., & Mullen, R. E. (1996). Soybean seed composition under high day and night growth temperatures. Journal of the American Oil Chemists' Society, 73(6), 733-737.

Helms, T. C., Hurburgh, C. R., Lussenden, R. L., & Whited, D. A. (1990). Economic analysis of increased protein and decreased yield due to delayed planting of soybean. Journal of Production Agriculture, 3(3), 367-371.

Honary, L. A. (1996). An investigation of the use of soybean oil in hydraulic systems. Bioresource Technology, 56(1), 41-47.

Hothorn, T., Bretz, F. and Westfall, P. (2008). Simultaneous Inference in General Parametric Models. Biometrical Journal 50(3), 346-363.

Hymowitz, T., Collins, F. I., Panczner, J., & Walker, W. M. (1972). Relationship between the content of oil, protein, and sugar in soybean seed 1. Agronomy Journal, 64(5), 613-616.

Kane, M. V., Steele, C.C., Grabau, L.J., MacKown, C.T., & Hildebrand, D.F. (1997). Early-Maturing Soybean Cropping System: III. Protein and Oil Contents and Oil Composition, Agronomy Journal, 89, 464–469.

Kinney, A. J., & Clemente, T. E. (2005). Modifying soybean oil for enhanced performance in biodiesel blends. Fuel processing technology, 86(10), 1137-1147.

Krishnan HB (2001) Biochemistry and molecular biology of soybean seed storage proteins. J New Seeds 2:1–25

Krober, O. A., & Cartter, J. L. (1962). Quantitative Interrelations of Protein and Nonprotein Constituents of Soybeans 1. Crop Science, 2(2), 171-172.

Li, Y., Beisson, F., Pollard, M., & Ohlrogge, J. (2006). Oil content of Arabidopsis seeds: the influence of seed anatomy, light and plant-to-plant variation. Phytochemistry, 67(9), 904-915.

Marega Filho, M., Destro, D., Miranda, L. A., Spinosa, W. A., Carrão-Panizzi, M. C., & Montalván, R. (2001). Relationships among oil content, protein content and seed size in soybeans. Brazilian Archives of Biology and Technology, 44(1), 23-32.

Medic, J., Atkinson, C., & Hurburgh Jr, C. R. (2014). Current knowledge in soybean composition. Journal of the American oil chemists' society, 91(3), 363-384.

Nielsen N, Bassuner R, Beaman T (1997) The biochemistry and cell biology of embryo storage proteins. In: Larkins R, Vasil I (eds) Cellular and molecular biology of plant seed development. Kluwer Academic Publishers, Dordrecht, pp 151–220

Peterson, B. G., Carl, P., Boudt, K., Bennett, R., Ulrich, J., Zivot, E., ... & Wuertz, D. (2018). Package ‘PerformanceAnalytics’. R Team Cooperation.

Privett, O. S., Dougherty, K. A., Erdahl, W. L., & Stolyhwo, A. (1973). Studies on the lipid composition of developing soybeans. Journal of the American Oil Chemists' Society, 50(12), 516-520.

R Core Team (2018) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.

Ray, J. D., Fritschi, F. B., & Heatherly, L. G. (2006). Large applications of fertilizer N at planting affects seed protein and oil concentration and yield in the Early Soybean Production System. Field crops research, 99(1), 67-74.

Rennie, B.D., & Tanner J.W. (1989). Fatty Acid Composition of Oil from Soybean Seeds Grown at Extreme Temperatures, Journal of American Oil Chemists’ Society, 66, 1622–1624.

Singer, J. W., & Kohler, K. A. (2005). Rye cover crop management affects seed yield in a soybean-corn rotation. Crop Management, 4(1), 0-0.

Yadav N (1996) Genetic modification of soybean oil quality. In: Verma D, Shoemaker R (eds) Soybean: genetics, molecular biology, and biotechnology. CAB International, Wallingford, pp 165–188

Wilcox JR (1985) Breeding soybeans for improved oil quantity and quality. In: Shibles R (ed) Proc 3rd World Soybean Res. Con. Westview Press, Boulder/CO, pp 380-386

Wilcox, J. R., & Shibles, R. M. (2001). Interrelationships among seed quality attributes in soybean. Crop Science, 41(1), 11-14.

