SUBSURFACE DRAINAGE IN CLAY SOILS IN A NORTHERN CLIMATE AND ITS EFFECT ON VARIOUS SOYBEAN CULTIVARS AND SOIL PROPERTIES

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Brodshaug, Jack Adam, M.S., Department of Plant Sciences, College of Agriculture, Food Systems, and Natural Resources, North Dakota State University, April 2011. Subsurface Drainage in Clay Soils in a Northern Climate and its Effects on Various Soybean Cultivars and Soil Properties. Major Professor: Dr. Hans Kandel.

The Red River Valley of the North in North Dakota and Minnesota is a region with unique clay soils. Since 1993, the region has seen increased annual rainfall that has caused seasonal soil waterlogging, inhibiting crop yield potential. Prolonged waterlogging may cause debilitating physiological and chemical problems in plants. Subsurface (tile) drainage is relatively new to the region and offers an option farmers are exploring to help reduce excess water in the rootzone. The objective of this research was to identify the effect of subsurface drainage on soybean [*Glycine max* (L.) Merr.] productivity using various cultivars and to evaluate differences in soil temperature, soil penetration resistance, and water table depth between drainage treatments.

Two experiments (2009-2010) were conducted in the Red River Valley. The experimental area is unique as it has eight tiled units which can each regulate drainage using control structures. The experimental design was a randomized complete block (RCB) in a split-plot arrangement with four replicates. The whole plots were drained or undrained (control structures opened and closed, respectively), and the sub-plots were 29 soybean cultivars. Soybean cultivars were selected based on iron chlorosis resistance, phytophthora root rot tolerance, and growing capability in wet soils. Penetrometer readings, water table depth, and soil temperature were measured weekly.

Soybean yields between drained and undrained treatments were not significantly different according to the combined analysis. This was due to 2009 being a relatively dry year and 2010 a relatively wet year. However, in 2010, the non-genetically modified (non-

GMO) soybean cultivars and the cultivars chosen for their resistance to Phytophthora sojae were significantly better on the drained soil. In 2009 and 2010, drained treatments had a significantly higher soil penetration resistance, indicating that the drained soil is capable of a higher carrying capacity compared to the undrained soil. The wheat measurement site had a value of 1,420 kPa in the drained soil, while the undrained soil had a value of 1,267 kPa. The soybean measurement site had a value of 1,137 kPa in the drained soil, while the undrained soil had a value of 1,021 kPa. Finally, the bare ground measurement site had a value of 1,077 kPa in the drained soil, while the undrained soil had a value of 1,001 kPa. The water table was lower on drained soil compared to the undrained soil early and late in the growing season, causing the differences in soil penetration resistance. Temperature was significantly higher only on the drained soil planted to soybean compared to the undrained soil planted to soybean. The temperature difference was most pronounced in the spring.

Subsurface drainage is a valuable tool for farmers in the Red River Valley. Despite the clay soils, cold winter, and shorter growing season, subsurface drainage works and helps to improve the efficiency of farming large fields in an area that has consistently battled wet weather for the last ten years. At a time when commodity prices are at a record high, improving efficiency and productivity with subsurface drainage might be an option. Overall, tile drainage has the potential to drastically change how farming is conducted in the clay soils in eastern North Dakota and northwestern Minnesota.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

Table | Page

Article 1

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

Article 2

LIST OF TABLES (continued)

LIST OF FIGURES

Figure Page

Article 1

Article 2

LIST OF APPENDIX TABLES

PREFACE

This thesis was written as a series of two manuscripts that will be submitted for publication in the appropriate scientific journals. The 'Introduction' provides a general review of the importance of this study, some previous research, and how both chapters are related to the main issue: how subsurface drainage makes production more efficient in the Red River Valley of the North. After that, within each article, the 'Literature Review' reviews literature specific to the subject. Each article contains a literature review, materials and methods, results, discussion, and references cited section. The references for the 'Introduction' can be found in the 'General References Cited' section.

INTRODUCTION

North Dakota has historically been a state where the success of the economy is largely based on the strength of its agriculture. In particular, the Red River Valley region in eastern North Dakota is known for its fertile, very fine textured clay soils and accounts for a large majority of the state's wheat (*Triticum aestivum* L. emend. Thell.), corn (*Zea mays* L.), and soybean (*Glycine max* L. Merr.) production. However, farming success is dependent on the weather, which can be quite unpredictable. The Red River Valley of the North, despite its fertile soils, is very flat and crop production can be hampered by soil waterlogging following a heavy rainfall. One option that has recently become popular for farmers in the region is the installation of subsurface (tile) drainage. Subsurface drainage can help reduce waterlogging, thus reducing some of the unpredictability (or risk) of farming and in turn, reduce the risk to North Dakota's economy from year to year.

Subsurface drainage is a practice that has been used in farming for centuries and is commonly used on farm land in the Corn Belt in the United States (USDA, 1987). In the states of Indiana, Ohio, and Iowa, considered to be some of the most successful farming states in the U.S., 50% of the cropland has subsurface drainage (USDA, 1987). Traditionally, clay, or concrete, tiles were buried in the ground to drain the excess water off of farm land. Currently, perforated plastic tubing is buried in the ground to achieve the same result. Even though tile drainage is a common farming practice in areas of the Corn Belt, it is a new endeavor for the Red River Valley of the North with the clay soils that are located in this region. The Red River Valley has a very flat topography, high water table, the fine textured clay soils are poorly drained, and except for sugar beets (*Beta vulgaris* L.), higher value crops are rarely grown in the area. Installing drain tile involves a considerable investment, but because of the current higher commodity prices and the recent trend of more rainfall, the potential profit from tiling has become more substantial than in the past.

According to the USDA, the market value of the three main crops grown in the United States, corn, wheat, and soybeans, have steadily increase over the last ten years. Corn has risen from $1.91bu^{-1}$ in 2000 to $6.54 bu^{-1} in 2010. Soybean prices have risen from $4.62 bu^{-1} in 2000 to $14.00 bu^{-1} in 2010. Wheat prices have risen from $2.87 bu^{-1} in 2000 to $8.13 bu^{-1} in 2010 (USDA 2010). These are dramatic price increases in just ten years' time. This has caused an increased interest in maximizing yield, since each bushel of grain is so much more valuable.

Tile drainage can potentially increase yields and increase profits (Colwell, 1976; Datta et al., 2004). The growth in the area planted to high priced corn and soybean in the Red River Valley has greatly increased the interest in tile drainage in this region of the state. According to the USDA, corn and soybean acreage has steadily increased over the last ten years, specifically in the Red River Valley. Furthermore, the past 20 years have been abnormally wet and soil waterlogging has been an important factor in yield loss during that time period. From 1950 to 2002, 24 flooding events were reported in the Red River Valley and 1991-2000 was the wettest decade on record. More recently, the fall conditions of 2008 and 2009 were so wet that the majority of soybean and corn growers had to wait until the ground was frozen before harvesting could even be started. Tile drainage can allow soils to drain more quickly, reduce waterlogging stress, and increase the soil penetration resistance of the soil so that heavy equipment can access the field for crop management and harvest in a timely manner (Chieng et al., 1987).

RESEARCH OBJECTIVES

The objectives of this research were: i) to evaluate the effect of subsurface drainage on soybean productivity and various soybean diseases; ii) to determine if there are interactions between various soybean cultivars and subsurface drainage treatments; iii) to determine the effect of subsurface drainage on the water table and soil temperature; and iv) to determine if subsurface drainage alters the soil penetration resistance (the amount of weight that can be supported in a given area) of the soil.

ARTICLE 1.

SOYBEAN CULTIVAR INTERACTIONS WITH TILE DRAINAGE

LITERATURE REVIEW

Subsurface Drainage

Subsurface (tile) drainage can aid in a number of soil related issues in farming. The main problem solved by subsurface drainage is soil waterlogging. Waterlogging can cause irreversible and debilitating physiological and chemical problems in plants. These problems include stomatal closure within a day or two of the soil becoming flooded and result in leaf dehydration. Moreover, stomata closure reduces photosynthesis (Kozlowski, 1984). These effects reduce yield and overall plant growth. Ashraf and Rehman (1999) noted that long-term flooding caused both shoots and total plant dry weights to be reduced in corn. The authors concluded that anaerobic conditions caused by excessive water in the soil led to a reduction in plant growth. Data have shown that as the water table becomes closer to the surface of the soil, grain yield decreases (Ashraf and Rehman, 1999).

Subsurface drainage helps to reduce waterlogging and prevent saturated conditions by lowering the water table (Wiersma et al., 2010; Ale et al., 2010; Mejia et al., 2000; Datta et al., 2004; Jin et al., 2003; Pang et al., 2010; Skaggs et al., 1994). The main objective of subsurface drainage is to provide enough aeration to the root zone so that the roots of the crop grown will have sufficient oxygen (Marshall and Holmes, 1988). The optimal depth of the subsurface drain depends on the soil type and the rooting depth of the crop planted.

Research has shown that subsurface drainage can improve crop yield in poorly drained soils in many parts of the United States. Kladivko et al. (2005) found that subsurface drainage improved corn (*Zea mays* L.) yield from 0.3 to 0.6 Mg ha^{-1} in Indiana.

In 1998, Zucker and Brown found that corn yields were increased from 0.9 to 1.4 Mg ha^{-1} in Indiana and increased from 1.3 to 1.9 Mg ha^{-1} in Ohio.

The soil water table depth and soil temperature can greatly influence crop growth, particularly in northern climates where the growing season is limited in duration. Soil temperature can be affected by the water content of the soil. When drained, there will be less water present in the soil above the tile line. This makes a considerable positive difference in the temperature of the top soil in the spring when seeds are germinating and emerging from the soil. Jin et al. (2003) found that soils with tile drainage in Northwest Minnesota had a significantly higher soil temperature compared to undrained soils in the spring. There can be major agronomic benefits to having a warmer soil in the spring, especially in northern climates.

The optimal soil temperature for the growth of most plants is between 20 and 30°C (Voorhees et al., 1981). Germination is the first part of soybean development that is affected by low soil temperatures. Wuebker et al. (2001) found that flooding at any time and for any duration significantly lowered germination percentage in all treatments. For soybean (*Glycine max* L. Merr.), lower root zone temperatures can restrict the growth after germination more than non-legumes because generally, it obtains its N from N_2-fixation. At low temperatures, nitrogen can be the limiting factor in regard to yield in soybeans (Legros and Smith, 1994). Furthermore, Zhang et al. (1995) found that nodulation of soybeans sharply decreased when the root zone temperature dropped below 17°C. They determined that 17°C is a thermal critical point for nodulation in soybean. Moreover, plant weight, leaf area development, and the amount of dry matter that was allocated to roots or shoots varied with root zone temperature and corresponded with the amount of nodulation that occurred on the soybean plants. These researchers concluded that between 17°C and 25°C, N_2 fixation was delayed linearly by 2.5 days for each degree decrease in temperature, while below 17°C, the delay for N_2 fixation was 7.5 days for each degree decrease in temperature. N_2 fixation was based on the occurrence of nodules on the plant (Zhang et al., 1995).

Jin et al. (2008) found at three sites-years in the Red River Valley of the North that soil temperatures were greatly influenced by the presence of drainage and drain spacing in Northwest Minnesota. They found that the more intense the drainage (narrower the drain spacing), the higher the soil temperature was on a consistent basis. Also, when compared to the undrained ground, the drained ground had significantly higher soil temperature throughout the year and the magnitude depended on the depth of the measurement in the soil profile and drain spacing (Jin et al., 2008).

Jin et al. (2003) also found that the water table was affected by tile drainage. Drained soils in Northwest Minnesota had a lower water table than undrained soils from early spring to June. From July to October there was not a significant difference in the depth of the water tables, but there was limited rainfall during this period. It was also found that the water table in tiled areas receded quickly after rainfall events in the summer. The drained and undrained areas were found to be very similar in the retreat of the water table after these rainfall events later in the year. The lower water table during the summer allowed the water to infiltrate through the soil profile during a large rain event (Jin et al., 2003).

Soybean and Waterlogging

Plants need to have an ample supply of water throughout the growing season when they grow and produce seed. Hypoxia (lack of oxygen) is the most common stressor in waterlogged soils. However, excess water can be very harmful or even deadly because the transfer of oxygen and other gases between the soil and atmosphere is blocked (Sairam et al., 2008). Etherington (1984) found in his waterlogging study of fireweed (*Chamerion angustifolium*) that all plants completely wilted after only 12 hours of waterlogging. The author characterized wilting by the leaves hanging vertically in contrast with the horizontal posture of the leaves of the control plants. He found that the total leaf area of the waterlogged plants was reduced 28% compared with the control plants at the end of his experiment.

Linkemer et al. (1998) conducted a tile drained versus non-tile drained soybean growth experiment in Louisiana. The tile drained portion was on the high end of a field and contained subsurface drainage. The undrained portion was on the low end of the field and did not have subsurface drainage installed. The researchers found that waterlogging in soybean caused a significant decrease in overall yield. This yield decrease was attributed to a corresponding decrease in overall seed number, seed size, and pod number per plant. The most visible problem with the tiled versus untiled sites was the fact that the undrained portion had significant ponding after heavy rainfall, while the tile drained portion had no standing water. This led to significantly lower ($P \leq 0.05$) O_2 concentrations for the undrained portion compared to the tile drained portion. The research also showed that tiling resulted in increased yields by as much as 58%. Greater sensitivity to waterlogging was found in soybean in the R1-R5 growth stages (Fehr et al., 1971) compared to earlier growth stages (Linkemer et al., 1998).

Griffin and Saxton (1988) found similar results in soybeans in waterlogged soils. They found that soybeans flooded from the R2-R5 growth stages had significant ($P < 0.001$) yield losses when compared to soybeans flooded at the V6 (Fehr et al., 1971) growth stage. The soybeans at the V6 stage, though very chlorotic and stunted after the waterlogging, managed to recover and showed little yield loss. Also, when water was applied at the R2-R5 growth stages, the number of seeds per pod decreased as flood duration increased (Griffin and Saxton, 1988). Scott et al. (1989) also showed that soybean yield was affected by flooding duration and growth stage during the growing season in clay soils. The slope of the regression line for flooding duration at the R2 growth stage was -152 kg ha^{-1} $d^{-1}$and -124 kg ha^{-1} d^{-1} at the V4 growth stage (Scott et al., 1989).

The added factor of clay soils makes water management even more important for areas like the Red River Valley of the North because of the high water holding capacity of the clay. A study conducted on clay soils in Illinois demonstrated the importance of sound water management. Sipp et al. (1986) designed an intensive corn and soybean study that had four types of drainage (surface, subsurface, surface plus subsurface, and none) and three types of irrigation (furrow, sprinkler, and none). The results over a seven year period showed that soybeans on subsurface drainage alone yielded 0.8 tons ha^{-1} better than surface drainage alone. However, in some years, soybean yield was equal for surface drainage and subsurface drainage and depended on the amount of rainfall for the year. The authors also stressed that field operations were conducted when the poorly drained areas had the proper moisture conditions to allow machinery to operate, so delays in field work on all treatments caused potential yield loss throughout the experiment (Sipp et al., 1986).

Wuebker et al. (2001) conducted a germination study that incorporated soybean cultivars, waterlogging, and soil temperature as factors. Two cultivars, AG3301 and AG3002 were chosen because they were popular and high yielding cultivars in Iowa. Flooding stress occurred three times at six different durations and two different temperatures in the experiment. Germination was best for the higher temperature (25°C) with no flooding. Germination declined as flooding persisted. Furthermore, the further along the seedling was in the germination process when flooding occured, the more susceptible the seed was to waterlogging stress (Wuebker et al., 2001).

Waterlogging has a negative effect on nodulation in soybeans. A greenhouse study conducted by researchers in Australia found that waterlogging significantly reduced the size ($P \leq 0.05$) and number of nodules produced by experimental soybeans (Nathanson et al., 1984). This inevitably led to a significant difference in seed yield in this experiment. The treatment with the highest water table (closest to the surface) resulted in the lowest yield, which was 71% lower than the control. This yield difference was attributed to the fact that the non-stressed plants had more pods per plant (Nathanson et al., 1984).

Soybean and Disease

Iron deficiency chlorosis (IDC) in soybean is related to waterlogging. Chlorosis is the symptom of an iron deficiency commonly found in soybean and dry bean (*Phaseolus vulgaris* L.), but is also observed in many other crops under abnormal conditions (Hansen et al., 2006). Iron chlorosis often is exaggerated by cool, wet soil conditions. In a field study conducted in 2003, Hansen et al. (2003) found that chlorosis was more prevalent in low lying wet areas compared to higher, drier parts of the field. The extent of soil saturation is related to the amount of oxygen available in the soil and IDC is affected by the amount of oxygen available to the plant (Hansen et al., 2003).

Iron deficiency chlorosis can also vary in intensity based on cultivar. A study conducted in Iowa used fifteen different soybean cultivars in maturity groups I and II and evaluated yield differences amongst cultivars and related them to the amount of IDC that was present on the soybeans earlier in the season (Froehlich and Fehr, 1981). The study found that there was a significant linear relationship between yield loss and chlorosis scores. The more chlorotic the soybean, the more yield loss occurred (Froehlich and Fehr, 1981).

Helms et al. (2010) conducted a similar study on how IDC affects yield. In this study, 18 cultivars were evaluated in North Dakota and 20 cultivars were evaluated in Kansas. The authors concluded that within each environment (location and years), cultivars respond differently to the IDC and non-IDC soil conditions. Chlorosis scores are not a good indication for yield when seeding into soil that has no IDC history (Helms et al., 2010).

Soil salinity is another contributing factor to IDC in some crops, specifically soybean. Hansen et al. (2006) concluded that in a saline soil, decreased root growth and increased soil salinity both contributed to IDC. Furthermore, too many dissolved salts in soil water can affect the uptake of water by plants (Marshall and Holmes, 1988). Tile drainage has been proven to decrease soil salinity in a soil profile and reduction in salinity with tile drainage will help reduce the likelihood of IDC. In a tiled plot in India, soil salinity dropped 35% after only 5 years of tile drainage (Datta et al., 2004).

Phytophthora sojae (*P. sojae*) is a disease common to the Red River Valley of the North and it is exacerbated by saturated soils and could possibly be reduced by installing subsurface drainage. *P. sojae* root and stem rot is the second leading cause of yield loss in soybean in the U.S. (Wrather et al., 2001). Helms et al. (2007) conducted a study that evaluated the relationships between soybean cultivars that have resistance to *P. sojae* and their tolerance to water-saturated soil. There were eight different cultivars with single resistance genes (*Rps1a, Rps1b, Rps1c, Rps1d, Rps1k, Rps3a, Rps6, and Rps7*), three isolates of *P. sojae*, and a total of 37 soybean cultivars used in the study. The mean emergence (P=0.05), survival (P=0.01), and disease rating (P=0.01) of the eight water tolerant cultivars were significantly better compared with the mean of the cultivars that were intolerant of saturated soil conditions. Overall, this study showed that where *P. sojae* was present, resistance to *P. sojae* was a factor that affected the tolerance of a particular soybean cultivar to saturated soil conditions (Helms et al., 2007).

Economics

Tile drainage can produce anywhere from 15 to 30% return on investment over the first five years depending on the type of crop grown and commodity prices (Colwell, 1976; Datta, 2004). The economic return was calculated based on the cost of the drain tile, crop price and yield, and other management practices. The drain tile cost will depend on soil type and recommended drain spacing. A fine textured clay soil requires narrower spacing and shallower depths. Overall, the profitability of tile drainage depends on the crop yields that are achieved, but with a tiled field the potential for higher yields is so much greater that some of the risk of farming is reduced (Colwell, 1976).

The economic return on subsurface drainage is mainly due to the expected increase in harvested yield. Seed yield depends on a number of different factors. Some of these factors are waterlogging and salinity. Houk et al. (2004) found that total foregone profitability in Colorado due to waterlogging and salinity was an estimated \$4.3 million per year for the years 1999, 2000, and 2001. On a per hectare basis, that is \$168 ha^{-1} of foregone profit. If soil salinity and waterlogging were not an issue, Houk et al. (2004) estimates that there would be an estimated 39% profit increase in Colorado. This is based on a profit potential of \$598 ha^{-1} using the average price of all the crops that were grown on land in Colorado the previous year when the yield loss factors of soil salinity and waterlogging were not a problem.

The objectives of this research were to 1) determine the effect of subsurface drainage on soybean productivity; 2) determine the effect of subsurface drainage on IDC and *P. sojae*; and 3) determine if there is an interaction between soybean cultivar and drainage treatment.

MATERIALS AND METHODS

Soybean experiments were established at the NDSU research location called Northwest 22 (NW22) near Fargo, ND. The legal description is the NW quarter of Section 22, Township 140, Range 49 (Lat. N 46°55'55.8093"; Long. W 96°51'32.3561"). The experimental field consists of 2.5 hectares and the entire area is surface drained. In 2008, 10 cm diameter subsurface drainage pipes were installed at a depth of 1 meter with a 7.6 meter spacing. The drainage coefficient, based on the soil type and dimensions and spacing of the drainage pipes is between 6 and 10 mm per 24 hours.

The plot area is split into eight units (0.3 ha) with four subsurface drained (drained) and four non-subsurface drained (undrained). Each of the eight units has its own water table control structure (Agri-Drain Corp, Adair, IA). All eight units have drain tile, four of the control structures are open so that the plot land is considered drained, and four of the control structures are closed so that the plot land is considered undrained. There are seven subsurface drainage lines in each unit. Only the center five tile lines were used to minimize the potential effect of the neighboring drainage units. Plots were established perpendicular to the tile lines and individual plots were planted centered over a tile line. The experiment was a randomized complete block design with a split plot arrangement. There were two environments (2009 and 2010). Drainage practice (drained vs undrained) was the main plot factor, and soybean cultivar was considered the sub-plot factor. There were four replicates with each replicate containing one drained and one undrained unit. The plot in 2009 was laid out as shown in Fig. 1.1. Due to poor stands in 2010 because of seeding conditions and lack of timely rains early in the season, units one and two were destroyed and only three reps were used.

Rep 4		Rep 2	
Unit 8 Controlled tile System (closed)	**Unit 6** Controlled tile system (open)	**Unit 4** Controlled tile system (closed)	**Unit 2** Controlled tile system (open)
Unit 7 Controlled tile system (open)	**Unit 5** Controlled tile system (closed)	**Unit 3** Controlled tile system (open)	**Unit 1** Controlled tile system (closed)
Rep 3		**Rep 1**	

←North

Fig. 1.1. Layout of the replicates and units at the NW22 location in 2009.

The soil type of the area is classified as a Fargo-Ryan silty clay. The Fargo series (Fine, smectitic, frigid Typic Epiaquerts) consists of deep, poorly drained, slowly permeable, lacustrine soils. This soil type generally has a slope of 0-1%. The Ryan series (Fine, smectitic, frigid, Typic Natraquerts) is very similar to the Fargo series, except the Ryan series generally has an E soil horizon that is 0-2 inches deep (USDA-NRCS, 2008). According to a soil test taken at the site prior to planting in 2009, the soil pH is around 8.0, which is a high pH that would likely cause IDC in soybean. A baseline check for calcium carbonates was not conducted, although the Red River Valley region is known for IDC problems in soybean.

Roundup Ready Soybean Experiment

Twenty-nine soybean cultivars were chosen based on six different classification groups. The first four cultivar classification groups were planted together due to their common glyphosate resistance trait. The first group of cultivars was comprised of the top yield performers in the 2008 NDSU variety trials (Kandel, 2008). These cultivars varied somewhat in maturity so some inference as to the effect of maturity on drained versus undrained conditions can be made. Additional information about these cultivars is found in Table 1.1.

The second group of cultivars was chosen based on the IDC score they received in the 2008 NDSU variety trials (Kandel, 2008). The IDC scores were provided by Dr. Jay Goos and were based on a rating scale of one to five with one being no chlorosis and five being severe iron chlorosis. The cultivars range from tolerant to susceptible and all consistently produced high yields when IDC was not an issue. The list of these soybean cultivars and the relation to IDC is shown in Table 1.1.

