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Tillage effects on soybean growth, development, and yield

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Crop Production and Physiology

Program of Study Committee:
Palle Pedersen, Major Professor
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CHAPTER 1: GENERAL INTRODUCTION

Profit margins of soybean [*Glycine max* (L.) Merr.] in the United States have recently declined as a result of an increase in production and land costs. Decreased profits coupled with increasing environmental concerns such as erosion and runoff prompts more cost-efficient production practices. No-tillage production practices offer a lower cost of production in addition to decreased soil erosion and runoff. Additionally, soil quality can be improved over time in a no-tillage system, greatly increasing the yield benefits over time. Today, only 41% of Iowa's soybean production is under no-tillage production (Conservation Technology Information Center, 2010), although even more of the state has land that lends itself well to no-tillage systems. However, the Des Moines Lobe in north central Iowa is known for its poorly-drained soil, and is a result of late Wisconsinan glacial deposits (Steinwand and Fenton, 1995).

Soybean planted in fields with different soil types and drainage properties respond differently to tillage practices. No-tillage production of soybean is often less successful in poorly-drained soils (Dick and Van Doren, 1985), in part because of cooler and wetter soil conditions at planting (Meese et al., 1991). These soil conditions can lead to slower soybean germination and emergence, which makes the seedlings more vulnerable to seedling disease.

Little information exists regarding soybean growth and development in different tillage systems from Iowa and if the soybean plant compensates for slow early growth with different growth and development processes. The overall goal of this research was to evaluate soybean growth, development, and yield under conventional and no-tillage conditions in Iowa. This was accomplished based on two separate studies. Chapter two is a literature review, and the rest of this thesis is divided into two manuscripts, which constitute chapters three and four.

Chapter three examines the relationship between cultivar selection and tillage systems across Iowa. Twelve cultivars were used in conventional and no-tillage systems to determine how yield was affected by cultivar performance in different tillage systems. Four cultivars were also used in both tillage systems and at two locations to closely monitor the growth and development throughout the growing season.

Chapter four explores the relationship between plant population density and tillage system across Iowa. This study was conducted in conventional and no-tillage systems in two row spacing and with four seeding rates. A yield portion of the study was performed at six locations across Iowa to determine the widespread effect of row spacing and plant population density on yield in different tillage systems. A growth and development portion of the study was performed at two locations to examine the biomass accumulation, crop growth rate, and light interception and the effects these parameters would have on yield.

Together these manuscripts show the importance of tillage considerations when determining management practices to maximize yield. The overall goal of this work was to provide growers with more concrete management recommendations in different tillage systems across Iowa.

CHAPTER 2: LITERATURE REVIEW

History of Soybean Production

Soybean was first grown in the northeastern region of China in the eleventh century BC (Hymowitz, 1970). Soybean production moved through the rest of China and into Korea by the first century AD. In the fifteenth and sixteenth centuries, soybean was grown in Japan, Indonesia, the Philippines, Vietnam, Thailand, Malaysia, Burma, Nepal, and the northern portion of India (Hymowitz, 1970). European travelers in China and Japan discovered soy sauce and began to trade it by the seventeenth century (Hymowitz, 1970). Samuel Bowen first grew soybean in the United States in 1765 near Savannah, Georgia (Hymowitz and Shurtleff, 2005). Soybean was first cultivated in Illinois in 1851 and quickly moved through the rest of the Corn Belt. In China, most of the soybean production occurs in the regions of Manchuria and Shantung, which are similar in latitude to the Corn Belt in the United States. The greatest production areas in the United States and China are located between the 35^{th} and 45^{th} degrees north latitudes (Hymowitz, 1970).

William Morse began working with soybean cultivars in Virginia in 1907 and became known as "The Father of Soybean in the United States" (Hymowitz, 1970). Between 1924 and 1931, Morse and P.H. Dorsett collected soybean germplasm from China, Japan, and Korea, and brought back approximately 6000 accessions to the United States (Hymowitz, 1970). In 1930, the National Soybean Processors Association was formed to accommodate the booming soybean processing industry (Hymowitz, 1970). Production increased greatly during World War II and since then soybean has become a major crop in the United States. Soybean became well known for its protein and oil content to feed people and animals, as well as its use in an industrial capacity for printing inks and as a dust suppressant in grain elevators (Hymowitz, 1990).

In 1924, approximately 136 million kg of soybean were produced in the United States on 607 500 ha, with an average yield of 739 kg ha^{-1} (Hymowitz, 1990). In 2009, there were over 91.4 billion kg of soybean produced in the United States on 31 million ha (Figure 1), with an average yield of 2960 kg ha^{-1} (National Agricultural Statistics Service, 2010).

Iowa is the largest soybean-producing state in the United States and often also produces the highest yield per hectare (National Agricultural Statistics Service, 2010; Figures 2 and 3). In 2009, over 13 million tons of soybean were produced on over 3.8 million ha in Iowa, accounting for approximately 14% and 12% respectively of the national totals.

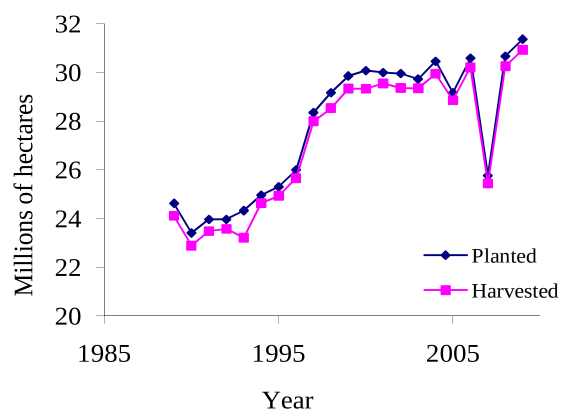

Figure 1. Soybean production in the United States from 1989 to 2009 (National Agricultural Statistics Service, 2010).

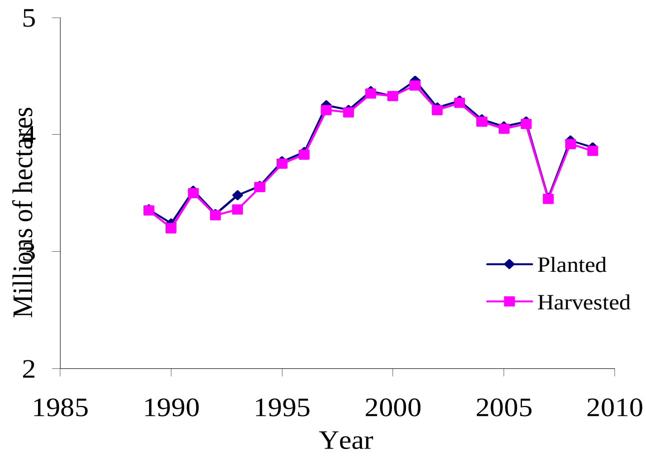

Figure 2. Soybean production in Iowa from 1989 to 2009 (National Agricultural Statistics Service, 2010).

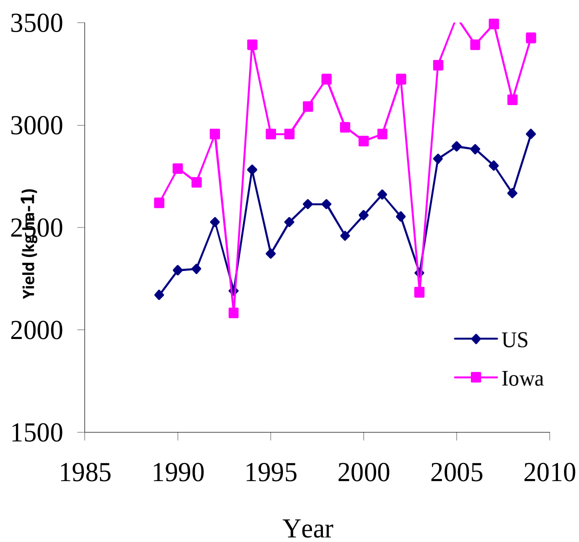

Figure 3. Comparison of United States and Iowa soybean production from 1989 to 2009 (National Agricultural Statistics Service, 2010).

Soybean growth and development

Emergence

Soybean seedling development rate is based on many factors. Muthiah et al. (1994) developed an identification of the prominent growth stages of seedlings, beginning with the seed's uptake of water and ending at emergence. Briefly, the seed begins growth and development by enlarging. Over time the testa splits and the radical elongates, protruding from the testa with the root hairs developing at the root axis. Between three and four-and-a-half days after planting, the presence of lateral root primordia are first noticed as small protrusions on the root surface. The hypocotyl then arches and begins to pull the cotyledons up through the soil surface (Muthiah et al., 1994).

Hadas and Russo (1974) describe soybean germination in three stages: the uptake of water, controlled by the seed's endosperm or cotyledon content; development, when meristematic activities begin to occur; and growth, when the radical begins to elongate and push through the seed coat. If the uptake of water in the first step is slow, emergence can be impaired, which will affect the final stand (Hadas and Russo, 1974).

Soybean emergence is affected by soil temperature (Gauer et al., 1982; Meese et al., 1991), moisture (Hunter and Erickson, 1952; Hobbs and Obendorf, 1972; Muendel, 1986; Hadas and Russo, 1974; Helms et al., 1996a;b), and oxygen (Hunter and Erickson, 1952). A soybean seed needs to absorb 50% of its weight in water to germinate (Hunter and Erickson, 1952). An excess of moisture, however, was found to have a negative effect on seeds because although there was sufficient humidity in the soil air and water films were present on the soil particles, the water in the soil was absorbed on the surface of the soil particles with a force greater than the absorbing capacity than the seed (Hunter and Erickson, 1952). Helms et al.

(1996b) suggested that no-tillage planting could help reduce seedbed drying and the desiccation of germinated seeds resulting from the dry soil.

Muendel (1986) and Hobbs and Obendorf (1972) made the connection between critical moisture levels and optimum air temperatures for emergence of soybean. Muendel (1986) observed that emergence was highest at the highest temperature tested (20.5ºC), and when moisture levels were low, even if temperature levels were optimum, emergence was reduced. Helms et al. (1996b) found that an increase in temperature of a few degrees could have a positive impact on soybean emergence even when soil water levels were low. Conversely, Fehr et al. (1973) found that temperature did not consistently affect soybean emergence.

Vegetative and reproductive stages

Soybean growth is divided into vegetative and reproductive growth stages. The first vegetative growth stage, which begins at emergence (Fehr et al., 1971), is called VE and is defined as unrolled and fully developed cotyledons (Fehr and Caviness, 1977). The next growth stage, VC, is defined as the stage at which the unifoliolate leaves are unrolled (Fehr and Caviness, 1977). A leaf is considered completely unrolled when the leaf at the node immediately above it has unrolled so that the edges of the leaflet are no longer touching (Fehr et al., 1971). Thereafter the vegetative growth stages are defined as V1 to Vn^{th} and are assigned according to the number of nodes on the main stem (Fehr and Caviness, 1977).

There are eight reproductive growth stages, defined as R1 to R8. The first reproductive stage, R1, is defined as an open flower anywhere on the soybean plant; R2 is an open flower on one of the two uppermost nodes; R3 is beginning pod, with a pod larger than 5 mm at one of the four uppermost nodes; R4 is full pod, with a pod larger than 2 cm on one of the four uppermost nodes; R5 is beginning seed, with a seed larger than 2 mm on one of the four uppermost nodes; R6 is full seed, when the pod cavity is completely expanded at one of the four uppermost nodes; R7 is physiological maturity, when one pod anywhere on the soybean plant has its mature color; and R8 is harvest maturity, when 95% of the pods have their mature color (Fehr et al., 1971).