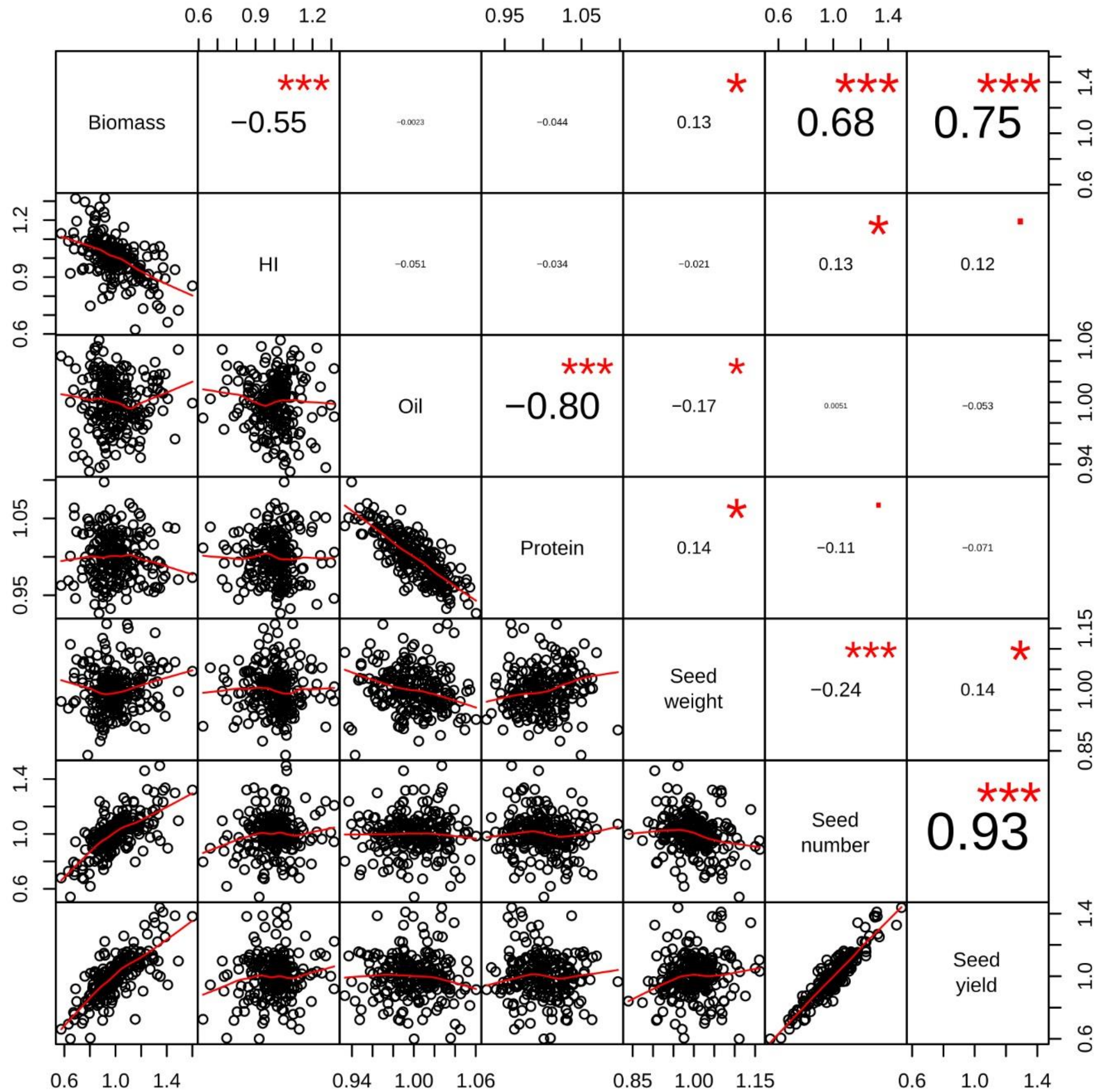


Figure 1. Correlation matrix comparing biomass, HI, oil, protein, seed weight, seed number and seed yield in relative values to the mean of all locations. On the bottom of the diagonal: the bivariate scatter plots with a fitted line are displayed (values for protein, oil, fiber and ash are expressed in %, seed is expressed in kg ha^{-1}). On the top of the diagonal: the value of the correlation (r) plus the significance level as stars. Each significance level is associated to a symbol: p-values (0.001, 0.05, 1) <=> symbols ("***", "*", " ").