Table 1.1. Roundup Ready soybean cultivars planted at the subsurface drainage location in both 2009 and 2010.

Company	Cultivar	Maturity	IDC Scale†	IDC Grade†	IDC Tolerance†	% of mean yield†
Top Yielding Soybeans						
Asgrow	AG0604RR	0.6	3.3	C	Slightly Tolerant	103
NuTech Seed, LLC	NT-0990RR	0.9	3.4	C-	Slightly Susceptible	117
Asgrow	AG0808RR	0.8	2.6	B	Med. Tolerant	107
Gold Country Seed	2806RR	0.6	3.4	C-	Slightly Susceptible	110
IDC Soybeans						
Asgrow	AG00603RR	00.6	1.9	A	Tolerant	106
ProSeed, Inc	RR80-50	0.5	2.8	B-	Med. Tolerant	102
Prairie Brand Seed	PB-0218RR	0.2	3.1	C	Slightly Tolerant	108
Thunder Seed	2906RR	0.6	3.6	D+	Med. Susceptible	108
NuTech Seed, LLC	NT-0886RR	0.8	4.0	D-	Susceptible	120

†Based on performance over multiple locations as reported in the 2008 NDSU soybean variety trials booklet (Kandel, 2008).

The third grouping was comprised of soybean cultivars that responded differently to saturated and unsaturated (rainfed) conditions. Two cultivars were chosen that performed significantly better than the others under saturated growing conditions, two cultivars that performed significantly better on rainfed ground and two cultivars that performed well above average on both rainfed and saturated growing conditions were selected. The relative performance of the selected cultivars is summarized in Table 1.2.

Table 1.2. Results of selected soybean cultivars grown under saturated and rainfed conditions in 2008.

			% of Mean†	
Company	Cultivar	Maturity	Saturated	Rainfed
Peterson Farms Seed	0704RR	0.4	123	76
Thunder Seed	2905RR	0.5	143	95
Pioneer, Inc.	90Y20RR	0.2	94	112
Dairyland Seed Co., Inc.	DSR-0401/RR	0.4	89	110
Wensman Seed	W2060RR	0.6	137	112
Proseed Inc.	RR60-40	0.4	102	111

†Data based on study by Dr. T. Helms as reported in the 2008 NDSU soybean variety trials booklet (Kandel, 2008).

***Phytophthora sojae* Soybean Experiment**

The fourth cultivar group was based on *P. sojae* root rot resistance. Additionally, each of these five cultivars were planted with and without a fungicide seed treatment. The treated seed received Apron Max (a.i. 1.10% mefenoxam and 0.73% fludioxonil), at a rate of 3.75 g of mefanoxam per 100 kg of seed and 2.5 g of fludioxonil per 100 kg of seed. The seed was treated in the lab due to the small amount of seed required for the experiment. These cultivars were chosen based on the *P. sojae* resistant genes and overall yield performance in the NDSU variety trials (Kandel, 2008). Table 1.3 lists the cultivars selected and the *P. sojae* resistance gene that the cultivar contained.

Table 1.3. Soybean cultivars chosen based on their *P. sojae* resistance genes and overall yield potential.

Company	Cultivar	Maturity	IDC Scale†	IDC Grade†	*P. sojae* Resistance Gene††	% of mean yield†
Asgrow	AG00501RR	00.5	2.31	A-	Rps1k	99
Dairyland Seed Co.	DSR-0602/RR	0.6	3.19	C	Rps1c	106
Prairie Brand Seed	PB0356RR	0.3	2.48	B+	Rps1a	98
Pioneer, Inc.	90Y41RR	0.4	3.01	C+	Rps1, Rps6	99
Peterson Farms Seed	0806RR	0.6	3.36	C-	None	110

†Data based on study by Dr. T. Helms as reported in the 2008 NDSU soybean variety trials booklet (Kandel, 2008).
††Based on data supplied by seed companies.

Non-GMO Soybean Experiment

The second experiment consisted of a group of non-GMO soybean cultivars. These plots were planted on the west side of the experimental units because they received a conventional herbicide application. Asgrow 0604RR, a Roundup Ready cultivar, was planted with the non-GMO cultivars and treated similar to the non-GMO entries in order to allow for comparisons with the rest of the soybeans in the larger study. The non-GMO soybeans were all developed by Dr. Helms' soybean breeding program. The cultivars used were Ashtabula, Sheyenne, Nornatto, and experimental Tofu line ND04-10327.

Early Maturing Soybean Experiment

The third experiment consisted of five early maturing soybean cultivars. These cultivars were all planted on the east side of the experimental area. In 2010, three of the cultivars that were used in 2009 were replaced. Peterson 0702 and 0901 were replaced with Peterson 0704 and 0905, respectively, in 2010 as the previous cultivars were discontinued by the company after 2009. Integra 97009 was replaced in 2010 with Pioneer 90Y20 due to a lack of that particular Integra cultivar in the region. The cultivars that were selected for this group are shown in Table 1.4 along with their respective maturities. There were also borders around all of the soybeans plots. The border cultivar for both years was Wensman W2064RR.

Table 1.4. Early maturing soybean cultivars that were planted in 2009 and 2010.

Company	Cultivar	Maturity	Year Planted
Peterson Farms Seed	0901RR	0.1	2009
Peterson Farms Seed	0702RR	0.2	2009
Integra	97009RS	00.9	2009
Croplan	RT 0268RR	0.2	2009, 2010
NuTech Seed, LLC	NT-6006RR	00.6	2009, 2010
Pioneer, Inc.	90Y20RR	0.2	2010
Peterson Farms Seed	0704RR	0.4	2010
Peterson Farms Seed	0905RR	0.5	2010

Measurements and Field Operations

Germination tests were performed on all seed. Germination tests were conducted by taking 100 seeds from a given cultivar and placing them on a moist paper towel for a week at room temperature. After a week, seeds with the hypocotyl showing were considered viable and the percentage of viable seeds was calculated. Based on germination test results, the amount of seed was adjusted so that the seeding rate was 445,000 viable seeds ha^{-1}. All seed was treated by hand with Apron Max (a.i. 1.10% mefenoxam and 0.73% fludioxonil), at a rate of 3.75 g of mefanoxam per 100 kg of seed and 2.5 g of fludioxonil per 100 kg of seed, except for the untreated seed checks used in the *P. sojae* resistant cultivars testing part of the study. All seed was inoculated with Rhizo-stick (Becker Underwood Inc., St. Joseph, MO) peat-based powder soybean innoculant (*Bradyrhizobium japonicum*) at planting at a rate of 6 mg per gram of seed. Planting took place when conditions allowed the machinery to get into the undrained portion of the field. A John Deere 1020 tractor (Moline, IL) and a seven row Great Plains 3P605NT drill (Great Plains Mfg Inc., Salina, KS) with 18 centimeter row spacing were used to seed the soybeans. Plots were 6.1 meters long. The same John Deere 1020 tractor with a 6.7 meter DTB Truss Boom sprayer (Demco, Boyden, IA) with XR Teejet 8001 VS nozzles at 200 kPa was used to apply pesticides when economic thresholds had been reached, according to NDSU extension recommendations. Pesticides were applied with an application volume of 94 L water ha^{-1}.

Broadleaf and grassy weeds were controlled using registered herbicides and supplemented with hand weeding when necessary. Glyphosate, (N-(phosphonomethyl) glycine, in the form of its isopropylamine salt) (Monsanto Co., St. Louis, MO) was applied at a rate of 1.6 L ha^{-1} (a.i. 0.88 L ha^{-1}) for weed control in the Roundup Ready soybeans. Bentazon (BASF Corp., Triangle Research Park, NC) was applied at a rate of 3.75 L ha^{-1} (a.i. 1.98 L ha^{-1}) to the non-GMO soybeans for weed control. The insecticide Asana XL (a.i. esfenvalerate (S)-cyano (3-phenoxyphenyl) methyl (S)-4-chloro-alpha-(1-methylethyl) benzeneacetate) (DuPont, Wilmington, DE) was applied at a rate of 0.70 L ha^{-1} (a.i. 0.056 L ha^{-1}) when the economic threshold was reached for soybean aphids (*Aphis glycines*) according to NDSU extension recommendations.

Stand counts were recorded once at emergence and then again at harvest, using a different random sample. Stand counts were obtained by counting the number of plants in a random representative meter of both rows three and four, then adjusted to represent plants per hectare. Vigor scores were recorded after emergence for each plot and based on plant health and greenness with stand using a scale of one to nine where nine was the best and one was the worst. Plant heights were recorded at physiological maturity, or the R8 growth stage (Fehr et. al, 1971), and were measured from the ground to the uppermost petiole base on the main stem of the plant. The iron chlorosis ratings were based on a scale of one to five with one being the least chlorotic and five being the most chlorotic using the same assessment as Goos and Johnson (2008). Ratings were taken at the three-trifoliate (V3) and six-trifoliate (V6) stages (Fehr et. al, 1971). All measurements except for root disease scoring were conducted throughout all of the plots at the research location.

In 2010, root disease scoring was rated between the R1 and R6 growth stage (Fehr et. al, 1971) on the *P. sojae* resistant cultivars with and without the seed treatment to determine if seed treatment, cultivar, or drainage had an effect on root disease. Ten plants were dug up from each of the plots and a percentage of the roots with visible lesions (root disease score) were recorded. Additionally, the roots for each plot were weighed to determine if there was lower biomass in the roots due to disease.

At physiological maturity, two randomly selected, representative plants were taken from each plot to determine the number of pods per plant, the number of seeds per pod, the lowest pod height, and the total number of seeds per plant.

Plots were harvested with a Wintersteiger Classic plot combine (Wintersteiger Ag, Ried, Austria) when the soybean pods were able to be readily threshed and when ground conditions allowed the combine to drive on both the drained and undrained parts of the research location. Both drained and undrained plots were harvested on the same day. Once harvested, the seed was dried and cleaned (Clipper Office Tester and Cleaner, Seedburo Equipment Co., Chicago, IL). Moisture and test weight were then recorded using a GAC 2100 moisture tester (DICKEY-John Corp., Minneapolis, MN). Grain yield was calculated by weighing the plot sample using a scientific scale (RS-232, Scientech Inc., Gaithersberg, MD) and adjusting to a moisture content of 13.5%. Plot length was measured at harvest time to account for plants that were removed for either root scoring or pod counting and yield was adjusted using the individual measured length of each plot. All seven rows of each plot were harvested. Grain protein and oil content were measured and corrected to a grain moisture content of 13.5% using a 0.5 kg sub-sample of seed from each plot on a Diode Array 7200 NIR Analyzer (Perten Instruments, Springfield, IL). Thousand kernel weights were calculated by counting five hundred seeds using a seed counter (Model 850-3, International Marketing and Designer Corp., San Antonio, TX) and then weighing the seeds with the RS-232 Scientech scale and multiplying by two to get the thousand kernel weight.

All pertinent measurements, field applications and the date they were taken for both 2009 and 2010 are shown in Tables 1.5 and 1.6, respectively. In 2010, herbicides had to be applied twice due to warm weather and better growing conditions for weeds. Iron deficiency chlorosis was not prevalent in 2010 due to warmer than average temperatures, so scores were taken only once. The soybean aphid threshold was not met in 2010 so Asana XL was not applied.

Table 1.5. Dates of important measurements and field applications for the growing year 2009.

Measurement/Application	Date
Soybeans seeded	May 19th
Vigor scores recorded	June 15th
Stand counts recorded	June 22nd
Roundup applied on Roundup Soybeans	June 25th
Rezult B applied on non-GMO Soybeans	July 9th
IDC scores recorded	July 10th
	July 17th
Root scoring for *P. sojae* study	July 21st
Asana XL applied	August 7th
Plant height recorded	September 18th
Plant samples taken for pod counting	October 18th
Stand counts recorded	November 4th
Soybeans harvested	November 5th

Precipitation was measured with a rain gauge set up at the NW22 location. The North Dakota Agricultural Weather Network (NDAWN) website was used to download weather data for the growing season for Fargo, about six km from the experiment location, including maximum and minimum air temperature. Rainfall amounts were downloaded to verify the rain gauge observations.

Data were analyzed using the generalized linear model (PROC GLM) and by analysis of variance (PROC ANOVA) of SAS 9.2 (SAS Institute, Cary, NC). The

Table 1.6. Dates of important measurements and field applications for the growing year 2010.

Measurement/Application	Date
Soybeans seeded	May 21st
Vigor scores recorded	June 29th
Stand counts recorded	June 28th
Roundup applied on Roundup Soybeans	June 22nd
	July 21st
Rezult B applied on non-GMO Soybeans	June 22nd
	July 21st
IDC scores recorded	July 29th
Root scoring for *P. sojae* study	July 30th
Plant height recorded	August 17th
Plant samples taken for pod counting	September 30th
Stand counts recorded	October 6th
Soybeans harvested	October 6th

generalized liner model was used to analyze across years and ANOVA was used to analyze within years. One replicate was unusable in 2010. Cultivar and drainage practice were considered fixed effects and replication and environment (year) considered as random effects. Main effects and interactions were tested using the appropriate error terms. Means were separated using Fisher's protected LSD at the 5% level of significance. All Roundup Ready soybeans that were treated with the fungicide ApronMax seed treatment except for the early maturing soybean cultivars were analyzed together, including the treated *P. sojae* cultivars. The *P. sojae* cultivars with seed treatment as a factor were analyzed separately. Non-GMO soybean cultivars and early maturing soybean cultivars were also analyzed separately. Expected mean squares and F-tests were determined for the *P. sojae* study according to Table 1.7. Table 1.8 was used for the Roundup Ready, early maturing, and non-GMO soybean experiments.

Table 1.7. Combined analyses of variance for the three-factor treatment (A, B, and C) design conducted in randomized complete blocks with a split-plot arrangement in 2009 and 2010.

Source of variation	df[†]	Mean Square		F-test
		Obs.	Expected[††]	
Environment (E)	(e-1) = 1	M1	$\sigma^2_e + bc\sigma^2_\delta + abc\sigma^2_{R(E)} + rabc\sigma^2_E$	-
Replicates (environment)	e(r-1) = 5	M2	$\sigma^2_e + bc\sigma^2_\delta + abc\sigma^2_{R(E)}$	-
A (drainage)	(a–1) = 1	M3	$\sigma^2_e + bc\sigma^2_\delta + rbc\sigma^2_{EA} + rbce\phi_A$	M3/M4
E x A	(e-1)(a-1) = 1	M4	$\sigma^2_e + bc\sigma^2_\delta + rbc\sigma^2_{EA}$	M4/M5
Error (a)	e(r-1)(a-1) = 5	M5	$\sigma^2_e + bc\sigma^2_\delta$	-
B (cultivar)	(b–1) = 4	M6	$\sigma^2_e + rac\sigma^2_{EB} + race\phi_B$	M6/M7
E x B	(e-1)(b-1) = 4	M7	$\sigma^2_e + rac\sigma^2_{EB}$	M7/M18
A x B	(a-1)(b-1) = 4	M8	$\sigma^2_e + rc\sigma^2_{EAB} + rec\phi_{AB}$	M8/M9
E x A x B	(e-1)(a-1)(b-1) = 4	M9	$\sigma^2_e + rc\sigma^2_{EAB}$	M9/M18
C (seed treatment)	(c-1)= 1	M10	$\sigma^2_e + rab\sigma^2_{EC} + rabe\phi_C$	M10/M11
E x C	(e-1)(c-1) = 1	M11	$\sigma^2_e + rab\sigma^2_{EC}$	M11/M18
A x C	(a–1)(c-1) = 1	M12	$\sigma^2_e + rb\sigma^2_{EAC} + reb\phi_{AC}$	M12/M13
E x A x C	(e-1)(a-1)(c-1) = 1	M13	$\sigma^2_e + rb\sigma^2_{EAC}$	M13/M18
B x C	(b-1)(c-1) = 4	M14	$\sigma^2_e + ra\sigma^2_{EBC} + rea\phi_{BC}$	M14/M15
E x B x C	(e-1)(b-1)(c-1) = 4	M15	$\sigma^2_e + ra\sigma^2_{EBC}$	M15/M18
Ax B x C	(a-1)(b-1)(c-1) = 4	M16	$\sigma^2_e + r\sigma^2_{EABC} + re\phi_{ABC}$	M16/M17
E x A x B x C	(e-1)(a-1)(b-1) = 4	M17	$\sigma^2_e + r\sigma^2_{EABC}$	M17/M18
Error (b)	ae(r-1)(b-1)(c-1) = 90	M18	σ^2_e	-
Total	[abcer]–1 = 139			

[†]df = degrees of freedom. The letters a, b, c, e, and r refer to the number of levels of factors A, B, and C the number of environments, and the number of replications per environment, respectively.

[††]$\phi_A = \Sigma A_i^2 / (a-1)$; $\phi_B = \Sigma B_j^2 / (b-1)$; $\phi_C = \Sigma C_k^2 / (c-1)$; $\phi_{AB} = \Sigma\Sigma(AB)_{ij}^2 / [(a-1)(b-1)]$; $\phi_{AC} = \Sigma\Sigma(AC)_{ik}^2 / [(a-1)(c-1)]$; $\phi_{BC} = \Sigma\Sigma(BC)_{jk}^2 / [(b-1)(c-1)]$; $\phi_{ABC} = \Sigma\Sigma\Sigma(ABC)_{ijk}^2 / [(a-1)(b-1)(c-1)]$.

Table 1.8. Combined analysis of variance for the two factor treatment (A and B) design conducted in randomized complete blocks with a split-plot arrangement in 2009 and 2010.

Source of variation	Roundup Soybeans df†	Non-GMO Soybeans df†	Mean Square Obs.	Mean Square Expected††	F-test
Environment (E)	(e-1) = 1	(e-1) = 1	M1	$\sigma^2_e + b\sigma^2_\delta + ab\sigma^2_{R(E)} + rab\sigma^2_E$	-
Replicates (environment)	e(r-1) = 5	e(r-1) = 5	M2	$\sigma^2_e + b\sigma^2_\delta + ab\sigma^2_{R(E)}$	-
A (drainage)	(a–1) = 1	(a–1) = 1	M3	$\sigma^2_e + b\sigma^2_\delta + rb\sigma^2_{EA} + rbe\phi_A$	M3/M4
E x A	(e-1)(a-1) = 1	(e-1)(a-1) = 1	M4	$\sigma^2_e + b\sigma^2_\delta + rb\sigma^2_{EA}$	M4/M5
Error (a)	e(r-1)(a-1) = 5	e(r-1)(a-1) = 5	M5	$\sigma^2_e + b\sigma^2_\delta$	-
B (cultivar)	(b–1) = 19	(b–1) = 3	M6	$\sigma^2_e + ra\sigma^2_{EB} + rae\phi_B$	M6/M7
E x B	(e-1)(b-1) = 19	(e-1)(b-1) = 3	M7	$\sigma^2_e + ra\sigma^2_{EB}$	M7/M10
A x B	(a-1)(b-1) = 19	(a-1)(b-1) = 3	M8	$\sigma^2_e + r\sigma^2_{EAB} + re\phi_{AB}$	M8/M9
E x A x B	(e-1)(a-1)(b-1) = 19	(e-1)(a-1)(b-1) = 3	M9	$\sigma^2_e + r\sigma^2_{EAB}$	M9/M10
Error (b)	a(r-1)(b-1) = 189	a(r-1)(b-1) = 30	M10	σ^2_e	-
Total	[aber]–1 = 278	[aber]–1 = 55			

† df = degrees of freedom. The letters a, b, e, and r refer to the number of levels of factors A, B, the number of environments, and the number of replications per environment, respectively.

†† $\phi_A = \Sigma A_i^2 / (a-1)$; $\phi_B = \Sigma B_j^2 / (b-1)$; $\phi_{AB} = \Sigma\Sigma(AB)_{ij}^2 / [(a-1)(b-1)]$.

RESULTS AND DISCUSSION

Environments (years) were found to be homogenous and all collected data were adequate for combined analysis of variance in the Roundup Ready soybean experiment, non-GMO soybean experiment, and *P. sojae* soybean experiment. However, due to the very different rainfall amounts and temperature differences in 2009 and 2010 (Tables 1.9, 1.10, and 1.11), both years were included in the analysis whether significant or not. A combined analysis was unable to be conducted in the early soybean experiment because of the change in three cultivars in 2010. Tests for homogeneity are located in Appendix 1.

The growing seasons in 2009 and 2010 were difficult due to poor planting conditions and some heavy rains. In 2009, the biggest production problem was a hail storm that occurred on June 21, which set the soybeans back and caused yield to be lower that it likely would have been. The hail was uniform throughout the plot area so all data could still be analyzed together. In 2010, two large rain events occurred that flooded the entire plot area and caused waterlogging. This would normally be preferable for a drainage experiment, but in June, more than 100 mm of rain fell in less than one hour. This rainfall was heaviest at the research location and was not as damaging in other areas nearby. Most of the water stood for a day before being drained through surface drainage. This caused intense crusting on the surface and soil conditions were poor for much of the summer. Rainfall and temperature data for the Fargo weather station are shown in Tables 1.9 and 1.10. The Fargo weather station is located approximately six km from the experiment location and is the closest weather station to the experimental location. According to the Fargo weather station data, the first frost date in 2009 was October 8th, while the first frost date in 2010 was October 21st (NDAWN, 2010). Table 1.11 shows rain gauge measurements at the experiment location. Despite these difficult weather issues, data were collected and analyzed for both 2009 and 2010.

Table 1.9. Monthly mean air temperature for 2009, 2010, and the twenty year average for the Fargo weather station.

Month	Mean Air Temperature		
	Fargo		
	2009	2010	Historical†
	°C		
April	5	11	6
May	12	15	14
June	18	19	19
July	19	22	21
August	19	22	21
September	19	14	14
October	5	10	7

†Historical data are 20 year average 1991-2010, (NDAWN, 2010).

Table 1.10. Monthly mean rainfall amounts for 2009, 2010, and the twenty year average for the Fargo weather station.

Month	Total Rainfall		
	Fargo		
	2009	2010	Historical†
	mm		
April	16	37	35
May	44	68	66
June	82	86	89
July	16	105	73
August	47	68	64
September	50	151	55
October	137	61	50
Total	392	576	433

†Historical data are 20 year average 1991-2010, (NDAWN, 2010).

Roundup Ready Soybean Cultivar Experiment

Table 1.12 provides the mean squares for the Roundup Ready soybean experiment and levels of significance for environment, drainage, cultivars, and the various interactions.

Table 1.11. Monthly mean observed rainfall amounts at the Northwest 22 (NW22) experiment location rain gauge for 2009 and 2010.

Month	Total Rainfall NW22 2009	Total Rainfall NW22 2010
	mm	
April	0	40
May	51	61
June	70	155
July	35	104
August	72	69
September	41	142
October	114	69
Total	383	639

Drainage

There were no significant differences between subsurface drainage treatments for all of the agronomic traits measured when the data were combined across years for Roundup Ready soybean cultivars (Table 1.12). The mean for the agronomic traits measured and combined across years for drainage treatments are shown in Tables 1.13 and 1.14. There were also no significant interactions involving drainage. This was likely due to the fact that 2009 was a much drier year than 2010, so when the data were combined, there was no significance.

Environment x Drainage

There were no significant differences for the environment x drainage interaction in any of the agronomic traits measured for Roundup Ready soybean cultivars in the combined analysis (Table 1.12), despite the fact that some of the values are very different between years. Tables 1.15 and 1.16 show the agronomic traits measured and broken down by year. The first chlorosis score in 2009 was not significantly different, but trends show

Table 1.12. Combined mean squares for the ANOVA for agronomic traits measured in both years 2009 and 2010 Roundup Ready soybeans.

