SOYBEAN PRODUCTIVITY AS AFFECTED BY RAISED SEEDBEDS AND SUBSURFACE DRAINAGE

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Soybean Productivity as Affected by Raised Seedbeds
and Subsurface Drainage

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ABSTRACT

Soils of the Red River of the North Valley (RRNV) are susceptible to waterlogging upon excessive rainfall events. Raised seedbeds and subsurface drainage are methods to reduce waterlogging in soils. The objectives of this research were to evaluate soybean [*Glycine max* (L.) Merr.] productivity when grown on raised seedbeds and/or with subsurface drainage. Soybean grain yield on raised seedbeds averaged across six environments in 2012 was similar to flat seedbeds during a dry year. Subsurface drainage increased soybean grain yield by 17% in 2011, a year which had above normal rainfall during the majority of the growing season. In 2012, a year with below normal rainfall, soybean grain yield was similar across subsurface drainage treatments. Although grain yield did not increase on raised seedbeds, grain yield was not reduced in a dry year. Subsurface drainage may be a useful tool to improve soybean productivity in the RRNV.

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INTRODUCTION

Soybean is a prominent world crop originating from Southeast Asia (Blessitt, 2008) and has become widely grown in the United States, ranking first in the world in total metric tons produced (FAO, 2011). Over the last several decades soybean production has moved northward into the Red River of the North Valley (RRNV) region of Northwest Minnesota and North Dakota. The development of earlier maturing soybean cultivars has allowed producers to include this legume crop into their rotations in more non-traditional areas. In 2011, the United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS) reported that soybean was planted to approximately 2.9 and 1.6 million ha in Minnesota and North Dakota, respectively (USDA-NASS, 2011a); accounting for a production value of 3.4 and 1.4 billion dollars, respectively (USDA-NASS, 2011b).

The RRNV, once Lake Agassiz, is known for its fertile soil that was formed when Lake Agassiz drained at the end of the age of glaciers, and deposited thick layers of fine silt over the existing mass of silt, clay, and gravel (glacial till) (Hoffman, 1979). A nearly flat plain was formed with considerably thick topsoil. Upon intense rainfall events, soil internal drainage can be poor, causing water-saturated soil. Water-saturated soil, commonly known as soil waterlogging, has long been recognized as a major production constraint in the RRNV for the field crops of soybean, corn (*Zea mays* L.), and spring wheat (*Triticum aestivum* L. emend. Thell.). Although dry-land crop production is largely dependent upon rainfall, excessive rainfall events can cause producers to be faced with major production risk.

The soybean growing season in the RRNV typically starts in May and ends in September. This relatively short growing season can limit the amount of crop growth and can cause lower grain yield compared to other growing regions with longer seasons. In the event of cool, wet springs, producers face crop production challenges. An initial struggle can be timeliness of planting which directly affects the length of the growing season. Once the crop is planted another concern can be seedling emergence and stand establishment. Poor stand establishment may force producers to replant. A third issue can be delayed or stunted plant growth. Lower yield and profitability can result from these concerns. The RRNV and surrounding areas susceptible to soil waterlogging could benefit from a raised seedbed tillage system and/or subsurface drainage which could reduce soil waterlogging and provide a more suitable rooting environment; thus, having the potential for an increase in grain yield and profitability for the producer (Siler et al., 2002; Bakker et al., 2005; Blessitt, 2008).

RESEARCH OBJECTIVES

The objectives for the soybean research were to: 1) evaluate growth and grain yield when grown on raised seedbeds in soils potentially susceptible to waterlogging; 2) determine if there is an interaction regarding grain yield among various soybean cultivars to raised seedbeds; 3) evaluate the subsurface drainage effect on growth and grain yield; 4) evaluate the foliar-applied pyraclostrobin fungicide effect on growth and grain yield; and 5) determine if there is an interaction for grain yield among various soybean cultivars with raised seedbeds and subsurface drainage, or subsurface drainage and pyraclostrobin fungicide.

LITERATURE REVIEW

Raised Seedbeds

Raised seedbed formation is described as ridging soil with intentions to have the seedbed raised on poorly drained soils (Heatherly and Elmore, 2004). Raised seedbed designs can vary in height, width, and the number of crop rows planted on each bed (Bruns and Young, 2012; Bakker et al., 2005; Tomar et al., 1996). Bed cultivation may occur prior to planting in order to clean debris out of drainage furrows (Bakker, 2005). An alternative raised seedbed system is a ridge system, commonly known as ridge-till. Ridge systems are beneficial in gentle sloping areas, soils that possess poor internal drainage, and fields with furrow irrigation (Heatherly and Elmore, 2004). In a ridge system, crops are planted into previously formed ridges. After the crop is harvested, the soil is left undisturbed to provide maximum residue cover on the soil. Pre-plant tillage may or may not occur depending upon management approach. Post-plant cultivation is used to maintain the ridges at a desired height.

In the literature reviewed, the terms raised seedbed and ridge-till are both used. Throughout this thesis the term raised seedbed will be used even if the original document called the system ridge-till. In poorly drained soils, crop production yields world-wide were higher on raised seedbeds than on traditional flat seedbeds (Bruns and Young, 2012; Blessitt, 2008; Bakker et al., 2005; Tomar et al., 1996). A 5-yr study with multiple locations covering a range of soil types in Western Australia observed that raised seedbeds increased grain yield of various crops by 18% while enhancing soil structure and reducing waterlogged effects on plants (Bakker et al., 2005). Grain yield increased in all years and at all locations, except for one dry year when grain yield was similar to the control. Bakker et al. (2005) noted that the main benefit of raised seedbeds was that the soil remained unsaturated within the top 15 cm of the bed which was influenced by lower bulk density, higher infiltration rates, and the presence of drainage furrows. The researchers suggested that unsaturated conditions in the topsoil of the raised seedbeds should reduce the negative effects of waterlogging, such as denitrification, root pruning, and collapse of soil structure, which are all related to lower productivity.

An experiment in Missouri compared corn grown on raised and flat seedbeds in a poorly drained Crowley silt loam soil (Siler et al. 2002). Corn grown on raised seedbeds resulted in increased total biomass, plant height, and root growth, which translated into 34% higher grain yield. The researchers indicated that the raised seedbeds provided a more suitable rooting environment with improved gas exchange.

Research conducted in fine-textured Vertisol soils in central India proved that soybean productivity increased when grown on raised seedbeds as compared to flat seedbeds (Tomar et al., 1996). Soybean grain yields averaged across a 12-yr study with 6 m and 9 m wide raised seedbeds yielded 2 329 and 2 218 kg ha^{-1} respectively, while the control yielded only 1 080 kg ha^{-1}. Tomar et al. (1996) also observed that root density, measured in mass per unit area, was highest in plots with 6 m wide raised seedbeds, while lowest root density was in the flat control plots.

Raised seedbeds are a common tillage strategy throughout the flat alluvial Delta soils of the Mississippi River Valley. Scientists at research and extension centers in the Mississippi Delta noticed increased soybean grain yield when grown on raised seedbeds (Henggeler, 2009; Bennett, 2008; Laws, 2007). One of the contributing factors to increased yield was more established plants on raised seedbeds early in the season after excessive rainfall created flooding and anaerobic conditions which killed germinating seeds in the flat seedbeds (Bruns and Young, 2012). Two Mississippi studies indicated that soybean grain yield increased when grown on raised seedbeds as compared to flat seedbeds (Bruns and Young, 2012; Blessitt, 2008). In the first Mississippi study, two soybean cultivars were planted in twin rows on raised and flat seedbeds (Bruns and Young, 2012). Soybean plots were furrow irrigated for raised seedbeds and flood irrigated for flat seedbeds. When comparing both cultivars in separate years, grain yield was highest on raised seedbeds, except for one cultivar in one of two years when grain yield did not differ across seedbed treatments. In the second Mississippi study, Blessitt (2008) found 23-43% greater net returns to soybean grown on raised seedbeds. Soybean was irrigated in the same manner as the previous study. In 2006, when irrigation was the primary source of soil moisture, plants were 14 cm taller, leaf area index was 52% greater, and grain yield was 620 kg ha^{-1} higher on raised seedbeds. In 2007, early season moisture was low, but excessive rainfall occurred during pod fill. Plants on raised seedbeds were 9 cm taller, leaf area index was 107% greater, and grain yield was 730 kg ha^{-1} higher.

Additionally, raised seedbed systems can be found in horticultural production (Wright et al. 2001). In raspberry (*Rubus occidentalis* L.) production, raised seedbeds are typically used to minimize moisture stress on the plants. Too much water can increase risk for soil-borne diseases and root death, while too little water can stress plants and cause reduced growth and fruit production (Goulart and Funt, 1986). When comparing shoot dry weight of raspberry grown on raised versus flat seedbeds, Wright et al. (2001) found that average total shoot dry weight was almost three-fold higher on raised seedbeds for one cultivar and three-and-a-half fold higher for another cultivar. Addition of organic matter to fine-textured clay soils improved water permeability and drainage through the soil (Funt and Bierman, 2001). Also, higher organic matter in coarse-textured sandy soils improved the soils ability to retain moisture and increased water availability to plants (Funt and Bierman, 2000). A raised seedbed system with minimal tillage in a soybean-corn rotation may allow for build-up of organic matter in the soil, thus improving soil permeability in fine-textured clay soils and water retention in coarse-textured sandy soils.

Subsurface Drainage

Subsurface drainage has been reported to reduce soil waterlogging while improving farm efficiency and productivity (Cihacek et al., 2012; Nelson et al., 2012; Brodshaug, 2011; Nelson and Meinhardt, 2011; Sands, 2001). Sands (2001) defined subsurface drainage as “the practice of placing perforated pipe at a specified grade (slope) at some depth below the soil surface.” The objective is to gravitationally drain excess water from the crop root zone through the perforations and into the subsurface drainage pipe so the water can flow to an outlet point such as a ditch. The elimination of excess water in poorly drained soils increases soil aeration and enables quicker soil drying and warming. Additional benefits include a favorable environment for crop emergence and early growth, decreased soil compaction (Sands, 2001), lower crop production risks, increasing management options, reduced seasonal wetness, and improved timeliness of field operations (Cihacek et al., 2012).

The installation of subsurface drainage has become popular in North Dakota due to the presence of soluble salts in soils and the current climatic wet periods which have caused high water tables (Cihacek et al, 2012). The advantage of subsurface drainage in North Dakota is to control the water table, but also to encourage leaching and removal of soluble salts from above the drainage pipes. As a result, soil productivity is enhanced and crop yields are improved. Franzen and Richardson (2000) identified soluble salts to cause iron deficiency chlorosis (IDC) in soybean; therefore, subsurface drainage promoting the leaching of soluble salts may reduce IDC in soybean.

Nelson et al. (2012) evaluated soybean cultivar response to drainage water management (subsurface drainage only and drainage plus subirrigation). Plant population was similar across drainage water management systems during a 2-yr study. In year one with below average precipitation, plant height was taller with drainage plus subirrigation in comparison to the control, and in the following year with high rainfall, the subsurface drainage only treatment increased plant height over the undrained control. Grain yield had mixed responses among five cultivars and drainage water management. Some cultivars responded with 18-46% higher grain yield with drainage only or drainage plus subirrigation while other cultivars had no response, which was attributed to cultivar tolerance to saturated conditions.

In another study with drainage water management, Nelson and Meinhardt (2011) observed drainage only or drainage plus subirrigation to increase soybean grain yield by 18-22%. Additionally, grain oil concentration was greater in the undrained control when compared to drainage plus subirrigation treatments. Other research found that oil content decreased as the drainage coefficient increased (Wiersma et al., 2010). Minimal differences among drainage treatments were observed in grain protein (Nelson and Meinhardt, 2011).

Opposite to the previous studies, Wiersma et al. (2010) found no differences in grain yield of soybean or spring wheat in subsurface drained and undrained treatments; however, grain protein content of both crops was higher on drained treatments. Brodshaug (2011) also found no significant differences in soybean grain yield with subsurface drainage. However, when non-genetically modified cultivars and cultivars chosen for differences in resistance to Phytophthora root rot (*Pytophthora sojae*) were compared, grain yield on drained treatments was higher in one of two years. Phytophthora root rot resistant cultivars grown on drained and undrained treatments had no differences in grain yield; although numerically the drained grain yield was higher in both years. Additional research by Brodshaug (2011) showed that the depth to water table was greater in subsurface drained soil.

No scientific literature has reported on the interaction of growing soybean on raised seedbeds with subsurface drainage. In theory, upon rainfall, rainwater might be obtained in the furrows between the raised seedbeds and may have potential for reduced surface runoff and soil erosion. In a year with above average rainfall, rainwater obtained in the furrows with subsurface drainage will have the tendency to move through the soil profile instead of "ponding" or running off the soil surface. In contrast, in a year with below average rainfall, rain water obtained in the furrows with subsurface drainage may infiltrate into the soil profile and not runoff the soil surface; thus potentially increasing plant available water.

Soil Waterlogging and Decreased Soybean Root Nodulation

Soil waterlogging is a limiting factor in soybean growth and grain yield (Matsunami et al., 2007). Under waterlogged conditions, there is little to no oxygen for root growth and development. Maekawa et al. (2011) found that the oxygen content 5 cm below the soil surface declined to almost 0 kPa within two days of initial waterlogged conditions. Soil air porosity should not be less than 8-15% in order to enable proper oxygen diffusion in soils for plant growth (Wesseling, 1974). Evans and Fausey (1999) further found that 8-15% air porosity should occur within 24-36 h of initial waterlogging to prevent negative effects to plant growth.

Soybean has a symbiotic relationship with rhizobia (*Bradyrhizobium japonicum*) bacteria, allowing soybean to convert nitrogen gas from the atmosphere into nitrogen forms available for plant growth (Maekawa et al., 2011). Nitrogen fixation in the soil is dependent upon proper soil aeration (Andreeva et al., 1987). Waterlogged conditions can inhibit soybean nodule growth and nitrogen fixation, causing plants to lack the nitrogen needed during their life cycle unless supplemented with fertilizer (Bacanamwo and Purcell, 1999). Following extended periods of soil saturation, soybean nodule deterioration can occur and has been found to be a factor in limiting grain yield (Maekawa et al., 2011). Andreeva et al. (1987) performed an experiment with five soybean plants per pot and reported that plant root nodules at the middle and deeper levels of the pot died after four to five days of waterlogged conditions.

Soybean has the ability to develop additional adventitious roots after waterlogging stress in farm fields for more than a week (Bacanamwo and Purcell, 1999). Plant tissue known as aerenchyma is formed in the stem, roots, and nodules of the plant. This tissue partially improves the gas exchange in the plant. In contrast, short-term waterlogging, for less than a week, did not cause development of adventitious roots or formation of aerenchyma. Therefore, little to no nitrogen fixation occurred that would be utilized by the plant (Huang et al., 1975). Reduced soybean yield was documented when waterlogged conditions occurred for less than a week (Griffin and Saxton, 1988). Scott et al. (1989) noticed a reduction in soybean yield in situations with only four days of waterlogging and found that the reduction was even greater in clayey soil.

Water and Heat Transport in Soil

Climatic changes including temperature and rainfall can present planting challenges to producers in the RRNV region. Planting on a raised seedbed can increase germination rate while creating an environment that is well-suited for plant development (Benjamin et al., 1990). Therefore, raised seedbeds could be an excellent tool for managing cool, wet spring conditions.

Buchele et al. (1955) noted soybean seed in wet soil had delayed germination in flat surface fields due to cool temperatures compared to seeds planted in a raised seedbed exhibiting warmer temperatures. The researchers concluded that planting in a raised seedbed could improve stand establishment and early crop growth in poorly drained soils. The warmer soil temperatures found in a raised seedbed are partly due to gravitational water drainage within the raised seedbed and to the lower specific heat of dry soil, causing the soil to warm up faster compared with wetter soil (Shaw and Buchele, 1957).

According to Benjamin et al. (1990), raised seedbeds dried out quicker than the flat seedbed control, the flat seedbed dried out quicker than the furrows between raised seedbeds, and moisture under the furrow changed only slightly. Therefore, plants grown on raised seedbeds may experience less water stress, but may still have access to water from the moisture remaining in the furrow. Furthermore, a raised seedbed could be a positive seed environment in the spring due to warmer soil temperatures promoting quicker germination.

Soil temperature can greatly influence plant vigor and growth. Voorhees et al. (1981) recognized that the optimum soil temperature for growth of most plants ranges from 20 to 30 °C. Soybean grown with subsurface drainage had a higher soil temperature than undrained soil (Brodshaug, 2011). Another subsurface drainage study in poorly drained soils of Northwest Minnesota concluded that soil temperature in the spring was up to 4 °C higher on subsurface drained soils than undrained soils (Jin et al, 2008).

Soil Compaction

Soil compaction increases the density of the soil which reduces the ability of plant roots to penetrate and explore the soil, resulting in shallow root growth, malformation, and a reduced ability to uptake water and nutrients (DeJong-Hughes et al., 2001). Under compacted soil conditions, water flow and water storage ability are severely reduced. Repetitive farm equipment traffic across the same soil area will decrease the amount of oxygen and plant root growth in the soil. Singh et al. (1971) conducted a pot experiment with sandy loam and silty loam soils and found that as the soil bulk density increased from 1.1 to 1.6 g cm^{-3}, soybean height, shoot weight, and number of trifoliolate leaves were reduced. Soil bulk density describes the amount of compaction in a soil and is formulated as the total mass of dry soil divided by the known volume of soil.

Under ideal growing conditions, lower soil bulk density can generally translate into increased root growth, greater biomass accumulation, and higher yield (Bakker et al., 2005; Hazma and Anderson, 2003). In Western Australia, soil bulk density at a 0 to 20 cm depth was lower in raised seedbeds as compared to the flat seedbed control (Bakker et al., 2005). In the northern Corn Belt, in Minnesota, Bauder et al. (1985) showed that at 15 cm below the soil surface, maximum root mass of corn was greatest after moldboard plow tillage or in a raised seedbed as compared to chisel plow tillage or no-till. At a depth of 22 to 30 cm, maximum root mass was observed in the raised seedbeds. Bauder et al. (1985) concluded that a raised seedbed system would be an appropriate tillage system in the northern Corn Belt due to plants producing greater total root length and uniform root distribution.

Surface compaction, another form of soil compaction, also has the ability to inhibit soybean plant growth and grain yield (Johnson et al., 1990). Research in southern Minnesota by Johnson et al. (1990) found that surface compaction decreased grain yield by up to 27% in a single year and 15% over locations and years. In the same study surface compaction between plant rows reduced soybean grain yield 17% at six out of nine location-years. At certain locations, lower dry matter weight was measured in the treatments with surface compaction between rows. The lower dry matter weight was found to correlate with reduced grain yield.

The negative surface compaction effect on soybean growth and grain yield could be reduced in a raised seedbed system because rain water will shed off the raised seedbed and collect in the furrow, resulting in no ponding or flooding of rain water, as could be the case in a traditional flat seedbed. Reduced surface compaction could increase plant emergence and stand establishment which might translate into higher yield, although Johnson et al. (1990) found only occasional effects of surface compaction that reduced plant emergence. However, the reduction in plant emergence did not impact final grain yield.

Iron Deficiency Chlorosis

Soybean IDC can be a severe limiting factor of grain yield. Research documented that IDC can be a common condition in calcareous soils throughout the Upper Midwest (Hansen et al., 2003), in parts of western Minnesota, North Dakota (Inskeep and Bloom, 1986; Franzen and Richardson, 2000; Goos and Johnson, 2000), and in other parts of the world such as the Netherlands (Boxma, 1972). Hansen et al. (2003) reported that IDC can be difficult to research or manage due to temporal and spatial variability in appearance of chlorosis. In some years chlorotic symptoms, found amongst the youngest leaf tissue, will fade and disappear as the plants mature while in other years symptoms can be visible throughout the entire season. Symptoms can be patchy and oftentimes are noticed in low lying areas of a field; however, Franzen and Richardson (2000) concluded that chlorotic patches were not consistent as soil types changed in a field.