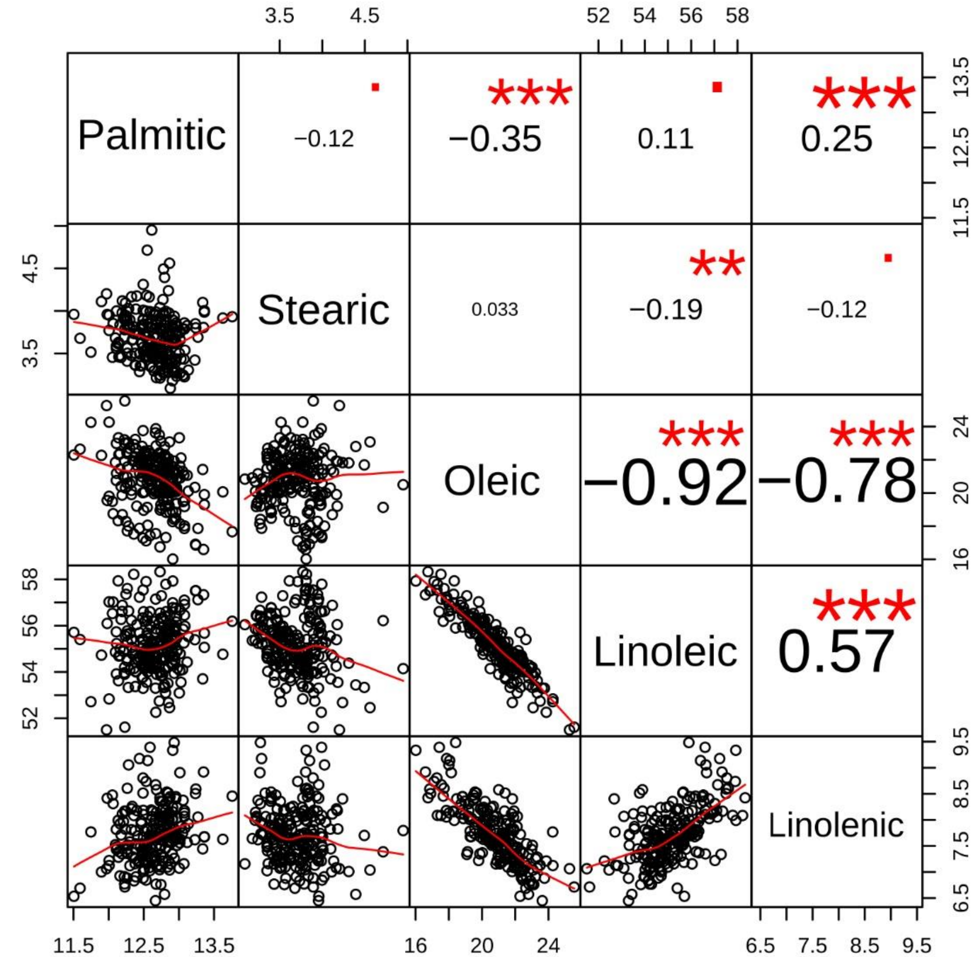


Figure 2. Correlation matrix comparing fatty acids relative to total fatty acids: linolenic, linoleic, oleic, stearic, palmitic. On the bottom of the diagonal: the bivariate scatter plots with a fitted line are displayed (all the values are relative to the mean of each experiment). On the top of the diagonal: the value of the correlation (r) plus the significance level as stars. Each significance level is associated to a symbol: p-values (0.001, 0.05, 1) <=> symbols ("***", "*", " ").

Table 1. Pre-plant soil characterization at 0-15 cm at Ottawa and Ashland Bottoms, Kansas, in 2016 and 2017.

Soil parameters	Ottawa		Ashland	
	2016	**2017**	**2016**	**2017**
pH	5.8	5.7	5.9	6.1
Mehlich P (ppm)	14.5	19.6	57.7	62.5
CEC (meq/100 g)	15.4	23.6	7	9.4
Organic matter (%)	2.8	3	1.1	1.5
Potassium (ppm)	79.3	122.9	223.0	206.3
Calcium (ppm)	2248.7	2447.4	1028.8	1061.1
Magnesium (ppm)	303.5	348.7	105.8	118.3

Table 2. Planting and harvesting date for each experiment.