Source of Variation	df†	Mean Squares								
		ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
Environment (E)	1	212,396*	537,888**	20.3	7.4	97,810**	100,564,968**	8,851**	94.4**	12.5
Replicates [E]	5	20,659	22,757	4.6	1.3	134	1,074,966	308	2.2	2.4
Drainage (D)	1	9,690	1,700	8.5	1.7	169	100,015	72	0.9	0.8
E x D	1	56,002	16,922	19.1	0.1	29	110,365	11	0.1	0.4
Error (a)	5	24,869	8,264	3.5	0.8	166	368,486	167	3.0	0.8
Cultivar (C)	19	32,387*	14,653	4.4**	1.7**	437**	1,746,450**	2,387**	7.3**	4.9**
E x C	19	12,833	9,645	1.4	0.6	116**	354,355**	105**	1.9**	0.9**
D x C	19	9,309	4,411	0.8	0.2	20	78,136	33	0.2	0.1
E x D x C	19	8,684	8,349	0.8	0.3	16	84,712	34	0.3	0.2
Error (b)	189	10,038	6,666	1.0	0.4	24	94,521	41.4	0.5	0.2
CV (%)		30.1	29.7	20.4	23.0	7.5	12.3	4.9	2.2	2.8

†df = degrees of freedom, ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.
*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

Source of Variation	df†	Mean Squares							
		LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
Environment (E)	1	35,030**	68.0*	744**	5	0.7	1,499	4,685	0.467
Replicates [E]	5	715	6.6	44	217	0.7	566	3,666	0.093
Drainage (D)	1	6	10.0	27	8	0.1	130	326	0.039
E x D	1	106	3.1	61	120	0.0	402	1,922	0.001
Error (a)	5	3,454	4.3	28	127	0.7	335	2,194	0.056
Cultivar (C)	19	1,425*	12.5	101*	55	0.6	219	996**	0.134**
E x C	19	507	7.0**	41**	46**	0.3**	219**	1,240	0.014
D x C	19	501	1.6	16	14	0.1	56	336	0.010
E x D x C	19	463	4.0	13	14	0.2	71	365	0.022
Error (b)	189	430	2.6	13	18	0.2	61	351	0.010
CV (%)		29.1	48.3	32.8	40.9	144.3	31.8	33.0	5.0

†df = degrees of freedom, LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.
*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

Table 1.13. Stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content averaged across drainage treatments for Roundup Ready soybean cultivars combined across years (2009 and 2010).

Drainage	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
Undrained	333	269	4.7	2.7	64	2,466	129	33.0	17.2
Drained	342	274	5.1	2.6	66	2,499	130	32.9	17.3
Mean	338	272	4.9	2.7	83	2,483	129	33.0	17.2
CV (%)	30.1	29.7	20.4	23.0	7.5	12.3	4.9	2.2	2.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Table 1.14. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod averaged across drainage treatments for Roundup Ready soybean cultivars combined across years (2009 and 2010).

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	----------------------------(#)----------------------------						
Undrained	71	3	11	10	0	24	57	2.38
Drained	71	3	10	10	0	24	55	2.30
Mean	71	3	11	10	0	24	56	2.34
CV (%)	29.1	48.3	32.8	40.9	144.3	33.3	33.0	5.1
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

that the soybeans in the drained units were less chlorotic than the soybeans in the undrained units. This was probably due to the temperatures being colder throughout May, which can exacerbate the likelihood of IDC in soybeans (Hanson et al., 2003). Drainage, especially in the spring, can result in increased soil temperature because the water from the melting snow is drained away more quickly (Jin et al., 2008).

In early May 2009 the measured soil temperature was colder in the undrained units (4.8˚C) compared to the drained units (5.2˚C). This likely caused the soybeans in the undrained units to be more chlorotic compared to the soybeans in the drained units early in the year. However, this advantage in chlorosis score did not impact yield. The lack of differences in the subsurface drainage treatments was probably due to the lack of large rainfall events in 2009 so there was little waterlogging. In fact, there were no rainfall events over 50 mm until October in 2009. For the entire year, rainfall was 50 mm below normal, so drainage would not have been expected to cause a significant difference in agronomic traits under these conditions.

The results from 2010 were similar to those in 2009 (Table 1.15). Vigor score was a whole point better (5.1 vs. 4.1) on the drained units compared to the undrained units, though again not statistically significant. This was likely due to the influence of soil temperature in May which was even more pronounced than in 2009 (drained soil temperature: 12.8°C; undrained soil temperature: 12.4°C). However, the temperature differences early in the growing season did not lead to any significant yield differences later in the growing season.

Table 1.15. Stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content averaged across years and drainage treatments for Roundup Ready soybean cultivars separated by year.

Drainage	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
2009									
Undrained	364	243	5.2	2.9	49	1961	124	33.6	17.0
Drained	348	234	5.1	2.7	50	1961	125	33.4	17.1
2010									
Undrained	284	294	4.1	2.5	86	3,132	136	32.3	17.4
Drained	327	314	5.1	2.4	88	3,216	136	32.3	17.6
Mean	338	272	4.9	2.7	83	2,483	129	33.0	17.2
CV (%)	30.1	29.7	20.4	23.0	7.5	12.3	4.9	2.2	2.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Cultivar

According to the combined ANOVA for the Roundup Ready soybean cultivars (Table 1.12), there were significant differences for cultivar treatments in all agronomic traits measured except for late stand, one, three, and four bean pods per plant, and total pods. Tables 1.17 and 1.18 show the means for all agronomic traits measured in both 2009

Table 1.16. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod averaged across years and drainage treatments for Roundup Ready soybean cultivars in separated by year.

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	----------------------			#	----------------------		
2009								
Undrained	60	4	12	10	0	24	59	2.46
Drained	62	4	12	11	0	27	62	2.30
2010								
Undrained	84	3	10	11	0	24	56	2.34
Drained	83	2	8	9	0	20	47	2.37
Mean	71	3	11	10	0	24	56	2.34
CV (%)	29.1	48.3	32.8	40.9	144.3	33.3	33.0	5.1
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

and 2010 and are separated into the groups used to select the cultivars for this experiment. The cultivars are ranked by yield after being separated into these cultivar groups.

Envrionment x Cultivar

According to the combined ANOVA for Roundup Ready soybean cultivars (Table 1.12), there were significant differences in the environment x cultivar interaction in all agronomic traits measured except for early stand, late stand, vigor, chlorosis score, low pod height, total seeds per plant, and seed per pod. Tables 1.19, 1.20, 1.21, and 1.22 show the mean values for the agronomic traits measured in 2009 and 2010 for each cultivar ranked by yield. In both 2009 and 2010, cultivars chosen because they were high yielding were predictably top yielders.

Stand counts varied between the two years (Tables 1.19 and 1.20). In 2009, the stand count dropped from early in the year to late in the year due to the hail event on June 21. In 2010, stand counts stayed the same throughout the year for most cultivars, which should be expected since there was no hail in 2010. The soybean cultivars from the company Asgrow turned out to be more susceptible to *P. sojae* in 2010, resulting in lower stand counts and ultimately lower yields for those cultivars.

Yields in 2010 showed no real surprises and continued trends that were seen in 2009. Yields were higher in 2010 because of adequate rainfall, temperature, no hail, and timely harvest. There was also a change in rank in 2010 due to the different weather conditions compared to 2009. The timely harvest and warmer temperatures during the growing season in 2010 resulted in higher thousand kernel weights compared to 2009 (Tables 1.19 and 1.21).

In 2009, thousand kernel weights were lower because of the cold temperatures and the inability of all the soybean cultivars to fully mature and dry down to adequate harvest moisture levels. The soybeans reached physiological maturity around October 15 and were not harvested until November 5. There was above average rainfall in the month of October which caused a lot swelling of the soybean seed in the pod. At harvest time, the soybean moisture for all the plots was consistently around 18-20%, and all of the seed had to be dried. This shrunk seed size, and combined with the lower mean temperatures in 2009 that prevented some of the soybean cultivars from fully maturing, caused the thousand kernel weight to be low.

Table 1.17. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for Roundup Ready soybean cultivars combined across years (2009 and 2010).

Cultivar	Early Stand Count	Late Stand Count	Vigor	IDC Score	Plant Height	Yield	1000 kernel weight	Protein Content	Oil Content
	-(1000 plants ha^{-1})-		(1-9)	(1-5)	(cm)	(kg ha^{-1})	(g)	(%)	(%)
Top Yielding Soybeans									
NT-0990RR	356	293	4.9	2.5	69	2,805	136	33.2	17.1
2806RR	362	287	5.0	3.0	66	2,794	126	32.8	16.6
AG0808RR	343	261	4.5	2.1	76	2,700	137	30.8	17.1
AG0604RR	351	266	5.6	2.5	41	2,587	125	32.3	17.8
Saturated Soybeans									
2905RR	362	319	5.5	2.3	67	2,781	111	33.5	17.0
DSR-0401/RR	387	304	5.6	3.2	71	2,686	132	34.0	17.0
W 2060RR	336	290	4.8	2.6	67	2,630	109	33.3	17.1
0704RR	376	307	5.0	2.9	69	2,439	133	32.2	18.2
90Y20	334	291	5.3	2.4	64	2,220	122	33.9	16.9
RR60-40	257	218	3.7	3.0	62	2,090	131	32.8	17.8
IDC Soybeans									
2906RR	404	287	5.1	3.0	67	2,865	127	32.7	16.8
NT-0886RR	362	312	5.1	2.7	65	2,861	119	33.3	16.5
RR80-50	231	240	4.2	2.4	65	2,529	110	33.6	16.9
PB-0218RR	255	222	3.7	3.3	58	1,906	170	33.4	17.0
AG00603RR	347	246	5.4	2.5	57	1,838	133	33.3	17.0
P. sojae Soybeans									
DSR-0602/RR	345	266	5.0	2.3	68	2,747	129	33.3	17.7
0806RR	424	304	5.6	3.0	66	2,677	125	32.8	16.8
PB-0356RR	321	255	4.9	2.5	65	2,441	131	32.9	17.6
90Y41	274	261	4.4	2.7	62	2,285	145	32.4	19.1
AG00501RR	319	222	4.5	2.2	51	1,758	133	32.8	17.1
Mean	338	273	4.9	2.7	83	2,483	129	33.0	17.2
CV (%)	30.1	29.7	20.4	23.0	7.5	12.3	4.9	2.2	2.8
LSD (0.05)	97	NS	1.0	0.7	9	509	9	1.2	0.8

Table 1.18. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for Roundup Ready soybean cultivars combine across years (2009 and 2010).

Cultivar	Low Pod Height	1 Bean Pods/Plant	2 Bean Pods/Plant	3 Bean Pods/Plant	4 Bean Pods/Plant	Total Pods/Plant	Total Seeds/Plant	Seeds/Pod
	(mm)	---	---	---	(#)	---	---	---
Top Yielding Soybeans								
NT-0990RR	86	2	10	10	0	22	53	2.41
2806RR	76	3	12	11	0	26	62	2.38
AG0808RR	80	5	11	14	0	30	68	2.27
AG0604RR	82	3	8	10	0	21	51	2.43
Saturated Soybeans								
2905RR	61	4	14	8	0	26	57	2.19
DSR-0401/RR	68	2	9	13	1	25	60	2.40
W 2060RR	63	4	14	7	0	25	55	2.20
0704RR	59	2	9	12	0	23	55	2.39
90Y20	61	3	11	10	0	24	55	2.29
RR60-40	80	4	12	10	0	26	60	2.31
IDC Soybeans								
2906RR	86	3	10	10	1	24	56	2.33
NT-0886RR	80	3	9	14	0	26	64	2.46
RR80-50	60	6	21	12	0	39	85	2.18
PB-0218RR	65	3	11	6	0	20	43	2.15
AG00603RR	70	2	7	10	0	19	49	2.58
P. sojae Soybeans								
DSR-0602/RR	78	3	8	9	0	20	49	2.45
0806RR	74	3	10	10	0	23	53	2.30
PB-0356RR	77	4	11	9	0	24	52	2.17
90Y41	58	2	10	10	0	22	52	2.36
AG00501RR	55	3	10	9	0	22	49	2.23
Mean	71	3	11	10	0	24	56	2.33
CV (%)	29.1	48.3	32.8	40.9	144.3	31.8	33.0	5.0
LSD (0.05)	19	NS	5	NS	NS	NS	30	0.10

Chlorosis score did not seem to affect yield in either year and appeared random. In fact, some of the most chlorotic soybeans had some of the higher yields (Tables 1.19 and 1.21). Also, the soybean cultivars that were selected based on their tolerance/susceptibility to iron chlorosis did not perform as expected. The most chlorotic cultivar out of the IDC soybean group in both years was PB-0218RR, which was selected as a medium tolerant cultivar (Tables 1.19 and 1.21).

The E x C interaction for number of pods showed that the number of pods on each soybean plant in 2010 was less than the number of pods on each soybean plant in 2009 (Tables 1.20 and 1.22). In 2010, there were much higher yields compared to 2009, so 2010 would be expected to have a higher pod count, but 2009 actually had the higher pod count. The reason for the higher number of pods in 2009 was because there was less of a stand because of the hail. A soybean plant tends to branch out when there are fewer plants in a given area, and will therefore put on more pods. In 2010, there were more plants, so even though there were less pods, there was more yield because of the higher stand count.

***Phytophthora sojae* Resistant Soybean Cultivar Experiment**

Table 1.23 provides the mean squares for the *P. sojae* resistant soybean cultivar experiment with and levels of significance for environment, drainage, cultivars, and the various interactions.

Drainage

There were no significant differences between subsurface drainage treatments for all of the agronomic traits measured when the data were combined across years for the *P. sojae* resistant soybean cultivar experiment (Table 1.23), except for protein content. Also, there were no significant interactions for the combined analysis, except for vigor for the D x C x S interaction, four bean pods per plant for the C x D interaction, and total seeds per plant for the E x D x S interaction. These significant interactions did not impact yield. The lack of significant differences was due to the fact that there was such a difference in temperature and rainfall between the years (Tables 1.9 and 1.10). Tables 1.24 and 1.25 show the average values over drainage treatments for the agronomic traits measured combined over years.

Environment x Drainage

There were no significant differences for the environment x drainage interaction for any of the agronomic traits measured in the *P. sojae* resistant soybean cultivar experiment (Table 1.23). In 2009, there were no signs of *P. sojae*, so different measurements based on different *P. sojae* genes in the various cultivars were not expected. Tables 1.26 and 1.27 show the average values for all the agronomic traits measured across drainage treatments and separated by year for soybean cultivars selected for their *P. sojae* resistance genes.

Yield was not significantly higher in the drained units compared to the undrained units in 2010, but trends showed that yield was better on the drained units (Tables 1.26 and 1.27). There were more seeds per pod in the drained units compared to the undrained units, so with equal number of pods, there was a yield advantage on the drained units.

Numerically late stand counts, vigor, chlorosis, and thousand kernel weight were also all better on the drained units in 2010, and although these measured traits were not significant different (Table 1.26).

Table 1.19. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for Roundup Ready soybean cultivars in 2009.

Cultivar	Early Stand Count	Late Stand Count	Vigor	Chlorosis Score #1	Plant Height	Yield	1000 kernel weight	Protein Content	Oil Content
	-1000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
Top Yielding Soybeans									
AG0808RR	373	238	4.9	2.3	61	2,411	134	31.5	17.0
AG0604RR	407	261	5.8	3.0	50	2,258	122	32.7	17.6
2806RR	434	223	5.5	2.9	49	2,223	120	33.1	16.2
NT-0990RR	354	246	4.9	2.8	50	2,159	131	33.9	17.0
Saturated Soybeans									
2905RR	358	269	6.0	2.4	55	2,427	106	33.6	17.2
DSR-0401/RR	431	308	6.4	3.3	56	2,187	128	34.6	16.7
W 2060RR	346	269	4.8	2.9	53	2,164	104	33.1	17.1
0704RR	388	246	4.9	3.2	50	1,900	130	32.7	18.1
90Y20	342	231	5.9	2.6	43	1,609	119	34.8	16.6
RR60-40	304	192	3.8	3.5	44	1,354	125	33.9	17.9
IDC Soybeans									
2906RR	423	246	5.3	2.9	50	2,318	121	33.0	16.7
NT-0886RR	384	238	5.4	2.8	49	2,203	110	33.9	16.7
RR80-50	246	254	4.1	2.4	53	2,065	105	33.7	16.7
AG00603RR	400	254	6.0	2.4	42	1,491	135	33.8	16.8
PB-0218RR	246	161	3.8	3.3	39	1,149	166	34.1	16.5
P. sojae Soybeans									
DSR-0602/RR	346	231	4.8	2.6	51	2,145	121	33.4	17.6
0806RR	454	284	5.9	3.1	49	2,104	121	33.2	16.6
PB-0356RR	315	238	5.3	2.8	48	1,946	123	33.6	17.4
90Y41	360	228	4.9	2.8	46	1,637	139	33.4	19.0
AG00501RR	323	200	4.5	2.2	39	1,433	130	33.5	16.4
Mean	362	241	5.1	2.8	80	1,961	124	33.5	17.1
CV (%)	30.1	29.7	20.4	23.0	7.5	12.3	4.9	2.2	2.8
LSD (0.05)	NS	NS	NS	NS	3	178	4	0.4	0.3

Table 1.20. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for Roundup Ready soybean cultivars in 2009.

Cultivar	Low Pod Height	1 Bean Pods/Plant	2 Bean Pods/Plant	3 Bean Pods/Plant	4 Bean Pods/Plant	Total Pods/Plant	Total Seeds/Plant	Seeds/Pod
	mm	#						
Top Yielding Soybeans								
AG0808RR	79	4	10	11	0	25	56	2.29
AG0604RR	66	4	9	12	1	25	60	2.40
2806RR	67	4	15	13	1	33	77	2.33
NT-0990RR	79	3	12	11	0	27	62	2.34
Saturated Soybeans								
2905RR	51	5	15	8	0	29	60	2.11
DSR-0401/RR	57	3	11	14	1	29	69	2.42
W 2060RR	57	5	17	8	0	31	64	2.10
0704RR	46	2	10	13	0	26	63	2.47
90Y20	47	4	12	10	1	26	59	2.27
RR60-40	77	5	14	10	0	29	62	2.14
IDC Soybeans								
2906RR	72	3	11	10	1	24	55	2.34
NT-0886RR	59	3	11	14	0	29	68	2.39
RR80-50	47	7	26	15	0	50	107	2.16
AG00603RR	69	2	6	8	0	16	38	2.38
PB-0218RR	50	3	12	5	0	21	43	2.10
P. sojae Soybeans								
DSR-0602/RR	66	3	9	9	0	22	49	2.28
0806RR	70	3	13	10	0	27	60	2.26
PB-0356RR	71	4	12	9	0	25	56	2.24
90Y41	48	3	11	8	0	22	48	2.23
AG00501RR	49	3	10	8	0	21	47	2.29
Mean	61	4	12	10	0	26	60	2.38
CV (%)	29.1	48.3	32.8	40.9	144.3	31.8	33.0	5.0
LSD (0.05)	NS	1	2	2	0.4	5	NS	NS

Table 1.21. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for Roundup Ready soybean cultivars in 2010.

Cultivar	Early Stand Count	Late Stand Count	Vigor	Chlorosis Score #1	Plant Height	Yield	1000 kernel weight	Protein Content	Oil Content
	-1000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
Top Yielding Soybeans									
NT-0990RR	359	339	5.0	2.3	94	3,666	143	32.4	17.3
2806RR	267	351	4.3	3.2	88	3,555	135	32.3	17.2
AG0808RR	302	283	3.9	1.9	97	3,084	141	29.8	17.2
AG0604RR	277	271	5.3	1.9	95	3,025	129	31.8	18.0
Saturated Soybeans									
DSR-0401/RR	328	300	4.7	3.0	90	3,352	137	33.3	17.5
2905RR	369	368	4.9	2.1	84	3,253	117	33.5	16.7
W 2060RR	323	311	4.8	2.3	84	3,252	116	33.5	17.2
0704RR	359	368	5.1	2.5	94	3,158	139	31.5	18.4
RR60-40	195	243	3.6	2.4	86	3,073	140	31.4	17.7
90Y20	323	351	4.6	2.2	91	3,035	127	32.8	17.3
IDC Soybeans									
NT-0886RR	333	385	4.7	2.7	86	3,738	131	32.6	16.3
2906RR	379	328	4.9	3.2	91	3,595	134	32.5	17.0
RR80-50	210	226	4.3	2.3	81	3,148	117	33.4	17.2
PB-0218RR	267	283	3.6	3.3	84	2,914	175	32.6	17.7
AG00603RR	277	237	4.5	2.8	78	2,301	131	32.7	17.3
P. sojae Soybeans									
DSR-0602/RR	343	300	5.3	1.8	91	3,550	141	33.1	17.8
0806RR	384	323	5.3	3.0	89	3,441	130	32.2	17.1
PB-0356RR	328	271	4.3	2.1	88	3,101	142	31.8	17.8
90Y41	174	294	3.9	2.5	80	3,041	154	31.1	19.2
AG00501RR	313	243	4.5	2.3	66	2,192	137	31.9	18.1
Mean	305	305	4.6	2.5	87	3,174	136	32.3	17.5
CV (%)	30.1	29.7	20.4	23.0	7.5	12.3	4.9	2.2	2.8
LSD (0.05)	NS	NS	NS	NS	3	178	4	0.4	0.3

Table 1.22. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for Roundup Ready soybean cultivars in 2010.

Cultivar	Low Pod Height	1 Bean Pods/Plant	2 Bean Pods/Plant	3 Bean Pods/Plant	4 Bean Pods/Plant	Total Pods/Plant	Total Seeds/Plant	Seeds/Pod
	mm	#						
Top Yielding Soybeans								
NT-0990RR	95	2	7	8	0	17	41	2.36
2806RR	89	2	8	9	0	18	43	2.38
AG0808RR	83	6	12	18	0	36	85	2.35
AG0604RR	103	2	7	8	0	16	39	2.37
Saturated Soybeans								
DSR-0401/RR	83	2	7	10	1	20	49	2.48
2905RR	75	3	12	9	0	24	53	2.23
W 2060RR	70	3	10	6	0	20	43	2.19
0704RR	76	2	7	9	0	18	44	2.41
RR60-40	85	3	10	11	0	24	56	2.35
90Y20	80	2	9	10	0	21	50	2.39
IDC Soybeans								
NT-0886RR	107	2	7	14	0	23	59	2.47
2906RR	105	2	9	11	0	23	56	2.44
RR80-50	77	3	13	9	0	25	56	2.20
PB-0218RR	85	3	10	6	0	19	42	2.16
AG00603RR	71	3	8	14	1	26	63	2.48
P. sojae Soybeans								
DSR-0602/RR	93	3	8	10	0	20	48	2.41
0806RR	80	2	7	9	0	18	43	2.37
PB-0356RR	85	3	9	8	0	21	47	2.24
90Y41	72	2	9	12	0	23	58	2.43
AG00501RR	62	3	10	10	0	23	52	2.36
Mean	84	3	9	10	0	22	51	2.35
CV (%)	29.1	48.3	32.8	40.9	144.3	31.8	33.0	5.0
LSD (0.05)	NS	1	2	2	0.4	5	NS	NS

Table 1.23. Combined mean squares for the analysis of variance for agronomic traits measured in both years 2009 and 2010 for *P. sojae* resistant soybean cultivars.

Source of Variation	df†	Mean Squares								
		ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
Environment (E)	1	248,808*	148,644*	14.6	3.1	43,797**	55,498,453**	7,095**	63.2**	12.6*
Replicates [E]	5	26,820	15,404	2.5	1.1	141	855,082	297	3.2	1.4
Drainage (D)	1	4,618	19,143	4.3	3.4	103	161,231	153	0.2*	0.1
E x D	1	30,544	5,854	14.6	1.1	8	148,441	26	0.0	0.8
Error (a)	5	17,178	5,700	2.8	0.7	127	210,024	131	2.9	0.4
Cultivar (C)	4	61,584	25,247*	8.4	3.1*	1,208*	4,591,232*	1,676*	1.9	17.6*
E x C	4	24,012	3,886	1.6	0.5	112	382,471	152	3.6	2.2
C x D	4	31,573	7,655	1.5	0.1	7	22,262	67	0.1	0.1
E x C x D	4	15,417	2,551	0.4	0.3	11	42,143	64	0.2	0.1
Seed Treatment (S)	1	203	2,757	1.5	0.6	10	14,930	0	0.5	0.1
E x S	1	43,170	1,893	2.6	0.1	14	68,376	0	0.2	0.0
D x S	1	14,948	272	0.1	0.0	0	13,203	121	0.0	0.3
E x D x S	1	6,442	56	4.9	0.2	51	310	2	0.1	0.0
C x S	4	8,306	4,889	0.8	0.1	34	117,119	23	0.5	0.2
E x D x S	4	13,296	7,671	0.7	0.4	29	208,081	19	0.3	0.1
D x C x S	4	8,975	3,339	2.8*	0.2	30	72,841	21	0.7	0.2
E x D x C x S	4	24,199	2,717	0.3	0.1	24	153,032	37	0.2	0.3
Error (b)	90	9,377	6,064	0.9	0.4	17	76,709	38	0.4	0.2
CV (%)		28.6	29.3	19.7	24.4	6.6	11.8	4.6	1.9	2.8

†df = degrees of freedom, ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content, LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant.