Additional research has indicated that IDC can be correlated with soil moisture and soil temperature in calcareous soils. Boxma (1972) found that at soil saturation, bicarbonate content increased which correlated with an increased chlorosis incidence in pears (*Pyrus communis* L.), roses (*Rosa* sp.), and apples (*Malus sylvestris* Mill.). Boxma (1972) stated that the high bicarbonate content in the soil affected the iron uptake in the plants. Inskeep and Bloom (1986) concluded that the soil-physical variables, matric potential and air-filled porosity are good indicators for associating soil moisture with IDC in soybean. Matric potential is the potential energy of water attracted to soil particles and at values near zero, soil pores are filled with water and air-filled porosity is low (Faculty of Land and Food Systems, 2004). Matric potential and air-filled porosity can define the moisture status of the root environment and the ability for gas exchange (Inskeep and Bloom, 1986). Soybean chlorophyll content significantly decreased as the soil matric potential and fraction of air-filled porosity approached zero. Inskeep and Bloom (1986) researched the soil temperature effect on the severity of IDC and found that at a low soil temperature of 12 °C and at a high soil temperature of 26 °C, chlorotic symptoms in soybean were the greatest; whereas mid-range soil temperatures of 16 or 19 °C did not affect chlorosis. Additional research by Inskeep and Bloom (1987) in western Minnesota reported that chlorosis was associated in areas that had a concentration of the mobile soil solution ions of K^+, Na^+, Mg^{2+}, and NO_3^-.

In an effort to manage IDC in calcareous soils, proper selection of IDC tolerant soybeans for optimal yield was suggested by Froehlich and Fehr (1981). Fifteen soybean cultivars were evaluated for agronomic performance on both calcareous and noncalcareous soils. Differences in the intensity of chlorotic symptoms on calcareous soils were noted across environments while no chlorotic symptoms were expressed on noncalcareous soils. A linear relationship was found between the amount of chlorosis expression and total yield reduction. Additionally, percentage height reduction was correlated to reduction in yield, confirming that proper cultivar selection is crucial in calcareous soils. Goos and Johnson (2000) also found that cultivar selection was important for managing IDC in soybean when planted in narrow rows (15 cm). Besides selecting for IDC tolerant soybeans, perhaps a raised seedbed system or subsurface drainage may reduce excess soil moisture stress on soybean and allow for soybean to grow in a more micro-managed environment with increased oxygen availability; thus, potentially reducing IDC and generating more grain yield.

Foliar Fungicide Application in Soybean

The fungicide active ingredient pyraclostrobin {carbamic acid, [2,[[[1-(4-chlorophenyl)-1*H*-pyrazol-3-yl]oxy]methyl]phenyl]methoxy-, methyl ester} has been marketed by manufacturers to protect field crops such as soybean and corn from foliar diseases that can impair yield. Nelson and Meinhardt (2011) studied the effects of pyraclostrobin and drainage water management on soybean grain yield, grain quality, and severity of Septoria brown spot (SBS) (*Septoria glycines*) and frogeye leaf spot (FLS) (*Cercospora sojina*). Depending on the year, the severity of SBS and FLS was reduced 2-8% upon application of pyraclostrobin with or without lambda-cyhalothrin insecticide and as a result grain yield increased 20-27%. The combination of drainage water management and pyraclostrobin application resulted in a 36% increase in grain yield. Drainage water management did not change the severity of the diseases (Nelson and Meinhardt, 2011).

Blessitt (2008) conducted an experiment with soybean on raised and flat seedbeds and also applied pyraclostrobin fungicide. Analyses showed an interaction for grain yield between year and fungicide application. In the first year of the study a positive yield response occurred, but in the second year no response was detected. Environmental conditions contributed to the year responses since the first year had high rainfall early in the season that created an environment favorable for disease development and in the second year less rainfall occurred which was less favorable for disease development.

MATERIALS AND METHODS

General Description of Field Studies

Soybean field studies were conducted in North Dakota and Minnesota within the RRNV region during the 2011 and 2012 growing seasons. In 2011, field research was conducted in North Dakota on the research farm NW22 near Fargo (46˚ 55’55.81” N lat.; 96˚ 51’32.36” W long.) and near Prosper (47˚ 0’12.27” N lat.; 97˚ 6’35.09” W long.). In 2012, field research was conducted again at Fargo and Prosper with three additional locations in Minnesota near Barnesville (46˚ 30’55.76” N lat.; 96˚ 29’57.88” W long.), Rothsay (46˚ 24’45.66” N lat.; 96˚ 25’46.13” W long.), and Hitterdal (47˚ 0’23.96” N lat.; 96˚ 24’12.81” W long.). Throughout this thesis, experimental locations will be referred to as Fargo, Prosper, Barnesville, Rothsay, and Hitterdal. A description and a geographical map of the experiment locations are presented in Table 1 and Figure 1, respectively.

Table 1. Year, soil series, taxonomic class, slope, and soil pH at Fargo and Prosper, ND; and Hitterdal, Barnesville, and Rothsay, MN.

Location	Year	Soil series†	Taxonomic class†	Slope†	pH‡
				--%--	
Fargo	2011 and 2012	Fargo	Fine, smectitic, frigid Typic Epiaquerts	0-1	7.7
		Ryan	Fine, smectitic, frigid Typic Natraquerts		
Prosper	2011 and 2012	Kindred	Fine-silty, mixed, superactive, frigid Typic Endoaquolls	0-2	6.7
		Bearden	Fine-silty, mixed, superactive, Frigid Aeric Calciaquolls		
		Lindaas	Fine, smectitic, frigid Typic Argiaquolls		
Hitterdal	2012	Hamerly	Fine-loamy, mixed, superactive, frigid Aeric Calciaquolls	1-4	8.0
		Flaming	Sandy, mixed, frigid, Oxyaquic Hapludolls		
Barnesville	2012	Hamerly	Fine-loamy, mixed, superactive frigid Aeric Calciaquolls	0-2	7.7
Rothsay	2012	Hamerly	Fine-loamy, mixed, superactive, frigid Aeric Calciaquolls	0-2	7.7

† Information obtained from (USDA-NRCS, 2011).
‡ Soil pH data from a depth of 0-15 cm collected in fall 2011.

The Fargo research location is unique in the fact that it is the only replicated subsurface drainage experimental site in the RRNV. In 2008, subsurface polyethylene drainage pipe, 10 cm in diameter, was installed at 7.6 m spacings and at an approximate depth of 1 m below the soil surface. Based on the soil type, drain tile depth, slope, and pipe spacing, the drainage coefficient is 7.5 mm per 24 h.

Figure 1. Geographical map of experimental locations.
Map obtained from Google (2013) with experimental locations added.

The entire experimental area is subsurface drained and is divided into eight drainage units, each approximately 0.3 ha in size. Each unit is controlled via a water table control structure (Agri-Drain Corp, Adair, IA). Four of the units have the control structures open to represent subsurface drainage and the remaining four units have the control structures closed to represent an undrained field (Figure 2). Each unit has seven subsurface drainage lines installed with the inside five having individual research plots centered over each line as to reduce potential border effect from neighboring drainage units.

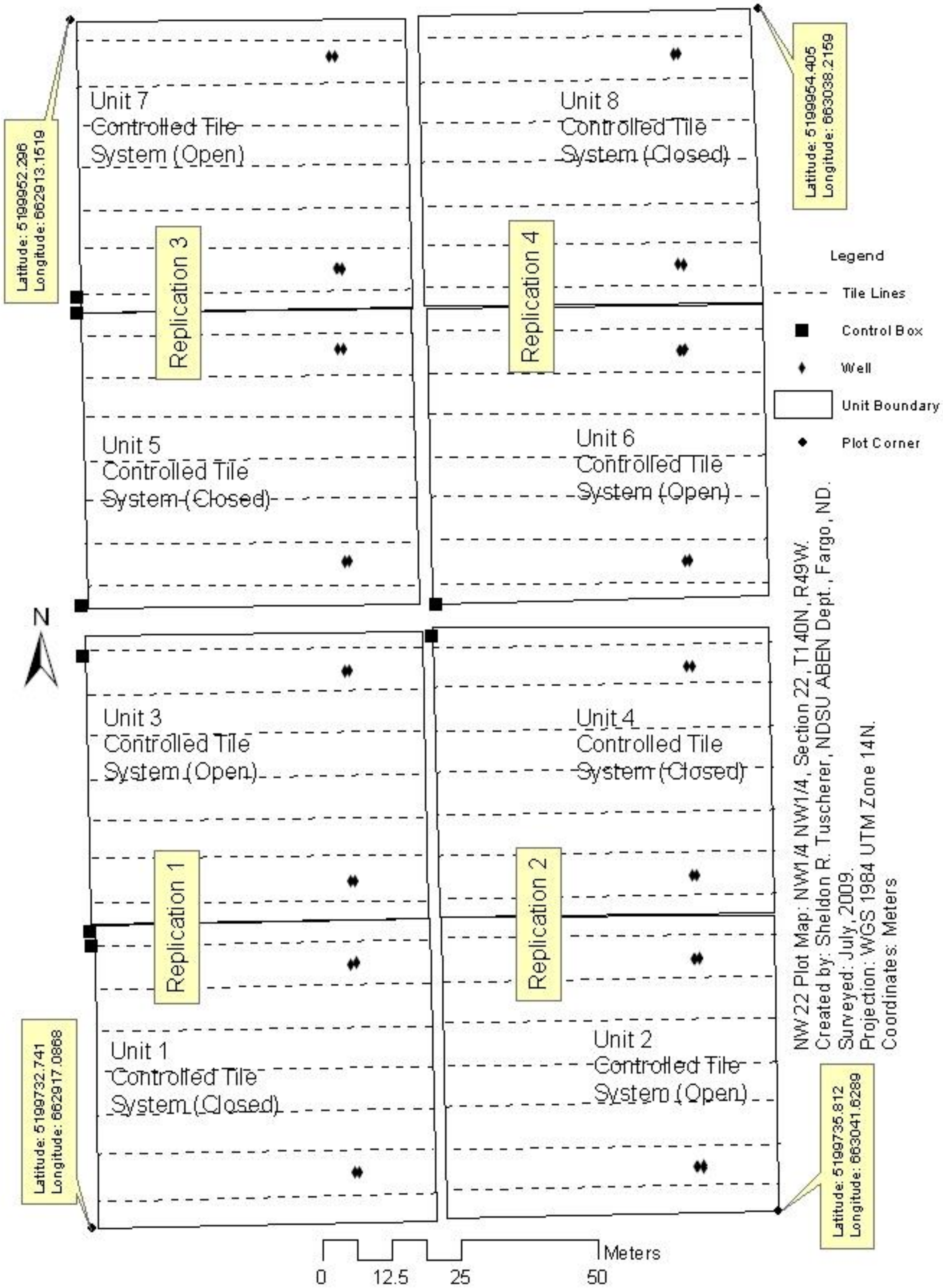

Figure 2. Experimental area at Fargo.
The area is divided into eight units: four undrained and four subsurface drained.

The experimental design at Fargo (2011 and 2012) was a randomized complete block (RCB) with a split-split-plot arrangement and four replicates. Treatment factors were different among years. In 2011, the whole-plot factor was drainage practice (undrained vs. drained), the subplot factor was foliar-applied fungicide (no fungicide vs. fungicide), and the sub-subplot factor was soybean cultivar. In 2012, the whole-plot factor was drainage practice (undrained vs. drained), the subplot factor was seedbed (flat vs. raised), and the sub-subplot factor was soybean cultivar. The experimental design used at Prosper (2011 and 2012), Barnesville, Rothsay, and Hitterdal was also a (RCB), but with a split-plot arrangement and four replicates. The whole-plot factor was seedbed (flat vs. raised) and the subplot factor was soybean cultivar. Ten glyphosate-tolerant soybean cultivars were selected based on relative maturity and level of resistance to IDC (Table 2). These ten cultivars were utilized in both years and at all locations.

Table 2. Characteristics of soybean cultivars included in the field experiments.

Company	Cultivar	Maturity†	IDC‡
Asgrow	AG 0231	0.2	2.07
Dairyland Seeds Co. Inc.	DSR-0747/R2Y	0.7	2.99
DuPont Pioneer	90Y42	0.4	2.50
DuPont Pioneer	90Y70	0.7	1.99
Dyna-Gro Seed	32RY08	0.8	1.90§
Hyland Seeds	HS 01RY02	0.1	2.17
Northstar Genetics	NS 0853RR	0.9	3.07
Proseed Inc.	90-40	0.4	2.20
Syngenta NK Brand	S02-K3	0.2	2.07
Thunder Seed	2703RR	0.3	2.61

† Maturities are based on information provided by company.
‡ IDC is based on averaged performance score over multiple locations as reported in the 2010 NDSU Soybean Performance Testing booklet (Kandel, 2010). The scale is 1 to 5 with 5 being most chlorotic.
§ IDC for cultivar 32RY08 is based on averaged performance score over multiple locations as reported in the 2011 NDSU Soybean Performance Testing booklet (Kandel, 2011).

The plots with cultivars in 2011 and 2012 at all locations were 3.04 m wide by 7.6 m long with alleys cut to separate individual plots. Individual plots had four planted rows spaced 76 cm apart. Final plot lengths were measured pre-harvest and then grain yields were adjusted to the exact plot dimensions.

A Hipper Roller (Pitonyak Machinery Corp., Carlisle, AR) was used to form the raised seedbeds at all experimental locations. The Hipper Roller was an experimental model, HR6, which was attached to a 75 horsepower tractor (New Holland, Turin, Italy) via three-point linkage. In one tractor pass, two raised seedbeds spaced 76 cm apart were formed and firmed by a 40.6 cm diameter steel drum at the rear of the machine.

General Field Procedures

Raised seedbed formation

Before seedbed formation, soil fertility levels were tested for each experimental location. A soil probe (Clements Associates, Inc., Newton, IA) was used to extract soil samples while walking in a "W" pattern throughout the complete experimental area. Five random samples were extracted from a soil depth of 0 to 15 cm and five samples from a depth of 15 to 60 cm were extracted and sent to the NDSU soil testing laboratory for analysis of NO_3^-N, P, K, pH, and OM. Supplemental fertilizer was added to the soil via a mechanical broadcast Gandy spreader (Gandy Co., Owatonna, MN) if soil test results were low, for a grain yield goal of 3 400 kg ha^{-1} based on NDSU Extension recommendations (Franzen, 2010). Trial areas were then cultivated to a depth of 15 cm to loosen the soil for raised seedbed formation.

In the spring of 2011, raised seedbeds were formed at Prosper prior to planting. At Fargo, saturated field conditions were unfavorable for raised seedbed formation; therefore, the field experiment subplot and sub-subplot factors were altered. Above average rainfall occurred in 2011 at Prosper which resulted in overland flooding and abandonment of the location. In preparation for the 2012 growing season, raised seedbeds were formed in the fall of 2011 at Fargo, Prosper, and Hitterdal. Raised seedbeds were initially formed and then formed again on a separate day as to achieve maximum height in the fall before the soil froze anticipating settling of soil when the soil thawed in the spring. At Rothsay and Barnesville raised seedbeds were only formed once due to a short period of time before the soil froze in the fall. However, two passes were completed each day so that raised seedbeds were formed to a maximum height. Raised seedbeds were formed in wheat stubble at Fargo, Prosper, and Barnesville, soybean stubble at Rothsay, and prevent plant ground at Hitterdal.

In order to monitor the raised seedbed heights during the research period, raised seedbed heights were measured in the fall of 2011 when the raised seedbeds were formed, the next spring after the soils thawed, and then again after harvest. Raised seedbed heights were not measured at Prosper in the spring 2011 due to site abandonment. In the fall 2011, the average raised seedbed height was 19 cm from top of ridge to bottom of furrow (Figure 3 and Table 3). The raised seedbed bases were approximately 50 cm wide and the surface tops of the raised seedbeds were approximately 10 cm wide. In the spring of 2012, the raised seedbeds had settled to an average height of 16 cm and by the fall of 2012, the raised seedbeds had settled to an average height of 13 cm. Data for the fall 2011 at Barnesville and Rothsay and fall 2012 at Fargo were not recorded.

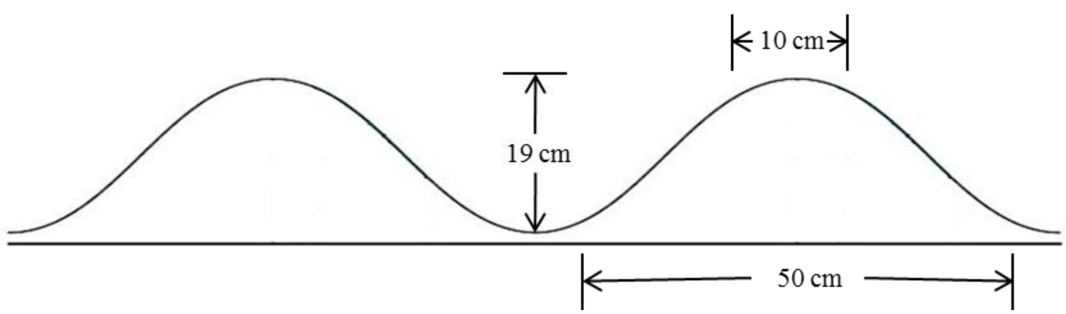

Figure 3. Diagram and size description of a raised seedbed.
Raised seedbed heights were measured with a straight edge lying on two raised seedbeds and a ruler perpendicular to the straight edge extending into the furrow.

Seed preparation

In 2011 and 2012, soybean seed received from the seed companies not having a fungicide/insecticide seed treatment was treated in a Hege 11 liquid seed treater (Hans-Ulrich, Hege, Western Germany) with the fungicide Apron Maxx RTA (Syngenta Crop Protection, Inc., Greensboro, NC) (a.i. mefenoxam and fludioxonil) at a rate of 3 ml kg^{-1} seed (a.i. mefenoxam 11.3 g L^{-1} and a.i. fludioxonil 7.55 g L^{-1}) (Table 4).

Table 3. Raised seedbed heights in fall 2011, spring 2012, and fall 2012.

Time	Fargo (undrained)	Fargo (drained)	Prosper	Hitterdal	Barnesville	Rothsay	Avg.
	-------------	-------------	-------------	cm	-------------	-------------	-------------
Fall 2011	19.9	19.8	19.4	18.4	--	--	19
Spring 2012	17.3	16.2	16.0	16.5	13.8	15.8	16
Fall 2012	--	--	11.3	14.1	10.6	13.9	13

Table 4. Soybean cultivars described with fungicide/insecticide seed treatment in 2011 and 2012.