	Ashland Bottoms				Ottawa			
	2016		2017		2016		2017	
	Early	Late	Early	Late	Early	Late	Early	Late
Planting date	10-Jun	22-Jun	13-Jun	23-Jun	13-Jun	22-Jun	16-Jun	23-Jun
Harvest date	6-Nov	6-Nov	11-Nov	11-Nov	5-Nov	5-Nov	3-Nov	3-Nov

Table 3. Description of the management practices treatments.

Trt	Description	Seed treatment	Fungicide / insecticide	Fertility	Density (seeds m^{-2})	Rows (cm)	Late nitrogen
1	Common practice	No	No	No	35	75	No
2	No seed treatment	No	Yes	Yes	35	38	Yes
3	Non-stay green	Yes	No	Yes	35	38	Yes
4	High plant density	Yes	Yes	Yes	45	38	Yes
5	Wide rows	Yes	Yes	Yes	35	75	Yes
6	Nitrogen fixation	Yes	Yes	Yes	35	38	No
7	Kitchen sink	Yes	Yes	Yes	35	38	Yes

Table 4. Crop and yield parameters for double-crop soybean field experiments. Treatments are as follows: 1) common practice (no inputs added), CP, 2) no seed treatment, NST; 3) non-stay green (without fungicide/insecticide application), NSG; 4) high plant density (45 seeds m^{-2}), HP; 5) wide rows, WR (75 cm); 6) N effect (without late-season fertilizer N), (NE); and 7) kitchen sink, KS, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization. Letters presented significance, when comparing in rows. $p < 0.05$.

	Treatments						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Yield (kg ha^{-1})	3617	4064	3999	4057	3915	3896	4029
Biomass (kg ha^{-1})	10116	11186	11052	11496	11039	10451	11179
Seed Number (ha)	2258	2442	2463	2458	2374	2380	2386

Interaction	**PD**	1		2		3		4		5		6		7	
Seed Weight (g)(1000)	**1**	160.4	**b**	166.3	**ab**	169.6	**ab**	171.6	**ab**	162.4	**b**	166.8	**ab**	177.1	**a**
	2	166.4		176.3		165.3		166.6		170.9		173.8		171.0	
Harvest index	**1**	0.34	**b**	0.41	**a**	0.35	**b**	0.34	**b**	0.35	**b**	0.36	**ab**	0.37	**ab**
	2	0.38		0.35		0.37		0.36		0.37		0.39		0.36	

Table 5. Concentration and content of ash, fiber, oil and protein in soybean seeds at harvest. Treatments are as follows: 1) common practice (no inputs added), CP, 2) no seed treatment, NST; 3) non-stay green (without fungicide/insecticide application), NSG; 4) high plant density (45 seeds m^{-2}), HP; 5) wide rows, WR (75 cm); 6) N effect (without late-season fertilizer N), (NE); and 7) kitchen sink, KS, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization. Letters presented significance, when comparing in rows. $p < 0.05$.

	Concentration $g\ kg^{-1}$													
	1		**2**		**3**		**4**		**5**		**6**		**7**	
Ash	52.93		53.12		53.03		53.20		53.23		53.21		53.16	
fiber	60.26		59.83		59.96		59.31		59.51		59.68		59.60	
Oil	215.64	**a**	212.61	**ab**	214.26	**a**	211.97	**ab**	210.19	**b**	212.39	**ab**	212.68	**ab**
protein	390.78	**b**	395.47	**ab**	393.85	**ab**	399.49	**a**	401.66	**a**	396.62	**ab**	396.73	**ab**
	Content $g\ seed^{-1}$													
	1		**2**		**3**		**4**		**5**		**6**		**7**	
Ash	8.42	**b**	8.72	**ab**	8.52	**b**	8.65	**ab**	8.67	**ab**	8.64	**ab**	8.89	**a**
fiber	9.58	**b**	9.82	**ab**	9.63	**ab**	9.64	**ab**	9.69	**ab**	9.70	**ab**	9.97	**a**
Oil	34.30		34.90		34.43		34.46		34.22		34.50		35.58	
protein	62.15	**b**	64.92	**ab**	63.28	**ab**	64.95	**ab**	65.39	**a**	64.43	**ab**	66.37	**a**