Yield formation

Soybean yield is determined by seed number and seed size with seed number being the most important yield component (Egli, 1975). Seed size, in part, is determined by the duration of the effective filling period (Egli et al., 1978). Seed size is influenced by the duration of the effective filling period and the amount of photosynthate available to the seed (Egli et al., 1978). The accumulation of seed mass is related to the plant's ability to fix carbon during the seed filling period or the translocation of storage carbohydrates (Egli, 1975). Seed size is also determined by the genetic makeup of the plant (Egli et al., 1978; Pfeiffer and Egli, 1988; Hanson and Burton, 1994). There is a negative correlation between seed size and the number of seeds produced (Egli et al., 1978).

Cultivar selection

Cultivar selection is an important management practice to maximize yield. An environment free of stress allows each cultivar to attain its maximum genetic yield potential (Evans and Fischer, 1999); however, plant growth and yield are reduced by abiotic and biotic stresses occurring in the environment (Cook, 2000). Guy and Oplinger (1989) found different responses of cultivars based on environment. As a result, cultivar selection must be made based on genotypic interactions with the environment to maximize yield (Bradley et al., 1988).

The most detrimental pathogen for soybean in the United States is soybean cyst nematode (*Heterodera glycines* Ichinohe), or SCN (Wrather, 2006). Yield can be greatly reduced by SCN (Pedersen and Lauer, 2002), thus the methods used to reduce losses to SCN include: rotating host crops, use of SCN-resistant soybean cultivars, and rotating the source of SCN resistance (Niblack, 2005).

Cultivars with resistance to SCN had greater yield stability and higher yields than SCN-susceptible cultivars (De Bruin and Pedersen, 2008a; b). The SCN population was not only lower when resistant cultivars were grown, but the SCN pressure was lower in the year following the growth of a resistant cultivar in the same fields (Chen, 2007). This makes cultivar selection an even more valuable tool in maximizing yield.

Tillage has been shown to impact cultivar performance (Lueschen et al., 1991), however, no specific genotypic characteristic was found to be responsible for this. In contrast, the majority of studies performed in evaluating cultivar performance in various tillage systems have shown no significant interactions, indicating that a cultivar would show the same yield potential in both conventional tillage and no-tillage systems (Elmore, 1987; 1990; 1991; Guy and Oplinger, 1989; Philbrook et al., 1991; Pedersen and Lauer, 2003b).

Row spacing and plant population

Soybean planted in narrow rows has been shown to yield between 5 and 15% greater than soybean planted in wide rows (De Bruin and Pedersen, 2008c; Taylor et al., 1982). In contrast, Pedersen and Lauer (2003a) did not observe any yield advantage to planting in rows narrower than 76-cm. Of the four main yield components (weight seed^{-1}, seeds pod^{-1}, seeds plant^{-1}, and pods plant^{-1}), only seeds plant^{-1} and pods plant^{-1} are positively affected by narrow rows (Lehman and Lambert, 1960). The seed yield, number of pods plant^{-1}, plant height, number of branches plant^{-1}, and harvest index all decreased linearly with increasing row width (Bullock et al., 1998). Along with greater yields, narrow rows were found to have more uniform yields in comparison to wide rows (Ethredge et al., 1989).

The observation of greater yield, biomass accumulation, and crop growth rate (CGR) in narrow rows by Bullock et al. (1998) is consistent with the greater leaf area index (LAI) found in narrow rows compared to wide rows. The increase in LAI seen in narrow rows, however, only occurred prior to R2 growth stage (Bullock et al., 1998). Based on this, it was determined that the increases in LAI (Bullock et al., 1998) and LI (Board et al., 1992) before the main seed filling period were critical for yield maximization.

In contrast, greater light interception by narrow-row canopies during late seed development was observed to be the driving force behind the yield advantage seen in narrow rows (Taylor et al., 1982). Canopies reaching 95% light interception yielded greater than those that did not reach this level, stressing the importance of canopy closure to achieve 95% light interception by the R5 growth stage (Board, 2004).

Andrade et al. (2002) observed the greatest yield increases due to narrow rows to be based on radiation interception differences at the R3 growth stage. As row spacing decreased, yield and radiation interception were observed to increase (Andrade et al., 2002).

Dry matter accumulation is also dependent upon canopy interception of 95% light interception at the R5 growth stage (Shibles and Weber, 1965). The rate of dry matter accumulation is a linear function of both percent solar radiation and LAI, but reached a maximum level in which increasing LAI no longer produced more dry matter (Shibles and Weber, 1965). Dry matter accumulation is observed to be dependent on both the light intercepted and how efficiently the intercepted light is used (Shibles and Weber, 1966).

Soybean plants in wide row spacing do not always reach 95% light interception by R5, which is found to be required for maximum dry matter accumulation (Shibles and Weber, 1966).

Dry matter accumulation decreased as the width between rows increased (Herbert and Litchfield, 1984). A higher crop growth rate (CGR) until the R5 growth stage was observed to be crucial to soybean yield formation in the comparison of narrow and wide rows (Bullock et al., 1998; Board and Harville, 1994). This coincides with the conclusion that the time of greatest yield benefits to narrow rows occurred before the main seed-fill period (Bullock et al., 1998).

Great variation exists in the study of row spacing and seeding rate. At low seeding rates, wide rows have a yield advantage over narrow rows, but at a high seeding rate the yield advantage is shifted to narrow rows (Devlin et al., 1995). In one study, narrow rows produced greater yields, but no correlation was observed between plant population and yield (Costa et al., 1980). Higher plant populations, however, were found to increase lodging, seed weight, and LAI but decrease the number of branches plant^{-1} (Costa et al., 1980). In contrast, another study observed that increased plant population in narrow rows increased yield by 27%, while not affecting lodging and harvest index (Herbert and Litchfield, 1984). Soybean planted in lower populations was observed to produce more lateral branches (Shibles and Weber, 1966). As a result of greater lateral branching, soybean plants in lower populations were found to fill the inter-row spaces at lower LAI than higher populations (Shibles and Weber, 1966). The period of vegetative growth is lengthened in greater plant populations, leading to a competition for carbohydrates between vegetative growth and seed fill (Shibles and Weber, 1966). As a result of this competition, less carbohydrate is often available for seed fill, decreasing yield in high populations (Shibles and Weber, 1966).

While increased plant populations appeared to increase yield (De Bruin and Pedersen, 2008c), many studies have also found an optimum seeding rate, beyond which yield will not increase (De Bruin and Pedersen, 2008c; Oplinger and Philbrook, 1992; Weber et al., 1966). The range of plant population density to maximize yield is found between 104 500 seeds ha^{-1} (Weber et al., 1966) and 680 000 plants ha^{-1} (Oplinger and Philbrook, 1992). Though an optimum plant population density of 462 000 plants ha^{-1} was observed, 95% of the maximum soybean yield could be attained with a final harvest population of 258 600 plants ha^{-1} (De Bruin and Pedersen, 2008c).

No-tillage

Tillage loosens the soil and buries crop residue; which leaves the soil vulnerable to pounding rain and strong winds, which are both contributing factors to erosion (Lal et al., 2007). Following the Dust Bowl during the Great Depression, farmers realized that plowing was too harsh on the soil and contributed to poor soil quality. When the soil surface dries after excessive tillage, a heavy rain can create a crust that makes germination and emergence difficult (Lal et al., 2007).

The idea of no-tillage was strongly encouraged by Edward Faulkner in 1942, who examined the background of plowing and questioned this long-standing agricultural practice (Lal et al., 2007). In the 1950s and 1960s conventional vs. no-tillage became a greatly disputed issue, similar to the debate between tractors and horses (Lal et al., 2007). Moody et al. (1961) described some of the earliest research on no-tillage, citing it as a good practice for certain crops. This work showed that the soil conditions greatly improved and the soil surface was well-protected as a result of no-tillage. Water conservation was also gaining popularity and this work discussed the benefits of no-tillage in conservation. Since then, no-tillage farming has become increasingly popular, due in part to rising costs of fuel, time, and labor. Soil conservation has also become a highly-discussed topic and no-tillage farming has shown that it can reduce runoff and erosion, as well as cut down on fuel consumption (Lal et al., 2007).

Tillage can be separated into four types: no-tillage, conservation tillage, reduced tillage, and conventional tillage. No-tillage is defined as soil with no tillage occurring after harvest and before the next planting with 70 to 100% residue cover (Conservation Technology Information Center, 2007). Conservation tillage refers to ridge-tillage and mulch-tillage with 30-70% residue cover in the field after planting (Conservation Technology Information Center, 2007). Reduced tillage leaves 15-30% residue cover on the field and indicates light tillage such as ridge-tillage, mulch-tillage, and disking, while conventional tillage leaves 0-15% residue cover on the field (Table 1; Conservation Technology Information Center, 2007).

Table 1. Tillage types associated with the amount of residue remaining on the field (Conservation Technology Information Center, 2007).

Percent residue cover	Tillage type
0-15	Conventional
15-30	Reduced
30-70	Conservation
70-100	No-tillage

Iowa has not seen a notable difference in reduced tillage production area from 1997 to 2002 (Conservation Technology Information Center, 2007). In 2007, approximately 29% of Iowa soybean production was done using no-tillage practices (Figure 4 Conservation

Technology Information Center, 2007). In 2009 the percentage of soybean production in a no-tillage system in Iowa had increased to 41% (Conservation Technology Information Center, 2010).

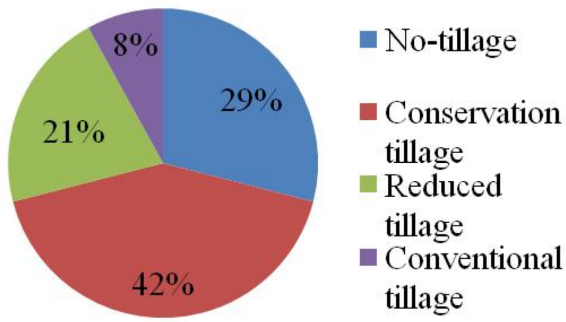

Figure 4. Percent distribution of tillage practices in Iowa (Conservation Technology Information Center, 2007).

Soil properties

Reduced tillage results in increased organic matter and more water-stable aggregates near the soil surface over time, along with higher bulk densities as compared to conventional tillage (Kladivko et al., 1986). Similarly, Hernanz et al. (2001) and Heard et al. (1988) found that no-tillage soils had higher bulk densities down to 15 cm compared to conventional tillage soils. In contrast, Papiernik et al. (2007) found that soil bulk density was lower in uncultivated areas than in cultivated areas. When plants were grown on poorly-drained, low organic matter, poorly-structured soils, reduced tillage helped to improve the soil structure as the soil organic matter and aggregation of the soil increased (Kladivko et al., 1986).

Heard et al. (1988) found more channels of pores in no-tillage than conventional tillage systems, with a greater continuity of these conducting pores from 10- to 20- and 30-cm depths. This greater pore continuity with depth for no-tillage was confirmed by increased air permeability (Heard et al., 1988). Voorhees and Lindstrom (1984) found that reduced tillage produced better soil porosity and overall soil quality (tilth), but three to four years of reduced tillage were required for these changes to take full effect. Though tillage can be used to increase immediate soil porosity, it has negative long-term effects on surface soil structural stability, surface residue accumulation, and surface soil organic carbon, thus, no-tillage may be slow to show its full benefits, but after a few years will show improvement over conventional tillage (Franzluebbers, 2002).