	Fungicide/Insecticide Treatment	
Cultivar	2011	2012
AG 0231	Poncho/Votivo (a.i. clothianidin and *Bacillus firmus*)†	Poncho/Votivo (a.i. clothianidin and *Bacillus firmus*)†
32RY08	Acceleron (a.i. pyraclostrobin and metalaxyl)‡	Acceleron (a.i. pyraclostrobin and metalaxyl)‡
HS 01RY02	Apron Maxx RTA (a.i. mefenoxam and fludioxonil)§	CruiserMaxx Plus (a.i. thiamethoxam, mefenoxam, and fludioxonil)§
DSR-0747/R2Y	Apron Maxx RTA (a.i. mefenoxam and fludioxonil)§	CruiserMaxx (a.i. thiamethoxam, mefenoxam, and fludioxonil)§
S02-K3	CruiserMaxx (a.i. thiamethoxam, mefenoxam, and fludioxonil)§	CruiserMaxx (a.i. thiamethoxam, mefenoxam, and fludioxonil)§
NS 0853RR	Acceleron (a.i. pyraclostrobin and metalaxyl)‡	Acceleron (a.i. pyraclostrobin and metalaxyl)‡
2703RR	Apron Maxx RTA (a.i. mefenoxam and fludioxonil)§	CruiserMaxx Plus (a.i. thiamethoxam, mefenoxam, and fludioxonil)§
90-40	Trilex (a.i. trifloxystrobin and metalaxyl)†, Allegiance (a.i. metalaxyl)†	Trilex (a.i. trifloxystrobin and metalaxyl)†, Allegiance (a.i. metalaxyl)†
90Y42	Gaucho (a.i. imidacloprid)†, Trilex (a.i. trifloxystrobin and metalaxyl)†	Gaucho (a.i. imidacloprid)†, Trilex (a.i. trifloxystrobin and metalaxyl)†
90Y70	Gaucho (a.i. imidacloprid)†, Trilex (a.i. trifloxystrobin and metalaxyl)†	Gaucho (a.i. imidacloprid)†, Trilex (a.i. trifloxystrobin and metalaxyl)†

† Bayer Crop Science LP, Research Triangle Park, NC.
‡ Monsanto Co., St. Louis, MO.
§ Syngenta Crop Protection, Greensboro, NC.

Germination tests were completed using the “rag doll method”, where 100 seeds from each cultivar were placed onto moist paper and sealed in a plastic bag (Leary, 1945). Bags were kept at room temperature, and after one week, any seeds with a radicle visible were counted as viable. Based on the number of viable seeds and kernel weight, seed packets were prepared to plot size and at a rate of 530 000 viable seeds ha^{-1}. Seed was inoculated with Rhizo-Stick (Becker Underwood Inc., St. Joseph, MO) peat-based powder soybean inoculant containing TA-

11 NOD+ (*Bradyrhizobium japonicum*). Inoculant was applied dry at time of planting at a rate of 6 mg product per g of seed.

Planting

In 2011, at Fargo, planting occurred on the same day for both drainage treatments, when undrained soil conditions were suitable for equipment traffic. Prior to planting, soil was lightly cultivated with a field cultivator (Alloway Standard Industries, Fargo, ND) to prepare the seedbed and control any weed growth. Soybean was planted using the 75 horsepower tractor and a 4-row planter (John Deere, Moline, IL) set at 76 cm row spacing with a cone seed distribution system. In order to obtain proper seed to soil moisture contact seeding depth was chosen to be 4 cm.

Prior to planting at all five locations in 2012, flat seedbed plots were lightly cultivated to prepare the seedbed. Due to good, smooth soil conditions in the raised seedbed plots, no pre-plant tillage or reforming of raised seedbeds occurred. Soybean was seeded into both flat and raised seedbeds on the same day. The same tractor and planter were used as in 2011. Due to drier soil conditions in 2012, the seeding depth was about 5 cm. The depth of the planter was difficult to adjust between flat and raised seedbed treatments and planting depth was about 6 cm deep in raised seedbed plots.

Pesticide control

In 2011, weed control occurred at the three-trifoliolate (V3) and again at the beginning bloom (R1) growth stages (Fehr et al., 1971). Roundup WeatherMAX (a.i. glyphosate, N-(phosphonomethyl) glycine, in the form of its potassium salt) (Monsanto Co., St. Louis, MO) at a rate of 2.4 L ha^{-1} (a.i. 1.58 kg ha^{-1}) was applied through TeeJet 8001 XR nozzle tips in 93.5 L ha^{-1} spray volume at 200 kPa spray pressure. In 2011, insecticide was applied due to soybean aphid (*Aphis glycines*) levels reaching the 250 aphid plant^{-1} economic injury threshold. Asana XL (a.i. esfenvalerate (S)-cyano (3-phenoxyphenyl) methyl (S)-4-chloro-alpha-(1-methylethyl) benzeneacetate) (DuPont, Wilmington, DE) at a rate of 0.55 L ha^{-1} (a.i. 0.04 kg ha^{-1}) was applied through TeeJet 8001 XR nozzle tips in 93.5 L ha^{-1} spray volume at 200 kPa spray pressure.

In 2012, weed pressure existed in the raised seedbed plots at planting time. Herbicidal control occurred within a few days after planting, as to ensure no weed competition before crop emergence. Roundup WeatherMAX at a rate of 2.4 L ha^{-1} (a.i. 1.58 kg ha^{-1}) was applied through TeeJet 8001 XR nozzle tips in 93.5 L ha^{-1} spray volume at 200 kPa spray pressure. Post emergence weed control was performed at the V3 growth stage and again at the full bloom (R2) growth stage. Roundup WeatherMAX was applied with the same practices as early in the season.

In 2012, the soybean aphid economic injury threshold was not reached; however, two-spotted spider mite (*Tetranychus* urticae) pressure occurred late in the growing season. Insecticide was applied when leaf stippling (i.e. tiny white spots) was evident. At Hitterdal, Dimethoate 4E (a.i. Dimethoate: O,O-dimethyl-S-[(methylcarbamoyl) methyl] phosphorodithioate) (Cheminova, Inc., Research Triangle Park, NC) at a rate of 1.17 L ha^{-1} (a.i. 0.56 kg ha^{-1}) was applied through TeeJet 8001 XR nozzle tips in 140 L ha^{-1} spray volume at 200 kPa spray pressure. Leaf stippling was also evident at Barnesville and Rothsay; however, due to a small supply of Dimethoate 4E, Cobalt Insecticide (a.i. chlorpyrifos: O,O-diethyl-O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate) (Dow Agro Sciences, Indianapolis, IN) at rate of 2.78 L ha^{-1} (a.i. 0.82 kg ha^{-1}) was applied through 8001 XR nozzle tips in 140 L ha^{-1} spray volume at 200 kPa spray pressure. One insecticide application appeared to be effective in managing spider mite populations.

Fungicide application

Headline fungicide (a.i. pyraclostrobin: {carbamic acid, [2-[[[1-(4-chlorophenyl)-1*H*-pyrazol-3-yl]oxy]methyl]phenyl]methoxy-, methyl ester}) (BASF Corp., Ludwigshafen, Germany) was applied to the sub-subplots at the beginning pod (R3) growth stage. A backpack sprayer (Bellspray, Inc., Opelousas, LA) with TeeJet 8001 XR nozzles set at 200 kPa spray pressure was used to apply the fungicide at a rate of 0.44 L ha^{-1} (a.i. 0.11 kg ha^{-1}) with a spray volume of 93.5 L ha^{-1}. The nonionic surfactant, Preference (principal functioning agents: alkylphenol ethoxylate, sodium salts of soya fatty acids, and isopropyl alcohol) (WinField Solutions, St. Paul, MN), was added to the tank mixture at 0.125% total volume basis. No disease data were recorded for each cultivar during the growing season.

Agronomic data collection

Throughout the growing season, agronomic data were collected from the two inside rows of the four row plots for stand counts, vigor, IDC, canopy closure, and plant height in both years and at all locations. At the V2 growth stage, stand counts were obtained by counting the number of plants in rows two and three of a 90 cm length of a randomly selected representative area. Stand count values were then adjusted to represent plants ha^{-1}. Vigor scores were recorded twice within the growing season, early vigor at the V4 growth stage, and late vigor at the R3 growth stage. A visual score (1-9) was recorded for each plot with one indicating poor plant vigor, and nine indicating best plant vigor. Ratings for IDC were scored for each plot at the V4 growth stage. A visual score (1-5) was recorded with one indicating no chlorotic plant tissue and five indicating necrotic/dead plant tissue, as described by Goos and Johnson (2008). Canopy closure was visually scored at the full seed (R6) growth stage as a percent of plant canopy closure. Plant heights were measured at the physiological mature growth stage (R8) by measuring from the soil surface to where the uppermost pod on the main stem of the plant was attached. Also at the R8 growth stage two random-representative plants from each plot of either rows one or four were cut with a shears at the soil surface and then collected. Plant samples were examined in the laboratory for lowest pod height (measured from the stem cutoff point to where the lowest pod was attached to the main stem), number of pods per plant with one, two, three, and four seeds, total number of seeds per plant, and the average number of seeds per pod was calculated. Data were averaged across both plants for analysis.

Soybean root analysis

Soybean plants of two cultivars, 01RY02 and NS 0853RR, were dug and removed from a random part of the plot in either row one or four (these rows were not used for yield data) at the R6 growth stage at Prosper, Hitterdal, and Barnesville. These experimental locations were selected based on a geographical representation of all locations. The sample distance for soybean plants removed was equal to the width of a 19 cm spading fork. The spading fork was then used to remove the plants and roots from an approximate depth of 15 cm in the soil. Soybean roots were carefully washed in water. Roots were separated by cutting the stem at the point where the cotyledon leaves had previously been joined to the main stem. Roots were placed in a paper bag and dried at 95 °C. After 100 h the roots were removed and weighed with a scientific scale (Mettler-Toledo XS6001S, Columbus, OH). Average mass per plant root system was calculated by dividing total sample root mass by total number of plant roots in each sample.

Soybean harvest data

Soybean plots were harvested with a Wintersteiger Classic plot combine (Wintersteiger Ag, Ried, Austria). Only the two inside rows of the four row plot were harvested for grain yield in order to reduce bordering treatment effects. Harvest samples were brought to the laboratory, cleaned (Clipper Office Tester and Cleaner, Seedburo Equipment Co., Chicago, IL), and weighed with the above mentioned scientific scale. Harvest moisture and test weight were then recorded with a GAC 2100 moisture tester (DICKEY-John Corp., Minneapolis, MN). Final plot grain yield was adjusted to a moisture content of 13%. Thousand kernel weights were calculated by counting five hundred seeds with a seed counter (Model 850-3, International Marketing and Designer Corp., San Antonio, TX), weighing the seeds with the scientific scale, and then doubling the weight which was adjusted to a moisture content of 13%. Protein and oil content were measured with a Diode Array 7200 NIR Analyzer (Perten Instruments, Springfield, IL) and adjusted to 13% grain moisture. Dates of field measurements or applications are presented in Tables 5 through 7.

Table 5. Dates of field measurements or applications at Fargo for growing season 2011.

Measurement/Application	Date
Soybean seeded	6 June
Weed control	20 June
	13 July
Stand counts	30 June
Vigor scores	11 July
	8 Aug.
IDC scores	18 July
Insecticide applied	4 Aug.
Fungicide applied	4 Aug.
Canopy closure scores	8 Aug.
Plant heights	16 Sept.
Plant analysis	20 Sept.
Soybean harvested	6 Oct.

Table 6. Dates of field measurements or applications at Prosper for growing season 2011.

Measurement/Application	Date
Raised seedbed formation	8 June
Soybean seeded	8 June
Stand counts	8 July
Site abandonment	15 July

Table 7. Dates of field measurements or applications at Fargo, Prosper, Hitterdal, Barnesville, and Rothsay for growing season 2012.

	Date				
Measurement/Application	Fargo	Prosper	Hitterdal	Barnesville	Rothsay
2011	----------Date----------				
Raised seedbed formation - (1st time)	9 Sept.	7 Sept.	3 Oct.	16 Nov.	1 Nov.
Raised seedbed Formation - (2nd time)	19 Oct.	20 Oct.	26 Oct.	--	--
2012					
Soybean seeded	10 May	9 May	11 May	11 May	14 May
Weed control	14 May	14 May	14 May	14 May	14 May
	12 June	5 June	12 June	12 June	12 June
	9 July	29 June	9 July	9 July	9 July
Stand counts	25 June	6 June	5 June	7 June	7 June
Vigor scores	29 June	28 June	28 June	28 June	28 June
	20 Aug.	21 Aug.	20 Aug.	20 Aug.	20 Aug.
IDC scores	29 June	28 June	28 June	28 June	28 June
Canopy closure scores	24 July	24 July	20 July	20 July	20 July
Insecticide applied	--	--	6 Aug.	14 Aug.	14 Aug.
Root analysis	--	23 Aug.	27 Aug.	24 Aug.	--
Plant heights	12 Sept.	12 Sept.	12 Sept.	12 Sept.	12 Sept.
Plant analysis	17 Sept.	17 Sept.	17 Sept.	17 Sept.	17 Sept.
Soybean harvested	26 Sept.	20 Sept.	19 Sept.	19 Sept.	19/26 Sept.†

†Reps 2 through 4 were harvested later due to delayed maturity.

Bulk density measurements

In 2012, soil bulk density was measured in flat and raised seedbed plots at Prosper, Barnesville, and Hitterdal. Experiment locations were selected based on differences in soil type and geographical representation of all locations. The procedure was completed three times at Barnesville on 7 June, 14 August, and 15 October, twice at Prosper on 6 June and 6 August, and twice at Hitterdal on 5 June and 3 August. During the process, a hole was carefully dug as to not compress the hole edges to an approximate size of 30 cm wide, 60 cm long, and 38 cm deep. The location of the hole was between rows three and four, but as close to row four as possible. A soil core of 90 cm^3 was extracted, nearest row four, from sample depths of 5 cm, 15 cm, and 30 cm, measuring from the soil surface of flat seedbeds and from the soil surface top of the raised seedbeds. Each sample was placed into a tin container, weighed, and then put into a soil drying oven (Thelco-Model 18, GCA Corp., Chicago, IL) at 105 °C. After 24 h the samples were taken out of the drying oven, cooled for five minutes, and then reweighed. Bulk density was then calculated as oven dry weight of soil/volume of soil.

Soil and ambient temperature sensors

In 2012, soil temperature sensors (HOBO Model U23 Pro v2 2x External Temperature Data Logger – U23-003) (Onset Computer Corporation, Inc., Posasset, MA) were installed at Fargo and Hitterdal to collect soil temperature data. These locations were selected based on differences in soil type. Sensors were installed in one flat and one raised seedbed plot per rep, approximately 3 cm below the soil surface of flat seedbeds and below the soil surface top of the raised seedbeds. At Fargo, the soil temperature sensors were installed with the same method as Hitterdal, but only in the undrained whole plots. Soil temperature sensors were programmed to start collecting data on 11 May soon after planting and were removed on 3 August after soybean rows had mostly canopied the soil between the plant rows. Soil and ambient temperatures were logged every 30 minutes and then were averaged across time of day. Only three replicates per location were analyzed due to sensor operation error.

Weather data

Weather data including maximum, minimum, and mean (average of maximum and minimum) air temperature and rainfall for the 2011 and 2012 growing seasons were obtained for the experimental locations via the North Dakota Agricultural Weather Network (NDAWN, 2013). The data source for all experimental locations was the nearest located weather station. Weather stations were selected as follows (text in the parentheses state what station was the source and approximately how far located from the experiment location): Fargo (Fargo station, 6 km); Prosper (Prosper station, right at experiment station); Hitterdal (Perley, MN station, 32 km), Barnesville and Rothsay (Wahpeton, ND station, 32 km from Barnesville and 24 km from Rothsay).

Water table depth

Water table depths of subsurface drained and undrained units (whole plot effect) were measured at Fargo. Within each of the eight units (four subsurface drained and four undrained) there are four wells that extend into the ground which were used to measure the water table depth below the soil surface (Figure 2). Two adjacent wells are located on the north side of the unit and two adjacent wells are on the south side of the unit. Of the two adjacent wells, one well is 1.2 m deep and the other is 2.1 m deep. Once each week water depths of the eight water table control structures (each controlling one unit) and the 32 total wells were measured using a Solinst water level meter model 101 (Solinst, Georgetown, ON, Canada). Water table depths were recorded from top of well to water depth. Late in the 2011 growing season, some water table values were not obtained in the shallow well due to a low water table from the crop using water in the soil profile and limited rainfall. During 2012, even less rainfall occurred which caused the water table to lower even more than in 2011; therefore, many of the water table depths were not obtained in the shallow wells and even in the deeper wells. Recorded water depths were averaged across each drainage treatment. Due to too few measurable wells late in 2012, only data from 4 April to 1 September were used for 2012 comparisons. Two rain gauges were stationed at Fargo and used to observe the rainfall for 2011 and 2012. Figures were created to compare water table depths of drainage treatments as affected by the observed rainfall from the two rain gauges of which the values were averaged together.

Statistical analysis

The statistical software SAS with the PROC MIXED procedure (SAS Institute Inc., Cary, NC) and Type 3 ANOVA tests were used to analyze treatment data. Six environments of data were available for the raised seedbed experiment in 2012 [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay]. In order to combine the split-split plot design arrangement at Fargo with the split-plot design of the other environments, Fargo data were divided into undrained and drained data, creating two environments at one location. The three factor experiments for Fargo 2011(drainage x fungicide x cultivar) and Fargo 2012 (drainage x seedbed x cultivar) were analyzed as a separate environments and then combined for drainage x cultivar data. In order to combine the drainage experiments, fungicide data in 2011 and seedbed data in 2012 were not considered a factor for analysis. Fixed effects in the analysis were drainage, fungicide, seedbed, and cultivar with all other factors considered random effects. At Barnesville replicate four was eliminated due to outside influences that were considered a non-treatment effect. All means were separated using a paired t-test at the 5% level of significance, except for soil temperature, soil bulk density, and root mass means which were analyzed at the 10% level of significance.

Note: Mention of trade names, proprietary products, or vendors does not constitute a guarantee or warranty for the product by North Dakota State University and does not imply its approval to the exclusion of other products or vendors that may be suitable.

RESULTS AND DISCUSSION

2011 Weather Data

The production years 2011 and 2012 differed widely from each other for total rainfall precipitation and air temperature as observed by NDAWN weather stations (Tables 8-11). Above normal snowfall during the 2010-2011 winter, along with unseasonably cool air temperatures and above normal rainfall in April and May, led to an abnormally late soybean seeding date. During the time period of April through August, total rainfall was above the 30-yr (1981-2010) historical average (normal) at Fargo and Prosper (Table 8). The Fargo weather station recorded 93 mm of rainfall above normal from April to August which caused some periodic overland flooding at the Fargo experimental site. Flooded field surfaces typically drained within two days either via surface or subsurface drainage. The Prosper weather station recorded 126 mm of rainfall above normal from April to August, and 62 mm above normal for July alone, all which led to major overland flooding and forced abandonment of the Prosper experiment. Rainfall occurrence and amounts of rainfall at Fargo and Prosper declined in mid-August, with months thereafter recording below normal rainfall. Total growing season rainfall was close to normal.

Table 8. Monthly total rainfall for 2011, 2012, and historical data at Fargo and Prosper, and 2012 rainfall and historical data at Hitterdal, Barnesville, and Rothsay.

	Total rainfall									
	Fargo			Prosper			Hitterdal		Barnesville and Rothsay	
Month	2011	2012	Historical†	2011	2012	Historical	2012	Historical	2012	Historical
	mm									
April	46	29	35	45	30	37	15	36	80	45
May	110	43	71	80	46	78	38	82	37	81
June	101	57	99	132	67	100	56	114	75	83
July	104	30	71	150	16	88	16	93	46	81
August	73	21	65	89	23	67	36	70	52	62
September	4	1	65	6	15	66	3	67	9	74
October	21	62	55	9	45	62	50	57	38	61
Total	457	244	461	511	242	496	214	519	336	486

† Historical data represent a 30-yr average from 1981-2010 (NDAWN, 2013).

Monthly mean air temperatures were below normal at the beginning of the 2011 growing season and were above normal towards the end of the growing season (Table 9). Mean maximum air temperatures were below normal during April, May, and June and above normal during July, August, September, and October (Table 10). Mean minimum air temperatures were above normal for all months except September (Table 11).

Table 9. Monthly mean air temperature for 2011, 2012, and historical data at Fargo and Prosper, and 2012 and historical data at Hitterdal, Barnesville, and Rothsay.