*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

Table 1.23 (continued).

Source of Variation	df†	Mean Squares							
		LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
Environment (E)	1	12,113**	4.3	109	157.87	0.2	0.1	172	0.5831**
Replicates [E]	5	343	2.1	43	94.51	0.3	310	2034	0.0557
Drainage (D)	1	4,111	14.4	58	7.16	0.0	189	674	0.0617
E x D	1	98	4.9	11	3.91	0.1	47	176	0.0317
Error (a)	5	1,740	8.0	20	70.79	0.2	218	1283	0.0369
Cultivar (C)	4	4,654*	7.0	26	7.27	1.1	31	93	0.0794
E x C	4	507	2.4	35	32.42	0.2	142	803*	0.0205
C x D	4	239	4.8	19	4.17	0.2*	58	240	0.0145
E x C x D	4	209	3.9	26	21.95	0.0	127	632	0.0120
Seed Treatment (S)	1	309	1.2	19	49.71	0.3	193	1193	0.0121
E x S	1	61	0.4	7	43.71	0.0	114	757	0.0155
D x S	1	251	2.8	1	10.85	0.0	35	199	0.0001
E x D x S	1	141	11.8	22	46.33	0.1	258	1293*	0.0017
C x S	4	729	0.3	5	13.05	0.1	11	90	0.0100
E x D x S	4	616	1.9	3	7.05	0.3	16	103	0.0131
D x C x S	4	736	0.9	32	30.03	0.2	123	748	0.0145
E x D x C x S	4	116	0.5	9	6.23	0.1	39	193	0.0052
Error (b)	90	353	1.7	12	14.30	0.3	52	300	0.0150
CV (%)		26.8	41.9	33.2	38.3	199.1	31.0	32.2	5.3

†df = degrees of freedom, LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

End of Table 1.23.

Table 1.24. Stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content averaged across drainage treatments for soybean cultivars selected for their *P. sojae* resistance genes combined across years (2009 and 2010).

Drainage	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
Undrained	334	246	4.7	2.7	61	2,320	131	32.9	17.6
Drained	342	270	5.0	2.4	63	2,380	134	32.7	17.7
Mean	338	258	4.8	2.6	62	2,350	132	32.8	17.6
CV (%)	28.6	29.3	19.7	24.4	6.6	11.8	4.6	1.9	2.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	0.2	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Table 1.25. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod averaged across drainage treatments for soybean cultivars selected for their *P. sojae* resistance genes combined across years (2009 and 2010).

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	-----------	-----------	-----------	#	-----------	-----------	-----------
Undrained	64	3	11	10	0	24	56	2.29
Drained	75	3	10	10	0	22	52	2.32
Mean	70	3	10	10	0	23	54	2.31
CV (%)	26.8	41.9	33.2	38.3	199.1	31.0	32.2	5.3
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Table 1.26. Stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for drainage treatments for soybean cultivars selected for their *P. sojae* resistance genes separated by year.

Drainage	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
2009									
Undrained	380	230	5.3	2.8	46	1,783	125	33.4	17.4
Drained	366	243	5.0	2.7	47	1,807	128	33.3	17.3
2010									
Undrained	269	262	3.9	2.7	81	3,009	140	32.0	17.9
Drained	311	296	5.0	2.2	83	3,145	141	31.9	18.1
Mean	338	258	4.8	2.6	62	2,350	132	32.8	17.6
CV (%)	28.6	29.3	19.7	24.4	6.6	11.8	4.6	1.9	2.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Table 1.27. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for drainage treatments for soybean cultivars selected for their *P. sojae* resistance genes separated by year.

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	--------------------			#	--------------------		
2009								
Undrained	57	4	13	11	1	29	66	2.30
Drained	60	3	13	12	0	29	67	2.35
2010								
Undrained	76	3	10	11	0	25	58	2.34
Drained	85	2	8	11	0	21	52	2.42
Mean	70	3	11	10	0.3	26	61	2
CV (%)	26.8	41.9	33.2	38.3	199.1	31.0	32.2	5.3
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Cultivar

The combined analysis for the *P. sojae* soybean experiment (Table 1.23) showed that there were significant differences between cultivars in late plant stand, chlorosis score, plant height, yield, thousand kernel weight, oil content, and low pod height. Trends continued from 2009 and 2010, with 0806RR and DSR-0602/RR at the top for yield and AG00501RR at the bottom due to *P. sojae* occurrence (Table 1.28 and 1.30). Chlorosis score was significantly different between cultivars and 0806RR had the highest score, but also the highest yield (Table 1.28). This shows that stand has more of an influence on yield than chlorosis score. There were no significant interactions for the combined analysis of the cultivars chosen for resistance to *P. sojae* study that impacted yield. Table 1.28 and 1.29 show the mean values for all of the agronomic traits measured for soybean cultivars chosen for resistance to *P. sojae*, ranked from highest yield to lowest yield.

Table 1.28. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for cultivars selected for their *P. sojae* resistance genes combined across years (2009 and 2010).

Cultivar	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kgha^{-1}	g	%	%
DSR-0602/RR	350	273	4.8	2.4	68	2,747	128	33.1	17.7
0806RR	413	292	5.8	3.1	66	2,732	125	32.7	16.8
PB-0356RR	301	264	4.6	2.5	64	2,359	131	32.7	17.6
90Y41	290	244	4.3	2.6	59	2,108	145	32.5	18.9
AG00501RR	337	217	4.6	2.3	52	1,804	133	32.8	17.1
Mean	338	258	4.8	2.6	62	2,350	132	32.8	17.6
CV (%)	28.6	29.3	19.7	24.4	6.6	11.8	4.6	1.9	2.8
LSD (0.05)	NS	71	NS	0.8	12	701	14	NS	1.7

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Table 1.29. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for cultivars selected for their *P. sojae* resistance genes combined across years (2009 and 2010).

Cultivar	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	-------------------------			#		--------------------------	
DSR-0602/RR	72	3	9	11	0	23	54	2.37
0806RR	79	3	10	10	0	24	55	2.33
PB-0356RR	84	4	11	10	0	25	56	2.23
90Y41	57	2	11	9	0	23	53	2.30
AG00501RR	56	3	10	9	0	22	50	2.30
Mean	70	3	10	10	0	23	54	2.31
CV (%)	26.8	41.9	33.2	38.3	0	31.0	32.2	5.3
LSD (0.05)	26	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Environment x Cultivar

The only significant difference for the environment x cultivar interaction according to the combined analysis (Table 1.23) was total seeds per plant. Seeds per plant was significant because of a change in rank between years. AG00501RR and 90Y41 were last in total seeds per plant in 2009 and first in 2010 (Table 1.31). This was due to those cultivars having a low stand and the plant trying to compensate with more seeds per plant for a lower plant stand. This increase in seeds per plant did not lead to an increase in yield, as these two cultivars ranked last in 2010 for seed yield (Table 1.30).

In 2009, the yield for all five cultivars, though not statistically significant, trended to be higher with later cultivar maturity (Table 1.30). These cultivars also had the most seeds per pod and seeds per plant which contributed to their yield advantage (Table 1.31).

Another factor that appeared to influence yield in 2009 was plant stand. AG00501RR had the lowest stand and the lowest yield (Table 1.30). In 2009 all cultivars, had a large drop from early to late stand counts because of the hail event in June. Cultivar 0806RR had the highest percentage drop from early to late stand counts. This cultivar also has no known *P. sojae* resistance genes, which suggests that this drop in stand may have been due to the occurrence of *P. sojae*. However, there were no confirmed cases of *P. sojae* at the research location in 2009.

In 2010, trends continued from 2009, with the only change in yield being that 0806RR was slightly higher than DSR-0602/RR. AG00501RR was again the lowest yielding cultivar and had a confirmed *P. sojae* infection based on the NDSU plant diagnostic lab results. This *P. sojae* infection caused higher root disease ratings and a lower yield compared to the other cultivars (Table 1.30). Table 1.31 shows the results from all pod and seed per pod information for soybean cultivars chosen for their *P. sojae* resistance in both 2009 and 2010.

In 2010, roots were evaluated for disease by inspecting the surface area of the root that had lesions. Also, dry roots were weighed and the results are shown in Table 1.32. Dry roots were shown to be significantly different for the cultivar x drainage interaction (Appendix I, Table A2). These results indicate that the root weights do not necessarily correspond to the root score. The reason for this is because the root score is based on any visible lesion, which means it is not limited to just *P. sojae*. The lesions were possibly caused by the fungus *Rhizoctonia solani* or the fungus *Fusarium solani*. The basis for the significant weight difference in the dry root weights is likely related to the different cultivars' genetic resistance to waterlogging rather than *P. sojae* resistance genes. For example, AG00501RR was the cultivar that tested positive for *P. sojae*, but according to the dry root weight (Table 1.32), the undrained units' roots weighed more than the roots on drained units. The root score for AG00501RR was less than the other cultivars. Three of the cultivars had a higher root weight on the undrained units while the remaining two cultivars had a higher root weight on the drained units. This suggests that drainage had no effect on *P. sojae* occurrence in this study.

Table 1.30. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for cultivars selected for their *P. sojae* resistance genes separated by year.

Cultivar	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
2009									
DSR-0602/RR	355	258	4.9	2.7	52	2,214	120	33.2	17.6
0806RR	477	273	6.3	3.3	49	2,181	120	33.1	16.6
PB-0356RR	309	227	5.0	2.7	47	1,808	122	33.6	17.5
90Y41	352	219	4.7	2.6	45	1,411	139	33.4	18.7
AG00501RR	369	208	4.8	2.3	39	1,387	130	33.5	16.4
2010									
0806RR	328	311	5.1	3.0	89	3,468	131	32.1	17.1
DSR-0602/RR	328	288	4.9	2.0	89	3,427	139	32.9	17.8
PB-0356RR	290	302	4.0	2.3	87	3,094	142	31.5	17.7
90Y41	208	269	3.8	2.7	79	3,038	154	31.3	19.1
AG00501RR	295	226	4.3	2.2	69	2,358	138	32.0	18.0
Mean	338	258	4.8	2.6	62	2,350	132	32.8	17.6
CV (%)	28.6	29.3	19.7	24.4	6.6	11.8	4.6	1.9	2.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Table 1.31. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for cultivars selected for their *P. sojae* resistance genes separated by year.

Cultivar	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	--------	--------	--------	#	--------	--------	--------
2009								
DSR-0602/RR	61	3	10	10	0	23	55	2.34
0806RR	67	3	13	10	0	26	59	2.26
PB-0356RR	77	4	12	10	0	27	59	2.20
90Y41	49	3	11	7	0	21	46	2.22
AG00501RR	53	3	9	8	0	20	45	2.25
2010								
0806RR	94	2	7	11	0	21	50	2.43
DSR-0602/RR	87	3	8	11	0	22	53	2.40
PB-0356RR	94	3	10	10	0	23	53	2.29
90Y41	68	2	11	12	0	26	62	2.40
AG00501RR	59	3	10	11	0	24	57	2.37
Mean	70	3	10	10	0	23	54	2.31
CV (%)	26.8	41.9	33.2	38.3	199.1	31.0	32.2	5.3
LSD (0.05)	NS	NS	NS	NS	NS	NS	7	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Table 1.32. Means for the cultivar x drainage interaction for root score and dry root weight for cultivars selected for their *P. sojae* resistance genes in 2010.

Cultivar	Root Score		Dry Root Weight	
	% lesions		Grams	
	Undrained	Drained	Undrained	Drained
AG00501RR	7.4	5.7	3.6	3.1
DSR-0602/RR	9.2	5.3	2.7	4.7
PB0356RR	6.7	5.9	2.5	3.6
90Y41	7.3	8.5	3.2	2.8
0806RR	5.8	4.9	3.3	3.1
Mean	7.3	6.1	3.1	3.4
CV (%)	72.0	72.0	24.3	24.3
LSD (0.05)	NS	NS	1.3	

Seed Treatment

Fungicide seed treatment was the sub-sub-plot factor in the *P. sojae* soybean experiment. There were no significant differences between fungicide seed treatments in any agronomic traits measured in the combined analysis for soybean cultivars chosen for their resistance to *P. sojae* (Table 1.23).

Non-GMO Soybean Cultivar Experiment

Table 1.33 provides the mean squares combined across years for the non-GMO soybean cultivar experiment with levels of significance for environment (years), drainage, cultivars, and the various interactions. Due to the very different weather conditions of each year, environment was significant for all agronomic traits measured except for late stand, chlorosis score, and all pod and seed counting data. Also, there were significant environment x cultivar interactions.

Drainage

There were no significant differences between subsurface drainage treatments for any of the agronomic traits that were measured in the combined ANOVA for non-GMO soybean cultivars (Table 1.33). The trends do show that yield, chlorosis score, stand, vigor, and plant height were all better on the drained units, however not statistically significant (Table 1.34). Table 1.35 shows the results of the pod counting for drainage treatments for the non-GMO soybean cultivars.

Environment x Drainage

There were no significant differences for the environment x drainage interaction for any of the agronomic traits measured for the non-GMO soybean cultivars (Table 1.33). Tables 1.36 and 1.37 show the mean values for the different drainage treatments for non-GMO soybean cultivars in 2009 and 2010.

Table 1.33. Combined mean squares for the ANOVA for agronomic traits measured in years 2009 and 2010 in non-GMO soybean cultivars.

Source of Variation	df†	Mean Squares								
		ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
Environment (E)	1	105,459*	211,830	40.5**	6.0	14,215**	12,121,623**	2,256**	15.2*	2.5*
Replicates [E]	5	7,695	22,688	2.0	2.0	53	374,397	103	0.9	0.3
Drainage (D)	1	11,495	5,957	1.7	4.3	75	429,907	116	0.6	1.4
E x D	1	546	32,362	2.5	0.1	63	378,494	137	0.1	0.0
Error (a)	5	6,434	11,684	1.6	0.7	68	116,202	107	1.4	0.7
Cultivar (C)	3	28,392	5,900	5.8*	1.8	294	3,677,581*	3,457**	10.4	11.2*
E x C	3	5,424	3,280	0.4	1.8*	138**	336,754*	65	2.9**	0.9*
D x C	3	5,440*	1,155	0.3	0.2	9	49,615*	125	0.3	0.4
E x D x C	3	637	1,679	1.8*	0.1	10	4,988	132	0.7	0.2
Error (b)	30	7,365	5,408	0.6	0.4	25	105,908	102	0.4	0.2
CV (%)		32.1	31.0	21.3	23.7	8.0	16.2	8.4	1.9	2.9

† df = degrees of freedom, ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.
*,** Significant at (P≤0.05) and (P≤0.01), respectively.

Source of Variation	df†	Mean Squares							
		LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
Environment (E)	1	715	4.7	7	2	0.5	0.1	3	0.002
Replicates [E]	5	270	2.5	19	50	0.2	131.1	879	0.034
Drainage (D)	1	538	8.1	33	25	0.9	16.0	2	0.101
E x D	1	124	0.3	6	1	0.1	5.9	13	0.013
Error (a)	5	213	8.9	47	23	0.1	183.3	821	0.034
Cultivar (C)	3	311	30.9*	302*	41	0.6	809.3	3,199*	0.144
E x C	3	548	1.7	13	34	1.1*	93.6	711	0.018
D x C	3	798	3.4	24	18	0.2	82.1	428	0.005
E x D x C	3	300	6.4	13	11	0.6	41.2	221	0.025
Error (b)	30	323	3.5	36	31	0.2	158.3	859	0.010
CV (%)		29.1	48.6	46.3	46.9	109.3	43.5	43.9	4.8

†df = degrees of freedom, LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.
*,** Significant at (P≤0.05) and (P≤0.01), respectively.

Table 1.34. Stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content averaged across drainage treatments for non-GMO soybean cultivars combined across years (2009 and 2010).

Drainage	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
Undrained	243	226	3.2	3.0	62	1,871	124	33.0	16.9
Drained	282	244	3.6	2.5	65	2,081	122	32.6	17.3
Mean	262	235	3.4	2.8	64	1,976	123	32.8	17.1
CV (%)	32.1	31.0	21.3	23.7	8.0	16.2	8.4	1.9	2.9
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Table 1.35. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod averaged across drainage treatments for non-GMO soybean cultivars combined across years (2009 and 2010).

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	---------------------------#---------------------------						
Undrained	58	4	13	11	0	29	67	2.28
Drained	64	3	12	12	0	28	67	2.36
Mean	61	4	13	12	0	29	67	2.32
CV (%)	29.1	48.6	46.3	46.9	109.3	43.5	43.9	4.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

In 2010, vigor was higher on the drained units because of rains early in the growing season that caused emergence to be an issue, so drainage had an advantage (Table 1.36). Yield was improved on the drained units in 2010, and this was due to the above average rainfall received for the year. The plants grew taller, had a better stand, and had less chlorosis, and although these traits were not significantly different, they led to more yield for the drained units in 2010. Drainage helped reduce the stress of waterlogging to create a numerical yield advantage in 2010 for non-GMO soybean cultivars.

Table 1.36. Stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content averaged across drainage treatments for non-GMO soybean cultivars separated by year.

Drainage	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
2009									
Undrained	298	200	4.3	2.8	48	1,603	114	32.9	16.9
Drained	321	173	4.3	2.2	49	1,618	114	32.7	17.2
2010									
Undrained	185	234	2.1	3.4	77	2,157	135	33.2	16.9
Drained	240	294	3.0	3.0	82	2,574	129	32.6	17.3
Mean	262	235	3.4	2.8	64	1,976	123	32.8	17.1
CV (%)	32.1	31.0	21.3	23.7	8.0	16.2	8.4	1.9	2.9
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Cultivar

There were significant differences between non-GMO soybean cultivars for vigor, yield, thousand kernel weight, oil content, one and two bean pods, and total seeds per plant when years were analyzed together for the non-GMO soybean cultivars (Tables 1.33). The Roundup Ready check (AG0604RR) was the highest yielding cultivar, followed by Sheyenne, Ashtabula, and Nornatto (Table 1.38). This was the same order in 2009 and 2010 (Table 1.37). Means for all agronomic traits measured are shown in Tables 1.37, 1.38, and 1.39.

Environment x Cultivar

There were significant differences for the environment x cultivar interaction for chlorosis score, plant height, seed yield, protein content, oil content, and four been pods per plant (Table 1.33). These significant differences were likely due to a change in magnitude. In 2009, AG0604RR, the Roundup Ready check, yielded the best (Table 1.40). Sheyenne was close behind, with Ashtabula next and Nornatto yielding the lowest of the four cultivars. Nornatto had the most pods per plant out of all the cultivars, but yielded the least

Table 1.37. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod averaged across drainage treatments for non-GMO soybean cultivars separated by year.

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	----	----	----	#	----	----	----
2009								
Undrained	57	4	13	11	1	29	66	2.30
Drained	60	3	13	12	0	29	67	2.35
2010								
Undrained	61	5	13	11	0.2	30	67	2.26
Drained	70	4	11	13	0.6	28	66	2.36
Mean	61	4	13	12	0	29	67	2.32
CV (%)	29.1	48.6	46.3	46.9	109.3	43.5	43.9	4.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Table 1.38. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for non-GMO soybean cultivars combined across years (2009 and 2010).

Cultivar	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
AG0604RR††	286	264	4	3	67	2,496	124	32.0	17.9
Sheyenne	330	250	4	3	65	2,342	130	33.5	16.3
Ashtabula	248	233	3	3	59	1,830	128	32.4	18.0
Nornatto	222	215	3	3	58	1,387	96	31.5	16.6
Mean	271	241	4	3	62	2,014	120	32.3	17.2
CV (%)	29.1	33.6	20.7	12.8	8.9	10.6	9.8	4.1	3.7
LSD (0.05)	NS	NS	1	NS	NS	754	10	NS	0.6

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.
††Roundup Ready Check.

because of the small seed size that caused a low thousand kernel weight compared to the other cultivars (Tables 1.40 and 1.41). Nornatto also had the least seeds per pod despite having the most pods, which contributed to its yield disadvantage. Nornatto, however, is a specialty natto bean and it was expected that the yield would be lower. The cultivars Sheyenne and AG0604RR likely out yielded the other non-GMO soybean cultivars because they have a higher genetic yield potential.

Table 1.39. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for non-GMO soybean cultivars combined across years (2009 and 2010).

Cultivar	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	-----------------------------			#	-----------------------------		
AG0604RR††	60	4	11	11	1	26	61	2.32
Sheyenne	60	3	11	13	0	28	65	2.35
Ashtabula	56	2	9	10	1	22	52	2.42
Nornatto	69	6	20	14	0	40	88	2.20
Mean	61	4	13	12	0	29	67	2.32
CV (%)	29.1	48.6	46.3	46.9	109.3	43.5	43.9	4.8
LSD (0.05)	NS	2	5	NS	NS	NS	35	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.
††Roundup Ready Check.

In 2010, AG0604RR was again the highest yielding cultivar, followed by Sheyenne, Ashtabula, and Nornatto in last (Table 1.40). Trends that were seen in 2009 continued into 2010, with Nornatto again having the most pods but one of the lower yields due to low thousand kernel weight and seeds per pod. Chlorosis score was significantly different, with AG0604RR at least a full point better than the other cultivars.

Table 1.40. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for non-GMO soybean cultivars separated by year.

Cultivar	ES†	LS†	V†	C1†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	1-5	cm	kg ha^{-1}	g	%	%
2009									
AG0604RR	314	203	5.4	2.7	52	2,029	120	32.9	17.5
Sheyenne	387	215	4.3	2.1	50	1,965	122	33.4	16.4
Ashtabula	271	172	4.1	2.1	43	1,291	124	32.7	17.9
Nornatto	271	160	3.4	3	48	1,159	91	32.1	16.3
2010									
AG0604RR	252	323	3.2	2.3	86	3,119	129	30.8	18.5
Sheyenne	258	271	2.6	3.3	84	2,844	141	33.5	16.2
Ashtabula	221	294	2.5	3.3	80	2,549	134	31.9	18.2
Nornatto	154	266	2.0	3.7	71	1,690	103	30.8	16.9
Mean	271	241	4	3	62	2,014	120	32.3	17.2
CV (%)	29.1	33.6	20.7	12.8	8.9	10.6	9.8	4.1	3.7
LSD (0.05)	NS	NS	NS	1.2	11	715	NS	1.2	0.8

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

Table 1.41. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for non-GMO soybean cultivars separated by year.

Cultivar	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	----------------------------			#	----------------------------		
2009								
AG0604RR††	55	3	12	11	1	27	64	2.36
Sheyenne	54	3	13	14	0	30	72	2.37
Ashtabula	50	3	8	8	0	19	45	2.38
Nornatto	74	5	19	14	0	39	86	2.20
2010								
AG0604RR†	82	3	9	10	0	23	54	2.35
Sheyenne	69	3	10	11	0	24	55	2.32
Ashtabula	64	2	10	12	1	25	61	2.48
Nornatto	63	6	20	15	0	41	91	2.19
Mean	61	4	13	12	0	29	67	2.32
CV (%)	29.1	48.6	46.3	46.9	109.3	43.5	43.9	4.8
LSD (0.05)	NS	NS	NS	NS	0.4	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.
††Roundup Ready Check.