Soil surface aggregation was found to be dependent on surface residue management, primarily the accumulation of residues without incorporation (Franzluebbers, 2002). No-tillage production has been found to produce more stable aggregates than conventional tillage (Hernanz et al., 2001). In a long-term no-tillage study, more macro-aggregates were found in no-tillage soils than in conventional tillage soils, as well as greater macro-aggregate stability (Franzluebbers, 2002). Papiernik et al. (2007) found that uncultivated areas had better wet aggregate stability. No-tillage fields were found to have surface soil with more aggregates larger than 1000 µm compared to other tillage treatments after seven years (Wuest, 2007). Water-stable aggregates are important in minimizing crusting and erosion, as well as for maximizing water and air movement into the soil (Kladivko et al., 1986). Increased aggregate stability offered by no-tillage creates better aeration of the soil (Kladivko et al., 1986).

Seed yield

Inconsistent observations exist for yield in no-tillage systems compared to conventional tillage systems. In a long-term rotation study in Wisconsin, Pedersen and Lauer (2003a) observed a 6% greater yield in soybean planted in a no-tillage system compared to a conventional tillage system. Similarly, in Alabama, Edwards et al. (1988) showed a soybean yield advantage of 736 kg ha^{-1} in a no-tillage system than in a conventional tillage system in three out of four years. In the fourth year of the study, no yield differences were observed between tillage systems (Edwards et al., 1988). In a fertility study in Illinois, soybean planted in a no-tillage system was observed to yield less than soybean planted under other various tillage practices (Vasilas et al., 1988). Soybean grown in a conventional tillage system was observed to have a yield advantage of 538 kg ha^{-1} over soybean grown in a no-tillage system across multiple locations and years (Guy and Oplinger, 1989). However, no yield differences were observed when comparing tillage practices in irrigated and non-irrigated systems in Wisconsin (Pedersen and Lauer, 2003b).

Soil moisture and temperature

The impacts of tillage on soybean yield also differ based on environmental conditions and soil properties. Soils in no-tillage systems have temperatures throughout the day up to 5.9°C cooler at depths of 5 cm at planting than soils in conventional tillage fields (Johnson and Lowery, 1985), resulting from saturated soils and the amount of residue in no-tillage fields (Meese et al., 1991). Soil moisture content is higher in no-tillage soils at planting as a result of the increased residue cover (Gauer et al., 1982; Kladivko et al., 1986), due to decreased evaporation (Chastain et al., 1995). Infiltration in no-tillage soils is deemed higher as a result of less compacted, rougher soil, and better soil aeration (Meyer and Mannering, 1961). The germination and early growth of soybean is slowed by the cool and moist soil conditions in a no-tillage system and, thus, the time to maturity of plants in a no-tillage system compared to a conventional tillage system may increase (Gauer et al., 1982; Meese et al., 1991). During drought conditions, these moist soil conditions in a no-tillage system can help to protect soybean more so than in a conventional tillage system (Edwards et al., 1988).

In high rainfall conditions, though, no differences in soil moisture have been observed between tillage systems, likely caused by the soil nearing field moisture capacity (Pedersen and Lauer, 2004a). Wilhelm et al. (1986) found that 70% of yield variation associated with tillage treatments could be attributed to differences in total available water.

Soybean yield responses can also be influenced by soil drainage properties (Dick and Van Doren, 1985). In well-drained soils no yield differences existed between conventional tillage and no-tillage systems, however, in poorly-drained soils conventional tillage soybean yielded 283 kg ha^{-1} greater than soybean in a no-tillage system (Dick and Van Doren, 1985).

Growth and development

In a comprehensive study of soybean growth and development in conventional tillage and no-tillage systems, no yield differences were observed between tillage systems, as a result of compensatory growth displayed by soybean in a no-tillage system (Yusuf et al., 1999). Prior to the R6 growth stage, soybean plants in the conventional tillage system accumulated more biomass than the no-tillage soybean plants; however, no differences were observed thereafter (Yusuf et al., 1999). This was the result of a higher crop growth rate (CGR) seen in plants in the no-tillage system between the R2 and R6 growth stages (Yusuf et al., 1999). This same compensatory growth was observed in a study by Pedersen and Lauer (2004b). Although greater biomass accumulation and a higher CGR after the R1 growth stage was observed for plants in a no-tillage system in Wisconsin, there were no yield differences between tillage systems (Pedersen and Lauer, 2004b). In contrast, plants in a no-tillage system were observed to accumulate equal biomass to plants in a conventional tillage system prior to the R1 growth stage, but at harvest, had accumulated 6% more biomass, were 7%

taller, and yield 9% more than soybean plants in a conventional tillage system (Pedersen and Lauer, 2004a).

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CHAPTER 3: TILLAGE EFFECTS ON SOYBEAN YIELD, GROWTH, AND DEVELOPMENT IN IOWA

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Abstract

Cultivar selection is a crucial component to maximizing soybean [*Glycine max* (L.) Merr.] yield. Little research exists on the relationship between cultivars and tillage practices in Iowa. Two experiments were established to address this relationship using conventional tillage and no-tillage systems. The first experiment evaluated twelve soybean cultivars at six locations across Iowa from 2007 to 2009 to determine the effect of cultivar performance in two tillage systems. The second experiment was conducted at two locations in Iowa during 2008 and 2009, and examined growth and development of four soybean cultivars in two tillage systems biweekly throughout each season. Few interactions were observed in both experiments. In the first experiment, no interaction was observed between tillage system and cultivar, indicating that a high yielding cultivar is high yielding regardless of tillage system. No yield differences were observed between tillage systems. Plants in the tilled system were 3 cm taller than in the no-tillage system at harvest. Yield differences existed among soybean cultivars, ranging from 4254 to 4930 kg ha^{-1}. Cultivars resistant to soybean cyst nematode (SCN; *Heterodera glycines* Ichinohe) yielded 108 kg ha^{-1} less than cultivars susceptible to SCN. No differences were observed in yield components between tillage systems or cultivars. Based on both experiments, it was concluded that no differences exist between soybean grown in conventional tillage and no-tillage systems in Iowa and that local adapted cultivars can be selected to maximize yield regardless of tillage system in Iowa.

Abbreviations: SCN, soybean cyst nematode.

Introduction

Iowa is the largest soybean [*Glycine max* (L.) Merr.] producing state in United States (National Agricultural Statistic Service, 2010) but only 41% of soybean grown in Iowa is produced in a no-tillage production system (Conservation Technology Information Center, 2010). This is low compared to other large soybean-producing states, such as Illinois and Indiana (Conservation Technology Information Center, 2010).

Various soybean responses to tillage system have been observed in the United States. Pedersen and Lauer (2003a) found in a long-term rotation study in Wisconsin that soybean planted in a no-tillage system produced on average 6% greater yield than soybean planted using conventional tillage practices. In Alabama, Edwards et al. (1988) found in three out of four years an average yield advantage of 736 kg ha^{-1} in a no-tillage production system compared to a conventional tillage system with no yield differences between tillage systems in the fourth year of the study. In contrast, Vasilas et al. (1988) reported that soybean planted using no-tillage practices consistently yielded less than soybean planted under various tillage practices in Illinois. Two studies from Wisconsin found that soybean planted in conventional tillage systems yielded 537 kg ha^{-1} greater than in no-tillage systems (Guy and Oplinger, 1989) or no yield difference at all (Pedersen and Lauer, 2003b).

Environmental conditions and soil properties influence the effect of tillage system on soybean yield. At time of planting, soils under no-tillage conditions were found to have lower soil temperatures by up to 5.9°C throughout the day at a 5-cm depth (Johnson and Lowery, 1985). Differences in soil temperature were most likely associated with differences in soil water content and the amount of surface residue at planting (Meese et al., 1991). Cool and moist soil conditions slowed the germination and early growth of soybean and increased days to maturity of no-tillage plants compared to plants in a tilled system (Gauer et al., 1982; Meese et al., 1991). The increased residue cover under no-tillage practices resulted in higher soil moisture content at planting (Gauer et al., 1982; Kladivko et al., 1986) due to decreased evaporation (Chastain et al., 1995). There are conflicting reports regarding soil moisture in no-tillage systems. In a no-tillage system, the conservation of soil moisture protected soybean more than soybean planted using conventional tillage practices during drought conditions (Edwards et al., 1988). In contrast, Pedersen and Lauer (2004a) reported no differences in soil moisture between conventional tillage and no-tillage systems during early vegetative growth stages because of high rainfall and soil at field moisture capacity.

Soil drainage properties influence the soybean yield response to tillage practices. Dick and Van Doren (1985) observed no yield difference between conventional tillage and no-tillage systems when planted in well-drained soils, while in poorly-drained soils conventional tillage systems yielded 283 kg ha^{-1} greater than soybean planted in a no-tillage system.

Yusuf et al. (1999) conducted a comprehensive study documenting soybean growth and development differences between no-tillage and conventional tillage systems. No yield differences were observed between the two tillage systems as a result of compensatory growth by no-tillage plants. Aboveground biomass accumulation was greater in conventional tillage than in no-tillage systems from emergence until the R6 growth stage but thereafter no differences were observed because of a higher crop growth rate in the no-tillage system from the R2-R6 growth stages (Yusuf et al., 1999; Fehr and Caviness, 1977). Pedersen and Lauer (2004b) made similar observations of compensatory growth between tillage systems. At a silt loam soil location in Wisconsin, no yield differences were observed among tillage systems despite greater biomass accumulation and crop growth rates for no-tillage systems compared to conventional tillage systems after the R1 growth stage. In a second study, Pedersen and Lauer (2004a) reported that soybean in a no-tillage system accumulated 6% more biomass, were 7% taller, and yielded 9% more than soybean plants in a conventional tillage system. No differences had been observed in biomass accumulation between the two tillage systems prior to the R1 growth stage.

Cultivar selection is the most important management decision a grower makes every year. Each cultivar has a genetic yield potential (Evans and Fisher, 1999) that can only be attained in a stress-free environment. Abiotic and biotic stresses within the environment influence plant growth and reduce yield (Cook, 2000). Determination of environment by genotype interactions remains important for cultivar selection (Bradley et al., 1988). Cultivar selection must be based on environment, and previous yield performance must be taken into consideration (Bradley et al., 1988). In three studies in Nebraska no effect of tillage system was observed on cultivar performance, and Elmore (1987; 1990; 1991) concluded that a high yielding soybean cultivar would be high yielding regardless of tillage system. This observation was supported by studies from Wisconsin (Guy and Oplinger, 1989; Philbrook et al., 1991; Pedersen and Lauer, 2003b). In contrast, Lueschen et al. (1991) observed an interaction between tillage system and cultivar performance for yield, but they were not able to determine the particular genotypic characteristic contributing to this interaction.

Soybean cyst nematode (*Heterodera glycines* Ichinohe), or SCN, is the most economically important pathogen for soybean producers in the United States (Wrather, 2006). Rotating host crops, use of SCN-resistant soybean cultivars, and rotating source of resistance to SCN are the current recommendations to manage SCN (Niblack, 2005). The effect of tillage on SCN population densities is inconclusive. Workneh et al. (1999) reported that the prevalence and population densities of SCN were consistently greater in conventional tillage than in no-tillage fields across 1462 fields in five states in the northern United States. Similarly, Noel and Wax (2003) found that no-tillage production in general fostered greater SCN reproductive rates. Contrary to this, Chen (2007) and Edwards et al. (1988) reported no consistent differences in SCN population densities based on tillage.