Table 6. Concentration, content, fatty acid yield and relative to total fatty acids values for linolenic, linoleic, oleic, stearic and palmitic acids. Treatments are as follows: 1) common practice (no inputs added), CP, 2) no seed treatment, NST; 3) non-stay green (without fungicide/insecticide application), NSG; 4) high plant density (45 seeds m^{-2}), HP; 5) wide rows, WR (75 cm); 6) N effect (without late-season fertilizer N), (NE); and 7) kitchen sink, KS, considering all the inputs evaluated in previous treatments (seed treatment, with fungicide and insecticide, high plant density, narrow rows (38 cm) and the addition of late-season N fertilization. Letters presented significance, when comparing in rows. $p < 0.05$.

	Concentration μg FAMEs mg^{-1}						
	1	**2**	**3**	**4**	**5**	**6**	**7**
linolenic	17.54	17.44	17.23	17.45	17.16	17.40	17.45
linoleic	126.69	125.24	122.50	125.24	122.39	123.97	124.23
Oleic	46.95	47.85	46.58	47.35	45.58	46.71	46.50
stearic	8.40	8.58	8.17	8.36	8.19	8.30	8.31
palmitic	25.33	25.35	25.14	25.57	25.18	25.42	25.26
total	224.90	224.47	219.62	223.96	218.51	221.79	221.74
	Content mg $seed^{-1}$						
	1	**2**	**3**	**4**	**5**	**6**	**7**
linolenic	2.79	2.86	2.77	2.84	2.79	2.83	2.92
linoleic	20.15	20.56	19.68	20.36	19.93	20.14	20.78
Oleic	7.47	7.86	7.49	7.70	7.42	7.59	7.78
stearic	1.34 **ab**	1.41 **a**	1.31 **b**	1.36 **ab**	1.33 **ab**	1.35 **ab**	1.39 **ab**
palmitic	4.03	4.16	4.04	4.16	4.10	4.13	4.23
total	35.77	36.85	35.29	36.42	35.57	36.03	37.09
	Fatty acid yield kg ha^{-1}						
	1	**2**	**3**	**4**	**5**	**6**	**7**
linolenic	30.9	35.6	33.1	34.5	32.6	32.5	33.9
linoleic	92.0	103.1	101.0	104.3	99.6	98.9	101.7
Oleic	169.9 **b**	191.8 **a**	183.9 **ab**	190.6 **ab**	176.6 **ab**	180.5 **ab**	184.8 **ab**

	1		2		3		4		5		6		7	
stearic	64.1	**b**	71.6	**a**	70.0	**ab**	71.4	**ab**	67.9	**ab**	67.9	**ab**	70.9	**ab**
palmitic	461.9	**b**	512.2	**a**	493.9	**ab**	511.3	**a**	484.9	**ab**	482.3	**ab**	501.1	**ab**
total	818.9	**b**	914.3	**a**	881.9	**ab**	912.0	**a**	861.7	**ab**	862.2	**ab**	892.3	**ab**

	Relative to total fatty acids													
	mol% FAMEs													
	1		**2**		**3**		**4**		**5**		**6**		**7**	
linolenic	7.70		7.66		7.74		7.68		7.75		7.73		7.77	
linoleic	55.53		55.00		54.97		55.12		55.20		55.09		55.23	
Oleic	20.59		21.03		20.93		20.86		20.59		20.78		20.67	
stearic	3.68		3.77		3.66		3.68		3.70		3.69		3.70	
palmitic	12.50	**b**	12.53	**b**	12.69	**ab**	12.66	**ab**	12.78	**a**	12.71	**ab**	12.63	**ab**

Chapter 4 - General Discussion

Conclusions and implications to agriculture

In a world with increasing human population, producing more food in less area is key. In addition, increasing crop intensification enables for the resources to be used in a more efficient way, cycling inputs and incrementing profitability for farmers. Therefore, studying ways to raise viability of systems that enable more intensive use of arable land is a sustainable approach to add efficiency and seize the resources for greater production and profit.