In 2009, the Tofu cultivar had too low of a stand count to be included in the final analysis. However, in 2010, the stand was adequate and results that include Tofu are shown in Tables 1.42 and 1.43. Tofu ended up being the lowest yielding, but as expected, easily had the highest protein content and lowest oil content, which is ideal for food grade soybean production. The ANOVA table for 2010 is located in Appendix I, Table A4.

Drainage x Cultivar

There were no D x C interactions in the combined analysis for non-GMO soybean cultivars, except for seed yield (Table 1.33). Table 1.44 shows the results for the four cultivars and the two drainage treatments planted in both 2009 and 2010. This interaction is significant for yield because AG0604RR was slightly less on the drained units while the other cultivars yielded more on the drained units compared to the undrained units.

Table 1.42. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for non-GMO soybean cultivars in 2010.

Cultivar	ES†	LS†	V†	C1†	RS†	PH†	SY†	TKW†	PC†	OC†
	-1000 plants ha^{-1}-		1-9	1-5	%	cm	kg ha^{-1}	g	%	%
AG0604RR†	252	323	3.2	2.3	0.3	86	3,119	129	30.8	18.5
Sheyenne	258	271	2.6	3.3	0.3	84	2,844	141	33.5	16.2
Ashtabula	221	294	2.5	3.3	0.0	80	2,549	134	31.9	18.2
Nornatto	154	266	2.0	3.7	2.5	71	1,690	103	30.8	16.9
Tofu	178	170	2.4	3.3	0.7	76	1,623	153	37.5	15.7
Mean	215	266	2.5	3.2	0.8	79	2,365	132	32.9	17.1
CV (%)	29.1	33.6	20.7	12.8	342.6	8.9	10.6	9.8	4.1	3.7
LSD (0.05)	74	NS	0.7	0.5	NS	9	308	16	1.7	0.8

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, RS = root disease score, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.
††Roundup Ready Check.

Table 1.43. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for non-GMO soybean cultivars in 2010.

Cultivar	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	----------	----------	----------	#	----------	----------	----------
AG0604RR††	82	3	9	10	0	23	54	2.35
Sheyenne	69	3	10	11	0	24	55	2.32
Ashtabula	64	2	10	12	1	25	61	2.48
Nornatto	63	6	20	15	0	41	91	2.19
Tofu	67	4	10	11	0	25	58	2.26
Mean	69	4	12	12	0	28	64	2.32
CV (%)	20.4	45.8	44.5	48.5	163.9	42.8	44.0	4.9
LSD (0.05)	NS	2.4	6.7	NS	NS	NS	NS	0.14

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.
††Roundup Ready Check.

Early Maturing Soybean Experiment

Drainage

2009

In 2009, the early maturing soybean cultivar study was not significantly different between subsurface drainage treatments for any of the agronomic traits measured, except for late stand count (Appendix I, Table A6). The late stand count was significantly higher

Table 1.44. Yield results averaged across 2009 and 2010 for non-GMO soybean cultivars for drainage treatments.

Cultivar	Drainage Type	
	Undrained	Drained
	------- kg ha^{-1}---	
AG0604RR†	2,505	2,487
Ashtabula	1,728	1,931
Nornatto	1,287	1,487
Sheyenne	2,220	2,464
Mean	1,935	2,092
CV (%)	10.6	
LSD (0.05)	170	

†Roundup Ready Check.

in the drained units compared to the undrained units. This was likely due to temperature differences early in the season which helped the soybeans planted on the drained units to emerge earlier and led to a better plant stand. Unfortunately, this stand advantage did not lead to a yield advantage on the drained units, and in fact the undrained units yielded slightly higher than the drained units at the end of the year. Tables 1.45 and 1.46 provide the mean values for all agronomic traits measured in 2009 early maturing soybean cultivars based on drainage.

Table 1.45. Stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content averaged across drainage treatments for early maturing soybean cultivars in 2009.

Drainage	ES†	LS†	V†	C1†	C2†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	------1-5-----		cm	kg ha^{-1}	g	%	%
Undrained	303	194	4.5	2.7	3.0	50	1,657	126	34.0	16.8
Drained	374	218	4.3	2.7	2.8	53	1,523	123	34.2	16.7
Mean	338	206	4.4	2.7	2.9	51	1,590	124	34.1	16.8
CV (%)	27.8	24.5	21.6	23.4	19.8	10.3	24.4	4.7	1.7	4.0
LSD (0.05)	NS	14	NS	NS	NS	NS	NS	NS	NS	NS

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

2010

There were no significant differences between subsurface drainage treatments in any of the agronomic traits measured in 2010 for the early maturing soybean cultivars (Appendix I, Table A7). However, the drained units did have a slight advantage in the traits measured, although not statistically significant. Tables 1.47 and 1.48 show the means from all of the agronomic traits measured for the drainage treatments.

Table 1.46. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod averaged across drainage treatments for early maturing cultivars in 2009.

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	----------------------------	----------------------------	----------------------------	#-	----------------------------	----------------------------	----------------------------
Undrained	57	3	12	11	0	27	62	2.29
Drained	56	3	12	11	0	27	62	2.33
Mean	57	3	12	11	0	27	62	2.31
CV (%)	25.9	52.7	33.1	34.7	127.5	28.2	28.0	6.3
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Table 1.47. Stand counts, yield, thousand kernel weight, protein content, and oil content averaged across drainage treatments for early maturing soybean cultivars in 2010.

Drainage	Late Stand Count	Yield	1000 kernel weight	Protein Content	Oil Content
	1000 plants ha^{-1}	kg ha^{-1}	g	%	%
Undrained	291	3,071	138	32.3	17.9
Drained	324	3,138	140	32.3	18.0
Mean	276	2,999	170	32.4	17.8
CV (%)	34.0	6.4	4.6	2.4	2.8
LSD (0.05)	NS	NS	NS	NS	NS

Table 1.48. Low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod averaged across drainage treatments for early maturing soybean cultivars in 2010.

Drainage	LP†	1P†	2P†	3P†	4P†	TP†	TS†	LP†
	mm	-------------	-------------	-------------	#	-------------	-------------	-------------
Undrained	71	3	10	11	0	23	56	2.34
Drained	77	2	9	9	0	21	49	2.37
Mean	74	2	9	10	0	22	52	2.36
CV (%)	25.9	32.3	35.4	36.6	153.1	26.6	27.8	5.2
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Cultivar

2009

There were significant differences between early maturing soybean cultivars in all agronomic traits measured in 2009 except for vigor, one and three bean pods per plant, and seeds per pod (Appendix I, Table A6). As seen in the previous soybean experiments conducted at this research location, stand influenced yield. The lower stand count resulted in a lower yield (Table 1.49). Chlorosis score did not affect yield. RT 0268RR was the most chlorotic of the five cultivars, but also yielded the most.

Pods and seeds per pod also corresponded with stand (Table 1.50). The lower the stand, the more pods and seeds per pod occurred on the plant. For example, RT 0268RR had the least amount of pods and seeds per plant, but it ended up yielding the most because of the advantage it had in overall plant stand.

Table 1.49. Means for stand counts, vigor, chlorosis scores, height, yield, thousand kernel weight, protein content, and oil content for early maturing soybean cultivars in 2009.

Cultivar	ES†	LS†	V†	C1†	C2†	PH†	SY†	TKW†	PC†	OC†
	-1,000 plants ha^{-1}-		1-9	------1-5-----		cm	kg ha^{-1}	g	%	%
RT 0268RR	488	284	6.8	3.0	3.4	56	2,174	116	35.1	16.3
NT-6006RR	342	231	5.0	3.1	3.4	50	1,652	134	32.9	17.0
0702RR	338	184	4.5	2.9	3.1	51	1,524	134	34.6	16.3
0901RR	292	169	3.1	2.1	2.5	49	1,395	121	34.6	16.8
97009RS	231	161	2.6	2.3	2.1	50	1,208	117	33.3	17.5
Mean	338	206	4.4	2.7	2.9	51	1,590	124	34.1	16.8
CV (%)	27.8	24.5	21.6	23.4	19.8	10.3	24.4	4.7	1.7	4.0
LSD (0.05)	39	22	NS	0.6	0.6	5	401	6	0.6	0.7

†ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.

2010

There were no significant differences between early maturing soybean cultivars in 2010 for any agronomic traits measured except for thousand kernel weights (Appendix I, Table A7). 90Y20 had a higher thousand kernel weight than the other cultivars (Table 1.51). There were no yield differences because stand was very similar throughout and all cultivars are similar in maturity and overall genetics, so drastic differences would not be expected. Table 1.52 shows the results from counting seeds and pods for early maturing soybeans in 2010.

Table 1.50. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for early maturing soybean cultivars in 2009.

Cultivar	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	----------------------------#--------------------------						
RT 0268RR	75	4	7	8	0	20	45	2.28
NT-6006RR	67	3	15	11	0	29	66	2.27
0702RR	45	4	10	10	0	24	54	2.29
0901RR	46	3	12	12	0	27	65	2.37
97009RS	52	3	16	14	1	34	81	2.35
Mean	57	3	12	11	0	27	62	2.31
CV (%)	25.9	52.7	33.1	34.7	127.5	28.2	28.0	6.3
LSD (0.05)	15	NS	4	NS	0.6	8	18	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

Table 1.51. Means for stand counts, yield, thousand kernel weight, protein content, and oil content for early maturing soybean cultivars in 2010.

Cultivar	Late Stand Count	Yield	1000 kernel weight	Protein Content	Oil Content
	-1000 plants ha^{-1}-	kg ha^{-1}	g	%	%
0905RR	324	3,138	140	32.3	18.0
NT-6006RR	324	3,138	140	32.3	18.0
0704RR	291	3,071	138	32.3	17.9
RT 0268RR	291	3,071	138	32.3	17.9
90Y20RR	276	2,999	170	32.4	17.8
Mean	276	2,999	170	32.4	17.8
CV (%)	34.0	6.4	4.6	2.4	2.8
LSD (0.05)	NS	NS	8	NS	NS

Table 1.52. Means for low pod height, number of one, two, three, and four bean pods per plant, total pods per plant, total seeds per plant, and seeds per pod for early maturing soybean cultivars in 2010.

Cultivar	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
	mm	-----	-----	-----	#	-----	-----	-----
0905RR	83	2	7	6	0	16	36	2.29
NT-6006RR	70	3	13	15	0	31	75	2.42
0704RR	75	3	11	7	0	22	49	2.22
RT 0268RR	67	3	8	10	1	21	51	2.41
90Y20RR	76	2	8	11	0	21	51	2.45
Mean	74	2	9	10	0	22	52	2.36
CV (%)	25.9	32.3	35.4	36.6	153.1	26.6	27.8	5.2
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

†LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

SUMMARY DISCUSSION

Subsurface drainage showed no significant difference for yield for any of the cultivar groupings. However, in 2010 in non-GMO soybean cultivars and soybean cultivars chosen for their resistance to *P. sojae,* there was a yield advantage on the drained units. In 2010, there was above average rainfall and differences were expected based on drainage. These results are similar to other studies conducted when above average rainfall occurred (Linkemer et al., 1998; Sipp et al., 1986; Kladivko et al., 2005; Zucker and Brown, 1998). However, in 2009 and when data from both years 2009 and 2010 were combined, there were no positive or negative significant differences in yield for any of the cultivar groups in the study. This was due to the below average rainfall for 2009. Other authors have also concluded that yield was not affected by subsurface drainage (Alvino and Zerbi, 1986; Beer et al., 1965; Benz et al., 1978; King and Evans, 1987; Walker et al., 1982; Wiersma et al., 2010). These other studies had a lack of available water in the soil profile and therefore showed no response to subsurface drainage.

In this study, the surface drainage of the field was enough to handle the amount of rainfall in 2009, but varied based on the water tolerance ability of the soybean cultivars in 2010. Subsurface drainage helped only in certain situations in 2010 and didn't help overall yield. Therefore, the conclusion can be made from this study that the advantage of subsurface drainage and its effects on soybean yield are uncertain and depend on cultivar and rainfall amounts. Subsurface drainage can help to alleviate risk involved in flooded soils and aid in accessing a field in a timely manner, which is what happened in the fall of 2009.

Cultivar selection is a very important aspect of farming and when subsurface drainage is installed in a field, cultivar selection continues to be an important subject. Results from this study indicate that during a drier than average year, similar to 2009, 2905RR and AG0808RR would be the top two cultivars to plant. During a year with above average rainfall, such as 2010, NT-0990RR and NT-0886RR would be the best cultivars to plant. The later maturing soybean cultivars were the highest yielding. Most of the cultivars were different in the other agronomic traits measured. This was an expected outcome based on the cultivars' different genetic backgrounds and past performances in the NDSU variety trials (Kandel, 2008).

In 2010, three of the soybean cultivars (AG0808RR, AG00603RR, and AG00501RR) showed signs of *P. sojae* and it was verified by the NDSU plant diagnostic lab. These three soybean cultivars had the Rps1k resistance gene. The other cultivars with other resistance genes and some cultivars with no resistance gene showed no ill effects from *P. sojae*. According to personal communication with Dr. Berlin Nelson (2011), *P. sojae* can occur in patches throughout a field.

Seed treatment is another important option that farmers have to protect the soybean plant from disease. The results from this study indicated that ApronMax did not help increase yield. In 2010, soybean cultivar AG00501RR was the only cultivar with root disease issues, but the seed treatment helped to reduce the problem. However, combined data from 2009 and 2010 showed no difference for the amount of disease, vigor, or stand counts. Therefore, based on this research, seed treatment fungicide did not increase yield or help plant health earlier in the growing season.

Future research should focus on more of a range of cultivars, planting date effect, and different types of seed treatment. Despite the large number of cultivars in this study, there were no longer growing season cultivars (above a 1.0 maturity level). Testing longer than normal maturity levels for the region on subsurface drainage would be useful. Planting earlier on the drained units would also be useful, since that is one of the main advantages of tile drainage. By extending the growing season, soybeans could possibly yield more and an advantage could be gained by using tile drainage in this manner. Lastly, using different types of seed treatments besides ApronMax could help test the effect of other active ingredients on the effect of *P. sojae*.

The data from this research should be viewed carefully since it is based on two years of data in one location. Although drainage and seed treatment did not make a difference in most cases, they did create a slight advantage in 2010 when there was above average rainfall. The research location is also a relatively small area. In a large farm setting, subsurface drainage may help alleviate excess water in low areas in fields where water is held and where surface drainage does not work. Subsurface drainage basically makes the subsurface field drainage consistent across the entire area where it is installed, increasing efficiency. Although the data in this study shows no difference for the majority of agronomic traits measured in various soybean cultivars in regards to drainage, subsurface drainage may increase efficiency in a large farm setting.

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ARTICLE 2.

SUBSURFACE DRAINAGE EFFECTS ON VARIOUS SOIL PROPERTIES AND WATER AVAILABILTY

LITERATURE REVIEW

Subsurface Drainage and Soil Penetration Resistance

Increased soil penetration resistance (trafficability) after a rainfall event is one of the most important benefits of subsurface drainage because higher soil penetration resistance will increase trafficability, which could allow farmers to enter a field earlier. Trafficability impacts the efficiency of a farming operation. When the soil can carry a tractor and the timing of required farming operations is appropriate for the stage of crop development, profit is maximized. Trafficability is most affected by the amount of water in the soil (Bradford, 1986). According to Bradford (1986), soil penetration resistance (which is a proxy for trafficability), is quantified by a pressure measurement, and is expressed in kilopascals. It is influenced by water content, bulk density, soil compressibility, soil strength parameters, and soil structure.

According to Marshall and Holmes (1988), the strength of a soil can affect the soil's load bearing capacity, compaction, and root penetration and is related to the soil's bulk density and water content. In particular, soil strength increases as water content decreases. They concluded that the reason soil strength usually decreases with increasing water content is because the bonds that hold the soil particles together in structural units are weakened as more water is adsorbed (Marshall and Holmes, 1988).

Bornstein and Hedstrom (1982) conducted a study on trafficability and how it is affected by subsurface drainage and various drain spacings. They found that drainage can allow tilling earlier in the season. Early planting and the ability to get into a field sooner in the spring is generally considered the largest benefit of subsurface drainage. Early planting provides a longer growing season which may increase yield potential. Bornstein and

Hedstrom (1982) concluded that trafficability increased more rapidly in the spring with subsurface drainage in their three year study regardless of the drain spacings they tested.

Kornecki and Fouss (2001) looked at the effects of subsurface drainage on trafficability in Louisiana. They found that as soil moisture increased, soil strength decreased. Kornecki and Fouss (2001) concluded that the "breaking point" for trafficable conditions was a cone penetrometer measurement of 1660 kPa at the 10 cm depth. The "breaking point" refers to the soil condition when a tractor is able to drive over an area without wheel slippage.

Measuring Trafficability

Bradford (1986) outlined several different ways that soil penetration resistance can be measured, including the soil cone penetrometer. The soil cone penetrometer was developed by the U.S. Army Corps of Engineers for predicting the carrying capacity of soils for vehicles engaged in off-road military operations. Penetrometers are commonly used in agricultural settings to find hard pans and compaction areas and to measure the physical status of the soil. Bradford (1986) outlined methods to take cone penetrometer measurements. In order to get useable readings, the cone penetrometer must be inserted into the soil at a steady rate of 3 cm s^{-1} to the desired measurement depth. The shaft should be wiped clean between uses and an area must be tested multiple times to avoid outlier measurements due to random soil disturbances.

The American Society of Agricultural and Biological Engineers (ASABE) (2006) outlined similar methods for using the cone penetrometer accurately and further recommends breaking the field into smaller sections and taking random samples within each section to obtain more accurate readings. The researchers also found that the main factors affecting the penetration resistance of a particular soil are soil density and water content. The ASABE (2006) stated that cone penetrometer data can be analyzed by either averaging across depths or by plotting penetration resistance at each depth.

Objectives for this study were: 1) to determine the effect of subsurface drainage on the water table and soil temperature; and 2) to determine if subsurface drainage alters the soil penetration resistance of the soil.

MATERIALS AND METHODS

The experimental field was located at the Northwest 22 (NW22) location near Fargo, ND. The legal description is the NW quarter of Section 22, Township 140, Range 49 (Lat. N 46°55'55.8093"; Long. W 96°51'32.3561"). The location consists of 2.5 hectares and the entire area is surface drained. In 2008, subsurface drainage was installed at a 1 meter deep with a 7.6 m spacing. The tile drainage pipes are 10 cm in diameter in this particular study. The drainage coefficient, based on the soil type and dimensions and spacing of the drainage pipes is between 6 and 10 mm per 24 hours. The plot area contained wheat (*Triticum aestivum* L. emend. Thell.), soybean (*Glycine max* L. Merr.), and corn (*Zea mays* L.).

The plot area is split into eight units, all of which have subsurface drain tile. The layout of the eight units is shown in Figure 2.1. There are seven tile lines in each unit. Each of the eight units has its own water table control structure (Agri-Drain Corp, Adair, IA). Four of the control structures were open so that the land was subsurface drained (drained) and four of the control structures were closed so that the land was non-subsurface drained (undrained). The experiment was designed as a random complete block design with a split-split plot arrangement. Drainage was the main plot factor with position of observations considered the sub-plot factor and depth considered the sub-sub-plot factor.

The soil type of the area is classified as a Fargo-Ryan silty clay. The Fargo series (fine, smectic, frigid Typic Epiaquerts) consists of deep, poorly drained, slowly permeable, lacustrine soils. This soil generally has a slope of 0-1%. The Ryan series (fine, smectic, frigid, Typic Natraquerts) is a very similar to the Fargo series, except the Ryan series generally has an E soil horizon that is 0-5 cm deep (USDA-NRCS, 2008).

Rep 4		Rep 2	
Unit 8 Controlled tile System (closed)	**Unit 6** Controlled tile system (open)	**Unit 4** Controlled tile system (closed)	**Unit 2** Controlled tile system (open)
Unit 7 Controlled tile system (open)	**Unit 5** Controlled tile system (closed)	**Unit 3** Controlled tile system (open)	**Unit 1** Controlled tile system (closed)
Rep 3		**Rep 1**	

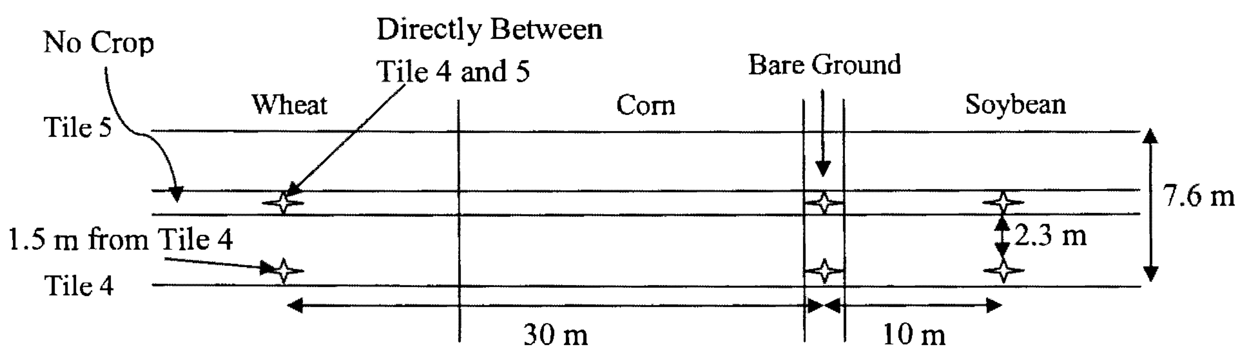
←North

Fig. 2.1. Layout of the replicates and units at the NW22 location in 2009 and 2010.

Soil penetration resistance, soil water table, and soil temperature were measured to determine the influence of subsurface drainage on soil properties. A Field Scout SC900 cone penetrometer (Spectrum Technologies, Inc., Plainfield, IL) was used to measure soil penetration resistance. This particular penetrometer gives a digital reading in kilopascals (kPa) from 0 to 45 centimeters soil depth. One reading was obtained for every 2.54 cm so trends could be established based on depth. A digital handheld thermometer (Model 82021-168, VWR International LLC, Radnor, PA) was used to determine soil temperature. The soil thermometer gave a point temperature reading at a soil depth of 15 cm. Penetrometer readings and water table measurements were compared to overall rainfall at the research location.

The penetrometer and soil temperature readings were taken at the same time at each location on a weekly basis. The dates of observations can be seen on Table B1 in Appendix II. The soil thermometer was damaged on observations 13, 15, and 33 and repaired after, but those observations were not included in the final analysis. A rain gauge was placed at the north end of the field and rainfall was recorded on a weekly basis.

Penetrometer readings and soil temperature were taken at six selected areas per unit for a total of 48 penetrometer and temperature readings per week. Of the six observations per unit, three were taken directly between subsurface drainage lines 4 and 5 and three were taken 1.5 meters from subsurface drainage line 4. Since the drain tile was installed in 2008, the assumption was that the soil had not settled right on top of the tile line. In order to get readings from undisturbed soil, readings 1.5 meters from the line were considered viable in 2009 and 2010. The measurement points directly in between tile lines or 1.5 meters from tile line 4 are referred to as "position." The three crops planted at the location were wheat, corn, and soybean. Different measurement points based on crop planted and ground conditions are referred to as measurement "sites" and are wheat, bare ground, and soybean. Measuring points in each unit are indicated in Fig. 2.2.



Each star represents a measurement point. There are two measurement "positions" (one directly between tile lines 4 and 5 and one 1.5 meters from tile 4) at three different "sites" (the wheat measurement site, bare ground measurement site, and soybean measurement site) in each of the eight units at the research area. There are 7.6 m between tile lines 4 and 5. From the wheat measurement site to the bare ground measurement site is approximately 30 m and the bare ground to the soybean measurement site is approximately 10 m.

Fig. 2.2. The layout (not to scale) in each unit where penetrometer and temperature measurements were taken at the research location.