	Mean air temperature									
	Fargo			Prosper			Hitterdal		Barnesville and Rothsay	
Month	2011	2012	Historical†	2011	2012	Historical	2012	Historical	2012	Historical
	°C									
April	6	9	7	5	8	6	8	7	9	7
May	13	16	14	12	15	13	15	14	16	15
June	19	21	19	19	20	19	20	19	21	20
July	24	25	22	23	24	21	24	22	24	22
August	22	21	21	21	20	20	20	21	19	21
September	15	15	15	15	15	15	14	15	15	16
October	11	7	8	11	6	7	6	8	6	8

† Historical data represent a 30-yr average from 1981-2010 (NDAWN, 2013).

Table 10. Monthly mean maximum air temperature for 2011, 2012, and historical data at Fargo and Prosper, and 2012 and historical data at Hitterdal, Barnesville, and Rothsay.

	Mean maximum air temperature									
	Fargo			Prosper			Hitterdal		Barnesville and Rothsay	
Month	2011	2012	Historical†	2011	2012	Historical	2012	Historical	2012	Historical
	°C									
April	11	15	13	9	15	13	15	14	15	14
May	18	23	21	18	23	21	22	21	23	22
June	24	27	25	24	27	25	27	25	28	26
July	29	31	28	29	32	28	31	28	31	29
August	28	28	27	28	29	28	28	27	27	28
September	23	23	22	23	24	22	23	22	24	22
October	17	11	13	17	11	14	11	13	12	14

† Historical data represent a 30-yr average from 1981-2010 (NDAWN, 2013).

2012 Weather Data

During the 2011-2012 winter, abnormally low snowfall occurred along with unseasonably warm air temperatures. Contrary to 2011, soybean seeding dates were normal. Total rainfall was well below normal during majority of the months of the 2012 growing season

(Table 8). Between the months of April and October, Hitterdal received about 60% less rainfall, Fargo and Prosper received about 50% less rainfall, and Barnesville and Rothsay received 30% less rainfall than normal. At all six environments monthly mean, maximum, and minimum air temperatures were mostly above normal except in the latter months of the growing season (Tables 9-11).

Table 11. Monthly mean minimum air temperature for 2011, 2012, and historical data at Fargo and Prosper, and 2012 and historical data at Hitterdal, Barnesville, and Rothsay.

	Mean minimum air temperature									
	Fargo			Prosper			Hitterdal		Barnesville and Rothsay	
Month	2011	2012	Historical†	2011	2012	Historical	2012	Historical	2012	Historical
	°C									
April	2	3	0	0	1	-1	1	0	2	1
May	8	9	7	6	8	6	8	7	9	8
June	14	15	13	13	13	12	13	13	14	13
July	18	19	15	17	17	14	17	15	18	16
August	16	13	14	14	11	13	12	14	12	14
September	8	7	9	7	5	8	5	9	5	9
October	5	2	2	4	0	1	1	2	0	2

† Historical data represent a 30-yr average from 1981-2010 (NDAWN, 2013).

Raised Seedbed Experiment

Agronomic data from the six individual environments were analyzed. Mean square tables for individual environments are presented in Appendix A1-A6. Residual mean squares of agronomic traits were homogenous across environments; and therefore, environments were combined for analysis. A mean square table for the combined analysis can be viewed in Appendix A7. Levels of significance for agronomic traits for seedbed (flat or raised), cultivar, and various interactions averaged across environments are provided in Table 12.

Seedbed

The 2012 growing season was relatively dry with below normal rainfall, and no differences in agronomic traits were observed across seedbed effect (Table 13). Individual environment tables indicating means of agronomic traits for seedbed effect can be viewed in Appendix A8-A13. One of the main purposes of raised seedbeds is to promote growth and development of crops in poorly drained soils which likely can translate into higher grain yield (Blessitt, 2008; Bakker et al., 2005; Heatherly and Elmore, 2004).

Table 12. Levels of significance for the ANOVA of agronomic traits for six seedbed environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

SOV†	df	df‡	SC	EV	LV	IDC§	CC	PH	TKW	GY
Environment (E)	5	4								
Rep (E)	17	14								
A [seedbed]	1	1	ns	ns	ns	ns	ns	ns	ns	ns
A x E	5	4	ns	*	*	***	*	*	ns	ns
Error (a)	17	14								
B [cultivar]	9	9	***	***	ns	**	**	**	***	ns
B x E	45	36	ns	**	**	***	***	***	***	**
A x B	9	9	ns	ns	ns	ns	ns	ns	**	ns
A x B x E	45	36	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	306	252								

SOV†	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Environment (E)	5										
Rep (E)	17										
A [seedbed]	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A x E	5	*	ns	*	ns	ns	ns	ns	ns	ns	ns
Error (a)	17										
B [cultivar]	9	***	***	***	***	***	*	***	***	***	*
B x E	45	**	**	ns	ns	ns	ns	ns	ns	ns	***
A x B	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A x B x E	45	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	306										

ns, *, **, *** = not significant, significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ df for five combined environments due to no visual IDC differences at Prosper.

§ IDC is averaged over five environments due to no visual IDC differences at Prosper.

Tomar et al. (1978) suggested that during periods of time with little rainfall, soybean grown on raised seedbeds may experience stress due to lack of moisture. However, these data indicate that in a dry year, grain yield from soybean grown on raised seedbeds was similar to the flat seedbed control. Bakker et al. (2005) documented that crops grown on raised seedbeds in poorly drained soil conditions had increased grain yield each year of a five-year study, except for one dry year when grain yield was similar to the control.

Table 13. Agronomic traits averaged across cultivars for seedbed effect and combined across six environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Hitterdal] in 2012.

Seedbed	SC†	EV	LV	IDC‡	CC	PH	TKW	GY	PC	OC
	plants ha^{-1}	----1-9§----		1-5¶	%	cm	--g--	kg ha^{-1}	----g kg^{-1}----	
Flat	314 894	6.2	7.3	1.58	68	77	130.8	3 038	308	185
Raised	302 774	6.2	7.4	1.44	68	76	131.5	2 999	307	185
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Seedbed	LP	1S	2S	3S	4S	TS	TP	SP
	mm	----------number----------						
Flat	116	3.0	11.3	15.1	0.4	72.5	29.8	2.40
Raised	114	3.3	12.1	16.8	0.5	80.0	32.7	2.42
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significant.

† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ IDC is averaged over five environments due to no visual IDC differences at Prosper.

§ Based on a visual score, with 9 being the most vigorous.

¶ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Environment x seedbed

Analysis of variance showed an environment x seedbed interaction for agronomic traits of early and late vigor, IDC, canopy closure, plant height, protein content, and lowest pod height (Table 12). Early vigor scores from 28 or 29 June indicated that plants grown on raised seedbeds had lower vigor at Fargo (undrained) while early vigor was higher for plants grown on raised seedbeds at Prosper, Barnesville, and Rothsay (Table 14). Late vigor scores from 20 or 21 August showed that soybean grown on raised seedbeds at Prosper had higher plant vigor scores (Table 15). Vigor scores recorded at all other environments showed no differences between seedbed treatments.

Table 14. Early vigor averaged across cultivars for seedbed effect at six environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

Seedbed	Fargo (undrained)	Fargo (drained)	Prosper	Hitterdal	Barnesville	Rothsay
	----------1-9†----------					
Flat	6.3	6.0	6.4	7.4	6.4	4.7
Raised	5.0	4.7	7.7	7.1	7.0	5.6
LSD (0.05)	0.8	ns	1.2	ns	0.1	0.4

ns = not significant.

† Based on a visual score, with 9 being the most vigorous.

Table 15. Late vigor averaged across cultivars for seedbed effect at six environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

Seedbed	Fargo (undrained)	Fargo (drained)	Prosper	Hitterdal	Barnesville	Rothsay
			1-9†			
Flat	7.4	7.5	8.2	8.0	7.3	5.3
Raised	7.0	7.3	8.5	8.0	7.8	6.2
LSD (0.05)	ns	ns	0.2	ns	ns	ns

ns = not significant.
† Based on a visual score, with 9 being the most vigorous.

Lower vigor scores on raised seedbeds at Fargo (undrained) and Fargo (drained) were likely due to delayed emergence. At these two environments, soybean was planted on 10 May and within the next two weeks, only 14 mm of rainfall occurred. Since soybean was planted 1 cm deeper in raised seedbeds, from the difficulties in adjusting planting depth, and may have contributed to the lower vigor scores. Higher early vigor scores recorded for plants grown on raised seedbeds at Prosper, Barnesville, and Rothsay, indicate that plants grown on raised seedbeds did not lack vigor from below normal rainfall in 2012.

Ratings for IDC at Rothsay were 0.5 lower for plants grown on raised seedbeds while no differences were observed at the other environments (Table 16). Low IDC expression is expected with dry weather (Inskeep and Bloom, 1986). However, in 2012, from the early to mid-part of the growing season, the Barnesville and Rothsay environments, as well as, many soybean fields across the RRNV region had noticeable IDC.

Table 16. Iron deficiency chlorosis averaged across cultivars for seedbed effect at five environments [Fargo (undrained), Fargo (drained), Hitterdal, Barnesville, and Rothsay] in 2012.

Seedbed	Fargo (undrained)	Fargo (drained)	Hitterdal	Barnesville	Rothsay
			1-5†		
Flat	1.0	1.1	1.2	1.5	3.1
Raised	1.1	1.0	1.2	1.4	2.6
LSD (0.05)	ns	ns	ns	ns	0.3

ns = not significant.
† Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Soluble salts have been documented to induce IDC expression in soybean. Franzen and Richardson (2000) found that electrical conductivity (EC) was correlated with chlorosis expression in soybean. At Barnesville and Rothsay, soil samples extracted from a 0 to 15 cm depth in a chlorotic plot of a flat seedbed treatment and a non-chlorotic plot of a raised seedbed treatment, were tested for EC by the North Dakota State University Soil Testing Lab. Although soil sampling was not replicated, soil test results indicated that the EC at Barnesville was 2.3 and 1.5 dS m^{-1} in flat and raised seedbeds, respectively, and soil test results for Rothsay showed that EC was 2.8 and 1.6 dS m^{-1} in flat and raised seedbeds, respectively. The lower EC in the raised seedbeds might explain why IDC expression was lower on raised seedbeds at Rothsay. However, more research is needed to form this conclusion.

Soybean plants at Hitterdal were 4 cm shorter when grown on raised seedbeds while no differences were detected at other environments (Table 17). Lower plant height at Hitterdal likely resulted from 60% less rainfall than normal which supports the hypothesis of Tomar et al. (1978) that plants grown on raised seedbeds can experience drought stress in periods with low rainfall.

Table 17. Plant height averaged across cultivars for seedbed effect at six environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

Seedbed	Fargo (undrained)	Fargo (drained)	Prosper	Hitterdal	Barnesville	Rothsay
	----------	----------	----------	cm	----------	----------
Flat	76	78	107	75	75	50
Raised	71	75	107	71	76	58
LSD (0.05)	ns	ns	ns	2	ns	ns

ns = not significant.

Protein content at Prosper was 2 g kg^{-1} higher for plants grown on raised seedbeds while protein content at Rothsay was 6 g kg^{-1} lower for plants grown on raised seedbeds (data not shown). Since protein and yield typically have an inverse relationship, the higher protein observed at Prosper is unusual as grain yields were similar across seedbeds. Nitrogen fixation is important for grain yield production and seed protein content (Fabre and Planchon, 2000). Tomar et al. (1996) found that soybean root mass increased when grown on raised seedbeds as compared to flat seedbeds, and Andreeva et al. (1987) found that nitrogen fixation is dependent upon proper soil aeration. Therefore, higher protein content from soybean grown on raised seedbeds might be explained by better root development which could have allowed for greater nitrogen fixation. At Rothsay, the lower protein content for plants grown on raised seedbeds was likely due to numerically higher grain yield on raised seedbeds, 2 178 kg ha^{-1} as compared to 1 782 kg ha^{-1} on flat seedbeds.

At Hitterdal, lowest pod height was 30 mm lower for plants grown on raised seedbeds while no differences in lowest pod height occurred across seedbed effect for other environments. The shorter plant height (Table 17) likely caused the plants to produce pods closer to the soil surface.

Cultivar

Cultivars were significantly different for stand count, early vigor, IDC, canopy closure, plant height, thousand kernel weight, protein content, oil content, lowest pod height, number of pods per plant with one to four seeds, total seeds per plant, total pods per plant, and average seeds per pod (Table 12). Cultivar 90-40 had the lowest stand count (230 253 plants ha^{-1}) but produced the highest total seeds per plant (102.2) and highest total pods per plant (43) (Table 18). Although this cultivar tried to compensate for the low plant stand, grain yield was still the lowest (2 877 kg ha^{-1}) of all cultivars. Contrary to a low stand count, cultivar DSR-0747/R2Y had the highest stand count (333 158 plants ha^{-1}) but the second lowest grain yield (2 952 kg ha^{-1}). Total seeds per plant for cultivar DSR-0747/R2Y were second lowest (70.2), suggesting that at a high stand count, individual plants may produce fewer seeds. However, DSR-0747/R2Y had the third highest IDC expression (1.71), which may have reduced grain yield.

Froehlich and Fehr (1981) found a linear relationship between the amount of chlorosis expression in plants and total grain yield reduction. In this research, cultivar 90Y70 had the least amount of IDC expression (1.28) and the second highest grain yield (3 129 kg ha^{-1}) while cultivar 32RY08 had the highest expression of IDC (1.86) but the highest grain yield (3 180 kg ha^{-1}). Brodshaug (2011) also noticed that the cultivar with the highest IDC expression had the highest grain yield. Cultivar 32RY08 likely recovered from iron deficiency soon after IDC ratings, and therefore, still achieved high grain yield.

Differences in IDC ratings for each cultivar were expected since the cultivars were selected based on their known IDC expression in the 2010 and 2011 NDSU Soybean Performance booklets (Table 2). Cultivars in this research responded similarly to the performance reported in the booklets; however, cultivar 32RY08 had the highest IDC expression in this research and did not in the previous performance research. At Rothsay where IDC was prevalent, a direct relationship between IDC expression and reduced grain yield was moderate ($r^2 = 0.62$) and is similar to research by Froehlich and Fehr (1981).

Environment x cultivar

An environment x cultivar interaction occurred for early and late vigor, IDC, canopy closure, plant height, thousand kernel weight, grain yield, protein and oil content, and average seeds per pod (Table 12). Differences in early and late vigor for each cultivar can be attributed to different environment effects such as rainfall, temperature, and soil type. Rothsay had higher overall IDC expression than any other environment which may be explained by the high EC at this site as explained in the environment x seedbed section. Cultivars DSR-0747/R2Y, 32RY08, and NS 0853RR tended to express the most chlorosis across all environments, except Hitterdal, where cultivars 90Y42 and 2703RR had the highest chlorosis expression (Table 19).

Table 18. Agronomic traits for cultivars averaged across seedbed effect for six environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

Cultivar	SC†	EV	LV	IDC‡	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	----1-9§----		1-5¶	%	cm	g	kg ha^{-1}	----g kg^{-1}----		mm	---number---						
AG 0231	320 742	7.1	7.6	1.34	73	80	146.1	3 002	305	179	100	2.6	9.9	15.0	0.5	69.3	28.0	2.46
DSR-0747/R2Y	333 158	6.3	7.2	1.71	66	77	131.0	2 952	306	181	111	2.8	10.7	14.5	0.6	70.2	28.7	2.44
90Y42	312 723	6.4	7.5	1.46	70	79	131.9	3 012	300	195	121	2.5	10.2	16.0	0.2	71.6	28.9	2.47
90Y70	316 284	6.4	7.8	1.28	71	78	137.6	3 129	314	186	139	2.6	10.9	16.0	0.4	74.0	29.9	2.48
32RY08	332 416	5.9	7.2	1.86	64	78	131.6	3 180	305	181	112	2.7	10.8	17.1	0.5	77.9	31.2	2.31
HS 01RY02	286 622	6.6	7.5	1.29	73	77	153.8	3 074	303	181	110	2.7	9.9	15.0	0.6	70.3	28.3	2.49
NS 0853RR	309 459	5.3	6.8	1.83	59	67	112.4	2 968	312	185	110	2.2	11.5	15.7	0.1	72.7	29.5	2.36
90-40	230 253	5.0	7.1	1.50	64	80	113.2	2 877	303	190	120	4.9	17.5	20.3	0.3	102.2	43.0	2.35
S02-K3	325 355	6.3	7.3	1.45	66	77	129.1	2 968	309	189	114	4.8	14.0	14.7	0.2	78.2	33.9	2.29
2703RR	321 329	6.4	7.6	1.40	73	74	124.5	3 026	314	184	116	3.2	11.6	15.3	1.0	76.1	31.0	2.44
Mean	308 834	6.2	7.4	1.51	68	77	131.1	3 019	307	185	115	3.1	11.7	16.0	0.4	76.3	31.2	2.41
LSD (0.05)	35 879	0.6	ns	0.33	8	6	7.1	ns	5	3	14	1.0	2.6	2.8	0.3	12.4	5.2	0.13

ns = not significant.

† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ IDC is averaged over five environments due to no visual IDC differences at Prosper.

§ Based on a visual score, with 9 being the most vigorous.

¶ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Table 19. Means for IDC of cultivars averaged across seedbed effect for five environments [Fargo (undrained), Fargo (drained), Hitterdal, Barnesville, and Rothsay] in 2012.

Cultivar	Fargo (undrained)	Fargo (drained)	Hitterdal	Barnesville	Rothsay
	---1-5†--				
AG 0231	1.03	1.03	1.03	1.00	2.63
DSR-0747/R2Y	1.03	1.09	1.13	1.97	3.39
90Y42	1.00	1.00	1.48	1.10	2.69
90Y70	1.00	1.01	1.05	1.00	2.34
32RY08	1.19	1.14	1.30	2.20	3.51
HS 01RY02	1.00	1.03	1.05	1.00	2.36
NS 0853RR	1.28	1.30	1.09	1.83	3.68
90-40	1.06	1.03	1.08	1.72	2.63
S02-K3	1.06	1.04	1.18	1.20	2.75
2703RR	1.00	1.00	1.43	1.12	2.44
Mean	1.07	1.07	1.18	1.41	2.84
LSD (0.05)	ns	0.15	0.19	0.42	0.55

ns = not significant.
† Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Cultivar DSR-0747/R2Y was the tallest (116 cm) at Prosper but was the second shortest at Rothsay (43 cm). The difference in plant height among the locations was due to this cultivar having the third highest IDC expression at Rothsay (3.39) (Table 19) which caused a reduction in plant height. This research showed that cultivars responded differently at each environment depending on tolerance to IDC.

Average seeds per pod for the same cultivar differed across environments likely due to plant stresses such as moisture and temperature and other agronomic factors such as stand count (Table 20). Brodshaug (2011) also noticed an environment x cultivar interaction for average seeds per pod and attributed the differences at each environment to differences in stand counts. Cultivars with a lower stand count will typically compensate by producing more seeds per plant. Cultivar 32RY08 had the third highest average seeds per pod (2.59) at Prosper and the fewest average seeds per pod at Rothsay (1.55) which was likely associated with high expression of IDC (Table 19).

Table 20. Average seeds per pod for cultivars at six environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

Cultivar	Fargo (undrained)	Fargo (drained)	Prosper	Hitterdal	Barnesville	Rothsay
	average seeds pod^{-1}					
AG 0231	2.46	2.41	2.56	2.55	2.53	2.26
DSR-0747/R2Y	2.44	2.49	2.55	2.49	2.51	2.17
90Y42	2.47	2.52	2.54	2.47	2.47	2.31
90Y70	2.50	2.36	2.64	2.43	2.52	2.44
32RY08	2.38	2.44	2.59	2.52	2.41	1.55
HS 01RY02	2.62	2.47	2.45	2.50	2.56	2.33
NS 0853RR	2.44	2.49	2.53	2.43	2.39	1.89
90-40	2.36	2.37	2.48	2.37	2.42	2.12
S02-K3	2.31	2.35	2.39	2.24	2.36	2.13
2703RR	2.42	2.44	2.63	2.43	2.49	2.23
Mean	2.44	2.43	2.54	2.44	2.47	2.14
LSD (0.05)	0.15	ns	0.14	0.14	ns	ns

ns = not significant.