The effect of cultivar performance in various tillage systems has not been examined in Iowa. Thus, the objectives in this study were to compare the yield of 12 soybean cultivars in two tillage systems, and to examine soybean growth and development of four soybean cultivars in two tillage systems. This was accomplished by two different experiments.

Materials and Methods

Experiment 1 – Cultivar performance

Research was conducted over three years (2007-2009) in Iowa at six locations representing the entire state and its diverse soils (Table 1). Three locations (Linn Grove, Ames, and Lenox) were lost due to wet conditions in 2007. In 2008, the Ames location was lost as a result of flooding. The experiment was a randomized complete block design in a split-plot arrangement with four replications. All fields were planted following corn (*Zea mays* L.). The main plots were conventional and no-tillage systems. Conventional tillage was accomplished by chisel-plowing in the fall and field cultivating twice in the spring prior to planting. The no-tillage system was a completely undisturbed system with soybean planted directly into the residue of the previous corn crop. Sub plots were twelve soybean cultivars (Table 2), chosen because they were locally adapted cultivars for Iowa and showed a variety of genetic backgrounds and differing SCN resistance properties.

The plots were planted with a Kinze 3000 no-tillage planter (Kinze, Williamsburg, IA) at 4-cm depth, in 38-cm rows, and at a seeding rate of 370 400 seeds ha^{-1}. The pre-emergence herbicides used contained S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methyl-ethyl) acetamide] and fomesafen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-nitrobenzamide], 1.22 kg a.i. ha^{-1} and 0.27 kg a.i. ha^{-1} respectively. Glyphosate [N-(phosphonomethyl)glycine] at a rate of 0.865 kg a.i. ha^{-1} was applied twice as a post-emergence herbicide. These applications were done at approximately the VC growth stage and V5 growth stage (Fehr and Caviness, 1977).

Data collected included stand counts, height, seed yield, and oil and protein at harvest. Yield was determined by harvesting the center four rows of the plot with an Almaco small-plot combine (Almaco, Nevada, IA) and yields were adjusted to 130 g kg^{-1} moisture. Protein and oil content was determined using near infrared spectroscopy (DA 7200 NIR Analyzer, Perten, Segeltorp, Sweden).

Experiment 2 - Growth and Development

Research was conducted in 2008 at Hudson and in 2009 in at Hudson and Ames, Iowa (Table 1). The experiment was a randomized complete block design in a split-plot arrangement with four replications. The previous crop was corn. The main plot was conventional and no-tillage systems and was accomplished as described for Experiment 1. Sub plots were four soybean cultivars (DeKalb DKB28-52, DeKalb DKB27-52, Pioneer P93M11, and Stine S-3128-4; Table 2). Plots were planted at 38-cm row spacing and at a seeding rate of 370 400 seeds ha^{-1}.

Three adjacent plots, each measuring 3-m by 7.6-m were planted of each cultivar in each replication, with one plot used for combining for yield and the other two adjacent plots for biomass sampling. Beginning at 21 days after emergence (DAE), plots were sampled every two weeks until harvest for a total of eight biomass sampling times using the sampling procedure of Pedersen and Lauer (2004b). Sampling areas measured 0.76 m^2. The two sampling plots each contained four sampling areas, staggered to avoid possible border-row effects. Plants were cut at the soil surface level, counted, and growth stages were determined based on Fehr and Caviness (1977). For the first, third, fifth, and seventh sampling times (21, 47, 76, and 107 DAE) the plant samples were collected from the field and dried as a whole sample for each plot at 60°C for five days and weighed to determine biomass accumulation throughout the season. For the second, fourth, sixth, and eighth sampling times (33, 61, 91, and 121 DAE) three plants from the harvested subsample area were chosen arbitrarily. The height, vegetative, and reproductive stages were determined for each of the three plants, before the three plants were separated into stems, leaves, and pods. The stems, leaves, and pods were weighed separately as well as the total biomass after drying at 60ºC for five days. The pod number, seed number, seed mass, and seeds pod^{-1} were determined after drying.

Data were analyzed using PROC MIXED (Littell et al., 1996) in SAS version 9.2 (SAS Institute, 2008). Data were analyzed with year and location considered as an environment (Milliken and Johnson, 1994). Environment and replication were considered random effects, while tillage system and cultivar were considered fixed effects. Mean separation was done using the Tukey-Kramer method.

Results and Discussion

Rainfall and temperature varied greatly throughout the three years of this study (Table 3). The environments studied in 2007 were moderately wet and warm during the growing season (May through August) compared to the 30-year average. In 2008, growing season temperatures were cool and very wet compared to the 30 year average. May through July was a particularly wet period with excessive flooding throughout most of the state. The 2009 growing season was close to the 30-year average in rainfall but one of the coolest growing seasons on record with the average temperature being 1.2°C lower than the 30-year average from May through August across the locations used.

Experiment 1 - Cultivar performance

An interaction was observed between tillage system and cultivars for seed moisture (Table 4). The cultivar P93M11 had greater seed moisture content in the no-tillage system (135 g kg^{-1}) than in the tillage system (129 g kg^{-1}) but no other cultivars showed differences in seed moisture content between tillage systems (data not shown). No other interactions were observed between tillage system and cultivar (Table 4). The lack of interaction between tillage systems and cultivar for yield is consistent with observations by Elmore (1987; 1990; 1991) and Philbrook et al. (1991).

Tillage did not influence yield (Table 4), which coincides with Pedersen and Lauer (2003b) and Yusuf et al. (1999). This study is to our knowledge one of the largest studies conducted in the Midwest comparing no-tillage to a traditional tillage system (a fall tillage pass followed by one to two passes with a field cultivator in the spring) for the region. The six locations used in this study represented Iowa’s diverse soils well (Steinwand and Fenton, 1995). Despite two out of three years being wetter than the 30-year average, no consistent yield penalty was observed at any location when the location was analyzed by itself across years (data not shown). Previous observations from Ohio documented that soil drainage appeared to have an impact on the yield response to tillage system (Dick and Van Doren, 1985). Based on this study, soil drainage does not appear to be a factor in the performance of tillage system in Iowa.

Yield differences existed among cultivars ranging from 4254 kg ha^{-1} (AG2422V) to 4930 kg ha^{-1} (P93M11) with the SCN-susceptible cultivars yielding 108 kg ha^{-1} more than the SCN-resistant cultivars. The yield advantage seen in SCN-susceptible cultivars is contrary to recent findings showing that SCN-resistant cultivars are higher yielding and have greater yield stability than SCN-susceptible cultivars (De Bruin and Pedersen 2008a; b). One possible explanation for this could be related to the wet growing seasons during this study. Johnson et al. (1993) observed that in wet soils, SCN-susceptible cultivars were less affected by SCN than in dry soils.

Final plant population density was not influenced by tillage system, cultivars, or resistance to SCN (Table 4). Our data are in agreement with Elmore (1991), who did not find differences in stand establishment between tillage systems, but contradicts results by Meese et al. (1991) and Philbrook et al. (1991), which could be due to differences in planters or other agronomic practices.

Soybean plants in a conventional tillage system were 3 cm taller at harvest than soybean plants in a no-tillage system (Table 4). Cultivar selection impacted plant height at harvest ranging from 76 cm (AG2403 and AG2422V) to 98 cm (AG2821V). Soybean plants with SCN-resistance were 3 cm taller at harvest than SCN-susceptible cultivars. The observation of plant height differences between tillage systems is contrary to the observations of Pedersen and Lauer (2003b), who reported no height differences between tillage systems. In contrast, Pedersen and Lauer (2003a; 2004a) observed taller plants in no-tillage systems compared with conventional tillage systems. The height difference between tillage systems observed in our study, however was small and did not appear to affect the yield.

Tillage system did not affect seed moisture at harvest (Table 4). Differences were observed among cultivars ranging from 123 g kg^{-1} (AG2403) to 135 g kg^{-1} (AG2821V). There was no difference in seed moisture observed between SCN-resistant and SCN-susceptible cultivars.

Seeds in the conventional tillage system had 1.2% more mass than in the no-tillage system, but did not appear to impact the final yield (Table 4) and these data are in agreement with Elmore (1987; 1990; 1991), De Bruin and Pedersen (2008b; 2008c), and Guy and Oplinger (1989). In contrast, Pedersen and Lauer (2003a; 2004c) reported that seed mass was greater in a no-tillage system than in a conventional tillage system. Seed mass differed among cultivars with SCN-resistant cultivars having 0.6 g 100 $seeds^{-1}$ greater seed mass than SCN-susceptible cultivars, which is contradictory to the observations of De Bruin and Pedersen (2008c), who found no differences.

Protein and oil content were not observed to be affected by tillage system; however, differences existed among cultivars (Table 4). Protein content was 1.3% greater in SCN-resistant cultivars but oil content was 0.9% lower than in SCN-susceptible cultivars. The observations made about the impact of tillage on protein and oil content coincide with findings by Pedersen and Lauer (2003b) and Yusuf et al. (1999).

Experiment 2 - Growth and Development

No interactions were observed between tillage system and cultivar selection in the measurement of biomass accumulation or pod and seed data. Biomass accumulation, pod mass, seed mass, pod number, and seed number did not differ between tillage systems or among cultivars throughout the growing season (Tables 5 and 6).

The similarities in biomass accumulation between tillage systems throughout the entire growing season are a unique observation. Yusuf et al. (1999) did not observe any seed yield differences between tillage systems but observed less biomass accumulation in the no-tillage compared to the tilled system up to the R6 growth stage, beyond which no differences were observed between tillage systems. In contrast, Pedersen and Lauer (2004a; 2004b) observed, in general, equal biomass accumulation until the R1 growth stage, after which plants in the no-tillage system accumulated more biomass than plants in the conventional tillage system until harvest. The yield component observations observed in this study are contrary to those found by Pedersen and Lauer (2004c), which showed conventional tillage systems to produce 12% more pods m^{-2} and 12% more seeds m^{-2} than no-tillage systems.

Small differences in biomass accumulation were observed between SCN-resistant and SCN-susceptible cultivars throughout the season. At 76 DAE, SCN-susceptible cultivars tended to have greater biomass than SCN-resistant cultivars (P=0.06). In contrast, at 107 and 121 DAE, SCN-resistant cultivars accumulated 65.8 g m^{-2} and 65.1 g m^{-2} more biomass, respectively, than SCN-susceptible cultivars. This is consistent with observations reported by De Bruin and Pedersen (2009). The inconsistency we observed between final biomass accumulation and yield also is supported by the observations of De Bruin and Pedersen (2009), in which no direct links were made between biomass differences and yield differences.

The SCN-resistant cultivars had a pod mass at harvest that was 58 g m^{-2} greater and a seed mass that was 38 g m^{-2} (P=0.06) greater than that of SCN-susceptible cultivars, respectively (Table 6). Pod and seed number was similar between SCN-resistant and SCN-susceptible cultivars (Table 6). Our observations are similar to those of De Bruin and Pedersen (2008c) that in five out of the six site-years, there were no differences in seed number between SCN-resistant and SCN-susceptible cultivars. In the sixth site-year, however, the SCN-resistant cultivars had 810 seeds m^{-2} more than SCN-susceptible cultivars. Although there was a trend toward greater biomass accumulation and yield components in SCN-resistant cultivars, the yield examined at the three sampling locations was found to be similar between SCN-resistant and SCN-susceptible cultivars. This suggests a lack of correlation between final biomass and seed mass, and overall yield. In contrast, Pedersen and Lauer (2004c.) showed a high positive correlation between seed mass and seed yield.