Water table depth measurements were taken once a week, on the same day as the penetrometer and temperature measurements, using the Solinst water level meter model 101 (Solinst, Georgetown, ON, Canada). The water table depth was measured using the 8 control boxes that control the subsurface drainage lines for each unit as well as the 32 wells (4 in each unit) that are located at the location (see Fig. 2.3). There are two adjacent wells on the north side of each unit and two adjacent wells on the south side of each unit with each pair of wells having one shallow well (1.2 m) and one deep well (2.1 m). The wells allowed the soil water table to be measured below the soil surface. During certain times of the year, the water table was below the depth of the shallow wells and only the depth of the water table level in the deeper well was recorded. Measurements were made from the top of the pipe to the depth of the water and then corrected for the height of the pipe above the adjacent ground surface. The wells were installed in May of 2009 using a soil probe. A schedule 40 PVC pipe (diameter 5.1 cm) was inserted into the hole created by the soil prove and sand was filled in around the pipe. The water level was monitored in order to observe differences between the subsurface drained and undrained units. Location of each well and topography of the land area is shown in Fig. 2.3. The wells are located in a straight line and allow for the measurement in only one crop. In 2009, corn was planted around the wells and in 2010 soybeans.

A rain gauge was set up at the NW22 location to observe the amount of precipitation of major rainfall events during the year. The North Dakota Agricultural Weather Network (NDAWN) website was used to download weather data for the growing season for Fargo, about 6 km from the experiment location, including maximum and minimum air temperature. Rainfall amounts were downloaded to verify the rain gauge observations.

Soil penetrometer readings were analyzed using analysis of variance (PROC ANOVA) of SAS 9.2 (SAS Institute, Cary, NC) combined across environments. There were 41 total environments with each environment being an individual day that readings were taken. It was determined that each day was its own random, independent environment with its own set of soil penetration resistance values. Years were considered environments in a separate analysis. In that analysis, there were only two environments. Each "site" (wheat, bare ground, and soybean) was analyzed separately since they were not randomly distributed across the field and crops may influence soil water content differently.

For depth, measurements were taken from 0-46 cm, but the values from 0-8 cm were not used because of irregularities in the soil at that shallow level. These soil irregularities included tilling between tile line four and five and intense surface crusting after large rainfall events. Drainage practice, position, and depth were considered fixed effects and replication and environment were considered random effects in the statistical analysis. Main effects and interactions were tested using the appropriate error term, as shown in Tables 2.1 and 2.2. Means were separated using Fisher's protected LSD at the 5% level of significance. Table 2.1 describes the model used to analyze the temperature data and Table 2.2 the model used to analyze the soil penetration resistance readings.

Table 2.1. Combined analyses of variance for the two-factor treatment (A (drainage) and B (position)) design conducted in randomized complete blocks with a split-plot arrangement in 2009 and 2010.

Source of variation	df†	Mean Square		F-test
		Obs.	Expected††	
E (environment)	(e-1) = 40	M1	$\sigma^2_e + b\sigma^2_\delta + ab\sigma^2_{R(E)} + rab\sigma^2_E$	-
Rep (E)	e(r-1) = 123	M2	$\sigma^2_e + b\sigma^2_\delta + ab\sigma^2_{R(E)}$	-
A (drainage)	(a–1) = 1	M3	$\sigma^2_e + b\sigma^2_\delta + rb\sigma^2_{EA} + rbe\phi_A$	M3/M4
E x A	(e-1)(a-1) = 40	M4	$\sigma^2_e + b\sigma^2_\delta + rb\sigma^2_{EA}$	M4/M5
Error (a)	e(r-1)(a-1) = 123	M5	$\sigma^2_e + b\sigma^2_\delta$	-
B (position)	(b–1) = 1	M6	$\sigma^2_e + ra\sigma^2_{EB} + rae\phi_B$	M6/M7
E x B	(e-1)(b-1) = 40	M7	$\sigma^2_e + ra\sigma^2_{EB}$	M7/M10
A x B	(a-1)(b-1) = 1	M8	$\sigma^2_e + r\sigma^2_{EAB} + re\phi_{AB}$	M8/M9
E x A x B	(e-1)(a-1)(b-1) = 40	M9	$\sigma^2_e + r\sigma^2_{EAB}$	M9/M10
Error (b)	ae(r-1)(b-1) = 123	M10	σ^2_e	-
Total	[abcer]–1 = 10,495			

†df = degrees of freedom. The letters a, b, c, e, and r refer to the number of levels of factors A, B, and C the number of environments, and the number of replications per environment, respectively.

††$\phi_A = \Sigma A_i^2 / (a-1)$; $\phi_B = \Sigma B_j^2 / (b-1)$; $\phi_{AB} = \Sigma\Sigma(AB)_{ij}^2 / [(a-1)(b-1)]$.

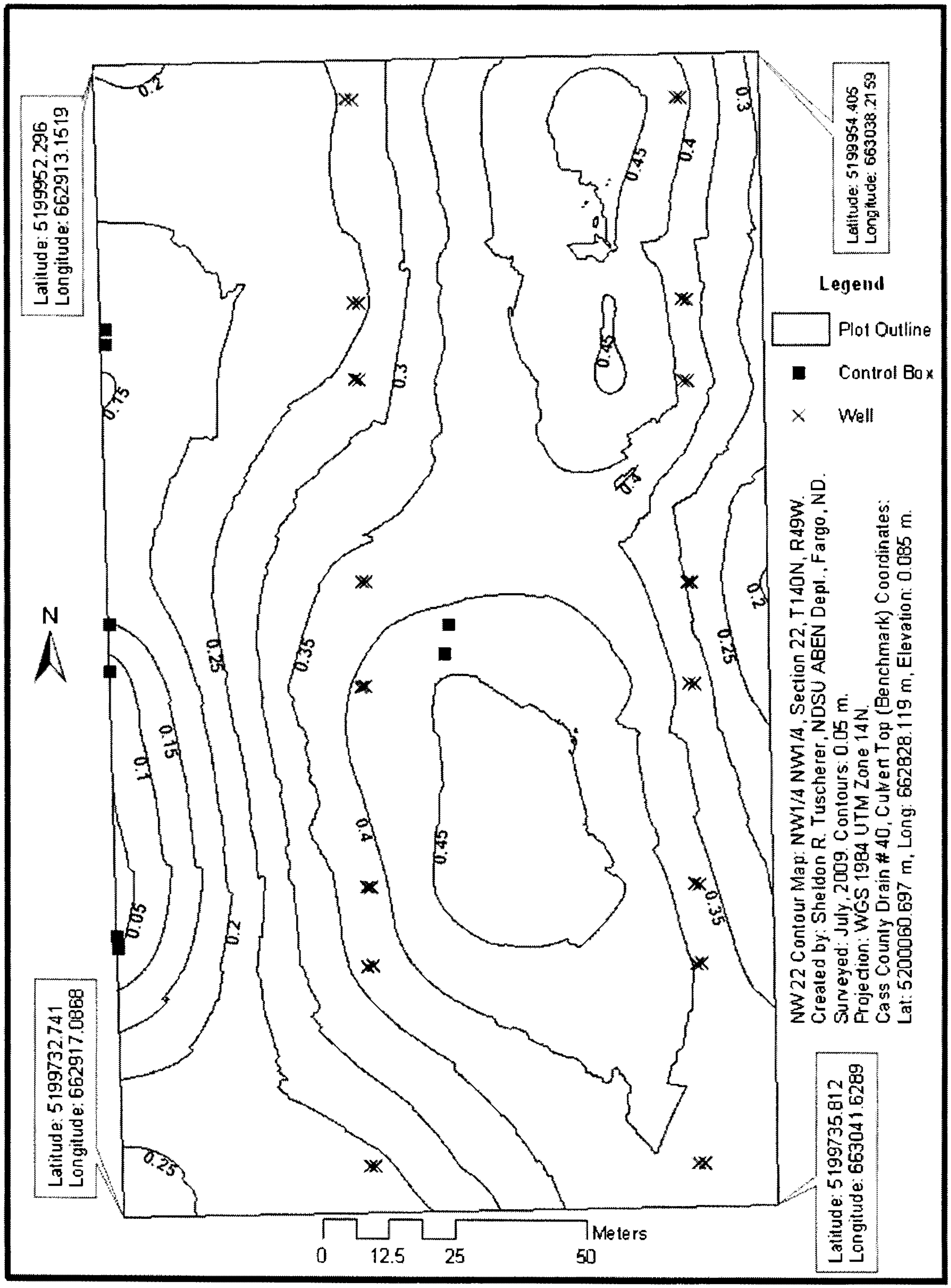


Fig. 2.3. Location of each well at the NW 22 research location. This map also shows the contours of the soil at the research location.

Table 2.2. Combined analyses of variance for the three-factor treatment (A (drainage), B (position), and C (depth)) design conducted in randomized complete blocks with a split-split-plot arrangement in 2009 and 2010.

Source of variation	df† (using date as environment)	df† (using year as environment)	Mean Square Obs.	Mean Square Expected††	F-test
E (environment)	(e-1) = 40	(e-1) = 1	M1	$\sigma^2_e + bc\sigma^2_\delta + abc\sigma^2_{R(E)} + rabc\sigma^2_E$	-
Rep (E)	e(r-1) = 123	e(r-1) = 6	M2	$\sigma^2_e + bc\sigma^2_\delta + abc\sigma^2_{R(E)}$	-
A (drainage)	(a–1) = 1	(a–1) = 1	M3	$\sigma^2_e + bc\sigma^2_\delta + rbc\sigma^2_{EA} + rbce\phi_A$	M3/M4
E x A	(e-1)(a-1) = 40	(e-1)(a-1) = 1	M4	$\sigma^2_e + bc\sigma^2_\delta + rbc\sigma^2_{EA}$	M4/M5
Error (a)	e(r-1)(a-1) = 123	e(r-1)(a-1) = 6	M5	$\sigma^2_e + bc\sigma^2_\delta$	-
B (position)	(b–1) = 1	(b–1) = 1	M6	$\sigma^2_e + rac\sigma^2_{EB} + race\phi_B$	M6/M7
E x B	(e-1)(b-1) = 40	(e-1)(b-1) = 1	M7	$\sigma^2_e + rac\sigma^2_{EB}$	M7/M10
A x B	(a-1)(b-1) = 1	(a-1)(b-1) = 1	M8	$\sigma^2_e + rc\sigma^2_{EAB} + rec\phi_{AB}$	M8/M9
E x A x B	(e-1)(a-1)(b-1) = 40	(e-1)(a-1)(b-1) = 1	M9	$\sigma^2_e + rc\sigma^2_{EAB}$	M9/M10
Error (b)	ae(r-1)(b-1) = 123	ae(r-1)(b-1) = 6	M10	$\sigma^2_e + rbc\sigma^2_\delta$	-
C (depth)	(c-1)= 15	(c-1)= 15	M11	$\sigma^2_e + rab\sigma^2_{EC} + rabe\phi_C$	M11/M12
E x C	(e-1)(c-1) = 600	(e-1)(c-1) = 15	M12	$\sigma^2_e + rab\sigma^2_{EC}$	M12/M19
A x C	(a–1)(c-1) = 15	(a–1)(c-1) = 15	M13	$\sigma^2_e + rb\sigma^2_{EAC} + reb\phi_{AC}$	M13/M14
E x A x C	(e-1)(a-1)(c-1) = 600	(e-1)(a-1)(c-1) = 15	M14	$\sigma^2_e + rb\sigma^2_{EAC}$	M14/M19
B x C	(b-1)(c-1) = 15	(b-1)(c-1) = 15	M15	$\sigma^2_e + ra\sigma^2_{EBC} + rea\phi_{BC}$	M15/M16
E x B x C	(e-1)(b-1)(c-1) = 600	(e-1)(b-1)(c-1) = 15	M16	$\sigma^2_e + ra\sigma^2_{EBC}$	M16/M19
Ax B x C	(a-1)(b-1)(c-1) = 15	(a-1)(b-1)(c-1) = 15	M17	$\sigma^2_e + r\sigma^2_{EABC} + re\phi_{ABC}$	M17/M18
E x A x B x C	(e-1)(a-1)(b-1) = 600	(e-1)(a-1)(b-1) = 15	M18	$\sigma^2_e + r\sigma^2_{EABC}$	M18/M19
Error (c)	ae(r-1)(b-1)(c-1) = 7,503	ae(r-1)(b-1)(c-1) = 10,350	M19	σ^2_e	-
Total	[abcer]–1 = 10,495	[abcer]–1 = 10,495			

†df = degrees of freedom. The letters a, b, c, e, and r refer to the number of levels of factors A, B, and C the number of environments, and the number of replications per environment, respectively.

††$\phi_A = \Sigma A_i^2 / (a-1)$; $\phi_B = \Sigma B_j^2 / (b-1)$; $\phi_C = \Sigma C_k^2 / (c-1)$; $\phi_{AB} = \Sigma\Sigma(AB)_{ij}^2 / [(a-1)(b-1)]$; $\phi_{AC} = \Sigma\Sigma(AC)_{ik}^2 / [(a-1)(c-1)]$; $\phi_{BC} = \Sigma\Sigma(BC)_{jk}^2 / [(b-1)(c-1)]$; $\phi_{ABC} = \Sigma\Sigma\Sigma(ABC)_{ijk}^2 / [(a-1)(b-1)(c-1)]$.

RESULTS AND DISCUSSION

The growing seasons in 2009 and 2010 were challenging due to poor planting conditions and some heavy rains. In 2010, two large rain events flooded the entire plot area and caused waterlogging. This would normally be preferable for a drainage experiment, but one rain in June had more than 100 mm of rainfall in less than one hour. Most of the water stood for a day and was drained through surface drainage and there was not enough time for the water to infiltrate through the soil and test the subsurface drainage system. This rain event and flooding caused intense crusting on the surface which caused soil conditions to be poor for plant growth for much of the summer. It also caused the surface soil penetration resistance readings to be higher following the heavy rainfall, when normally the opposite would be expected. Therefore, no readings from 0-8 cm were reported. Rainfall and temperature data are shown in Tables 2.3, 2.4, and 2.5. When comparing Tables 2.4 and 2.5, it is important to note that there was more rainfall at the research location compared to just 6 km away at the Fargo weather station. This was due to a few heavy, localized rains throughout the year. Despite these difficult weather issues, field data were collected and analyzed for both 2009 and 2010.

Table 2.3. Monthly mean air temperature for 2009, 2010, and the twenty year average for the Fargo weather station.

	Mean Air Temperature		
Month	Fargo		
	2009	2010	Historical†
	°C		
April	5	11	6
May	12	15	14
June	18	19	19
July	19	22	21
August	19	22	21
September	19	14	14
October	5	10	7

†Historical data are 20 year average 1991-2010, (NDAWN, 2010).

Table 2.4. Monthly mean rainfall amounts for 2009, 2010, and the twenty year average for the Fargo weather station.

Month	Total Rainfall		
	Fargo		
	2009	2010	Historical†
	mm		
April	16	37	35
May	44	68	66
June	82	86	89
July	16	105	73
August	47	68	64
September	50	151	55
October	137	61	50
Total	392	576	433

†Historical data are 20 year average 1991-2010, (NDAWN, 2010).

Table 2.5. Monthly mean observed rainfall amounts at the Northwest 22 (NW22) experiment location rain gauge for 2009 and 2010.

Month	Total Rainfall	
	NW22	
	2009	2010
	mm	
April	0	40
May	51	61
June	70	155
July	35	104
August	72	69
September	41	142
October	114	69
Total	383	639

Soil Penetration Resistance

Table 2.6 shows the mean squared values for the soil penetration resistance readings taken in 2009 and 2010. There were 41 total dates/environments when measurements were recorded.

Environment

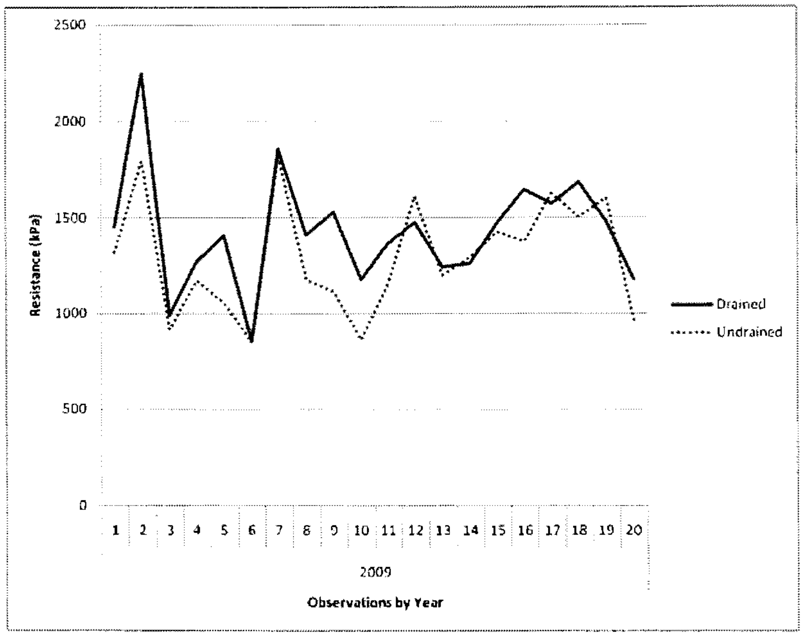
Environment (using date as environment) was significantly different for all three measurement sites (wheat, soybean, and bare ground) (Table 2.6). This basically means that soil conditions were always different at each date of taking penetrometer measurements. Figures 2.4 and 2.5 show how much soil penetration resistance changed over time in the drained and undrained units. As is depicted in the graphs, the drained units didn't always have a higher resistance value than the undrained units. This was mostly due to measurements that were taken immediately after rainfall events, before the drainage could affect the resistance level. A week or two following large rainfall events, the gap between the drained and undrained units was more pronounced. Rainfall amounts and the actual dates for the observations can be seen on Table B1 in Appendix II.

Table 2.6. Mean squares for the analysis of variance for soil penetration resistance measured in 2009 and 2010 using dates as environment.

Source of Variation	df†	Mean Squares		
		Bare Ground	Soybean	Wheat
Environment (E)	40	20,629,295**	23,996,971**	70,319,081**
Replicates [E]	123	4,009,079	5,715,002	5,800,530
Drainage (D)	1	14,806,684*	35,186,189**	61,219,551**
E x D	40	2,141,822	1,647,778	3,883,899
Error (a)	123	2,933,377	3,422,455	5,384,961
Position (P)	1	20,039,387**	16,376,751**	5,283,561
E x P	40	617,320	1,615,564**	4,620,113**
D x P	1	411,629	1,017	404,324
E x D x P	40	780,066	1,389,315*	1,345,044
Error (b)	123	1,013,134	914,208	1,744,912
Depth (De)	15	31,043,871**	28,630,789**	19,540,883**
E x De	600	606,941**	636,871**	942,332**
D x De	15	172,141**	296,090**	469,904**
E x D x De	600	67,943	68,062	93,823
P x De	15	261,395**	286,703**	372,351**
E x P x De	600	43,860	60,153	92,313
D x P x De	15	80,516	58,952	146,894
E x D x P x De	600	46,605	58,333	64,003
Error (c)	7503	81,970	93,960	134,338
CV (%)		27.6	28.4	27.3

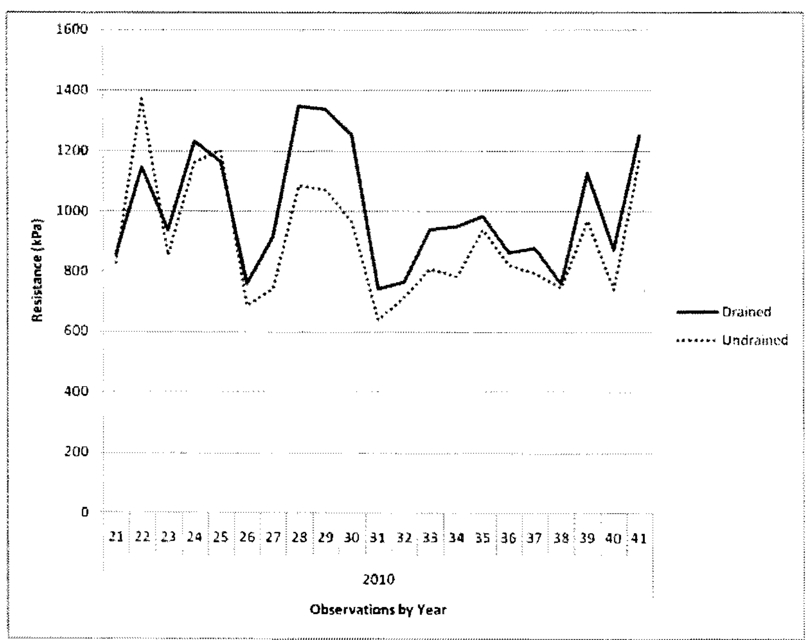
†df = degrees of freedom.

*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.



Since this is averaged over all three measurement sites, there is no LSD. This graph is to be used to observe the change from each observation. Actual date of the observations are shown on Table B1 in Appendix II.

Fig. 2.4. Soil penetration resistance for the two drainage types at each observation day averaged over all three measurement sites in 2009.



Since this is averaged over all three measurement sites, there is no LSD. This graph is to be used to observe the change from each observation. Actual date of the observations are shown on Table B1 in Appendix II.

Fig. 2.5. Soil penetration resistance for the two drainage types at each observation day averaged over all three measurement sites for 2010.

There was also a significant difference between environments for soil penetration resistance when the two different years were analyzed as separate environments. Mean squares based on years as environment are on Table B2 in Appendix II. Figure 2.6 shows the difference in crops and resistance values for both 2009 and 2010 when year was used for environment instead of each individual date. There was 383 mm of rainfall in the growing season of 2009, while in 2010 there was 639 mm of rainfall. When the ground was saturated and there was more rainfall in a given year, the soil penetration resistance value was lower.

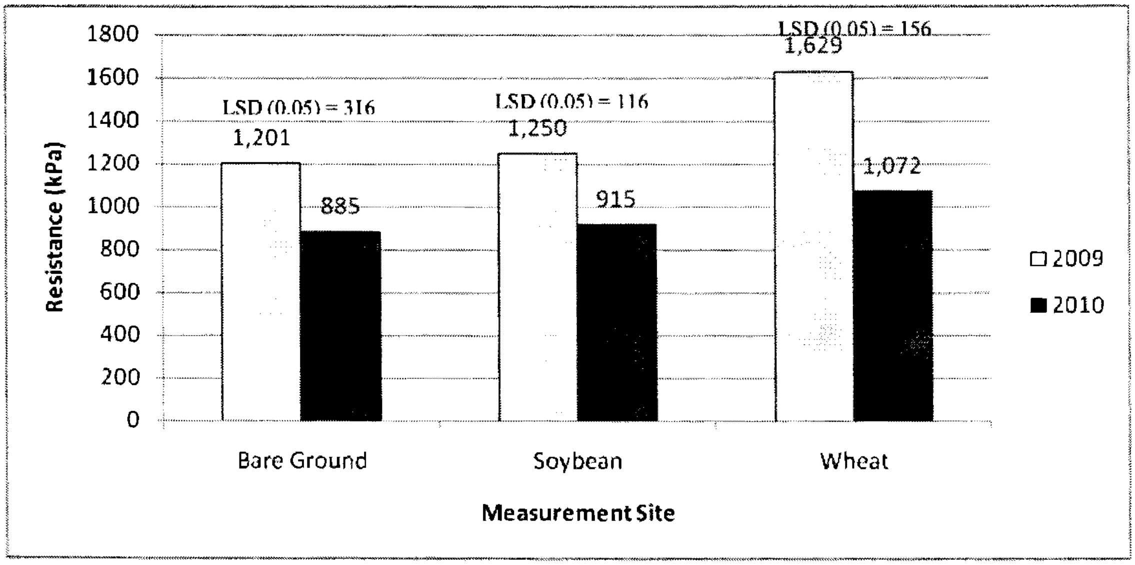


Fig. 2.6. Soil penetration resistance values for the three measurement sites in 2009 and 2010.