Seedbed x cultivar

An interaction regarding thousand kernel weight occurred between seedbed and cultivar due to differences in magnitude ranking (Table 12). All cultivars trended to have a greater thousand kernel weight when grown on a raised seedbed, except for 90Y70, HS 01RY02, and NS 0853RR (Table 21). Greater thousand kernel weight was most likely influenced by a lower stand count on the raised seedbeds. Fewer plants allowed for plants to have access to more moisture and nutrients than plants with greater competition in flat seedbed treatments.

Table 21. Seedbed x cultivar interaction for thousand kernel weight across six environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

Cultivar	Flat	Raised
	g	
AG 0231	145.7 b†	146.5 a
DSR-0747/R2Y	128.6 c	133.3 b
90Y42	130.1 c	133.8 b
90Y70	142.2 b	133.1 b *
32RY08	129.2 c	133.9 b
HS 01RY02	156.5 a	151.0 a *
NS 0853RR	113.2 d	111.7 c
90-40	111.6 d	114.8 c
S02-K3	127.9 c	130.4 b
2703RR	122.7 c	126.3 b
Mean	130.8	131.5

* Denotes significance across rows at ($p \leq 0.05$).
† Within columns, means followed by the same letter are not significantly different at ($p \leq 0.05$).

Soil temperature

Analysis of variance ($p \leq 0.10$) across 60 days of sampling showed that soil temperature was significantly different between flat and raised seedbed treatments (Table 22). Soil temperature for hour of day was also significantly different, as expected, since the soil temperature would change according to air temperature throughout the day.

Table 22. Mean squares for the ANOVA for recorded hourly soil temperature at two environments [Fargo (undrained) and Hitterdal] in 2012.

		Mean square	
SOV	df	Fargo	Hitterdal
Rep	2	5.39	50.13
A [seedbed]	1	238.48*	787.11*
Error (a)	2	14.93	81.64
B [hour]	11	4 034.07***	5 057.47***
A x B	11	31.80	177.12***
Error (b)	4292	21.55	21.65

* *** Significant at ($p \leq 0.10$) and ($p \leq 0.01$), respectively.

Averaged across hour of day, soil temperature was significantly warmer in the raised seedbed treatments at Fargo and Hitterdal by 0.4 and 0.8 °C, respectively (Table 23). At Fargo, the soil temperature between the hours of 14:00 and 20:00 was significantly warmer in the raised seedbeds compared to the flat seedbeds. At Hitterdal, the soil temperature between the hours of 12:00 and 20:00 was also significantly warmer in the raised seedbeds than the flat seedbeds.

The hourly soil temperature differences for Fargo and Hitterdal generated from the data in Table 23 can be viewed in Figures 4 and 5, respectively. Shaw and Buchele (1957) also observed raised seedbeds to have warmer soil temperatures. The warmer soil temperatures are partly due to gravitational water drainage within the ridge and to the lower specific heat of dry soil (Shaw and Buchele, 1957). The increase in soil temperature for this research was unimportant in 2012 since grain yield was similar across seedbed treatments; however, in a year with normal to above average rainfall, an increase in soil temperature should be beneficial for plant vigor which might result in increased grain yield.

Table 23. Hourly soil temperature from 11 May to 9 July (60 days) for flat and raised seedbeds at Fargo (undrained) and Hitterdal in 2012.

	Mean soil temperature			
	Fargo		Hitterdal	
Hour	Flat	Raised	Flat	Raised
	------°C------			
0	19.5 a†	19.6 a	19.2 a	19.1 a
2	18.3 a	18.2 a	18.1 a	17.6 a
4	17.4 a	17.1 a	17.2 a	16.6 a
6	16.6 a	16.2 a	16.5 a	15.8 a
8	17.0 a	16.9 a	17.1 a	16.7 a
10	19.3 a	19.7 a	19.1 a	19.9 a
12	21.8 a	22.6 a	22.0 b	24.1 a
14	23.8 b	24.8 a	24.1 b	27.0 a
16	24.9 b	26.1 a	25.1 b	28.0 a
18	24.7 b	25.9 a	24.4 b	26.8 a
20	23.3 b	24.5 a	22.9 b	24.1 a
22	21.3 a	21.9 a	20.8 a	21.2 a
Mean	20.7 b	21.1 a	20.6 b	21.4 a

† Means followed by the same letter within the row and within environment are not significantly different at ($p \leq 0.10$).

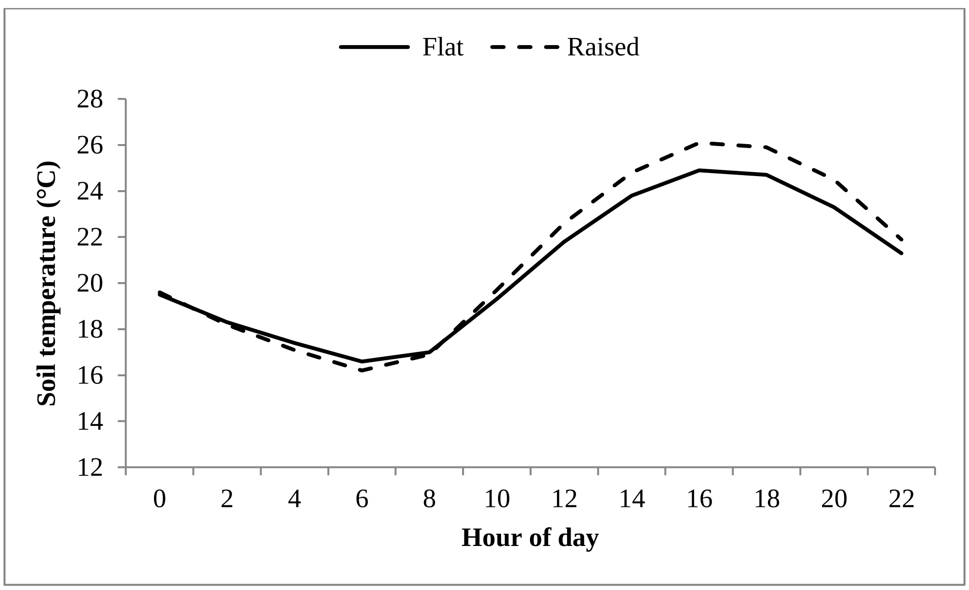

Figure 4. Hourly soil temperature for flat and raised seedbeds at Fargo in 2012.

Soil bulk density

The ANOVA ($p \leq 0.10$) for soil bulk density showed that seedbed effect was significantly different for three of seven sampled months (August at Hitterdal and June and October at Barnesville) (Table 24). Averaged over sampling depths, raised seedbed treatments had 0.12 g cm^{-3} lower bulk density at Hitterdal in August (Table 25) and had 0.07 and 0.08 g cm^{-3} lower bulk density at Barnesville in June and October, respectively (Table 26).

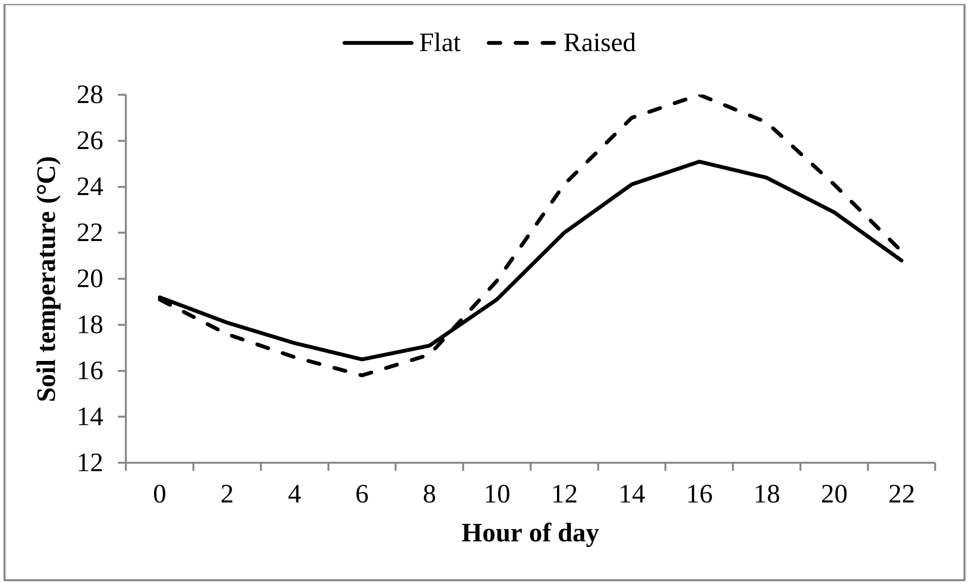

Figure 5. Hourly soil temperature for flat and raised seedbeds at Hitterdal in 2012.

Table 24. Mean squares for the ANOVA for soil bulk density measured at Prosper, Hitterdal, and Barnesville in 2012.

		Mean square						
		Prosper		Hitterdal		Barnesville		
SOV†	df	June	August	June	August	June	August	October
Rep	3	0.01	0.01	0.02	0.02	0.01	0.04	0.02
A [seedbed]	1	0.02	0.04	0.01	0.09*	0.03*	0.00	0.04**
Error (a)	3	0.02	0.02	0.02	0.01	0.00	0.01	0.00
B [depth]	2	0.26***	0.50***	0.40***	0.11***	0.32***	0.30***	0.46***
A x B	2	0.02	0.01	0.01	0.00	0.01	0.00	0.01
Error (b)	12	0.01	0.01	0.01	0.01	0.01	0.01	0.01

* ** *** Significant at ($p \leq 0.10$), ($p \leq 0.05$), and ($p \leq 0.01$), respectively.

Table 25. Soil bulk density by depth and seedbed at Hitterdal in June and August 2012.

	Hitterdal			
	June		August	
Depth	Flat	Raised	Flat	Raised
cm	g cm^{-3}			
5	1.13 a†	1.15 a	1.25 b	1.11 a
15	1.52 a	1.42 a	1.39 a	1.28 a
30	1.59 a	1.54 a	1.47 a	1.35 a
Mean	1.41 a	1.37 a	1.37 b	1.25 a

† For each depth, means followed by the same letter in the same row for each month are not significantly different at ($p \leq 0.10$).

Table 26. Soil bulk density by depth and seedbed at Barnesville in June, August, and October for 2012.

	Barnesville					
	June		August		October	
Soil depth	Flat	Raised	Flat	Raised	Flat	Raised
cm	-----------------	-----------------	----------------- g cm^{-3}	-----------------	-----------------	-----------------
5	1.12 a†	1.09 a	1.03 a	1.02 a	1.10 a	1.10 a
15	1.37 b	1.24 a	1.28 a	1.26 a	1.44 b	1.30 a
30	1.54 a	1.47 a	1.40 a	1.42 a	1.63 a	1.53 a
Mean	1.34 b	1.27 a	1.24 a	1.24 a	1.39 b	1.31 a

† For each depth, means followed by the same letter in the same row for each month are not significantly different at (p≤0.10).

Four of seven sampled months indicated lower bulk density in raised seedbeds at comparable depths. Soil bulk density at Prosper in June at the 15 cm depth was 0.17 g cm^{-3} lower in the raised versus flat seedbed treatments (Table 27). Bulk density at the 5 cm depth was 0.14 g cm^{-3} lower in raised versus flat seedbeds at Hitterdal in August (Table 25). Finding soil bulk density to be lower at the 5 cm depth indicates that surface compaction was reduced. At Barnesville, raised seedbeds reduced soil bulk density at the 15 cm depth, 0.13 g cm^{-3} and 0.14 g cm^{-3} for June and October, respectively (Table 26).

Table 27. Soil bulk density by depth and seedbed at Prosper in June and August 2012.

	Prosper			
	June		August	
Depth	Flat	Raised	Flat	Raised
cm	-----------------	----------------- g cm^{-3}	-----------------	-----------------
5	1.12 a†	1.14 a	1.06 a	1.02 a
15	1.48 b	1.31 a	1.52 a	1.38 a
30	1.49 a	1.47 a	1.51 a	1.46 a
Mean	1.36 a	1.47 a	1.51 a	1.41 a

† For each depth, means followed by the same letter in the same row for each month are not significantly different at (p≤0.10).

Bakker et al. (2005) also found that soil bulk density at a 0 to 20 cm depth was lower in raised seedbeds. At high levels of soil compaction plants are less able to penetrate and explore soil which results in shallow root growth, root malformation, and a reduced ability to uptake water and nutrients (Dejong-Hugues et al., 2001). Reduced soil bulk density in raised seedbed treatments suggests that soybean will have the ability to explore and penetrate soil easier than in flat seedbed treatments.

Root analysis

Soybean root analysis of variance at ($p\leq0.10$) showed that seedbed effect was significantly different for root mass (Table 28). Two cultivars (01RY02 and NS 0853RR) at three environments (Prosper, Hitterdal, and Barnesville) were sampled and trends for both cultivars indicated an increase in root mass in raised seedbeds (Table 29). When averaged across cultivar and environment, root mass was 0.37 g root system^{-1} higher for soybean grown on raised seedbeds.

Table 28. Mean squares for the combined ANOVA for measured root mass for three environments (Prosper, Hitterdal, and Barnesville) in 2012.

		Mean square
SOV	df	Root mass
Environment (E)	2	3.09
Rep (E)	9	0.75
A [seedbed]	1	1.69*
A x E	2	0.13
Error (a)	9	0.24
B [cultivar]	1	1.55
B x E	2	0.51
A x B	1	0.57
A x B x E	2	0.40
Error (b)	18	0.48

* significant at ($p\leq0.10$).

Table 29. Root mass for two cultivars combined across Prosper, Hitterdal, and Barnesville in 2012.

Seedbed	01RY02	NS0853RR	Mean
	---------------g root system^{-1}---------------		
Flat	2.02	2.16	2.09
Raised	2.17	2.75	2.46
LSD (0.10)	ns	ns	0.30

ns = not significant.

Bakker et al. (2005) and Hazma and Anderson (2003) found that under ideal growing conditions, lower bulk density can generally translate into increased root growth, greater biomass accumulation, and higher grain yield. Research conducted in Central India found that soybean productivity increased when grown on raised seedbeds and also observed root mass to be the greatest in raised seedbeds when compared to the flat seedbed control (Tomar et al., 1996). In this root mass study, root growth was likely facilitated due to lower soil bulk density in the raised seedbeds.

Drainage x Seedbed x Cultivar Experiment

A mean square table for the analysis of variance for the three factor experiment at Fargo in 2012 can be found in Appendix A14. Levels of significance for agronomic traits with drainage, seedbed, cultivar, and various interactions are provided in Table 30.

Table 30. Levels of significance for the ANOVA of agronomic traits at Fargo in 2012.

SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3								
A [drainage]	1	ns	ns	ns	ns	ns	ns	ns	ns
Error (a)	3								
B [seedbed]	1	**	ns	ns	ns	ns	ns	ns	ns
A x B	1	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	6								
C [cultivar]	9	ns	***	ns	***	**	***	***	***
A x C	9	ns	ns	ns	ns	ns	ns	ns	ns
B x C	9	ns	ns	ns	ns	ns	ns	ns	ns
A x B x C	9	*	ns	ns	ns	ns	ns	ns	ns
Error (c)	108								

SOV†	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3										
A [drainage]	1	ns	ns	ns	ns	*	ns	ns	*	*	ns
Error (a)	3										
B [seedbed]	1	ns	ns	ns	ns	**	*	ns	*	**	ns
A x B	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	6										
C [cultivar]	9	***	***	**	*	***	ns	***	*	**	**
A x C	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
B x C	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A x B x C	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (c)	108										

ns, *, **, *** = not significant, significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.
† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor (29 June), LV = late vigor (20 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Drainage

In 2012, in a year with below normal rainfall, no difference in grain yield occurred across drainage treatments. Drainage effect was significant for number of pods per plant with two seeds, total seeds per plant, and total pods per plant (Table 30). The number of pods per plant with two seeds, total seeds per plant, and total pods per plant increased by 2.3, 14, and 5.7 under the drained effect, respectively (Table 31). An interaction for drainage x seedbed x cultivar occurred for stand count (Table 30); however, the interaction did not impact grain yield.

Table 31. Agronomic traits for drainage averaged across seedbed and cultivar at Fargo in 2012.

Drainage	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	g	kg ha^{-1}	----g kg^{-1}----	
Undrained	305 247	5.7	7.2	1.06	58	74	119.9	3 017	301	197
Drained	291 613	5.3	7.4	1.07	58	77	119.1	3 043	301	196
LSD (0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Seedbed	LP	1S	2S	3S	4S	TS	TP	SP
	mm	----------number----------						
Undrained	108	3.5	12.0	16.7	0.4	79.0	32.5	2.44
Drained	99	3.9	14.3	19.6	0.4	93.0	38.2	2.43
LSD (0.05)	ns	ns	1.8	ns	ns	12.5	4.9	ns

ns = not significant.
† SC = stand count, EV = early vigor (29 June), LV = late vigor (20 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.
§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Seedbed

No differences in grain yield occurred across seedbeds (Table 30). However, the seedbed effect was statistically significant for stand count, number of pods per plant with two and three seeds, total seeds per plant, and total pods per plant. Plants grown on raised seedbeds had a lower stand count which likely caused pods per plant with two or three seeds, total seeds per plant, and total pods per plant to be higher than the flat seedbed control (Table 32). Finding lower stand counts to contribute to greater pods per plant is supported by research conducted by Bruns and Young (2012), who found that low seeding rates in raised seedbeds caused soybean to have greater pods per plant compared to high seeding rates in raised seedbeds having fewer pods per plant.

Table 32. Agronomic traits for seedbed averaged across drainage and cultivar for Fargo in 2012.

Drainage	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	g	kg ha^{-1}	----g kg^{-1}----	
Flat	317 267	6.1	7.5	1.07	61	77	119.1	3 127	302	196
Raised	279 593	4.8	7.1	1.06	54	73	119.8	2 933	301	196
LSD (0.05)	24 570	ns	ns	ns	ns	ns	ns	ns	ns	ns

Seedbed	LP	1S	2S	3S	4S	TS	TP	SP
	mm	--number--						
Flat	103	3.3	12.1	16.5	0.4	78.3	32.2	2.44
Raised	105	4.1	14.3	19.8	0.4	93.7	38.6	2.43
LSD (0.05)	ns	ns	1.5	3.1	ns	10.7	4.1	ns

ns = not significant.

† SC = stand count, EV = early vigor (29 June), LV = late vigor (20 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ Based on a visual score, with 9 being the most vigorous.

§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Cultivar

Cultivars were significantly different for early vigor, IDC, canopy closure, plant height, thousand kernel weight, grain yield, protein content, oil content, lowest pod height, number of pods per plant with one, two, or four seeds, total seeds per plant, total pods per plant, and average seeds per pod (Table 30). Cultivars NS 0853 RR and 32RY08 had the highest chlorosis expression (1.29) and (1.16) respectively, while cultivars 90Y42 and 2703RR had no noticeable IDC expression (Table 33). Grain yield for cultivar NS 0853RR was fifth highest (3 046 kg ha^{-1}) and grain yield for cultivar 32RY08 was the highest (3 346 kg ha^{-1}). In this case, chlorosis expression did not result in lower grain yield.

An inverse relationship seems to exist between seed size and total seeds per plant. Cultivar 90-40 had the highest total seeds per plant (115.0) and highest total pods per plant (48.6) but had the lowest thousand kernel weight (98.6 g). Highest total seeds and pods per plant did not increase yield; therefore, agronomic factors such as stand count most likely contributed to the total seeds and pods per plant being different from other cultivars. In contrast, cultivars 01RY02 and AG 0231 had the highest thousand kernel weights (152.5 and 143.5 g) but also the lowest total number of seeds per plant (76.5 and 79.7).