Double-crop (DC) soybean, specifically planted after wheat, is a system that has great potential and is being used throughout US. However, the effect of the previous wheat crop to soybean, in relation to water and nutrient supply; radiation; temperature; as well as the greater risks associated with harvesting later in the fall, generate the need for expanding studies on management practices for DC soybean.

The systematic literature review enlightened the effect of wheat as a previous crop, and the possibility of using the past crop wheat yield to predict DC soybean yield. Other management practices can be used as a tool for prediction, along with the previous crop yield. Added to the history of the farm, the knowledge of the farmer and weather predictions, the data from the probability analysis can help on the decision making process for planting or not DC soybean, and for assisting in the decision of investing inputs, depending on the expected DC soybean yield.

When deepening the understanding of plant response to specific management practices, seed quality is an important factor to be observed. Management practices can influence seed composition and quality. Protein concentration was reduced when no inputs were added, while oil concentration increased. There was more monounsaturated and saturated fatty acid yield as input levels increased, and consequently more good oil quality. Seed filling duration can be affected by management practices. As longer the duration of seed filling, less fatty acid concentration was observed.

Greatest differences in yield, were observed for planting earlier, right after wheat harvest, beginning of June relative to the late planting date in June. Initial soil moisture was crucial and had significant effect on yield, being negatively affected as initial soil moisture was 40% in comparison with 90%. Weather played an important role in affecting seed yield for DC soybean. The greatest differences in the effect of weather in DC soybean yield was for the dry and warm weather, when late planting greatly impaired yield.

Future research

One of the main obstacles for adopting DC soybeans is the delay of the crop cycle. The delay in planting soybean depends on wheat harvest (at least in many regions in the US). Planting before harvesting wheat can help in providing close to the ideal time for planting soybeans. Soybean is intercropped for a short period with the previous wheat. When planted before wheat harvest, soybean is not being planted on heavy undecomposed wheat residue and utilizes the available water while the wheat crop is already mature or maturing, and does not need the resource any longer. Intercropping can be studied as an alternative way to harvest two crops in the same year, without delaying the soybean cycle.

Seed quality can be tested for other management practices, cultivars and environments. Seed composition is greatly influenced by the soybean genetic background, and may respond differently or in other magnitudes to the management practices evaluated in the present study. Greater or lower intensity of inputs, or even other environmental conditions may play important roles on seed quality. Studying the different scenarios imposed by the environment, genotype, and management combinations can influence seed quality composition in different intensities.

Appendix 1

License Agreement Chapter 1

Hansel, D. S. S., Schwalbert, R. A., Shoup, D. E., Holshouser, D. L., Parvej, R., Prasad, P. V. V., and Ciampitti, I. A. (2019). A Review of Soybean Yield when Double-cropped after Wheat. Agron. J. 111. doi:10.2134/agronj2018.06.0371

Order detail ID: 71898632
ISSN: 1435-0645
Publication Type: e-Journal
Volume:
Issue:
Start page:
Publisher: AMERICAN SOCIETY OF AGRONOMY,
Author/Editor: American Society of Agronomy
Permission Status: Granted

Permission type: Republish or display content
Type of use: Thesis/Dissertation

Order License Id: 4587720639051

Requestor type	Author of requested content
Format	Print, Electronic
Portion	chapter/article
The requesting person/organization	Damaris Sulzbach Santos Hansel
Title or numeric reference of the portion(s)	A Review of Soybean Yield when Double-Cropped after Wheat
Title of the article or chapter the portion is from	A Review of Soybean Yield when Double-Cropped after Wheat
Editor of portion(s)	David Clay
Author of portion(s)	Damaris Sulzbach Santos Hansel, Rai A. Schwalbert, Douglas E. Shoup, David L. Holshouser, Rasel Parvej, P.V. Vara Prasad and Ignacio A. Ciampitti
Volume of serial or monograph	111
Issue, if republishing an article from a serial	2
Page range of portion	
Publication date of portion	January 24th, 2019
Rights for	Main product and any product related to main product
Duration of use	Life of current edition
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For distribution to	Worldwide
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Lifetime unit quantity of new product	Up to 499
Title	A Review of Soybean Yield when Double-Cropped after Wheat

Institution name Kansas State University
Expected presentation date Jul 2019

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