Conclusion

This study is one of the largest conducted from the upper Midwest to examine the effect of tillage system on soybean cultivar performance. Two of the three years were wetter than normal and did not accurately represent a typical growing season in Iowa. Cultivars differed in yield and many other harvest components studied, but no interactions were observed between tillage and cultivar selection in this study. Overall, tillage system did not have an effect on soybean yield or growth and development. Based on this study it was concluded that no soybean yield difference exists between conventional tillage and no-tillage systems in Iowa and that locally adapted cultivars can be selected to maximize yield regardless of tillage system.

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Table 1. Field characteristics, planting dates, and harvest dates for six locations where the two studies were conducted during 2007-2009.

	Linn Grove	Humboldt	Hudson	Ames	Lenox	Oskaloosa
Latitude	42°53’33”N	42°43’25”N	42°24’32”N	42°1’38”N	40°53’0”N	41°17’38”N
Soil series	Clarion silty clay loam	Webster silty clay loam	Dinsdale silty clay loam	Clarion loam	Shelby loam	Fayette silt loam
Soil family	Cumulic Haplaquolls	Typic Endoaquolls	Cumulic Endoaquolls	Typic Hapludolls	Typic Argiudolls	Typic Hapludalfs
Soil fertility						
pH	6.2-6.5	6.6-7.3	6.3-6.9	7.4-7.7	6.0-6.6	6.3-7.1
P, mg kg^{-1}	25-31	16-257	6-36	12-25	38-49	26-90
K, mg kg^{-1}	149-243	117-349	119-238	108-145	220-249	184-415
OM, g kg^{-1}†	54-61	40-56	26-68	49-55	43-48	37-41
SCN‡ population						
Planting date						
2007	-	May 21	May 1	-	-	May 19
2008	May 1	May 14	May 16	-	May 15	May 8
2009	May 2	May 4	May 11	May 7/8	May 20	April 24
Harvest date						
2007	-	October 5	September 26	-	-	September 28
2008	October 9	October 10	October 9	-	October 4	October 1
2009	October 27	October 10	October 13	October 10	October 19	October 20

†OM , organic matter.

‡SCN, soybean cyst nematode (*H. glycines* Ichinohe).

Table 2. Soybean cultivars used in the two studies, seed company, source of resistance to *H. glycines* Ichinohe, and maturity groups during 2007-2009.

Company	Cultivar	Maturity group	Reaction to *H. glycines* Ichinohe†
Monsanto Company	AG2403	2.4	Susceptible
Monsanto Company	AG2422V	2.4	R (PI 88788)
Monsanto Company	AG2821V	2.8	R (PI 88788)
Monsanto Company	DKB27-52‡	2.7	R (PI 88788)
Monsanto Company	DKB28-52‡	2.8	Susceptible
Latham Seeds	L2611RX	2.6	R (Hartwig)
Latham Seeds	L2620-RX	2.6	R (Hartwig)
Pioneer Hi-Bred International	P92M33	2.3	R (PI 88788)
Pioneer Hi-Bred International	P92M54	2.5	R (PI 88788)
Pioneer Hi-Bred International	P92M76	2.7	R (PI 88788)
Pioneer Hi-Bred International	P93M11‡	3.1	Susceptible
Stine Seed	S-3128-4‡	3.1	R (PI 88788)

†R=Resistant to *H. glycines* Ichinohe (source of resistance in parenthesis).
‡Used for Experiment 2.

Table 3. Precipitation and air temperature recorded at the six locations in Iowa during 2007- 2009 using weather stations from nearby airports. Deviation from the 30-year average reported in parentheses.

		May		June		July		August		Average†	
Year	Location	Air Temp	Rainfall	Air Temp	Rainfall	Air Temp	Rainfall	Air Temp	Rainfall	Air Temp	Rainfall
		°C	mm	°C	Mm	°C	mm	°C	mm	°C	mm
2007	Humboldt	17.8 (2.1)	111 (4)	21.1 (0.4)	66 (-56)	22.8 (0.1)	72 (-35)	22.2 (1.2)	424 (312)	21.0 (1.0)	168 (56)
	Hudson	17.8 (2.1)	118 (12)	21.1 (0.2)	130 (2)	22.8 (-0.2)	118 (5)	23.3 (1.8)	262 (154)	21.3 (1.0)	157 (43)
	Oskaloosa	18.9 (2.6)	155 (39)	21.7 (0.2)	81 (-46)	23.3 (-0.5)	62 (-50)	24.4 (1.8)	424 (296)	22.1 (1.1)	180 (59)
2008	Linn Grove	14.4 (-0.6)	141 (39)	20.6 (0.3)	223 (94)	23.3 (0.8)	132 (19)	21.7 (0.5)	30 (-93)	20.0 (0.2)	132 (15)
	Humboldt	13.3 (-2.4)	152 (45)	20.0 (-0.7)	239 (117)	22.2 (-0.4)	98 (-10)	20.0 (-1.0)	39 (-73)	18.9 (-1.1)	132 (20)
	Hudson	13.9 (-1.8)	159 (52)	21.1 (0.2)	223 (95)	23.3 (0.4)	140 (27)	21.1 (-0.4)	40 (-68)	19.9 (-0.4)	140 (26)
	Lenox	14.4 (-1.8)	127 (11)	21.1 (-0.4)	349 (236)	23.3 (-0.6)	230 (126)	21.7 (-1.1)	9 (-97)	20.1 (-1.0)	179 (69)
	Oskaloosa	14.4 (-1.9)	138 (22)	21.7 (0.2)	173 (46)	22.8 (-1.0)	174 (-49)	21.1 (-1.4)	66 (-61)	20.0 (-1.0)	138 (17)
2009	Linn Grove	15.6 (0.5)	46 (-56)	20.0 (-0.4)	135 (5)	20.0 (-2.5)	128 (14)	21.1 (-0.1)	50 (-72)	19.2 (-0.6)	90 (-27)
	Humboldt	14.4 (-1.2)	93 (-14)	20.0 (-0.7)	64 (-58)	20.6 (-2.1)	75 (-32)	20.6 (-0.4)	52 (-60)	18.9 (-1.1)	71 (-41)
	Hudson	15.6 (-0.1)	104 (-2)	20.0 (-0.9)	91 (-37)	20.0 (-3.0)	140 (27)	20.0 (-1.6)	117 (9)	18.9 (-1.4)	113 (-1)
	Ames	15.6 (-0.9)	102 (-14)	21.1 (-0.3)	104 (-15)	20.6 (-2.8)	70 (-49)	20.6 (-1.4)	89 (-33)	19.4 (-1.4)	91 (-28)
	Lenox	15.6 (-0.7)	80 (-36)	21.1 (-0.4)	162 (49)	20.0 (-3.9)	149 (45)	21.7 (-1.1)	129 (22)	19.6 (-1.5)	130 (20)
	Oskaloosa	15.6 (-0.8)	91 (-25)	21.1 (-0.4)	309 (182)	20.6 (-3.2)	104 (-8)	22.2 (-0.3)	156 (29)	19.9 (-1.1)	165 (44)

†Average taken throughout the growing season (May-August).

Table 4. Means of main effects of tillage and cultivar on final plant population, height, harvest seed moisture, seed mass, and protein and oil content of the seed in 14 environments from 2007 to 2009.

Treatment	Yield	Final plant density	Plant height	Moisture	Seed mass	Protein	Oil
	kg ha^{-1}	Plants ha^{-1}	cm	g kg^{-1}	g 100 $seeds^{-1}$	%	%
Tillage (T)							
Conventional	4700	305 100	90	127	16.1	34.6	18.1
No-Tillage	4642	299 100	87	129	15.9	34.5	18.2
HSD (0.05)	NS	NS	2	NS	0.2	NS	NS
Cultivar (C)							
AG2403†	4502	313 500	76	123	16.1	33.8	18.9
AG2422V‡	4254	304 900	76	125	16.5	34.5	18.0
AG2821V‡	4749	294 000	98	135	17.1	35.1	17.5
DKB27-52‡	4743	282 800	85	124	15.3	32.7	18.6
DKB28-52†	4823	289 600	96	127	16.0	33.4	18.4
L2611RX‡	4476	293 800	95	127	16.4	35.7	17.4
L2620RX‡	4430	299 800	96	128	16.4	35.7	17.3
P92M33‡	4742	292 800	92	128	16.1	35.6	17.9
P92M54‡	4745	303 700	88	127	15.8	35.2	18.1
P92M76‡	4813	316 100	84	130	16.8	35.0	18.2
P93M11†	4930	327 900	87	132	14.8	33.5	19.2
S-3128-4‡	4847	306 700	88	129	15.0	34.5	18.2
HSD (0.05)	179	NS	3	3	0.4	0.3	0.2

†SCN susceptible cultivar.
‡SCN resistant cultivar.
*,**,*** $P \leq 0.05, 0.01, 0.001$.

Table 4. (continued)

Treatment	Yield	Final plant density	Plant height	Moisture	Seed mass	Protein	Oil
	kg ha^{-1}	Plants ha^{-1}	cm	g kg^{-1}	g 100 $seeds^{-1}$	%	%
Contrast (*P*-value)							
Resistant vs Susceptible cultivars	0.01	0.21	<0.0001	0.22	<0.0001	<0.0001	<0.0001
ANOVA							
T X C	NS	NS	NS	***	NS	NS	NS

Table 5. Means of the main effects of tillage and cultivar on canopy biomass along with vegetative and reproductive growth stages of four cultivars in two tillage systems throughout the growing season in 2008 and 2009.

Treatment	Canopy Biomass (g m^{-2})							
	Days After Emergence (DAE)							
	21	33	47	61	76	91	107	121
	Growth Stages†							
	VC -	V2 -	V6 R1	V9 R2	V12 R3	V15 R5	V15 R6	V16 R8
<u>Tillage (T)</u>								
Conventional	4.6	18.1	83.0	190.0	440.5	549.6	729.8	591.6
No-Tillage	2.9	12.0	50.4	143.1	335.2	510.6	674.3	606.0
HSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
<u>Cultivar (C)</u>								
DKB27-52§	2.7	13.7	64.1	156.7	367.1	569.1	751.4	604.1
DKB28-52‡	4.3	16.7	77.4	179.4	419.6	516.7	669.4	572.6
P93M11‡	3.8	13.9	59.4	158.2	418.3	502.2	668.8	559.7
S-3128-4§	4.4	15.7	65.8	170.9	346.5	532.3	718.5	658.5
HSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
<u>Contrast (*P*-value)</u>								
Resistant vs Susceptible cultivars	0.57	0.76	0.59	0.69	0.06	0.15	0.03	0.04
<u>ANOVA</u>								
T X C	NS	NS	NS	NS	NS	NS	NS	NS

†Average vegetative (V) and reproductive (R) growth stages based on three plants per plot.
‡SCN susceptible cultivar.
§SCN resistant cultivar.

Table 6. Means of main effects of tillage and soybean cultivar on pod and seed mass and counts of four cultivars in two tillage systems at harvest maturity in 2008 and 2009.

Treatment	Yield	Pod mass	Pod count	Seed mass	Seed number
	kg ha^{-1}	g m^{-2}	Pods m^{-2}	g m^{-2}	Seeds m^{-2}
Tillage (T)					
Conventional	4457	446.9	1227	340.3	2900
No-Tillage	4449	481.7	1237	366.1	2963
HSD (0.05)	NS	NS	NS	NS	NS
Cultivar (C)					
DKB27-52‡	4293	485.9	1179	362.6	2678
DKB28-52†	4336	438.9	1266	335.4	2859
P93M11†	4498	431.7	1206	332.8	2989
S-3128-4‡	4684	500.7	1279	382.0	3200
HSD (0.05)	NS	NS	NS	NS	NS
Contrast (*P*-value)					
Resistant vs Susceptible cultivars	0.64	0.03	0.94	0.06	0.95
ANOVA					
T X C	NS	NS	NS	NS	NS

†SCN susceptible cultivar.
‡SCN resistant cultivar.