Low vigor, due to environmental stress or poor tolerance to IDC or disease, resulted in decreased grain yield. Cultivar AG 0231 had the highest early vigor (6.5) and the second highest grain yield (3 151 kg ha^{-1}). In contrast, cultivar 90-40 had the lowest early vigor (4.2) and the lowest grain yield (2 705 kg ha^{-1}).

Table 33. Agronomic traits for cultivars averaged across drainage and seedbed at Fargo in 2012.

Cultivar	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	----1-9‡----		1-5§	%	cm	--g--	kg ha^{-1}	----g kg^{-1}----		mm	---------------------------number---------------------------						
AG 0231	293 766	6.5	7.6	1.03	66	79	143.5	3 151	299	191	85	4.0	11.3	17.2	0.4	79.7	32.8	2.44
DSR-0747/R2Y	313 499	5.5	7.3	1.06	58	77	116.8	3 111	298	192	105	2.8	12.5	17.4	0.4	81.7	33.1	2.46
90Y42	296 457	5.8	7.1	1.00	59	76	119.1	2 998	291	210	105	2.4	11.1	18.2	0.2	79.9	31.9	2.49
90Y70	335 924	5.5	7.2	1.01	55	74	121.5	3 040	310	196	131	3.7	12.3	17.2	0.3	81.2	33.5	2.43
32RY08	323 815	5.5	7.7	1.16	59	79	117.1	3 346	295	192	102	4.0	14.6	19.3	0.3	92.3	38.2	2.41
HS 01RY02	276 274	5.6	7.3	1.01	62	75	152.5	3 064	298	192	106	2.9	9.4	17.2	0.8	76.5	30.3	2.54
NS 0853RR	293 766	5.1	7.0	1.29	54	67	101.2	3 046	304	196	94	3.0	12.1	17.8	0.1	80.9	33.0	2.46
90-40	239 049	4.2	7.0	1.04	51	76	98.6	2 705	300	200	98	5.5	19.9	22.9	0.2	115.0	48.6	2.36
S02-K3	322 918	5.8	7.0	1.05	55	74	113.7	2 817	305	199	105	4.8	15.4	16.6	0.2	86.2	37.0	2.33
2703RR	288 832	5.4	7.7	1.00	61	73	110.8	3 022	310	195	105	3.7	13.3	17.7	0.8	86.7	35.5	2.43
Mean	298 430	5.5	7.3	1.07	58	75	119.5	3 030	301	196	104	3.7	13.2	18.2	0.4	86.0	35.4	2.44
LSD (0.05)	ns	0.8	ns	0.13	7	4	5.3	241	5	4	19	1.6	3.6	ns	0.4	20.3	8.3	0.10

ns = not significant.

† SC = stand count, EV = early vigor (29 June), LV = late vigor (20 Aug.), IDC = iron deficiency chlorosis, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ Based on a visual score, with 9 being the most vigorous.

§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Drainage x Fungicide x Cultivar Experiment

A mean square table for the analysis of variance for the three factor experiment at Fargo in 2011 can be found in Appendix A15. The levels of significance for agronomic traits with drainage, seedbed, cultivar, and various interactions are provided in Table 34.

Table 34. Levels of significance for the ANOVA of agronomic traits at Fargo in 2011.

SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3								
A [drainage]	1	ns	ns	**	*	*	*	ns	*
Error (a)	3								
B [fungicide]	1	ns	ns	ns	ns	ns	ns	ns	ns
A x B	1	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	6								
C [cultivar]	9	ns	***	***	***	***	***	***	ns
A x C	9	*	ns	ns	ns	ns	ns	ns	ns
B x C	9	ns	ns	ns	ns	ns	ns	ns	ns
A x B x C	9	ns	ns	ns	ns	ns	ns	ns	ns
Error (c)	108								

SOV†	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3										
A [drainage]	1	ns	ns	ns	ns	ns	*	ns	*	*	ns
Error (a)	3										
B [fungicide]	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A x B	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	6										
C [cultivar]	9	**	***	ns	*	***	**	**	ns	**	***
A x C	9	ns	ns	ns	ns	*	ns	ns	ns	ns	ns
B x C	9	ns	ns	ns	ns	ns	*	ns	*	*	ns
A x B x C	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (c)	108										

ns, *, **, *** = not significant, significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.
† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor (11 July), LV = late vigor (8 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Drainage

The agronomic traits of late vigor, IDC, canopy closure, plant height, grain yield, number of pods per plant with three seeds, total seeds per plant, and total pods per plant were significantly different across drainage treatments (Table 34). Plants grown with subsurface drainage had increased late vigor, showed less IDC, had greater canopy closure, and were taller (Table 35). Inskeep and Bloom (1986) documented that soybean chlorophyll content deceased at levels of high soil moisture. The objective of subsurface drainage is to gravitationally drain excess water from the crop root zone; therefore, lower IDC was expected. Finding plants to be taller from subsurface drainage is similar to other research (Nelson et al., 2012).

Table 35. Agronomic traits averaged across cultivars for drainage and fungicide at Fargo in 2011.

Drainage	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	g	kg ha^{-1}	----g kg^{-1}----	
Undrained	318 433	5.8	5.9	1.62	62	64	138.1	2 686	329	191
Drained	358 529	7.0	7.2	1.48	80	73	137.2	3 132	330	187
LSD (0.05)	ns	ns	0.7	0.12	10	7	ns	443	ns	ns

Seedbed	LP	1S	2S	3S	4S	TS	TP	SP
	mm	----------number----------						
Undrained	102	2.3	10.0	9.5	0.1	51.2	21.9	2.34
Drained	106	2.8	10.9	13.0	0.2	64.5	26.9	2.39
LSD (0.05)	ns	ns	ns	2.3	ns	10.5	4.3	ns

ns = not significant.
† SC = stand count, EV = early vigor (11 July), LV = late vigor (8 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.
§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

These agronomic trait differences observed from subsurface drainage resulted in 17% higher grain yield. Yield components including number of pods per plant with three seeds, total seeds per plant, and total pods per plant were higher for subsurface drainage and contributed to this increase in grain yield. Subsurface drainage research conducted at the same research location in 2009 and 2010 by Brodshaug (2011) showed that IDC was lower and that vigor, plant height, and grain yield tended to be greater under drained treatments. Subsurface drainage research in Missouri, during two years with above normal rainfall, found that subsurface drainage increased soybean plant height and also increased grain yields 18 to 22%, as compared to the undrained control (Nelson and Meinhardt, 2011).

Cultivar

Cultivars were significantly different for the agronomic traits of early vigor, late vigor, IDC, canopy closure, plant height, thousand kernel weight, protein content, oil content, number of pods per plant with one to four seeds, total pods per plant, and average seeds per pod (Table 34). In 2011, IDC was pronounced across cultivars likely due to saturated soil from above normal rainfall after planting. Cultivar NS 0853RR had the highest IDC expression but also had the highest grain yield (Table 36), similar to cultivar 32RY08 having the highest chlorosis and the highest grain yield averaged across all six raised seedbed environments. This shows that some cultivars can produce high yield even when affected by IDC early in the growing season. However, this is not always true as documented by Froehlich and Fehr (1981) who found a linear relationship between the amount of chlorosis expression in plants and total grain yield reduction. Cultivar S02-K3 produced the lowest yield and had the fewest number of pods per plant with three seeds and fewest total seeds per plant. Cultivar HS 01RY02 had the highest thousand kernel weight and the highest average seeds per pod but the lowest total pods per plant.

Drainage x cultivar

An interaction regarding stand count and number of pods per plant with two seeds occurred between drainage and cultivar (Table 34). Stand count means across all cultivars comparing drainage treatments were not significantly different; however, cultivars 90Y70 and 90-40 had higher stand counts in subsurface drained plots (Table 37). In Table 37, a trend indicates that stand count increased for each cultivar under drained treatments, except cultivar 90Y42. Wuebker et al., (2001) observed that flooding stress negatively influenced soybean germination percentage. In saturated soil conditions, soil pores are filled with water causing limited oxygen throughout the soil, which is necessary for seed germination (Pezeshki, 1994; Pollock, 1972).

Table 36. Agronomic traits for cultivars averaged across drainage and fungicide at Fargo in 2011.

Cultivar	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	--g--	kg ha^{-1}	--g kg^{-1}--		mm	--------------------------number--------------------------						
AG 0231	326 506	7.4	8.1	1.38	85	78	157.1	2 895	328	188	92	2.2	9.1	12.6	0.1	58.6	24.0	2.44
DSR-0747/R2Y	327 403	6.5	5.6	1.66	58	68	133.6	3 014	328	181	103	2.8	9.2	11.8	0.3	57.8	24.1	2.39
90Y42	369 113	6.6	6.3	1.34	70	67	139.7	2 781	326	199	106	2.3	11.6	10.5	0.0	57.0	24.4	2.33
90Y70	344 446	6.1	6.6	1.68	74	67	142.2	2 911	331	193	121	2.1	10.1	10.6	0.1	54.6	22.9	2.38
32RY08	332 336	6.9	5.9	1.74	61	68	134.3	2 805	328	181	105	2.3	9.5	10.5	0.3	54.3	22.7	2.39
HS 01RY02	341 306	6.7	7.1	1.21	76	72	162.5	2 939	330	189	109	1.4	6.5	12.8	0.3	53.9	21.0	2.57
NS 0853RR	346 688	5.5	5.8	1.98	66	62	112.3	3 087	332	183	104	3.0	11.6	13.4	0.0	66.3	27.9	2.36
90-40	288 384	5.1	6.5	1.79	70	70	124.2	2 908	327	192	100	3.1	13.3	11.4	0.1	64.1	27.8	2.29
S02-K3	349 379	6.6	6.8	1.35	73	71	138.3	2 703	328	197	108	3.1	12.0	8.6	0.0	52.9	23.7	2.23
2703RR	359 246	6.5	7.1	1.36	78	62	132.2	3 050	335	187	92	3.2	12.0	10.3	0.2	58.6	25.6	2.28
Mean	338 481	6.4	6.6	1.55	71	69	137.6	2 909	329	189	104	2.6	10.5	11.3	0.1	57.8	24.4	2.37
LSD (0.05)	ns	0.9	0.8	0.32	7	3	5.1	ns	4	3	ns	1.0	2.0	2.5	0.2	ns	3.8	0.09

ns = not significant.

† SC = stand count, EV = early vigor (11 July), LV = late vigor (8 Aug.), IDC = iron deficiency chlorosis, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ Based on a visual score, with 9 being the most vigorous.

§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Previous subsurface drainage research in Missouri found an increase in stand count with subsurface drainage (Nelson and Meinhardt, 2011). Cultivar AG 0231 on subsurface drained treatments had a significant higher number of pods per plant with two seeds compared to the undrained control (Table 37). A general trend indicated that number of pods per plant with two seeds increased for each cultivar, except cultivars 32RY08 and 90-40.

Table 37. Drainage x cultivar interaction for stand count and number of pods per plant with two seeds at Fargo in 2011.

Cultivar	Undrained	Drained	Undrained	Drained
	SC†		2S	
	--------plants ha^{-1}--------		--------number--------	
AG 0231	312 154 b‡	340 858 ab	6.8 de	11.4 ab *
DSR-0747/R2Y	322 021 b	332 785 b	8.5 cde	9.8 bc
90Y42	401 854 a	336 373 b	11.3 bc	11.9 ab
90Y70	279 862 bc	409 029 a *	9.2 bcd	10.9 abc
32RY08	311 257 b	353 416 ab	10.7 bc	8.3 cd
HS 01RY02	334 579 ab	348 034 ab	6.2 e	6.8 d
NS 0853RR	324 712 b	368 664 ab	10.8 bc	12.4 ab
90-40	241 291 c	335 476 b *	14.3 a	12.2 ab
S02-K3	320 227 b	378 532 ab	11.6 ab	12.3 ab
2703RR	336 373 ab	382 120 ab	10.9 bc	13.1 a
Mean	318 433	358 529	10.0	10.9

* Denotes significance across rows for SC and 2S, respectively, at ($P \leq 0.05$).
‡ Within columns, means followed by the same letter are not significantly different for SC or 2S at ($P \leq 0.05$).
† SC = stand count, 2S = number of pods per plant with two seeds.

Fungicide x cultivar

A fungicide x cultivar interaction occurred in the analysis for number of pods per plant with three seeds, total seeds per plant, and total pods per plant (Table 34). Cultivar NS 0853RR responded positively to fungicide by producing an increase in number of pods per plant with three seeds, total seeds per plant, and total pods per plant (Table 38). Cultivar 32RY08 responded negatively to fungicide application by producing fewer total seeds per plant.

When grain yields of all cultivars were averaged for fungicide treatments, no difference in grain yield occurred between the treatments (data not shown). The previous agronomic trait differences from Table 38 did not contribute to differences in individual cultivar grain yield.

However, cultivar S02-K3 did respond with a significant positive increase in grain yield after fungicide application. Blessitt (2008) observed a year x fungicide interaction which showed that cultivars responded differently to fungicide among years; therefore, there seems to be an inconsistent response to fungicide application.

Table 38. Fungicide x cultivar interaction for number of pods per plant with three seeds, total seeds per plant, and total pods per plant at Fargo in 2011.

Cultivar	No fungicide	Fungicide	No fungicide	Fungicide	No fungicide	Fungicide
	3S†		TS		TP	
	---number---					
AG 0231	13.9 a‡	11.3 bc	61.6 ab	55.6 bc	24.9 ab	23.1 cde
DSR-0747/R2Y	13.2 ab	10.4 bc	64.2 a	51.4 c	26.3 ab	21.9 cde
90Y42	10.0 bc	11.0 bc	54.9 ab	59.2 bc	23.4 ab	25.4 bcd
90Y70	9.4 c	11.8 b	49.8 b	59.4 bc	21.3 b	24.6 bcde
32RY08	12.1 abc	8.9 bc	61.0 ab	47.5 c *	25.1 ab	20.3 de
HS 01RY02	13.6 a	12.0 b	56.7 ab	51.1 c	22.3 ab	19.8 e
NS 0853RR	11.0 abc	15.8 a *	56.4 ab	76.2 a *	23.8 ab	32.1 a *
90-40	10.6 abc	12.3 b	61.3 ab	66.9 ab	26.8 a	28.9 ab
S02-K3	8.9 c	8.3 c	51.2 ab	54.6 bc	22.7 ab	24.6 bcde
2703RR	11.3 abc	9.2 bc	59.1 ab	58.1 bc	25.3 ab	26.0 bc
Mean	11.4	11.1	57.6	58.0	24.2	24.7

* Denotes significance across rows for 3S, TS, or TP, respectively, at ($p \leq 0.05$).

‡ Within columns, means followed by the same letter are not significantly different for 3S, TS, or TP, respectively, at ($p \leq 0.05$).

† 3S = number of pods per plant with three seeds, TS = total seeds per plant, TP = total pods per plant.

Water table depth

Water table depth, as affected by total rainfall during the 2011 and 2012 respective growing seasons are shown in Figures 6 and 7. Observed rainfall data in 2011 and 2012 for the subsurface drainage environment are presented in Table 39. In 2011 the average depth to water table moved up or down depending upon major influences of rainfall or crop water usage (Figure 6). Following large rainfall events the depth to water table decreased. Overall, subsurface drained treatments had a greater depth to water table from the beginning of May until the end of August. Fewer rainfall events in mid-August, along with crop water usage for grain fill, increased the depth to water table of both drainage treatments. Subsurface drainage research also conducted by Kandel et al. (2013) and Wiersma et al., (2010), both observed average depth to water table to be greater in drained treatments. In another study, Jin et al., (2008), noticed that less intense drainage from wide drain pipe spacing or undrained field conditions resulted in more days with a high water table. Since grain yield in 2011 was higher on drained treatments as compared to undrained treatments, this research indicates that higher grain yield was likely due to lower water table depths throughout the growing season.

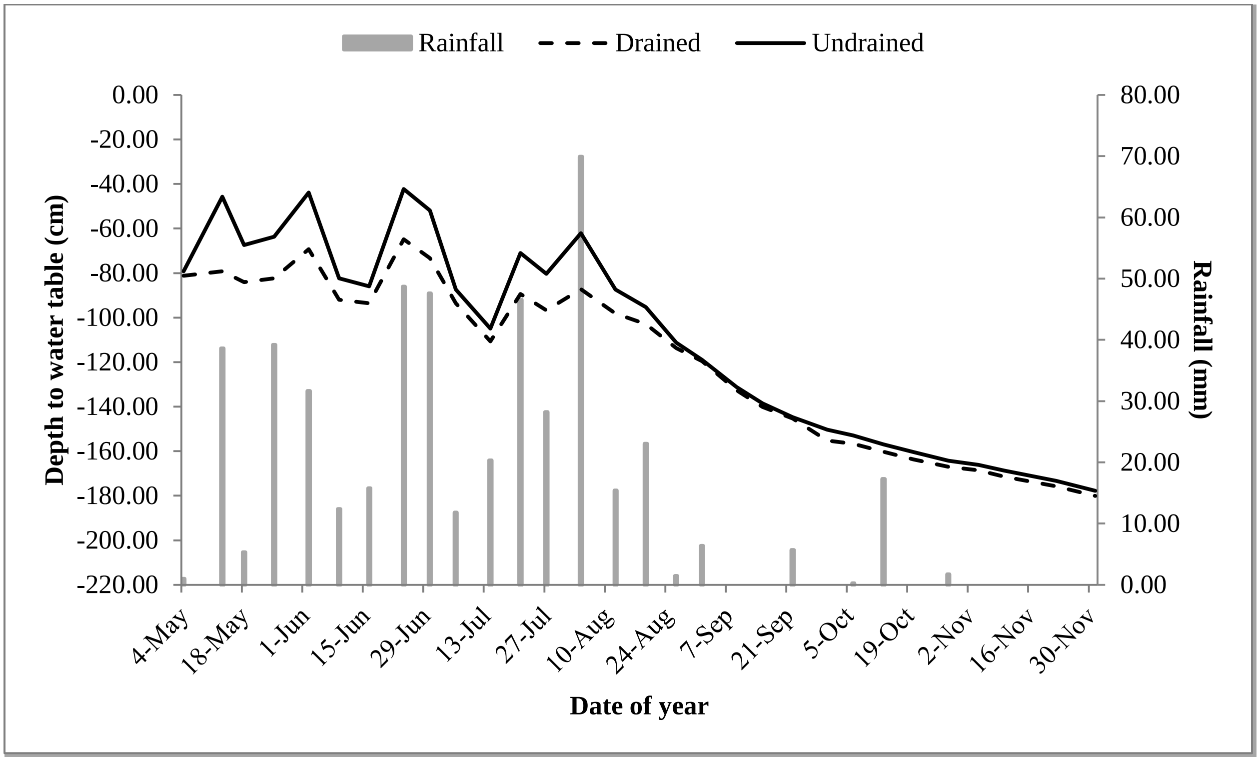

Figure 6. Depth of water table for drainage treatments as affected by rainfall at Fargo in 2011.

Table 39. Rain gauge observed monthly total rainfall at Fargo in 2011 and 2012.

	Total rainfall	
	Fargo	
Month	2011	2012
	--------------mm--------------	
April	--	19
May	32	41
June	124	83
July	107	74
August	110	21
September	12	3
October	19	--
Total	404	241

During the 2012 growing season, the depth to water table for both drained and undrained treatments was similar until August (Figure 7). The depth to water table in 2012 was below the drainage pipes (90 cm below soil surface) throughout the whole growing season; therefore, no grain yield differences would be expected in a dry year. The slight differences in the depth to water table for drained and undrained treatments for August are due to the water table dropping below pipe sampling depths, which did not allow for accurate measurements.