Drainage

Soil penetration resistance was significantly higher in the drained units for all three measuring sites (Fig. 2.7). Drainage resulted in significantly different resistance readings for all three measurement sites. During the 2010 growing season, precipitation was above normal (NDAWN, 2010). Tables 2.4 and 2.5 show the amount of rain at the time the measurements were taken. It was also visible in the field that drainage made a difference in soil penetration resistance. In October 2009, there was above average precipitation (Table 2.5), and since the crops were mostly mature and not using soil moisture, the subsurface drainage system was put to the test. The undrained soil was saturated and the plot combine had wheel slippage, while the drained soil was dry and the combine had no issues harvesting the crop. Figure 2.7 shows the soil penetration resistance values for all three sites. Wheat had the highest resistance because wheat used the most soil water during the months of July and August due to grain filling (there were soil cracks visible near the wheat and none for the other sites) and had a dense plant stand. In July and August of both years, there were not large rainfall events. Instead, both 2009 and 2010 had large rainfall events in the fall. Soybean had the next highest soil penetration resistance followed by bare ground, which would be expected to have the lowest resistance level because there is no crop using up excess water.

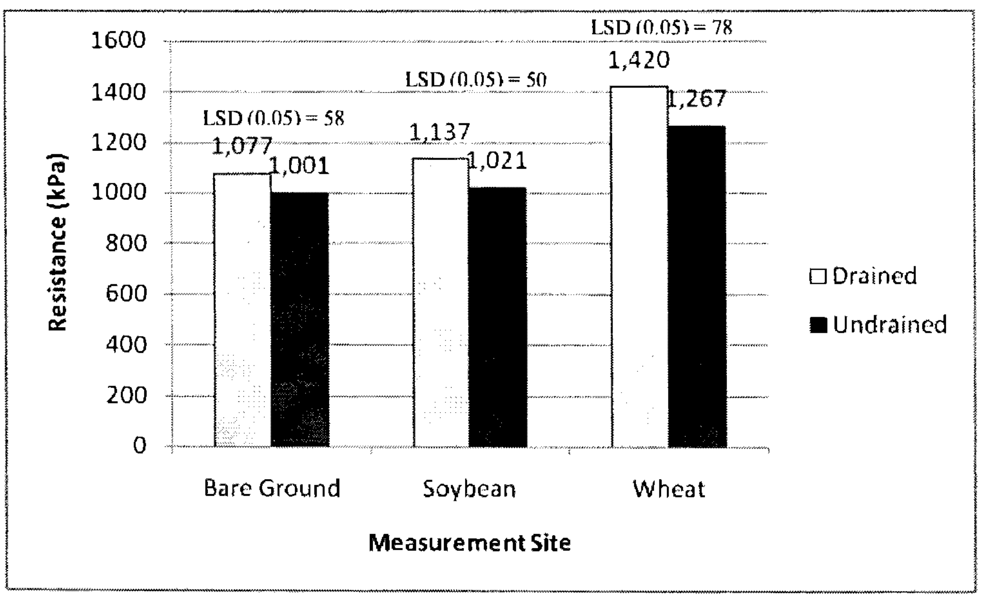


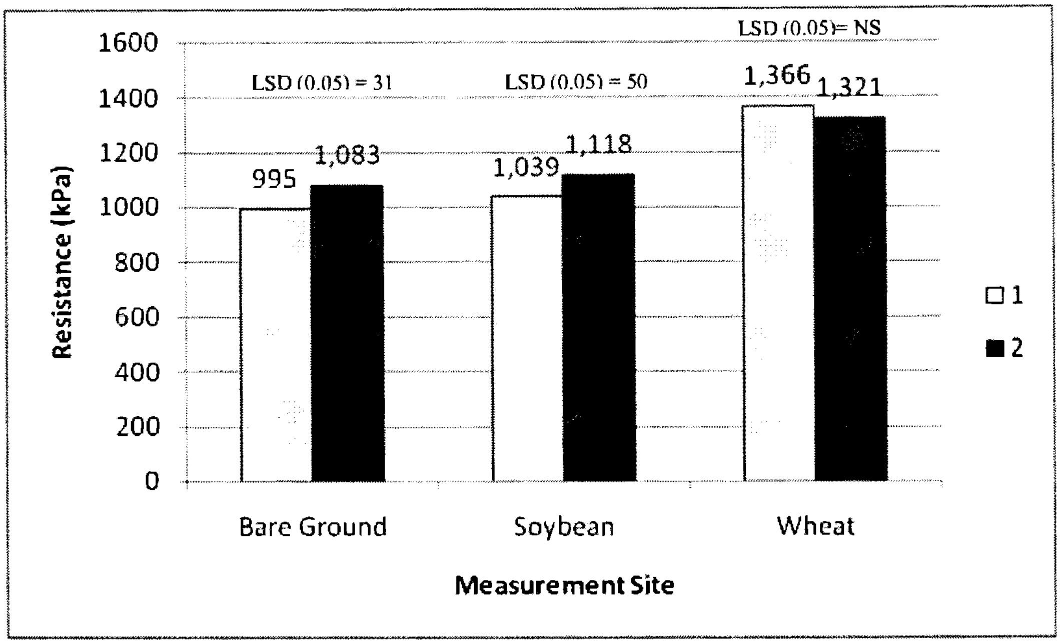
Fig. 2.7. Means of resistance (kPa) for the three measurement sites and two drainage types over the 41 observation dates.

Position

Position resulted in significantly higher resistance readings when observed between tile lines four and five compared to 1.5 m from the tile line in the bare ground and in the soybean measurement site, but not the wheat measurement site (Table 2.6). The results show that 1.5 meters from tile line four had significantly less penetration resistance than observations between tile lines four and five for the bare ground and the soybean measurement sites (Fig. 2.8). This is contrary to what was expected, and is likely due to the fact that between tile lines four and five had no crop and was tilled on a monthly basis. Tilling the soil on a monthly basis may have dried out the ground faster than the crop using soil moisture in the soybeans, so the higher resistance was measured between the tile lines. The wheat showed no difference because it likely was able to use more of the excess water and dried the soil similar to tilling the ground. Due to the fact that there were other influences involved in the drying of the soil in regards to the position, these data are difficult to interpret. Position did not significantly affect penetration resistance because of the distance of the measurements from the drain tile. Rather, the different soil conditions affected the soil penetration resistance because of tillage directly in between tile lines 4 and 5.

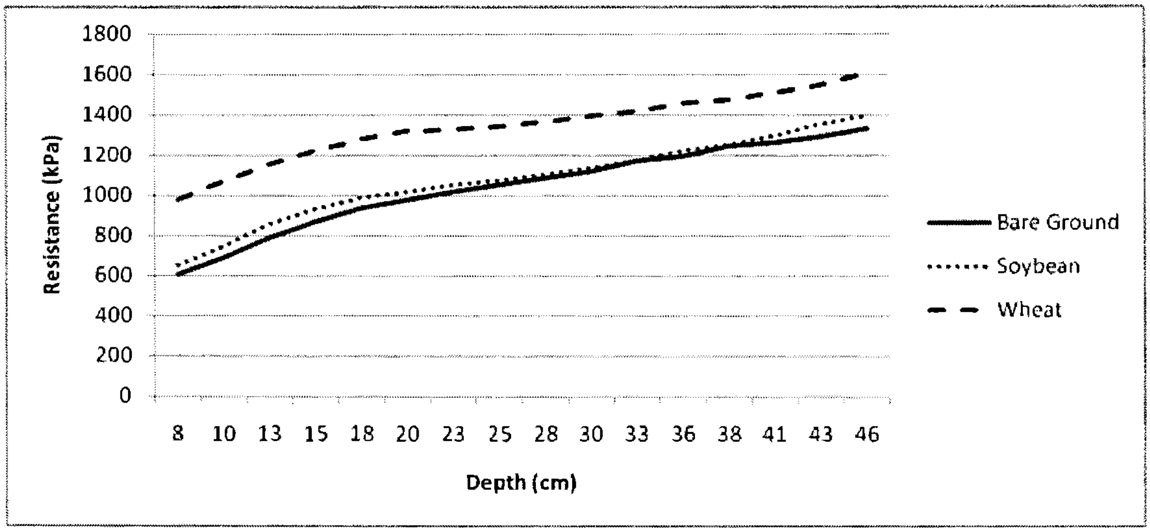
Depth

Depth penetrometer readings were significantly different for all three measurement sites (Table 2.6). Resistance increases as depth increases because the deeper into the soil, the more weight on top of that layer increases the soil penetration resistance in the area (Bornstein and Hedstrom, 1982). Figure 2.9 depicts the change in resistance level over depth for all three measurement sites. Wheat has the highest resistance level because it uses the most water early in the season compared to soybean and the bare ground.



1 = 1.5 meters from tile line 4; 2 = between tile lines 4 and 5.

Fig. 2.8. Means of different positions for three different measurement sites averaged from 8-46 cm.



For comparing readings at different depths: wheat LSD (0.05) = 105; soybean LSD (0.05) = 86; bare ground LSD (0.05) = 84

Fig. 2.9. Average soil penetration resistance at various depths and across drainage and position for the three different measurement sites.

Drain x Depth

The most important significant interaction was drainage x depth (Table 2.6). This was significant for all three crops and the graphs are shown in Figs. 2.10, 2.11, and 2.12. The drained units gained greater resistance than the undrained units the deeper measurements are taken. Both wheat and soybean are comparable in how much the drained units had an advantage, however bare ground had slightly less of an advantage due to the fact that there was no crop using excess moisture.

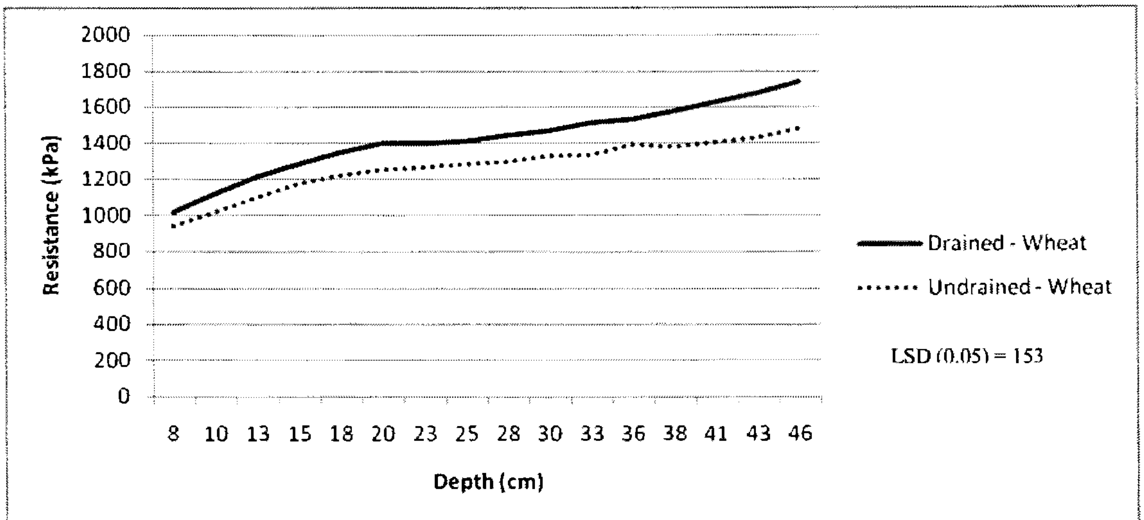


Fig. 2.10. Soil penetration resistance values for depths 8-46 cm on the drained and undrained units seeded into wheat, averaged over all environments in 2009 and 2010.

Water Table

Subsurface drainage helped lower the water table after rainfall events, and results from this study are shown in Figs. 2.13 and 2.14. In 2009, the water table was generally higher in the undrained units, and differences between drained and undrained were fairly even throughout the majority of the growing season. This was due to a lack of large rainfall events in 2009 which caused the water table to be below the tile drainage lines for much of July, August, and September. In October of 2009, there was above average rainfall (Table 2.4 and 2.5), which caused a rise in the water table and caused the drained units to have a much lower water table than the undrained units. This enabled the combine to harvest the soybeans late in the year as was described earlier. In 2010, there were many more large rainfall events than in 2009. Figure 2.14 shows that for most of the year, the water table for the undrained area was above the water table for the drained area.

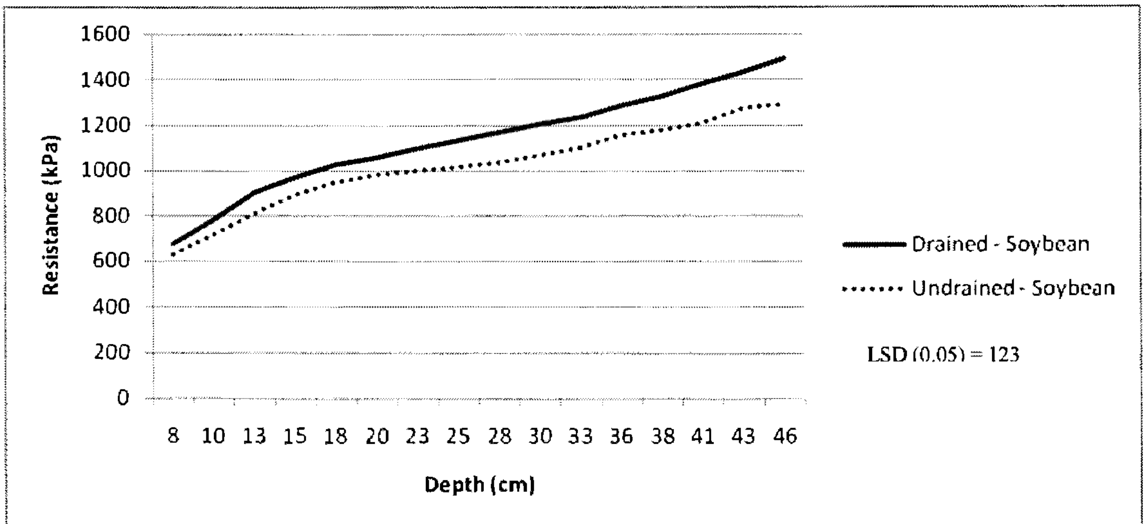


Fig. 2.11. Soil penetration resistance values for depths 8-46 cm on the drained and undrained units seeded into soybean, averaged over all environments in 2009 and 2010.

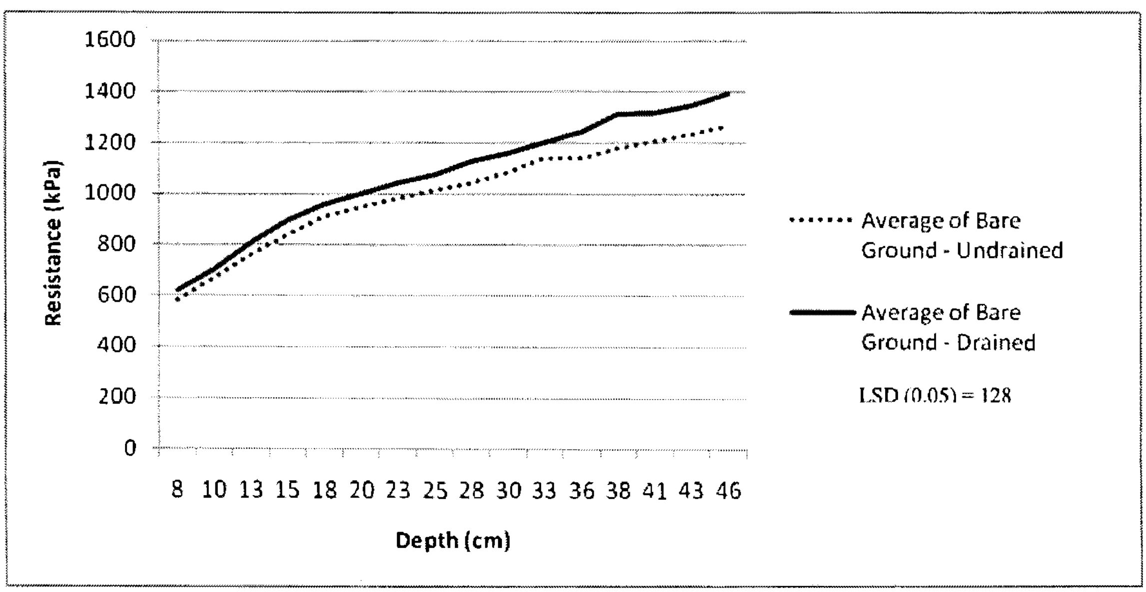


Fig. 2.12. Soil penetration resistance values for depths 8-46 cm on the drained and undrained units left as bare ground, averaged over all environments in 2009 and 2010.

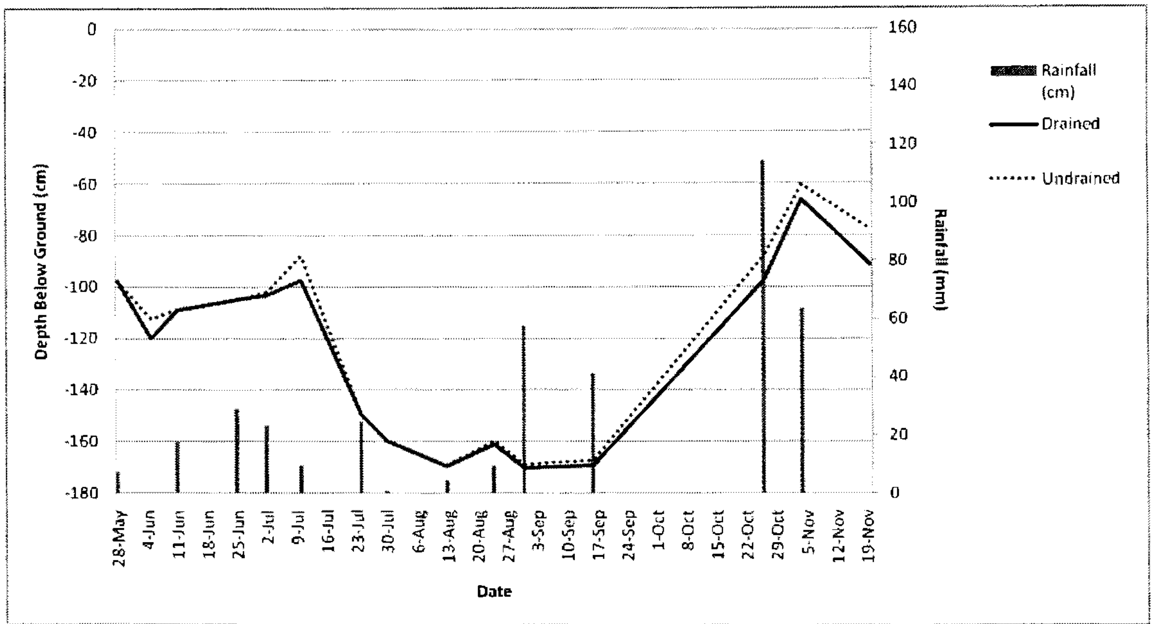


Fig. 2.13. Depth of the water table as affected by subsurface drainage over time, with rainfall for the week measurements were taken in 2009.

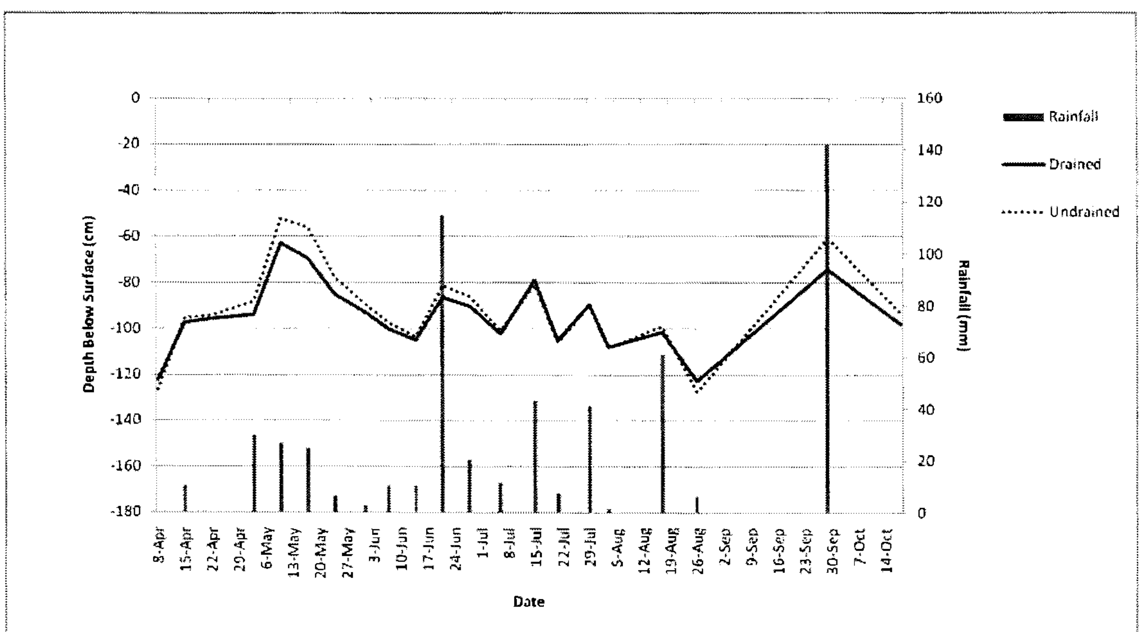


Fig. 2.14. Depth of the water table as affected by subsurface drainage over time, with rainfall for the week measurements were taken in 2010.

Temperature

Temperature was significantly higher in the drained units for only the soybean measuring site. The mean squares table for temperature is on Table B3 in Appendix II. Soybean was the only site that showed a higher temperature in the drained units because the soil was exposed early to the sun, unlike wheat which had an early crop canopy. The sun warmed up the dry soil faster because the specific heat of wet soil is more than dry soil (Marshall and Holmes, 1988). But in the wheat measurement site, being shaded due to earlier planting date and earlier growth, this warming up did not take place. Subsurface drainage had less effect on the soil temperature between drainage treatments for the bare ground likely because there was no crop grown to use excess moisture, and both drained and undrained were colder on average compared to the soybean measuring site. Table 2.7 illustrates the change in temperature for the drained and undrained units at the soybean measurement site.

Position and environment x position were significant for temperature for all three measurement sites, but due to the effect tillage had on the position values, these were not analyzed further. There were no other significant interactions based on temperature (Appendix II, Table B3).

Table 2.7. Temperature over time of the drained and undrained units at the soybean measurement site.

Observation	Undrained	Drained
2009	°C	°C
1	5.0	5.3
2	9.5	9.7
3	7.1	7.1
4	11.3	11.3
5	8.6	8.9
6	16.5	16.1
7	12.4	12.3
8	18.5	18.6
9	19.5	19.7
10	18.7	18.7
11	19.9	19.9
12	18.2	18.2
14	18.4	18.4
16	11.1	10.8
17	19.7	19.4
18	15.5	15.7
19	18.5	18.4
20	2.3	2.2
2009 Mean	**13.9**	**13.9**
2010		
21	4.2	4.5
22	8.9	9.6
23	9.6	9.8
24	7.6	7.6
25	8.0	8.4
26	12.3	12.8
27	16.7	16.9
28	17.1	17.3
29	17.8	18.0
30	15.3	15.5
31	23.1	23.3
32	18.8	18.8
34	19.3	19.2
35	21.0	21.2
36	20.7	20.3
37	22.8	22.6
38	16.5	16.8
39	18.7	19.0
40	13.7	13.7
41	10.7	11.2
2010 Mean	**15.1**	**15.3**
2009-2010 Mean†	**14.5**	**14.7**

†Temperature over time was not significant, only the 2009-2010 mean was significant (Table B3, Appendix II). The LSD to compare the 2009-2010 mean for undrained and drained is 0.18.

SUMMARY DISCUSSION

The soil penetration resistance readings and water table depth measurements were the most valuable data sets to come out of this study. Soil penetration resistance allows one to quantify the amount of force that a soil is able to withstand, allowing a certain amount of weight like a tractor to pass over that parcel of land. In this study, soil penetration resistance was significantly higher on the drained units for all of the measurement sites, which is similar to other studies that were conducted using penetrometer readings as a means to quantify trafficability (Kornecki and Fouss, 2001; Bornstein and Hedstrom, 1982). Increased soil penetration resistance means increased trafficability which allowed the soybeans in 2009 to be harvested on the tiled portion of the field without issue while on the untiled portion, soil had to be removed from the combine tires after every plot.