CHAPTER 4: EFFECTS OF TILLAGE SYSTEM, ROW SPACING, AND SEEDING RATE ON SOYBEAN YIELD

A.M. Kiszonas, Palle Pedersen, and Micheal D.K. Owen

Abstract

Row spacing, and seeding rates are crucial to maximize soybean [*Glycine max* (L). Merr.] yield. Little research exists on the relationship between plant distribution and tillage practices for yield in Iowa. The objective of this study was to determine the effect of tillage system, row spacing, and seeding rate on soybean growth, development, and yield. This was accomplished by conducting two separate experiments. The first experiment evaluated yield responses to tillage system (conventional tillage and no-tillage), row spacing (38- and 76-cm), and seeding rate (185 200, 308 600, 432 100, and 555 600 seeds ha^{-1}) across Iowa, and the second experiment examined growth and development in treatments of tillage system, row spacing, and seeding rate. The first experiment was conducted at six locations (15 site-years) across Iowa from 2007 to 2009 and the second experiment was conducted at two locations (3 site-years) in Iowa during 2008 and 2009. Tillage system did not affect soybean yield across Iowa. Plants in 38-cm rows yielded 288 kg ha^{-1} greater than 76-cm rows. Yield was not affected by seeding rates above 308 600 seeds ha^{-1}. Few differences were observed between tillage systems in the growth and development experiment, which included biomass accumulation, crop growth rate, pod and seed measurements, and light interception. It was concluded that no yield or growth and development differences exist between tillage systems in Iowa and the use of narrow rows and optimum seeding rate to maximize yield is the same regardless of tillage system.

Abbreviations: CGR, crop growth rate; LI, light interception.

Introduction

Although Iowa is the largest soybean [*Glycine max* (L.) Merr.] producing state in the United States (National Agricultural Statistic Service, 2010), only 41% of the soybean produced is grown using no-tillage production practices (Conservation Technology Information Center, 2010). Many studies have produced conflicting results in the examination of soybean yield under different tillage systems. Pedersen and Lauer (2003a) observed in a long-term rotation study in Wisconsin 6% greater yield in a no-tillage system compared to a conventional tillage system. Similarly, Edwards et al. (1988) observed 736 kg ha^{-1} greater yields in a no-tillage system than a conventional tillage system three out of four years in Alabama. However, studies from Illinois (Vasilas et al., 1988) and Wisconsin (Guy and Oplinger, 1989) observed greater yields in conventional tillage systems compared to no-tillage systems, while Pedersen and Lauer (2003b) reported no soybean yield differences between tillage systems in Wisconsin.

The impacts of tillage system on soybean yield are influenced by environmental conditions. Reduced early vegetative growth and increased days to maturity were observed to be the result of increased soil residue cover and cooler soil temperatures in no-tillage soybean production systems (Meese et al., 1991). Soils in a no-tillage system have been observed to be up to 5.9°C cooler than conventional tillage system soils at planting (Johnson and Lowery, 1985), likely due to the saturated soils and amount of residue at planting (Meese et al., 1991). Furthermore, soil drainage properties of a field impact the differences between conventional tillage and no-tillage yields of soybean. In well-drained soils no differences have been observed between conventional tillage and no-tillage yields, whereas in poorly-drained soils, conventional tillage systems showed a 283 kg ha^{-1} yield advantage over no-tillage production systems (Dick and Van Doren, 1985). The greater soil moisture seen in no-tillage fields is due to decreased evaporation (Chastain et al., 1995).

Conflicting results exist in tillage effects on soybean growth and development. Yusuf et al. (1999) did not find any yield differences between tillage systems, but reported differences in growth and development. Between emergence and the R6 growth stage, aboveground biomass accumulation was greater in conventional tillage than no-tillage systems (Yusuf et al., 1999; Fehr and Caviness, 1977). Beyond R6, no differences were observed between tillage systems as a result of a higher crop growth rate (CGR) in the no-tillage system from the R2 to R6 growth stages (Yusuf et al., 1999). This compensatory growth was also observed by Pedersen and Lauer (2004b), who found that prior to the R1 growth stage, no differences in growth and development were observed between tillage systems, but after R1 a greater biomass accumulation and CGR were observed in the no-tillage system compared to the conventional tillage system. Differences in biomass accumulation and CGR did not lead to yield differences (Pedersen and Lauer, 2004b). In contrast, no-tillage plants had 6% greater biomass accumulation, 7% greater plant height, and 9% greater yield than conventional tillage plants, despite similar biomass accumulation prior to R1 (Pedersen and Lauer, 2004a). The contradictory results observed from around the Midwest indicate that other factors influence the tillage effect on soybean yield, and that a compensatory effect can equalize the yield despite differences in growth and development.

Narrow rows have been observed to contribute to higher soybean yields compared to wide row production systems. Taylor et al. (1982) observed 15% greater yields in 25-cm rows than in 100-cm rows. Recently, soybean planted in 38-cm rows yielded 248 kg ha^{-1}

greater than soybean planted in 76-cm rows (De Bruin and Pedersen, 2008a). Pedersen and Lauer (2003a), however, did not find an effect of row-spacing on soybean yield.

The yield advantage of narrow rows over wide rows observed by Taylor et al. (1982) was attributed to greater light interception (LI) during late seed development for soybean planted in narrow rows. Maximum LI by soybean plants in narrow rows and the subsequent yield response was observed to be most important during vegetative and early reproductive growth stages (Board et al., 1992). Maintaining 95% LI at mid seed filling is critical to avoid any yield loss (Board, 2004). This level of 95% LI was also found to be necessary for maximum dry matter accumulation when soybean is in the R5 growth stage (Shibles and Weber, 1965). The rate of dry matter accumulation by soybean is a linear function of percent solar radiation interception and leaf area index (LAI); however, there is a point beyond which increases in LAI do not result in greater dry matter production (Shibles and Weber, 1965). Soybean plants in wide rows were not observed to consistently reach 95% LI (Shibles and Weber, 1966). Dry matter accumulation is especially dependent upon early canopy closure to maximize LI (Ball et al., 2000). Herbert and Litchfield (1984) observed increased dry matter in narrow rows over wide rows, the dry matter increasing at each interval between 25-, 50-, and 75-cm rows. Greater CGR in narrow rows compared to wide rows was found to be crucial to soybean yield formation until approximately R5 (Bullock et al., 1998; Board and Harville, 1994). This observation supported the hypothesis that the soybean yield increase seen in narrow rows was a result of benefits that occurred before main grain-fill periods (Bullock et al., 1998).

Plant population often has no effect on soybean yield as a result of branch productivity (Carpenter and Board, 1997; De Bruin and Pedersen, 2008a). In narrow rows, maximum yields can be attained through the use of increased seeding rates. Optimal seeding rates have been observed to increase in narrow rows (Devlin et al., 1995; Oplinger and Philbrook, 1992; Weber et al., 1966). Despite this, stress on the canopy can result from increased plant competition following increased seeding rates, which diminishes the benefits seen in narrow rows, more so when plant growth is limited by environmental stresses (Devlin et al., 1995; Elmore 1998). An optimum plant density of 462 000 plants ha^{-1} at harvest in Iowa was observed by De Bruin and Pedersen (2008a), but 95% of the maximum soybean yield could be attained with a final harvest population as low as 258 600 plants ha^{-1}.

Few observations have documented soybean yield, growth, and development responses to row spacing and seeding rates in tilled and no-tilled systems. Our objectives were i) to determine the effect of tillage system, row spacing, and seeding rate on soybean yield across Iowa, and ii) to determine the effect of tillage system, row spacing, and seeding rate on soybean growth and development.

Materials and Methods

Experiment 1 –Yield Response

Field research was conducted 2007-2009 at six locations in Iowa, which generally represent the entire state (Table 1). Two locations (Ames and Lenox) were lost in 2007 and the Ames location was lost in 2008, all due to flooding. The experiment was a randomized complete block design in a split-split plot arrangement with four replications. The main plots were conventional and no-tillage systems. Conventional tillage was accomplished by chisel-plowing in the fall and field cultivating twice in the spring prior to planting. All fields were previously planted to corn (*Zea mays* L.). The no-tillage system was a completely undisturbed system with soybean planted directly into corn residue. Sub-plots were planted in 38- and 76-cm rows. Sub-sub plots were seeding rates of 185 200, 308 600, 432 100, and 555 600 seeds ha^{-1}. The soybean variety used was AG2802 (Monsanto, St. Louis, MO), which has SCN resistance (PI 88788) and is a maturity group 2.8. Planting locations and details are shown in Table 1.

The experiments were planted with a Kinze 3000 no-tillage planter (Kinze, Williamsburg, IA) at a 4-cm depth. The preemergence herbicides used were S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methyl-ethyl) acetamide] and fomesafen [5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-nitrobenzamide], applied at 1.22 kg a.i. ha^{-1} and 0.27 kg a.i. ha^{-1} respectively. Glyphosate [N-(phosphonomethyl)glycine] at a rate of 0.865 kg a.i. ha^{-1} was applied twice as a post-emergence herbicide. The applications were done at approximately the cotyledon (VC) growth stage and V5 growth stage (Fehr and Caviness, 1977).

Plant stand, plant height, seed yield, protein and oil were determined at harvest. Yield was determined by harvesting the center four rows of the yield plot of 38-cm plots and the center two rows of 76-cm plots with an Almaco small-plot combine (Almaco, Nevada, IA) and yields were adjusted to 130 g kg^{-1} moisture. Protein and oil content was determined using near infrared spectroscopy (DA 7200 NIR Analyzer, Perten, Segeltorp, Sweden).

<u>Experiment 2 – Growth and Development</u>

Field research was conducted in 2008 and 2009 at Hudson and in 2009 at Ames in Iowa (Table 1). The experiment was a randomized complete block design in a split-split plot arrangement with four replications. The main plots were conventional and no-tillage systems and planted as described for Experiment 1. Sub plots were 38- and 76-cm row spacings. Sub-

sub plots were seeding rates of 185 200, 308 600, 432 100, and 555 600 seeds ha^{-1}. The soybean cultivar used was AG2802 (Monsanto, St. Louis, MO).

Three adjacent plots were planted of each treatment in each replication with each plot measuring 3-m by 7.6-m. One plot was used for yield and the remaining two plots for biomass sampling. Beginning at 21 days after emergence (DAE), the biomass plots were sampled every two weeks until harvest for a total of eight biomass sampling times. The sampling procedure followed that of Pedersen and Lauer (2004b). In each of the two sampling plots of each treatment, four sampling areas of 0.76 m^2 each were delineated. Sampling areas were staggered to avoid possible border-row effects. Soybean plants were cut at the soil surface in the 0.76 m^2 area of each plot and the plant number and growth stages were determined based on Fehr and Caviness (1977). For the first, third, fifth, and seventh sampling times (21, 47, 76, and 107 DAE) the plant samples were collected from the field and dried as a whole sample for each plot at 60°C for five days and weighed to determine biomass accumulation throughout the season. For the second, fourth, sixth, and eighth sampling times (33, 61, 91, and 121 DAE), in addition to determining biomass accumulation, of the harvested subsample area, three plants were chosen randomly. The height, vegetative, and reproductive growth stages were determined for the three plants, and the three plants were separated into stems, leaves, and pods. The stems, leaves, and pods from the three plants were weighed separately and dried at 60°C for five days. The pod number, seed number, seed mass, and seeds pod^{-1} were determined after drying. Crop growth rate (plant biomass accumulated day^{-1} from R1 to R5; Pedersen and Lauer, 2004b) was calculated.