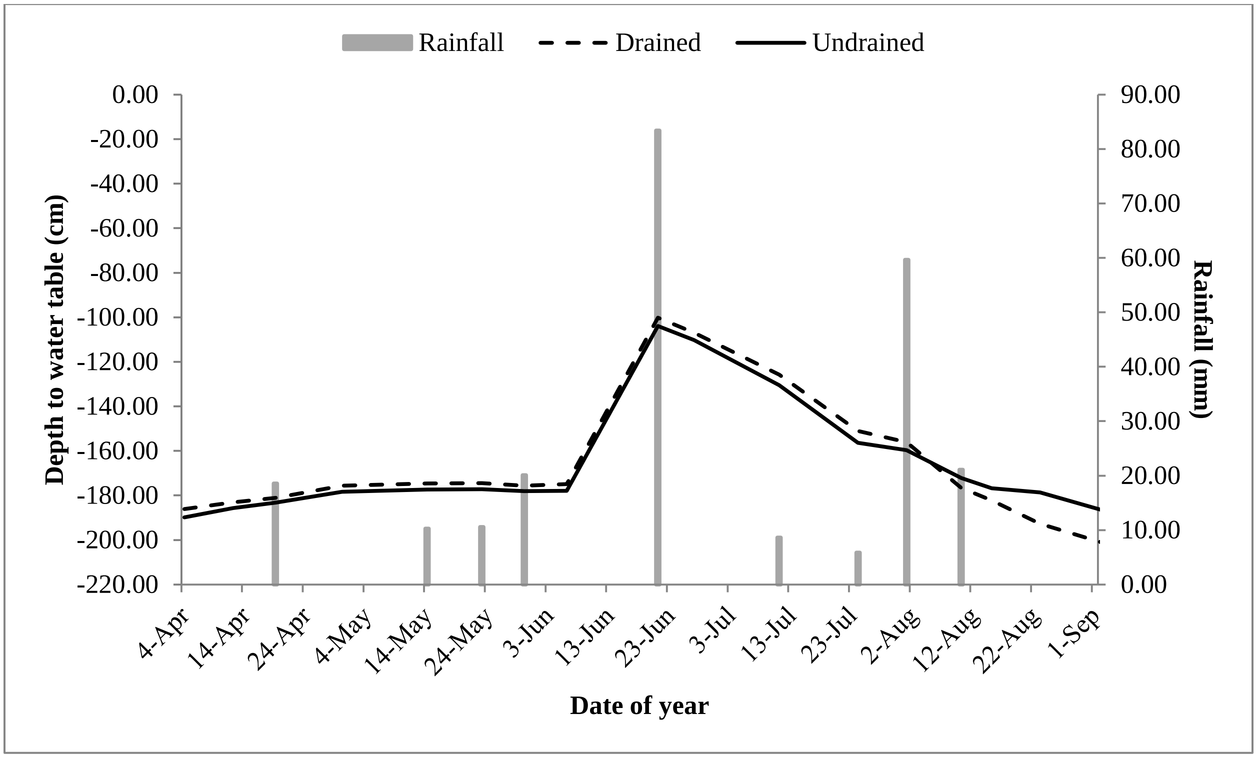

Figure 7. Depth of water table for drainage treatments as affected by rainfall at Fargo in 2012.

2011 and 2012 Combined Drainage x Cultivar

A combined mean square table for the analysis of variance for 2011 and 2012 combined drainage x cultivar experiment can be found in Appendix A16. Table 40 shows the levels of significance for the agronomic traits tested by experimental effects.

Drainage

In the combined analysis across years 2011 and 2012, the agronomic traits of thousand kernel weight, number of pods per plant with three seeds, total seeds per plant, and total pods per plant were significantly different for drainage effect (Table 40).

Table 40. Levels of significance for the ANOVA of agronomic traits for two drainage environments (Fargo 2011 and Fargo 2012).

SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Environment (E)	1								
Rep (E)	6								
A [drainage]	1	ns	ns	ns	ns	ns	ns	*	ns
A x E	1	ns	ns	ns	ns	ns	ns	ns	ns
Error (a)	6								
B [cultivar]	9	ns	***	ns	ns	ns	*	***	ns
B x E	9	ns	ns	*	**	ns	*	*	ns
A x B	9	ns	ns	ns	ns	ns	ns	ns	ns
A x B x E	9	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	108								

SOV†	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Environment (E)	1										
Rep (E)	6										
A [drainage]	1	ns	ns	ns	ns	ns	*	ns	*	*	ns
A x E	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (a)	6										
B [cultivar]	9	*	**	**	ns	*	ns	ns	ns	ns	**
B x E	9	*	**	ns	ns	ns	ns	ns	ns	ns	ns
A x B	9	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
A x B x E	9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error (b)	108										

ns, *, **, *** = not significant, significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.
† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor (11 July 2011 and 29 June 2012), LV = late vigor (8 Aug. 2011 and 20 Aug. 2012), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Under drained conditions, thousand kernel weight was 0.9 g lower which likely was due to a numerically higher stand count on drained conditions (Table 41). Number of pods per plant with three seeds, total seeds per plant and total pods per plant were 3.2, 13.6, and 5.4 higher in drained plots, respectively. Although not significantly greater, trends exist for greater stand count, early and late vigor, canopy closure, plant height, grain yield, numbers of pods per plant with one, two, and four seeds, and average seeds per pod for plants grown in drained treatments.

Cultivar

Significant differences among cultivars were observed for early vigor, plant height, thousand kernel weight, protein content, oil content, lowest pod height, number of pods per plant with two seeds, and average seeds per pod (Table 40). Grain yield ranged from 3 075 to 2 760 kg ha^{-1}; however the differences were not significant (Table 42). Cultivar AG 0231 had the highest early vigor (7.0) and was also the tallest (78 cm) but only had the fifth greatest grain yield (3 023 kg ha^{-1}). Cultivar NS 0853RR was the shortest plant (65 cm) but had the second greatest grain yield (3 067 kg ha^{-1}); therefore, plant height is not necessarily important for achieving high grain yield.

Table 41. Agronomic traits averaged across cultivars for drainage effect combined across two environments (Fargo 2011 and Fargo 2012).

Drainage	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	g	kg ha^{-1}	----g kg^{-1}----	
Undrained	311 840	5.7	6.6	1.34	60	69	129.0	2 852	315	194
Drained	325 071	6.2	7.3	1.27	69	75	128.1	3 088	315	192
LSD (0.05)	ns	ns	ns	ns	ns	ns	0.9	ns	ns	ns

Seedbed	LP	1S	2S	3S	4S	TS	TP	SP
	mm	--number--						
Undrained	105	2.9	11.0	13.1	0.2	65.1	27.2	2.39
Drained	102	3.3	12.6	16.3	0.3	78.7	32.6	2.41
LSD (0.05)	ns	ns	ns	3.2	ns	4.6	4.1	ns

ns = not significant.

† SC = stand count, EV = early vigor (11 July), LV = late vigor (8 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ Based on a visual score, with 9 being the most vigorous.

§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Environment x cultivar

An interaction between environment and cultivar occurred for the agronomic traits of late vigor, IDC, plant height, thousand kernel weight, protein content, and oil content (Table 40). All cultivars had greater vigor in 2012 than in 2011, except for cultivar AG 0231 which had lower (7.6 in 2012 versus 8.1 in 2011) (data not shown).

Table 42. Agronomic traits for cultivars averaged across drainage for two environments (Fargo 2011 and Fargo 2012).

Cultivar	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	--g--	kg ha^{-1}	---g kg^{-1}---		mm	---------------------------number---------------------------						
AG 0231	310 136	7.0	7.8	1.20	75	78	150.3	3 023	313	189	89	3.1	10.2	14.9	0.3	69.1	28.4	2.44
DSR-0747/R2Y	320 451	6.0	6.5	1.36	58	73	125.2	3 062	313	186	104	2.8	10.8	14.6	0.4	69.7	28.6	2.43
90Y42	332 785	6.2	6.7	1.17	64	71	129.4	2 889	308	205	105	2.4	11.3	14.3	0.1	68.5	28.1	2.41
90Y70	340 185	5.8	6.9	1.34	65	70	131.8	2 975	320	195	126	2.9	11.2	13.9	0.2	67.9	28.2	2.40
32RY08	328 076	6.2	6.8	1.45	60	74	125.7	3 075	312	187	103	3.2	12.0	14.9	0.3	73.3	30.4	2.40
HS 01RY02	308 790	6.2	7.2	1.11	69	74	157.5	3 002	314	190	108	2.2	7.9	15.0	0.5	65.2	25.6	2.56
NS 0853RR	320 227	5.3	6.4	1.63	60	65	106.7	3 067	318	189	99	3.0	11.8	15.6	0.0	73.6	30.5	2.41
90-40	263 716	4.6	6.7	1.42	60	73	111.4	2 806	313	196	99	4.3	16.6	17.2	0.1	89.6	38.2	2.33
S02-K3	336 149	6.2	6.9	1.20	64	73	126.0	2 760	317	198	107	3.9	13.7	12.6	0.1	69.5	30.3	2.28
2703RR	324 039	6.0	7.4	1.18	69	68	121.5	3 036	322	191	99	3.5	12.7	14.0	0.5	72.7	30.6	2.36
Mean	318 455	6.0	6.9	1.31	64	72	128.6	2 970	315	193	104	3.1	11.8	14.7	0.3	71.9	29.9	2.40
LSD (0.05)	ns	0.4	ns	ns	ns	5	8.6	ns	7	7	12	ns	3.4	ns	ns	ns	ns	0.10

ns = not significant.

† SC = stand count, EV = early vigor (11 July), LV = late vigor (8 Aug.), IDC = iron deficiency chlorosis, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ Based on a visual score, with 9 being the most vigorous.

§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

This greater vigor score in 2012 may have been due to the vigor scores being recorded later in the season than in 2011, which allowed for greater plant growth. The greater vigor score may also have been due to a longer growing season since planting occurred earlier in 2012. Iron deficiency chlorosis was more prevalent among cultivars in 2011 than in 2012 due to above normal rainfall in 2011; therefore, the interaction regarding IDC was caused by differences in magnitude between years (Table 43).

Table 43. Iron deficiency chlorosis for cultivars averaged across drainage at two environments (Fargo 2011 and Fargo 2012).

Cultivar	Fargo 2011	Fargo 2012
	-----------------1-5†	------------------
AG 0231	1.38	1.03
DSR-0747/R2Y	1.66	1.06
90Y42	1.34	1.00
90Y70	1.68	1.01
32RY08	1.74	1.16
HS 01RY02	1.21	1.01
NS 0853RR	1.98	1.29
90-40	1.79	1.04
S02-K3	1.35	1.05
2703RR	1.36	1.00
Mean	1.55	1.07
LSD (0.05)	0.31	0.14

† Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Plant height at physiological maturity for all cultivars was greater in 2012 than in 2011; therefore, the interaction between environment and cultivar was due to differences in magnitude between years (Table 44). Taller plants in 2012 was most likely due to the longer growing season. The interaction for thousand kernel weight was also due to differences in magnitude (Table 45). In 2011, thousand kernel weight was higher across cultivars than in 2012. Dornbos and Mullen (1990) found that drought or high air temperature stress caused fewer large seed and more small seed to be produced. Therefore, the difference in thousand kernel weight in this research was likely due to below normal rainfall in 2012 which may have caused adverse stress and reduced seed size during grain fill. In the southern RRNV region, grain fill generally occurs in late August and September, and although rainfall was below normal in both years during these months (max air temperature was the same across years), the total rainfall in 2012 was below normal with a greater depth to water table which likely caused the adverse stress.

Table 44. Plant height for cultivars averaged across drainage at two environments (Fargo 2011 and Fargo 2012).

Cultivar	Fargo 2011	Fargo 2012
	----------------cm-----------------	
AG 0231	78	79
DSR-0747/R2Y	68	77
90Y42	67	76
90Y70	67	74
32RY08	68	79
HS 01RY02	72	75
NS 0853RR	62	67
90-40	70	76
S02-K3	71	74
2703RR	62	73
Mean	69	75
LSD (0.05)	4	5

Table 45. Thousand kernel weight for cultivars averaged across drainage at two environments (Fargo 2011 and Fargo 2012).

Cultivar	Fargo 2011	Fargo 2012
	-----------------g------------------	
AG 0231	157.1	143.5
DSR-0747/R2Y	133.6	116.8
90Y42	139.7	119.1
90Y70	142.2	121.5
32RY08	134.3	117.1
HS 01RY02	162.5	152.5
NS 0853RR	112.3	101.2
90-40	124.2	98.6
S02-K3	138.3	113.7
2703RR	132.2	110.8
Mean	137.6	119.5
LSD (0.05)	5.4	5.3

The interaction between drainage and cultivar for protein content and oil content was due to differences in magnitude across years (data not shown). Protein content in 2011 and 2012 ranged from 326 to 335 g kg^{-1} and291 to 310 g kg^{-1}, respectively, and oil content in 2011 and 2012 ranged from181 to 199 g kg^{-1} and 191 to 210 g kg^{-1}, respectively. Overall grain yield in

2011 was lower than in 2012; therefore, protein content averaged across cultivars was higher and oil content was lower in 2011 than in 2012.

Drainage x cultivar

An interaction between drainage and cultivar occurred for lowest pod height (Table 40). Cultivar 90Y42 had a significant reduction in lowest pod height in drained treatments as compared to undrained treatments (Table 46). Although not significantly different, cultivar 90Y42 produced 30.3 and 25.9 total pods per plant in drained and undrained treatments, respectively. The decrease in lowest pod height from soil surface was perhaps due to the increase in pods per plant.

Table 46. Drainage x cultivar interaction for lowest pod height for two environments (Fargo 2011 and Fargo 2012).

Cultivar	Undrained	Drained	
	---------------mm---------------		
AG 0231	89 a	88 a	
DSR-0747/R2Y	99 ab	108 cde	
90Y42	120 cd	91 ab	*
90Y70	130 d	122 e	
32RY08	104 ab	102 abcd	
HS 01RY02	106 bc	109 de	
NS 0853RR	94 ab	104 bcd	
90-40	105 b	93 abc	
S02-K3	106 bc	108 cde	
2703RR	100 ab	97 abcd	
Mean	105	102	

* Denotes significance across rows at ($p \leq 0.05$).
‡ Within columns, means followed by the same letter are not significantly different at ($p \leq 0.05$).

CONCLUSION

Raised seedbed research across six environments in 2012 indicated that soybean growth and grain yield was not reduced when grown on raised seedbeds in a year with below normal rainfall. Bakker et al. (2005) also observed crop productivity on raised and flat seedbeds to be similar in a dry year. At one environment (Rothsay), where IDC was widely pronounced across the experiment area, IDC expression was reduced for plants grown on raised seedbeds. No interactions existed between drainage, seedbeds, and cultivars for grain yield. This research, under dry environmental conditions, suggests that raised seedbeds may be an effective annual practice in soybean production of the RRNV, assuming a positive yield response in a wet year; however, additional research is needed.

Higher soil temperatures, lower bulk density, and greater root mass were observed in the raised seedbeds as compared to the flat seedbed control. Soil temperatures throughout the day were higher in the raised seedbeds at the two environments tested (Fargo and Hitterdal). Research conducted by Benjamin et al. (1990) and Shaw and Buchele (1957) also found soil temperatures to be higher in raised seedbeds as compared to flat seedbeds. Higher soil temperatures in raised seedbeds should accelerate seed germination and seedling growth in northern climates like the RRNV. In 2012, this theory was difficult to examine due to delayed and reduced emergence from a lack of rainfall after planting.

Soil bulk density in the raised seedbeds was lower at comparable depths for four of the seven months sampled. A noticeable trend towards lower bulk densities in the raised seedbeds was recognized for six of the seven sampled months. Bakker et al. (2005) and Hazma and Anderson (2003) observed that lower bulk densities provided an increase in root growth, an increase in biomass, and also an increase in grain yield. Root growth for this research was found to be greater in the raised seedbeds, likely due to the lower bulk densities observed in the raised seedbeds. Raised seedbed heights were formed to an initial height of 19 cm in fall 2011. Raised seedbeds were not reformed throughout the next year and settled to 13 cm by fall 2012. The higher soil temperatures, lower soil bulk density, and increased root mass noticed in raised seedbeds for this research suggest that raised seedbeds have a potential to increase soybean productivity; however, additional research is needed to be conclusive.

In 2011, subsurface drainage research showed that soybean plant height was 9 cm taller and grain yield was 17% higher on drained treatments. Since total rainfall for the majority of the 2011 season was above normal, less soil saturation occurred in drained plots due to the depth to water table being greater. In 2012, in a dry year, soybean growth and grain yield were similar across drainage treatments, likely due to the depth to water table being below the drainage pipes throughout the growing season. When combined across years, grain yield was 8% higher on drained treatments, although not statistically higher. No interactions were observed between drainage and, fungicide (2011), seedbeds (2012), or cultivars for grain yield across the combined year environments (2011-2012). Increases in plant growth and grain yield in a wet year and no reduction in plant growth and grain yield in a dry year indicate that subsurface drainage should be considered by soybean producers in poorly drained soils of the RRNV. The foliar-applied pyraclostrobin fungicide (tested only in 2011) resulted in no grain yield difference across cultivars. More research is necessary to know if fungicide application improves grain yield across multiple cultivars and environments.

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APPENDIX

Table A1. Mean squares for the ANOVA for agronomic traits measured at Fargo (undrained) in 2012.

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3	6 015 192 300	2.51	3.90	0.33	1 148.33	732.18	98.76	1 295 157
A [seedbed]	1	11 386 039 720	32.51*	4.51	0.06	1 711.25	460.80	0.10	698 501
Error (a)	3	5 307 994 989	1.12	0.79	0.06	431.25	176.20	70.49	186 655
B [cultivar]	9	5 919 045 621	2.33	0.45	0.07	96.39	82.58*	2 454.58***	226 612
A x B	9	7 635 522 855	0.76	0.60	0.03	107.08	15.55	50.75	85 923
Error (b)	54	5 303 979 412	1.97	0.86	0.05	112.94	38.98	50.76	157 797

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3	4.27	0.39	1 968.10	10.83	7.66	38.26	0.83	647.68	128.82	0.01
A [seedbed]	1	0.00	0.04	56.11	5.25	79.00	64.80	0.45	1 725.15	344.45	0.00
Error (a)	3	0.08	0.16	2 081.45	15.73	25.90	15.36	1.23	498.44	103.99	0.04
B [cultivar]	9	2.93***	2.33***	1 674.81*	8.30	73.78**	22.29	0.42	676.26	161.69	0.06*
A x B	9	0.64	0.28	1 630.06*	5.04	14.71	12.02	0.12	197.55	35.05	0.02
Error (b)	54	0.50	0.35	759.45	5.38	22.83	32.69	0.39	625.20	105.80	0.02

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A2. Mean squares for the ANOVA for agronomic traits measured at Fargo (drained) in 2012.

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3	5 313 120 626	21.24	7.16	0.09	3 472.08	382.15	337.00	2 118 550
A [seedbed]	1	53 018 892 713*	35.78	0.80	0.14	451.25	94.61	33.02	813 779
Error (a)	3	2 757 327 110	27.24	2.01	0.04	1 503.75	298.45	94.93	1 334 635
B [cultivar]	9	13 050 155 894	4.42***	1.60*	0.07**	281.11***	123.95***	2 158.99***	416 874***
A x B	9	15 678 658 635	0.92	0.95	0.04	25.56	21.06	60.35	91 432
Error (b)	54	7 735 189 734	0.75	0.70	0.02	68.70	23.90	67.72	77 773

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3	2.72	1.74	745.11	2.42	24.46	188.34	0.35	2 849.41	408.44	0.02
A [seedbed]	1	0.86	0.22	125.00	25.31*	123.75**	492.53	0.38	9 331.20	1 518.15*	0.00
Error (a)	3	1.24	0.50	1 596.98	1.38	3.09	114.61	0.15	1 045.44	119.01	0.03
B [cultivar]	9	3.21***	3.17***	1 106.01	8.83	78.89*	81.29	0.76***	1 924.98	353.79	0.03
A x B	9	0.32	0.22	515.81	4.76	24.86	60.57	0.07	990.35	159.13	0.01
Error (b)	54	0.51	0.28	777.84	5.44	29.60	58.13	0.18	1 046.24	174.09	0.02

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A3. Mean squares for the ANOVA for agronomic traits measured at Prosper in 2012.