The difference in soil penetration resistance between drainage treatments increased with depth. This shows that the tile drainage not only dries out the surface faster, but impacts the soil deeper in the profile, allowing a good base to drive a heavy piece of machinery on. In a normal surface drained situation, the sun and the crop planted in an area can dry out the soil after the surface drainage has done its job, along with some water slowly infiltrating through the entire soil profile. Often times, the sun will dry out only soil at the surface, and if the crop is not actively growing, the subsurface soil will stay saturated. This is exactly what happened in the fall of 2009 when the plot combined had wheel slippage on the undrained soil. The subsurface drainage helped to drain the entire soil profile and not just the surface, allowing machinery to operate without any issues.

The soil penetration resistance was affected by the amount of rainfall that fell and how that rainfall, combined with the crops ability to utilize water, affected the water table depth. Water table depth was consistently lower on the drained units for the majority of time that measurements were taken. This has been proven to be true in a variety of other water table studies (Mejia et al., 1999; Wiersma et al., 2010). Also, after rainfall, the water table level increased and the drained and undrained units became closer to equal for a period of time. Several days following a rainfall event, the water table for the drained units would fall below the water table of the undrained units, creating the advantage in trafficability and overall soil water content. The water may take some time to travel through the soil profile and reach the drain tile. This has been found to be true in another study conducted in the Red River Valley (Pang et al., 2006). In that study, the water reached the pumps in the drain tile as soon as 2-3 hours after a heavy rainfall event, but could also take over 6 hours for the pumps to start. This shows the variability in a soil profile and how long it can take water to infiltrate through the soil.

Water table depth and soil penetration resistance are directly related, as can be seen in Figure 2.15. When the water table depth becomes shallower, the soil penetration resistance tends to decrease. Figure 2.15 only shows 2010 because water table measurements were not started in 2009 until May 28, once wells were installed. In 2010, there were some large rainfall events that caused drastic changes in the water table, and in turn in soil penetration resistance. The most obvious change in Fig. 15 is at the end of the year when the water table rose in September and dropped back down in October. The graph shows that the soil penetration resistance decreased when the water table became shallower.

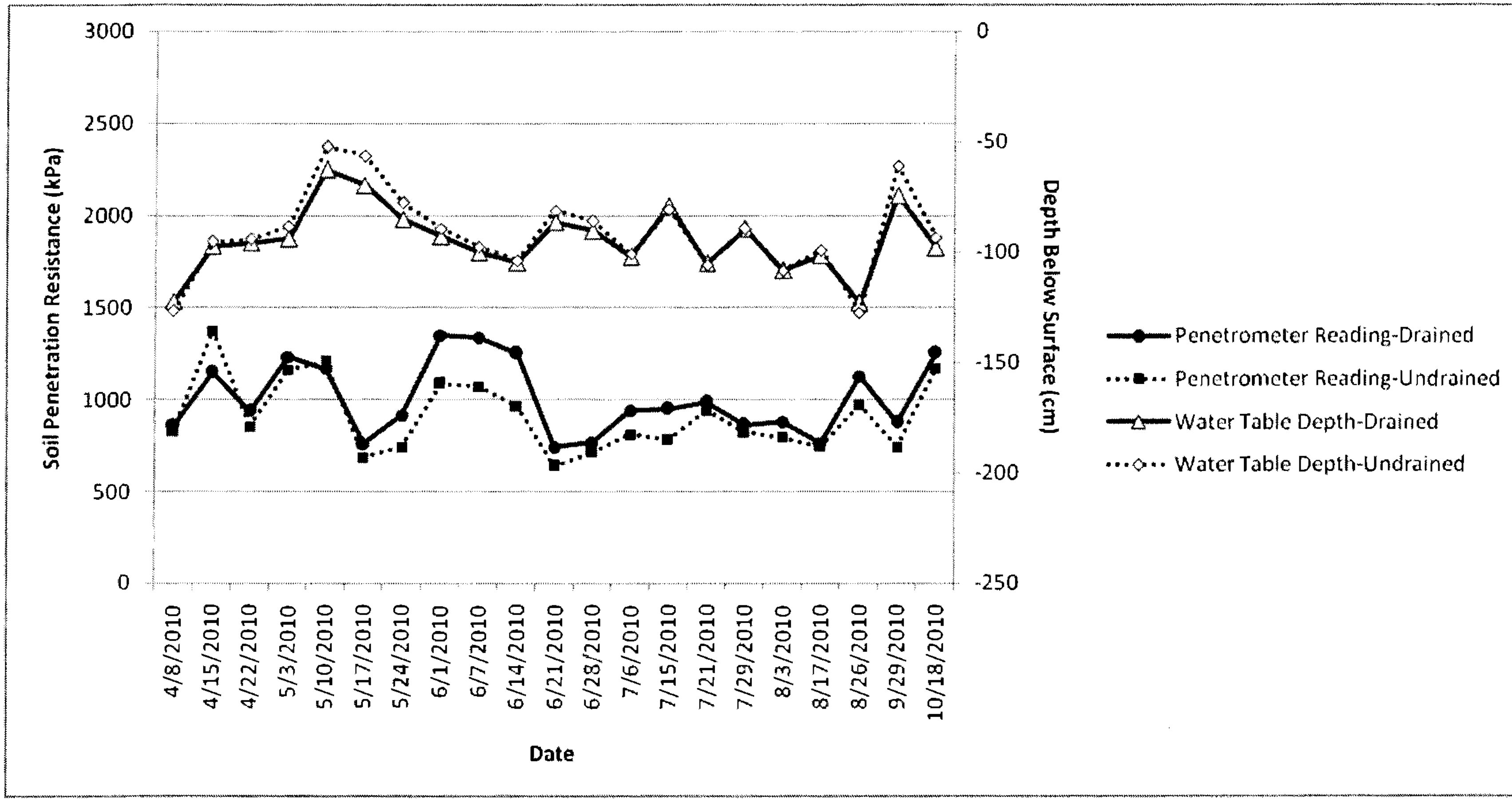


Fig. 2.15. Soil penetration resistance (kPa) with water table depth (cm) on dates of observation in 2010.

Drainage also had an effect on the temperature of the soil. The temperature was only significantly affected at the soybean measurement site. Temperature was significantly warmer on the drained units compared to the undrained units (Table B3, Appendix II). The difference was greatest in the spring when the temperature was warmer on the drained soil by as much as 0.5°C in one week in May 2010. This is similar to a study conducted by Jin et al. (2008) when they found that subsurface drainage in a cold climate can enable a soil to warm earlier in the year. Warming the soil early in the year helps a plant germinate early in the growing season, especially for warm season crops.

Future research should focus on water table effects throughout the year and on soil water content. Water table depth is very important in understanding how subsurface drainage is working. Analyzing two different crops in the same year would be beneficial to understand the effect different crops have on the water table in conjunction with tile drainage. Soil water content measurements where soil penetrometer readings take place would also be beneficial. The water table depth is useful in interpreting the soil penetration resistance, but soil water content would be more precise.

Overall, increased soil penetration resistance makes subsurface drainage desirable for farmers because it allows for timelier field applications and harvesting, possibly increasing the carry capacity of the soil allowing access for heavier equipment. The soil penetration resistance is affected by the amount of rainfall and the water table depth, which is improved with the installation of subsurface drainage. Subsurface drainage also helps improve soil temperature. The combination of soil penetration resistance, water table depth, and temperature and the results found in this study make subsurface drainage a favorable option for growers in the Red River Valley of the North.

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GENERAL CONCLUSIONS

The most important factor of this study in regards to subsurface drainage was the soil penetration resistance readings taken by the penetrometer. These readings show the true advantage of subsurface drainage is not necessarily in the yield advantage it can sometimes give a grower, but in the efficiency and timeliness of field applications and harvest. The best example of this is in 2009 when there were no yield differences between drained and undrained soybeans. However, there was a large difference in soil penetration resistance late in the year when harvest took place. There was soil that built up on the tires of the plot combine on the undrained units, but not on the drained units. From personal observations, a large commercial combine would not have been able to harvest the undrained plots and likely would not have harvested the crop prior to the ground freezing, increasing the potential for yield loss. Yield loss means a loss of money for growers, so installing subsurface drainage would mean that harvest could be completed in a timely manner so that yield loss is avoided. Also, by harvesting earlier in 2009, the quality of the soybean seed would have been better. The plants would have been harvested when they were ready, rather than getting rained on for a month so that the seeds would have been bleached and high in moisture. Therefore, despite that fact that no difference was shown in yield since both drained and undrained plots were harvested on the same day with a plot combine, subsurface drainage would likely still have increased profits in 2009.

In a large farm setting, subsurface drainage would also be able to solve inconsistencies throughout the field. Whether those inconsistencies are low areas where waterlogging occurs and cannot be solved by surface drainage or where there is a salty area in a field. Subsurface drainage in the long term might help increase productivity in a large farm setting and may allow timely field applications.

Future research should focus on water table management so that in dry years the water table is not kept too low. Over time, the open control structures will likely always outperform the closed control structures, but the issue occurs if there is a dry year and the water table is too low in the drained units. Water table management would allow for the control structures to be opened during planting, after large rainfall events, and during harvest. Opening the control structures would dry the soil and still avoid waterlogging, but closing them when there is no issue with field applications or waterlogging would keep water available in case the weather turns dry.

Overall, based on this research, subsurface drainage is a valuable tool for farmers in the Red River Valley of the North. Despite the fine textured clay soils, cold winter, and shorter growing season, subsurface drainage works and helps to improve the efficiency of farming large fields in an area that constantly has battled wet weather the last ten years. At a time when commodity prices are at a record high, improving efficiency and productivity with subsurface drainage might be an option.

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APPENDIX I

Table A1. Coefficient of variance (CV %), error mean square (EMS), and ratio between EMS of environments for agronomic traits evaluated in the Roundup Ready soybean cultivar experiment in two years, 2009 and 2010.

Trait	2009		2010		Ratio†
	CV (%)	Error Mean Square	CV (%)	Error Mean Square	
Early Stand	26.8	9,121	35.4	11,318	1.24
Late Stand	27.6	4,281	31.1	10,248	2.39
Vigor	21.6	1.2	17.4	0.6	2.00
Chlorosis Score #1	22.6	0.4	23.6	0.3	1.33
Plant Height	8.7	18.2	6.6	33.1	1.82
Seed Yield	15.2	87,971	10.2	105,253	1.20
Thousand Kernel Weight	6.0	55.9	3.3	20.6	2.71
Protein Content	1.8	0.4	2.6	0.7	1.75
Oil Content	2.9	0.3	2.6	0.2	1.50
Low Pod Height	28.5	301	29.7	622	2.07
One Bean Pods/Plant	47.2	3.2	47.8	1.7	1.88
Two Bean Pods/Plant	31.6	15	33.9	9.4	1.60
Three Bean Pods/Plant	38.7	16	44.0	20	1.25
Four Bean Pods/Plant	132.8	0.2	163.4	0.1	2.00
Total Pods/Plant	30.0	255	34.4	57	4.47
Seeds/Plant	30.8	345	36.6	354	1.03
Seeds/Pod	5.1	0.003	4.8	0.013	4.33

†Ratio: test of homogeneity (greatest EMS / smallest EMS) should be smaller than 10-fold.

Table A2. Mean squares for the analysis of variance for root scores and wet and dry root weights measured in 2010 *P. sojae* resistant soybean cultivars.

Source of Variation	df†	Mean Squares		
		Root Scores	Wet Root Weight	Dry Root Weight
Replicates (R)	2	17.4	11.3	1.1
Drainage (D)	1	11.1	20.3	1.0
Error (a)	2	30.5	11.6	0.7
Cultivar (C)	4	21.6	26.5	2.2
C x D	4	10.5	48.5**	3.7**
Seed Treatment (S)	1	2.0	0.1	0.1
D x S	1	45.2	13.7	0.7
C x S	4	64.1	10.7	0.5
D x C x S	4	12.9	20.0	1.4
Error (b)	36	23.0	11.3	0.6
CV (%)		72.0	22.0	24.3

†df = degrees of freedom.

*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

Table A3. Coefficient of variance (CV %), error mean square (EMS), and ratio between EMS of environments for agronomic traits evaluated in the seed treatment with *P. sojae* resistant soybean cultivar experiment in two years, 2009 and 2010.

Trait	2009		2010		Ratio†
	CV (%)	Error Mean Square	CV (%)	Error Mean Square	
Early Stand	24.8	8,536	33.8	9,564	1.12
Late Stand	24.5	3,355	33.2	10,152	3.03
Vigor	20.4	1.1	19.8	0.8	1.38
Chlorosis Score #1	24.0	0.4	24.7	0.4	1.00
Plant Height	7.2	12	6.0	24	2.00
Seed Yield	15.9	81,644	8.2	63,067	1.29
Thousand Kernel Weight	6.4	51	2.9	17	3.00
Protein Content	1.7	0.3	2.1	0.5	1.67
Oil Content	2.9	0.3	2.6	0.2	1.50
Low Pod Height	27.0	280	26.6	462	1.65
One Bean Pods/Plant	38.1	1.5	47.8	1.9	1.27
Two Bean Pods/Plant	31.8	12.3	35.3	11	1.12
Three Bean Pods/Plant	43.4	15.2	32.3	13	1.17
Four Bean Pods/Plant	218.0	0.3	180.8	0.3	1.00
Total Pods/Plant	31.2	112	30.5	20	5.60
Seeds/Plant	33.1	306	30.9	290	1.06
Seeds/Pod	5.9	0.0140	4.6	0.0120	1.17

† Ratio: test of homogeneity (greatest EMS / smallest EMS) should be smaller than 10-fold.

Table A4. Mean squares for the analysis of variance for agronomic traits measured in 2010 non-GMO soybean cultivars.

Source of Variation	df†	Mean Squares									
		ES†	LS†	V†	C1†	RS†	PH†	SY†	TKW†	PC†	OC†
Replicates (R)	2	14,397	48,539	3.3	0.8	17.6	32.9	119,184	54	2.5	0.2
Drainage (D)	1	22,283	31,300	5.6*	1.2	7.5	190.0	1,309,427**	264	3.3	1.8
Error (a)	2	9,445	23,597	0.1	0.1	7.5	62.2	7,729	190	7.7	3.2
Cultivar (C)	4	11,661*	22,313	1.1*	1.5**	6.0	238.1**	2,756,171**	2,021**	47.5**	8.7**
D x C	4	5,242	1,039	0.4	0.1	7.8	13.2	58,926	151	1.7	0.3
Error (b)	16	3,706	9,017	0.3	0.2	6.9	50.1	63,341	170	1.8	0.4
CV (%)		29.1	33.6	20.7	12.8	342.6	8.9	10.6	9.8	4.1	3.7

†df = degrees of freedom, ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, RS = root disease score, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.
*,** Significant at (P≤0.05) and (P≤0.01), respectively.

Source of Variation	df†	Mean Squares							
		LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
Replicates (R)	2	93	0.9	16	60	0.4	84	771	0.057
Drainage (D)	1	1,888	8.5	28	3	0.3**	48	90	0.065
Error (a)	2	408	10.1	15	11	0.0	110	431	0.030
Cultivar (C)	4	46	13.7*	115*	18	0.6	307	1257	0.086**
D x C	4	731*	6.3	21	16	0.2	53	216	0.018
Error (b)	16	177	3.8	30	33	0.2	149	827	0.013
CV (%)		20.4	45.8	44.5	48.5	163.9	42.8	44.0	4.9

†df = degrees of freedom, LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.
*,** Significant at (P≤0.05) and (P≤0.01), respectively.

Table A5. Coefficient of variance (CV %), error mean square (EMS), and ratio between EMS of environments for agronomic traits evaluated in the non-GMO soybean cultivar experiment in two years, 2009 and 2010.

Trait	2009		2010		Ratio†
	CV (%)	Error Mean Square	CV (%)	Error Mean Square	
Early Stand	26.4	2,356	29.1	3,706	1.57
Late Stand	32.6	9,864	33.6	9,017	1.09
Vigor	20.2	0.8	20.7	0.3	2.67
Chlorosis Score #1	31.9	0.6	12.8	0.2	3.00
Plant Height	8.0	15.3	8.9	50.1	3.27
Seed Yield	22.4	130,235	10.6	63,341	2.06
Thousand Kernel Weight	5.7	42	9.8	170	4.05
Protein Content	1.9	0.4	4.1	1.8	4.50
Oil Content	3.2	0.3	3.7	0.4	1.33
Low Pod Height	33.1	336	20.4	177	1.90
One Bean Pods/Plant	52.1	4.1	45.8	3.8	1.08
Two Bean Pods/Plant	48.4	37	44.5	30	1.23
Three Bean Pods/Plant	46.0	26	48.5	33	1.27
Four Bean Pods/Plant	96.0	0.2	163.9	0.2	1.00
Total Pods/Plant	45.2	159	42.8	149	1.07
Seeds/Plant	43.4	845	44.0	827	1.02
Seeds/Pod	4.6	0.010	4.9	0.013	1.30

†Ratio: test of homogeneity (greatest EMS / smallest EMS) should be smaller than 10-fold.

Table A6. Mean squares for the analysis of variance for agronomic traits measured in 2009 early maturing soybean cultivars.

Source of Variation	df†	Mean Squares									
		ES†	LS†	V†	C1†	C2†	PH†	SY†	TKW†	PC†	OC†
Replicates (R)	3	3,151	1,638	2.1	0.6	0.3	77	151,595	96	1.9	0.4
Drainage (D)	1	50,002	6,049*	0.4	0.0	0.6	93	179,734	67	0.7	0.1
Error (a)	3	12,949	252	0.9	0.4	0.4	59	341,976	224	1.7	0.8
Cultivar (C)	4	72,368**	21,126**	21.3	1.9**	2.5**	64**	1,066,367**	630**	7.3**	2.1**
D x C	4	21,468	7,703*	0.8	0.4	0.3	42	54,682	19	0.3	0.2
Error (b)	24	8,857	2,757	0.9	0.4	0.3	28	151,204	34	0.3	0.5
CV (%)		27.8	24.5	21.6	23.4	19.8	10.3	24.4	4.7	1.7	4.0

†df = degrees of freedom, ES = early stand, LS = late stand, V = vigor, C1 = chlorosis score #1, C2 = chlorosis score #2, PH = plant height, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content.
*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

Source of Variation	df†	Mean Squares							
		LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
Replicates (R)	3	632	5.5	1	91	0.6	177	689	0.0353
Drainage (D)	1	18	0.9	4	6	0.1	5	1	0.0040
Error (a)	3	520	2.3	8	31	0.3	239	461	0.0033
Cultivar (C)	4	1,426**	1.3	100**	39	1.2*	944*	1,457**	0.0078
D x C	4	507	2.3	9	10	0.2	141	221	0.0040
Error (b)	24	218	3.4	16	15	0.3	230	303	0.0054
CV (%)		25.9	52.7	33.1	34.7	127.5	28.2	28.0	6.3

†df = degrees of freedom, LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P=total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.
*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

Table A7. Mean squares for the analysis of variance for agronomic traits measured in 2010 early maturing soybean cultivars.

Source of Variation	df†	Mean Squares												
		LS†	SY†	TKW†	PC†	OC†	LP†	1P†	2P†	3P†	4P†	TP†	TS†	SP†
Replicates (R)	2	13,982	281,276	20	4.8	0.5	70	1.2	0.8	9	0.1	4	71	0.0319
Drainage (D)	1	8,062	32,815	39	0.0	0.1	617	0.0	6.5	12	0.1	0	13	0.0224
Error (a)	2	8,440	122,432	91	0.1	0.0	586	1.6	9.2	34	0.5	81	585	0.0473
Cultivar (C)	4	10,709	59,950	2,405**	1.6	0.3	206	2.3*	32.0	88**	0.7*	202*	1,355**	0.0573*
D x C	4	2,391	45,638	48	0.4	0.1	160	2.1	2.0	12	0.2	13	131	0.0261
Error (b)	16	10,897	38,924	41	0.6	0.2	370	0.7	11.4	14	0.2	35	213	0.0150
CV (%)		34.0	6.4	4.6	2.4	2.8	25.9	32.3	35.4	36.6	153.1	26.6	27.8	5.2

†df = degrees of freedom, LS = late stand, SY = seed yield, TKW = thousand kernel weight, PC = protein content, OC = oil content, LP = low pod height, 1P = total one bean pods per plant, 2P = total two bean pods per plant, 3P = total three bean pods per plant, 4P = total four bean pods per plant, TP = total pods per plant, TS = total seeds per plant, SP = average seeds per pod.

*,** Significant at ($P \leq 0.05$) and ($P \leq 0.01$), respectively.

APPENDIX II

Table B1. Actual date and rainfall (mm) of observation numbers for soil penetration resistance, water table, and temperature readings.

Observation	Date	Rainfall (mm)
1	5/1/2009	15
2	5/7/2009	2
3	5/14/2009	21
4	5/21/2009	6
5	5/28/2009	7
6	6/4/2009	0
7	6/11/2009	18
8	6/18/2009	18
9	6/25/2009	11
10	7/2/2009	23
11	7/10/2009	10
12	7/15/2009	11
13	7/22/2009	13
14	7/31/2009	1
15	8/5/2009	5
16	8/13/2009	10
17	8/24/2009	58
18	8/31/2009	0
19	9/16/2009	41
20	11/20/2009	114
21	4/8/2010	0
22	4/15/2010	10
23	4/22/2010	0
24	5/3/2010	30
25	5/10/2010	27
26	5/17/2010	25
27	5/24/2010	6
28	6/1/2010	3
29	6/7/2010	10
30	6/14/2010	10
31	6/21/2010	115
32	6/28/2010	20
33	7/6/2010	11
34	7/15/2010	43
35	7/21/2010	8
36	7/29/2010	41
37	8/3/2010	1
38	8/17/2010	61
39	8/26/2010	6
40	9/29/2010	142
41	10/18/2010	0

Table B2. Mean squares for the analysis of variance for soil penetration resistance measured in 2009 and 2010 using years as environment.

Source of Variation	df†	Mean Squares		
		Bare Ground	Soybean	Wheat
Environment (E)	1	263,224,713*	293,871,312**	814,444,748**
Replicates [E]	6	28,489,428	21,360,036	19,504,209
Drainage (D)	1	14,806,684	35,186,189	61,219,551
E x D	1	10,427,917	6,633,482	6,774,567
Error (a)	6	4,298,824	12,543,251	9,375,403
Position (P)	1	20,039,387	16,376,751	5,283,561
E x P	1	659,980	6,498,554**	2,935,240
D x P	1	411,629	1,017	404,324
E x D x P	1	293,511	173,342	5,690,271
Error (b)	6	2,880,249	666,597	2,814,806
Depth (De)	15	31,043,871**	28,630,789**	19,540,883*
E x De	15	4,034,966**	5,112,886**	6,915,272**
D x De	15	172,141	296,090	469,904*
E x D x De	15	139,674	197,802	187,337
P x De	15	261,395*	286,703**	372,351
E x P x De	15	79,356	21,127	212,797
D x P x De	15	80,516	58,952	146,894
E x D x P x De	15	79,551	80,196	95,107
Error (c)	10,350	238,250	288,464	520,717
CV (%)		47.0	50.0	53.7

†df = degrees of freedom.
*,** Significant at (P≤0.05) and (P≤0.01), respectively.

Table B3. Mean squares for the analysis of variance for temperature measured in 2009 and 2010 using dates as environment.

Source of Variation	df†	Mean Squares		
		Bare Ground	Soybean	Wheat
Environment (E)	40	652**	638**	630**
Replicates [E]	123	19	20	17
Drainage (D)	1	0.53	1.31*	0.13
E x D	40	0.20	0.22	2.15
Error (a)	123	7.60	7.70	4.43
Position (P)	1	0.01	3.53**	1.33
E x P	40	0.61**	0.73**	0.76**
D x P	1	0.01	0.01	0.27
E x D x P	40	0.08	0.10	0.11
Error (b)	246	0.10	0.10	0.16
CV (%)		2.3	2.3	2.4

†df = degrees of freedom.
*,** Significant at (P≤0.05) and (P≤0.01), respectively.