Light interception was measured using a 1-m light quantum sensor (Licor LI-191, Lincoln, NE) starting at 33 DAE (approximately V3) until approximately 91 DAE using the guidelines explained by Wells (1991). For each plot, there was one light measurement taken above the canopy. Three subsequent measurements were taken at ground level, below the canopy, at a diagonal through the plot. These measurements occurred between the hours of 10:00 and 15:00 on virtually cloudless days. The minimum amount of light intercepted considered an acceptable measurement was 1100 watts m^{-2}.

Data were analyzed using PROC MIXED (Littell et al., 1996) with the SAS version 9.2 (SAS Inst., 2008). Data were analyzed with year and location considered as an environment (Milliken and Johnson, 1994) after determining homogenous error variances. Environment and replication were considered random effects, while tillage system, row spacing, and seeding rate were considered fixed effects. Mean separation was done using the Fischer's protected LSD ($P \leq 0.05$). A regression analysis was performed to determine the effect of plant population on yield.

Results and Discussion

This study was conducted at a total of 15 site-years throughout from 2007 to 2009 in Iowa representing the state's diverse soil types. The environmental conditions during the three years varied greatly (Table 2). The 2007 growing season was moderately wet and warm in comparison to the 30-year average. In 2008 the growing season was cool and wet with extensive flooding in many parts of the state, whereas in 2009 the rainfall was close to the 30-year average but the temperatures were significantly cooler than the 30-year average. No differences in growth stage were observed between tillage systems with the average growth stage being V3, V7 (R1), V10 (R2), V14 (R3), V16 (R5), and V18 (R6) at 33, 47, 61, 76, 91, and 107 DAE, respectively (data not shown). Based on the regression analysis performed, data were not significant and thus, all results are based on seeding rate as opposed to plant population (data not shown).

Experiment 1 –Yield Response

No interactions were observed between tillage system, row spacing, or seeding rate on soybean yield (Table 3). Overall, tillage system did not affect yield, which is consistent with the observations of Pedersen and Lauer (2003b) and Yusuf et al. (1999). Although there was considerable variation in temperature and moisture, no yield effect was observed as a result of the excess moisture in 2007 and 2008. In Ohio, soil drainage properties appeared to have a great effect on the yield differences between conventional tillage and no-tillage systems (Dick and Van Doren, 1985); however, these trends were not observed across Iowa. The soybean yield in 38-cm row spacing was 288 kg ha^{-1} (6%) greater than in 76-cm rows. This supports prior research from the upper Midwest (Costa et al., 1980; De Bruin and Pedersen, 2008a; Taylor et al., 1982) but contradicts the work by Pedersen and Lauer (2003a), which did not find any yield difference between row spacings. Yield increased as seeding rate increased but no differences were observed among the three highest seeding rates, similar to the observations of De Bruin and Pedersen (2008a; 2008b). Our study contradicts the work by Oplinger and Philbrook (1992) which found that a higher seeding rate was necessary to maximize yield in a no-tillage system compared to a conventional tillage system.

A tillage system by row spacing interaction was observed on final plant population showing a greater final plant population in 38-cm rows than in the 76-cm rows in the conventional tillage system but with no differences in final plant populations in the no-tillage system (data not shown). Overall, tillage system did not influence final plant population.

Narrow rows (38-cm) had a greater final plant population than wide rows (76-cm) and final plant population increased with increasing seeding rate (Table 3). The lack of yield difference between the seeding rates of 308 600 and 555 600 seeds ha^{-1} indicates that a final plant population of 242 300 plants ha^{-1}, which was observed with the seeding rate of 308 600 seeds ha^{-1}, is sufficient to maximize yield and agrees with De Bruin and Pedersen (2008a; 2008b).

No interactions were observed between tillage system, row spacing, and seeding rate on plant height (Table 3). Plants were 4 cm shorter in the no-tillage system than in the conventional tillage system, whereas row spacing had no effect on plant height. Plant height increased with increasing seeding rate up to a seeding rate of 432 100 seeds ha^{-1}. Pedersen and Lauer (2003b) did not find an effect of tillage systems on plant height, whereas Pedersen and Lauer (2003a; 2004a) found plants in no-tillage systems to be taller than plants in conventional tillage systems.

Seed moisture was not affected by tillage system or seeding rate (Table 3); however, seed moisture was greater in 38-cm rows compared to 76-cm rows. Pedersen and Lauer (2003a) found seed moisture to be greater in conventional tillage systems and with no effect of row spacing on seed moisture content (Pedersen and Lauer, 2003a). Seed mass was not influenced by tillage system or row spacing but in general increased as seeding rate increased (Table 3). An interaction between row spacing and seeding rate was observed, but the data were inconsistent, so no conclusion was drawn (data not shown).

No difference was observed between tillage systems in soybean oil content, which supports the observations of Pedersen and Lauer (2003b), who found no difference in protein content between tillage systems. Protein content was unaffected by row spacing, which contrasts Weber et al. (1966), a study which found a slightly greater protein content in narrow rows. In general, protein content increased with increasing seeding rate, which supports the observations of Weber et al. (1966).

An interaction was observed between tillage system and row spacing and between tillage system and seeding rate on oil content (Table 3). The oil content in soybean in 38-cm rows was greater than in 76-cm rows in the no-tillage system, but no differences in oil content existed for conventional tillage plants.

In the conventional tillage system the oil content was not influenced by seeding rate whereas the oil content decreased as seeding rate increased in the no-tillage system. Overall, no differences were observed in oil content between conventional tillage and no-tillage systems (Table 3), which supports Pedersen and Lauer (2003b). Soybean in the 38-cm row spacing had greater oil content than soybean in 76-cm rows, which is the opposite of the observation by Weber et al. (1966). In general, oil content decreased as seeding rate increased, which agrees with Weber et al. (1966).

Experiment 2 – Growth and Development

A separate yield analysis was conducted for the 3 site-years used for the growth and development experiment. No effect on yield and any of the yield components measured was observed for tillage system, row spacing, or seeding rate (Table 4). This is in disagreement with our broad area yield response across 15 site-years, which showed differences in yield between row spacings and seeding rates (Table 3). Despite not being different at P=0.05 (Table 4) there was evidence that the 38-cm row spacing was greater yielding than 76-cm row spacing (P=0.13) for the 3 site-years used for the growth and development experiment, as was the case in the broad area yield response experiment. There was also evidence that yield differences existed among seeding rates (P=0.07). The trends of seeding rate effects on yield were similar to the analysis across 15 site-years (Table 3) but more variable. The lack of differences in yield components was expected because we did not observe any yield differences. However, our data disagree with the observation by Pedersen and Lauer (2004c), which showed a lower pod number m^{-2} and seed number m^{-2} but a greater seed mass and seed number pod^{-1} in the no-tillage than in the conventional tillage system, respectively.

Few differences were observed in canopy biomass accumulation throughout the growing season (Table 5). Overall, no differences were observed between tillage systems or row spacings at any of the eight sampling times. A tillage system by row spacing interaction was observed at 107 DAE with plants in 38-cm rows in the conventional tillage system accumulating 16% more biomass than the plants in 38-cm rows in the no-tillage system. The lack in difference in biomass accumulation throughout the growing season contradicts Yusuf et al. (1999). They observed a greater biomass accumulation in conventional tillage than in no-tillage system from V2 growth stage and until late in the R6 growth stage but no differences between tillage systems thereafter. Pedersen and Lauer (2004a; 2004b), however, saw no differences in biomass accumulation between tillage systems prior to the R1 growth stage, beyond which there was in general, greater biomass accumulation in the no-tillage system than in the conventional tillage system. Our lack in biomass accumulation differences between row spacing coincides with the similar yield produced, but disagrees with the observation by Herbert and Litchfield (1984) that found narrow rows to accumulate more biomass per area and yield greater than wide rows.

A tillage system by row spacing interaction was observed for CGR from R1-R5 showing no difference in CGR between row spacings in a conventional tillage system but a greater CGR for 76-cm rows in a no-tillage system (data not shown). No other differences were observed in either CGR at any sampling time or for CGR from R1-R5 between tillage systems, row spacings, and seeding rates (Table 6). The lack of differences in CGR and CGR from R1-R5 coincides with the similarities in biomass accumulation and yield (Tables 4 and 5) since the CGR pattern is highly associated with biomass accumulation (Pedersen and Lauer, 2004b). Yusuf et al. (1999) observed a greater CGR in conventional tillage systems until R2 growth stage, after which the plants in a no-tillage system displayed a greater CGR until the R6 growth stage. Pedersen and Lauer (2004b) observed a greater CGR from R1-R5 in the no-tillage compared to the conventional tillage system. Herbert and Litchfield (1984) found narrow rows and higher seeding rates to have a higher CGR than wider rows and lower seeding rates.

A tillage system by row spacing interaction was observed for LI at 91 DAE (Table 6). No differences in LI were observed between 38- and 76-cm rows in the no-tillage system whereas in the conventional tillage system plants in 38-cm rows (97.7%) intercepted more light than plants in 76-cm rows (93.4%). Interactions between seeding rate and tillage and between all three main effects of tillage system, row spacing, and seeding rate were observed, but there was no consistent pattern for these two interactions (data not shown). No differences in LI were observed between tillage systems throughout the growing season. At 76 DAE, plants in 38-cm rows (93.6%) intercepted more light than plants in 76-cm rows (89.4%). These similarities in LI between row spacings contradict previous work showing that plants in narrow rows intercept more light than plant in wider rows (Taylor et al., 1982). Differences in LI between seeding rates were detected from emergence through 76 DAE, but not beyond 91 DAE (Table 6). From emergence until 76 DAE the overall trend was an increased LI with increasing seeding rate.

Conclusion

This study is one of the largest studies conducted to evaluate the effects of row spacing and seeding rate in conventional tillage and no-tillage systems. Although the excessive moisture in two of the three years of this study and extremely cool weather in one year of this study were not ideal for a tillage study, tillage had no effect on yield across the 15 site-years. These similarities between tillage systems indicate that the no-tillage soybean production area in Iowa can be expanded without yield losses. Growth and development was observed throughout the growing season at three site-years with few differences observed. Narrow rows showed a yield advantage over wide rows and yield increased with seeding rate to a point, beyond which no increases were seen. Based on this study row spacing and seeding rate recommendations are the same regardless of tillage systems in Iowa.

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Table 1. Field characteristics, planting dates, and harvest dates for six Iowa locations where studies were conducted from 2007 to 2009.

	Linn Grove	Humboldt	Hudson	Ames	Lenox	Oskaloosa
Latitude	42°53’33”N	42°43’25”N	42°24’32”N	42°1’38”N	40°53’0”N	41°17’38”N
Soil series	Clarion silty clay loam	Webster silty clay loam	Dinsdale silty clay loam	Clarion loam	Shelby loam	Fayette silt loam
Soil family	Cumulic Haplaquolls	Typic Endoaquolls	Cumulic Endoaquolls	Typic Hapludolls	Typic Argiudolls	Typic Hapludalfs
Soil fertility						
pH	6.2-6.5	6.6-7.3	6.3-6.9	7.4-7.7	6.0-6.6	6.3-7.1
P (mg kg^{-1})	22-32	16-257	6-36	12-25	38-49	26-90
K (mg kg^{-1})	149-243	117-349	119-238	108-145	220-249	184-415
OM (g kg^{-1})†	53-61	40-56	26-68	49-55	43-48	37-41
SCN‡ population						
Planting date						
2007	May 17/18	May 21	May 1	-	-	May 19
2008	May 1	May 14	May 16	-	May 15	May 8
2009	May 2	May 4	May 11	May 7/8	May 20	April 24
Harvest date						
2007	October 23	October 5	September 26	-	-	September 28
2008	October 9	October 10	October 9	-	October 4	October 1
2009	October 27	October 10	October 13	October 10	October 19	October 20

†OM , organic matter.

‡SCN, soybean cyst nematode (*H. glycines* Ichinohe).

Table 2. Monthly average precipitation and air temperature recorded during the growing season at six Iowa locations from 2007 to 2009.

		May		June		July		August		Average†	
Year	Location	Air Temp	Rainfall	Air Temp	Rainfall	Air Temp	Rainfall	Air Temp	Rainfall	Air Temp	Rainfall
		°C	mm	°C	mm	°C	mm	°C	mm	°C	mm
2007	Linn Grove	17.8 (2.7)	279 (178)	21.7 (1.3)	127 (-2)	23.9 (1.4)	102 (-12)	23.3 (2.1)	330 (208)	21.7 (1.9)	210 (93)
	Humboldt	17.8 (2.1)	111 (4)	21.1 (0.4)	66 (-56)	22.8 (0.1)	72 (-35)	22.2 (1.2)	424 (312)	21.0 (1.0)	168 (56)
	Hudson	17.8 (2.1)	118 (12)	21.1 (0.2)	130 (2)	22.8 (-0.2)	118 (5)	23.3 (1.8)	262 (154)	21.3 (1.0)	157 (43)
	Oskaloosa	18.9 (2.6)	155 (39)	21.7 (0.2)	81 (-46)	23.3 (-0.5)	62 (-50)	24.4 (1.8)	424 (296)	22.1 (1.1)	180 (59)
2008	Linn Grove	14.4 (-0.6)	141 (39)	20.6 (0.3)	223 (94)	23.3 (0.8)	132 (19)	21.7 (0.5)	30 (-93)	20.0 (0.2)	132 (15)
	Humboldt	13.3 (-2.4)	152 (45)	20.0 (-0.7)	239 (117)	22.2 (-0.4)	98 (-10)	20.0 (-1.0)	39 (-73)	18.9 (-1.1)	132 (20)
	Hudson	13.9 (-1.8)	159 (52)	21.1 (0.2)	223 (95)	23.3 (0.4)	140 (27)	21.1 (-0.4)	40 (-68)	19.9 (-0.4)	140 (26)
	Lenox	14.4 (-1.8)	127 (11)	21.1 (-0.4)	349 (236)	23.3 (-0.6)	230 (126)	21.7 (-1.1)	9 (-97)	20.1 (-1.0)	179 (69)
	Oskaloosa	14.4 (-1.9)	138 (22)	21.7 (0.2)	173 (46)	22.8 (-1.0)	174 (-49)	21.1 (-1.4)	66 (-61)	20.0 (-1.0)	138 (17)
2009	Linn Grove	15.6 (0.5)	46 (-56)	20.0 (-0.4)	135 (5)	20.0 (-2.5)	128 (14)	21.1 (-0.1)	50 (-72)	19.2 (-0.6)	90 (-27)
	Humboldt	14.4 (-1.2)	93 (-14)	20.0 (-0.7)	64 (-58)	20.6 (-2.1)	75 (-32)	20.6 (-0.4)	52 (-60)	18.9 (-1.1)	71 (-41)
	Hudson	15.6 (-0.1)	104 (-2)	20.0 (-0.9)	91 (-37)	20.0 (-3.0)	140 (27)	20.0 (-1.6)	117 (9)	18.9 (-1.4)	113 (-1)
	Ames	15.6 (-0.9)	102 (-14)	21.1 (-0.3)	104 (-15)	20.6 (-2.8)	70 (-49)	20.6 (-1.4)	89 (-33)	19.4 (-1.4)	91 (-28)
	Lenox	15.6 (-0.7)	80 (-36)	21.1 (-0.4)	162 (49)	20.0 (-3.9)	149 (45)	21.7 (-1.1)	129 (22)	19.6 (-1.5)	130 (20)
	Oskaloosa	15.6 (-0.8)	91 (-25)	21.1 (-0.4)	309 (182)	20.6 (-3.2)	104 (-8)	22.2 (-0.3)	156 (29)	19.9 (-1.1)	165 (44)

Table 3. Means of main effects of tillage, row spacing, and seeding rate on final plant population, height, harvest seed moisture, yield, seed mass, and protein and oil content of the seed across 15 site-years in Iowa.

Treatment	Yield	Final plant population	Plant height	Seed moisture	Seed mass	Protein	Oil
Tillage (T)	kg ha^{-1}	Plants ha^{-1}	cm	g kg^{-1}	g 100 $seeds^{-1}$	%	%
Conventional	4552	271 000	104	124	16.0	33.3	18.7
No-Tillage	4639	269 000	100	126	15.9	33.1	18.7
LSD (0.05)	NS†	NS	3	NS	NS	NS	NS
Row Spacing (R)							
38-cm	4740	280 900	101	126	16.0	33.0	18.7
76-cm	4452	259 200	103	125	16.0	33.4	18.6
LSD (0.05)	97	10 900	NS	1	NS	NS	0.1
Seeding Rate (S)							
185 200 seeds ha^{-1}	4454	170 900	99	125	15.7	32.8	18.8
308 600 seeds ha^{-1}	4621	242 300	102	125	15.9	33.1	18.7
432 100 seeds ha^{-1}	4632	306 700	104	125	16.1	33.3	18.7
555 600 seeds ha^{-1}	4675	360 200	104	125	16.2	33.6	18.6
LSD (0.05)	91	15 400	2	NS	0.2	0.2	0.1
ANOVA							
T x R	NS	***	NS	NS	NS	NS	*
T x S	NS	NS	NS	NS	NS	NS	*
R x S	NS	NS	NS	NS	*	NS	NS
T x R x S	NS	NS	NS	NS	NS	NS	NS

† NS = no significant differences at $P \leq 0.05$.

*, ** Significant at the P = 0.05 and 0.01 probability level.

Table 4. Main effect means of tillage, row spacing, and seeding rate for yield and yield components at harvest across three site-years in Iowa.

Treatment	Yield	Pod number	Seed mass	Seed number	Seed number
Tillage (T)	kg ha^{-1}	# m^{-2}	g m^{-2}	# m^{-2}	Seeds pod^{-1}
Conventional	4195	1325	390.2	3099	2.4
No-Tillage	4376	1388	369.9	3486	2.6
LSD (0.05)	NS†	NS	NS	NS	NS
Row Spacing (R)					
38-cm	4413	1375	392.3	3343	2.5
76-cm	4158	1338	367.8	3243	2.5
LSD (0.05)	NS	NS	NS	NS	NS
Seeding Rate (S)					
185 200 seeds ha^{-1}	4062	1382	378.4	3245	2.5
308 600 seeds ha^{-1}	4346	1272	376.2	3118	2.5
432 100 seeds ha^{-1}	4180	1331	372.6	3346	2.6
555 600 seeds ha^{-1}	4555	1440	393.1	3462	2.4
LSD (0.05)	NS	NS	NS	NS	NS
ANOVA					
T x R	NS	NS	NS	NS	NS
T x S	NS	NS	NS	NS	NS
R x S	NS	NS	NS	NS	NS
T x R x S	NS	NS	NS	NS	NS

†NS = no significant differences at $P \leq 0.05$.

Table 5. Main effect means of tillage, row spacing, and seeding rate for canopy biomass throughout the growing season across three site-years in Iowa.

	Canopy Biomass							
	Days after emergence							
Treatment	21	33	47	61	76	91	107	121
Tillage (T)	g m^{-2}							
Conventional	5.8	16.5	82.6	206.2	408.8	601.0	788.8	702.5
No-Tillage	3.2	13.0	49.4	141.5	307.0	512.2	711.3	652.5
LSD (0.05)	NS†	NS	NS	NS	NS	NS	NS	NS
Row Spacing (R)								
38-cm	4.0	15.8	70.9	182.5	368.8	580.3	739.7	701.6
76-cm	5.0	13.7	61.0	165.2	347.3	532.9	760.5	653.4
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Seeding Rate (S)								
185 200 seeds ha^{-1}	2.1	9.6	42.8	127.1	286.0	503.2	710.8	653.5
308 600 seeds ha^{-1}	4.0	13.0	62.2	163.8	355.0	549.5	757.7	675.9
432 100 seeds ha^{-1}	5.2	17.0	73.6	183.9	366.8	564.5	749.7	668.0
555 600 seeds ha^{-1}	6.8	19.3	85.4	220.7	424.0	609.2	782.1	712.6
LSD (0.05)	1.0	NS	12.1	31.8	56.2	61.2	NS	NS
ANOVA								
T x R	NS	NS	NS	NS	NS	NS	*	NS
T x S	NS	NS	NS	NS	NS	NS	NS	NS
R x S	NS	NS	NS	NS	NS	NS	NS	NS
T x R x S	NS	NS	NS	NS	NS	NS	NS	NS

† NS = no significant differences at $P \leq 0.05$.

* Significant at the $P = 0.05$ probability level.

Table 6. Main effect means of tillage, row spacing, and seeding rate for crop growth rates (CGR) throughout the growing season and percent light interception across three site-years in Iowa.

	CGR						CGR	Light interception					
	Days after emergence (DAE)						R1-R5†	DAE					
Treatment	33	47	61	76	91	107		33	47	61	76	91	107
Tillage (T)	$g\ m^{-2}\ day^{-1}$						$g\ m^{-2}\ day^{-1}$	%					
Conventional	0.5	5.1	8.8	14.1	13.2	11.1	11.8	12.5	47.5	81.9	93.8	95.6	96.1
No-Tillage	0.4	2.8	6.6	11.5	14.8	12.0	11.0	8.4	31.4	72.0	89.2	94.3	96.7
LSD (0.05)	NS‡	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Row Spacing (R)													
38-cm	0.5	4.3	7.9	12.8	14.7	9.6	11.1	12.0	39.7	80.8	93.6	95.6	96.2
76-cm	0.4	3.6	7.5	12.8	13.2	13.5	11.7	8.9	39.2	73.1	89.4	94.3	96.6
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.1	NS	NS
Seeding Rate (S)													
185 200 seeds ha^{-1}	0.5	5.6	6.1	11.0	15.1	11.9	11.1	7.8	30.1	71.2	88.6	93.6	96.2
308 600 seeds ha^{-1}	0.5	4.6	7.3	13.3	13.4	12.7	11.6	10.1	37.6	76.4	91.3	95.6	97.0
432 100 seeds ha^{-1}	0.4	3.0	7.8	12.7	14.0	11.0	11.2	10.1	41.8	76.3	91.0	95.2	95.4
555 600 seeds ha^{-1}	0.4	2.7	9.6	14.1	13.3	10.5	11.6	13.9	48.3	84.0	95.2	95.3	97.0
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	3.5	6.2	6.4	3.6	NS	NS
ANOVA													
T x R	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	*	NS
T x S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
R x S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
T x R x S	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS

† Fehr and Caviness (1977).
‡ NS = no significant differences at $P \leq 0.05$.
* Significant at the $P = 0.05$ probability level.