		Mean square						
SOV†	df	SC	EV	LV	CC	PH	TKW	GY
Rep	3	13 198 033 181	0.68	0.02	50.83	34.53	84.42	550 678
A [seedbed]	1	20 855 303 820	30.01*	1.51*	45.00	6.05	49.46	35 167
Error (a)	3	8 838 224 720	2.75	0.07	9.17	9.25	66.71	139 865
B [cultivar]	9	9 507 858 542*	5.31***	1.04***	105.42**	291.02***	1 605.67***	211 588***
A x B	9	3 311 403 273	1.15	0.19	19.31	41.77*	19.06	93 681*
Error (b)	54	3 810 288 308	1.09	0.15	33.47	15.53	22.66	43 579

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3	0.48	0.26	148.73	0.84	3.31	65.67	0.00	471.63	40.59	0.03
A [seedbed]	1	0.84*	0.38	0.03	16.18	1.81	217.33***	0.50	2 891.92**	433.43***	0.00
Error (a)	3	0.06	0.08	2 018.97	1.65	2.09	0.86	0.46	22.99	1.81	0.00
B [cultivar]	9	1.93***	3.00***	2 806.17	9.40	110.49***	145.28*	1.97***	3 087.06**	548.88***	0.05*
A x B	9	0.16	0.12	2 339.24	2.38	21.27	35.54	0.80	566.38	88.86	0.01
Error (b)	54	0.26	0.09	1 688.75	4.99	18.61	56.18	0.49	899.71	135.85	0.02

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A4. Mean squares for the ANOVA for agronomic traits measured at Hitterdal in 2012.

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3	8 699 987 811	2.55	1.56	0.04	66.15	187.60	1 192.32	625 899
A [seedbed]	1	435 137 212	1.25	0.00	0.02	0.31	387.20**	7.74	1 144 632
Error (a)	3	12 023 067 114	0.55	0.08	0.09	19.48	8.60	179.76	144 060
B [cultivar]	9	8 439 091 095*	4.14***	0.95**	0.22***	561.15***	145.92***	1 434.74***	235 151***
A x B	9	4 806 445 850	0.78	0.64*	0.04	29.48	39.95*	91.83	65 192
Error (b)	54	3 960 493 071	0.56	0.29	0.04	40.50	15.01	49.73	47 078

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3	2.98	1.45	410.56	10.73	8.15	13.66	0.86	461.72	93.13	0.02
A [seedbed]	1	0.80	0.99*	17 925.00*	0.15	28.80	16.65	0.08	0.61	1.01	0.02
Error (a)	3	0.12	0.08	1 036.67	2.05	18.98	24.53	0.03	599.07	100.67	0.00
B [cultivar]	9	3.63***	2.04***	2 451.44*	9.51*	68.19***	11.97	1.39**	426.62	114.91*	0.06**
A x B	9	0.38	0.39	551.03	3.24	12.06	16.85	0.25	262.52	35.67	0.01
Error (b)	54	0.52	0.26	1 028.87	4.34	10.89	14.88	0.41	284.34	46.19	0.02

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A5. Mean squares for the ANOVA for agronomic traits measured at Barnesville in 2012.

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	2	353 598 835	5.72	5.25	0.80	1 201.67	210.62	22.30	198 845
A [seedbed]	1	625 657 500	6.02**	4.27	0.22	120.42	6.02	10.17	40 088
Error (a)	2	1 524 239 808	0.02	0.68	0.09	51.67	19.12	35.47	88 830
B [cultivar]	9	28 625 871 249**	4.77**	1.75	1.29***	225.05	153.12	714.11***	377 543
A x B	9	6 131 749 942	1.32	1.67	0.15	193.56	200.20	223.12	988 829
Error (b)	36	7 479 653 424	1.57	2.09	0.13	244.72	224.81	148.88	914 186

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	2	0.10	0.83	1 501.00	0.80	12.43	32.92	0.05	574.87	76.99	0.06
A [seedbed]	1	0.02	0.02	2 965.16	3.04	3.75	0.34	0.00	17.07	10.00	0.00
Error (a)	2	0.32	0.02	249.27	4.55	0.91	2.40	0.12	20.52	3.20	0.00
B [cultivar]	9	1.27*	1.33***	1 466.46	2.85	27.11	19.55	0.27	503.95	92.92	0.03
A x B	9	0.22	0.13	428.97	3.68	36.23	92.80*	0.14	1 668.90**	265.46**	0.06
Error (b)	36	0.53	0.20	1 535.61	2.27	20.64	31.71	0.25	524.45	83.05	0.06

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A6. Mean squares for the ANOVA for agronomic traits measured at Rothsay in 2012.

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3	11 484 090 551	27.78	65.16	8.06	8 584.95	3 593.73	1 024.80	23 614 368
A [seedbed]	1	25 234 757 778	16.20**	14.88	6.05*	4 176.05	1 185.80	173.87	3 018 546
Error (a)	3	18 319 053 783	0.28	1.50	0.22	614.88	326.07	76.08	596 674
B [cultivar]	9	13 611 947 612	6.45***	9.81*	1.97***	1 442.92***	868.74***	628.18***	1 861 474
A x B	9	8 745 163 921	0.73	1.84	0.31	143.41	123.19	206.28	358 975
Error (b)	54	8 622 142 869	1.13	3.66	0.30	381.98	192.87	129.66	1 164 862

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3	9.43	2.20	1 906.48	5.64	168.44	608.33	0.80	10 746.00	1 579.02	1.50
A [seedbed]	1	6.33*	0.21	28.07	20.50	25.88	20.50	1.38	12.80	15.31	0.39
Error (a)	3	0.55	0.17	830.91	4.79	20.01	48.56	0.26	332.14	44.58	0.11
B [cultivar]	9	3.77**	1.64***	865.91	29.24**	98.51*	67.58	0.43	1 984.79	425.97	0.52
A x B	9	1.16	0.27	1 175.09	4.71	36.33	63.41	0.66	1 200.27	195.75	0.13
Error (b)	54	1.00	0.33	591.98	8.58	39.74	74.48	0.55	1 415.20	233.30	0.38

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A7. Mean squares for the combined ANOVA for agronomic traits measured for six seedbed environments [Fargo (undrained), Fargo (drained), Prosper, Hitterdal, Barnesville, and Rothsay] in 2012.

			Mean square							
SOV†	df	df‡	SC	EV	LV	IDC§	CC	PH	TKW	GY
Environment (E)	5	4	20 719 128 845	68.10	63.86*	45.65***	24 193.00***	23 476.00***	10 718.00***	55 912 042***
Rep (E)	17	14	7 931 674 769	10.33	14.35	1.94	2 492.37	894.81	485.68	5 000 685
A [seedbed]	1	1	16 168 942 311	0.06	2.93	1.72	72.79	20.68	69.37	205 528
A x E	5	4	18 711 009 904	24.31*	4.69*	1.18***	1 288.58*	423.21*	40.82	1 113 157
Error (a)	17	14	8 516 793 104	5.64	0.86	0.10	461.11	146.70	90.28	434 314
B [cultivar]	9	9	44 583 373 988***	17.62***	4.01	1.78**	1 081.65**	679.71**	7 265.13***	345 072
B x E	45	36	7 237 306 679	2.02**	2.32**	0.50***	323.62***	189.95***	281.52***	597 270**
A x B	9	9	3 796 788 168	0.84	0.71	0.07	101.79	102.95	276.69**	359 173
A x B x E	45	36	8 501 838 916	0.97	1.04	0.13	86.08	70.84	81.24	279 757
Error (b)	306	252	6 073 858 060	1.16	1.24	0.11	141.31	76.97	72.14	373 442

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Environment (E)	5	81.75***	159.24***	60 640.00**	50.84	195.92	805.54*	2.54	13 046.00*	1 938.12*	1.48*
Rep (E)	17	3.52	1.16	1 090.53	5.47	38.88	165.81	0.51	2 745.76	406.11	0.28
A [seedbed]	1	1.92	0.27	389.95	11.27	90.99	325.62	0.77	6 430.48	1 008.10	0.03
A x E	5	1.42*	0.32	4 074.52*	11.91	33.65	92.42	0.40	1 430.69	252.27	0.08
Error (a)	17	0.40	0.18	1 364.32	5.05	12.48	36.27	0.39	443.25	65.68	0.03
B [cultivar]	9	10.63***	10.66***	4 514.10***	37.34***	240.35***	118.82*	2.79***	3 842.47***	836.48***	0.23*
B x E	45	1.14**	0.52**	1 132.34	5.57	38.66	43.11	0.48	858.31	152.77	0.10***
A x B	9	0.62	0.24	1 727.16	2.33	7.63	45.81	0.46	595.85	79.71	0.06
A x B x E	45	0.46	0.23	996.07	4.23	27.38	48.04	0.31	869.52	141.18	0.04
Error (b)	306	0.54	0.25	1 039.56	5.34	23.92	45.07	0.39	815.08	132.45	0.09

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

‡ df for five combined environments due to no visual IDC differences at Prosper.

§ IDC is averaged over five environments due to no visual IDC differences at Prosper.

Table A8. Agronomic traits averaged across cultivars for seedbed effect at Fargo (undrained) in 2012.

Seedbed	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	--g--	kg ha^{-1}	---g kg^{-1}---		mm	---number---						
Flat	317 177	6.3	7.4	1.0	63	76	119.8	3110	301	197	107	3.2	11.0	15.8	0.5	74.3	30.5	2.45
Raised	293 317	5.0	7.0	1.1	53	71	119.9	2924	301	196	109	3.8	13.0	17.6	0.3	83.6	34.6	2.43
LSD (0.05)	ns	0.8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significant.
† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.
§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Table A9. Agronomic traits averaged across cultivars for seedbed effect at Fargo (drained) in 2012.

Seedbed	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	--g--	kg ha^{-1}	---g kg^{-1}---		mm	---number---						
Flat	317 356	6.0	7.5	1.1	60	78	118.4	3144	302	195	98	3.3	13.1	17.2	0.3	82.2	33.9	2.43
Raised	265 869	4.7	7.3	1.0	55	75	119.7	2942	300	196	100	4.4	15.6	22.1	0.5	103.8	42.6	2.43
LSD (0.05)	37 363	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.8	1.3	ns	ns	ns	7.8	ns

ns = not significant.
† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure, PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.
§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Table A10. Agronomic traits averaged across cultivars for seedbed effect at Prosper in 2012.

Seedbed	SC†	EV	LV	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		%	cm	--g--	kg ha^{-1}	---g kg^{-1}---		mm	---number---						
Flat	326 506	6.4	8.2	94	107	145.8	4485	306	169	163	2.3	11.9	18.0	0.7	82.5	32.6	2.53
Raised	294 214	7.7	8.5	95	107	147.4	4528	308	168	162	3.2	12.2	21.6	0.8	95.6	37.9	2.54
LSD (0.05)	ns	1.2	0.2	ns	ns	ns	ns	2	ns	ns	ns	ns	1.5	ns	2.2	2.1	ns

ns = not significant.
† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.

Table A11. Agronomic traits averaged across cultivars for seedbed effect at Hitterdal in 2012.

Seedbed	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	--g--	kg ha^{-1}	---g kg^{-1}---		mm	--------------------------number--------------------------						
Flat	323 277	7.4	8.0	1.2	79	75	143.3	3230	328	185	140	2.7	10.7	14.3	0.5	69.0	28.2	2.46
Raised	318 612	7.1	8.0	1.2	79	71	142.7	2986	326	187	110	2.6	11.9	13.3	0.6	68.8	28.4	2.43
LSD (0.05)	ns	ns	ns	ns	ns	2	ns	ns	ns	2	23	ns	ns	ns	ns	ns	ns	ns

ns = not significant.
† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure, PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.
§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Table A12. Agronomic traits averaged across cultivars for seedbed effect at Barnesville in 2012.

Seedbed	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	--g--	kg ha^{-1}	---g kg^{-1}---		mm	--------------------------number--------------------------						
Flat	332 725	6.4	7.3	1.5	72	75	126.3	2455	300	198	113	1.7	9.0	12.9	0.3	59.6	23.9	2.46
Raised	339 183	7.0	7.8	1.4	75	76	125.4	2403	300	199	126	2.1	9.5	12.7	0.3	60.7	24.7	2.46
LSD (0.05)	ns	0.1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significant.
† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.
§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Table A13. Agronomic traits averaged across cultivars for seedbed effect at Rothsay in 2012.

Seedbed	SC†	EV	LV	IDC	CC	PH	TKW	GY	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
	plants ha^{-1}	---1-9‡---		1-5§	%	cm	--g--	kg ha^{-1}	---g kg^{-1}---		mm	--------------------------number--------------------------						
Flat	274 121	4.7	5.3	3.1	39	50	130.8	1782	309	165	78	4.6	11.6	12.5	0.1	65.6	28.7	2.07
Raised	309 642	5.6	6.2	2.6	53	58	133.9	2178	303	166	80	3.6	10.4	13.5	0.4	66.4	27.9	2.21
LSD (0.05)	ns	0.4	ns	0.3	ns	ns	ns	ns	6	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = not significant.
† SC = stand count, EV = early vigor (28 June to 29 June), LV = late vigor (20 Aug. to 21 Aug.), IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.
‡ Based on a visual score, with 9 being the most vigorous.
§ Based on the visual scale from Goos and Johnson (2008), with 5 being most chlorotic.

Table A14. Mean squares for the ANOVA for agronomic traits measured at Fargo in 2012.

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3	3 870 202 001	9.52	4.49	0.33	2 818.54	508.06	180.98	419 730
A [drainage]	1	7 435 779 094	4.06	1.41	0.00	5.63	363.01	26.90	27 507
Error (a)	3	7 458 110 925	14.23	6.57	0.09	1 801.88	606.27	254.78	2 993 978
B [seedbed]	1	56 772 269 194**	68.25	4.56	0.01	1 960.00	485.51	18.36	1 510 080
A x B	1	7 632 663 239	0.04	0.76	0.19	202.50	68.91	14.76	2 200
Error (b)	6	4 032 661 050	14.18	1.40	0.05	967.50	237.32	82.71	760 645
C [cultivar]	9	12 503 946 821	5.72***	1.31	0.14***	305.21**	185.88***	4 546.09***	488 604***
A x C	9	6 465 254 695	1.03	0.74	0.00	72.29	20.65	67.47	154 883
B x C	9	8 358 516 595	0.92	1.21	0.02	53.75	28.31	69.71	94 017
A x B x C	9	14 955 664 895*	0.76	0.34	0.05	78.89	8.30	41.39	83 338
Error (c)	108	6 519 584 573	1.36	0.78	0.04	90.82	31.44	56.74	117 785

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3	5.62	1.57	550.57	8.67	19.64	182.19	0.34	2 879.52	443.23	0.01
A [drainage]	1	0.01	0.38	3 581.56	5.08	216.23*	358.50	0.00	7 889.08*	1 291.06*	0.00
Error (a)	3	1.37	0.56	2 162.64	4.58	12.49	44.41	0.84	617.56	94.03	0.01
B [seedbed]	1	0.45	0.04	174.31	26.81	200.26**	457.31*	0.00	9 540.38*	1 654.44**	0.00
A x B	1	0.41	0.23	6.81	3.75	2.50	100.01	0.83	1 515.98	208.16	0.00
Error (b)	6	0.66	0.33	1 839.21	8.55	14.50	64.98	0.69	771.94	111.50	0.04
C [cultivar]	9	5.72***	5.23***	2 260.17**	13.89*	138.50***	53.94	0.99***	1 986.50*	432.89**	0.06**
A x C	9	0.42	0.27	520.65	3.24	14.17	49.63	0.19	614.74	82.59	0.03
B x C	9	0.55	0.27	1 464.04	4.38	9.68	42.70	0.07	565.03	88.76	0.01
A x B x C	9	0.41	0.23	681.83	5.42	29.89	29.90	0.12	622.87	105.43	0.02
Error (c)	108	0.50	0.32	768.65	5.41	26.22	45.41	0.29	835.72	139.95	0.02

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A15. Mean squares for the ANOVA for agronomic traits measured at Fargo in 2011.

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Rep	3	16 608 085 933	10.91	10.91	1.44	2 728.54	169.36	33.36	269 122
A [drainage]	1	64 306 325 670	56.41	66.31**	0.74*	11 731.00*	3 667.22*	36.77	7 937 295*
Error (a)	3	7 115 097 199	6.31	1.79	0.06	414.38	187.69	263.66	774 004
B [fungicide]	1	2 904 612 926	4.56	3.31	0.39	360.00	28.90	8.88	470 044
A x B	1	4 256 330 033	12.66	8.56	0.06	1 210.00	562.50	33.22	1 462 298
Error (b)	6	4 493 621 067	3.94	6.85	0.06	845.83	106.50	116.56	354 505
C [cultivar]	9	7 845 058 716	7.43***	8.70***	1.03***	1 054.86***	340.95***	3 379.77***	237 401
A x C	9	10 705 852 265*	1.67	1.50	0.09	200.42	21.45	36.87	184 237
B x C	9	3 794 991 272	0.82	1.00	0.16	69.38	13.65	91.30	235 929
A x B x C	9	10 552 229 712	1.50	0.56	0.13	67.99	10.03	61.34	109 823
Error (c)	108	4 773 271 352	1.52	1.19	0.21	113.62	19.67	53.29	177 687

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Rep	3	1.33	0.49	830.47	0.54	31.03	61.18	0.21	1 280.36	198.36	0.02
A [drainage]	1	0.50	4.19	470.94	11.29	30.63	488.25*	0.76	7 088.91*	1 015.06*	0.09
Error (a)	3	0.99	0.96	2 292.27	3.09	6.56	21.59	0.26	439.57	72.56	0.01
B [fungicide]	1	0.04	0.18	1 584.45	4.73	6.40	3.75	0.06	5.63	9.03	0.01
A x B	1	0.03	0.02	2 784.73	4.73	5.26	24.41	0.01	452.26	87.03	0.00
Error (b)	6	1.62	0.25	1 017.50	1.03	8.31	5.84	0.03	159.32	31.50	0.01
C [cultivar]	9	1.33**	6.69***	1 119.08	5.20*	62.92***	33.04**	0.26**	312.39	76.99**	0.15***
A x C	9	0.43	0.33	774.44	1.17	16.36*	8.33	0.13	195.40	39.51	0.01
B x C	9	0.38	0.13	259.14	2.20	14.41	28.33*	0.03	425.02*	62.39*	0.02
A x B x C	9	0.20	0.31	321.01	2.15	6.64	5.18	0.10	59.69	10.98	0.01
Error (c)	108	0.41	0.22	731.05	2.17	8.09	12.67	0.10	173.67	28.73	0.02

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.

Table A16. Mean squares for the combined ANOVA for agronomic traits measured for two drainage environments (Fargo 2011 and Fargo 2012).

		Mean square							
SOV†	df	SC	EV	LV	IDC	CC	PH	TKW	GY
Environment (E)	1	128 325 166 248	65.25	40.61	18.62*	13 781.00	3 373.50	2 6385.00	1 168 970
Rep (E)	6	10 239 143 967	10.21	7.70	0.88	2 773.54	338.71	107.17	344 426
A [drainage]	1	14 004 007 954	15.09	43.51	0.36	5 611.25	3 168.90	63.28*	4 449 664
A x E	1	57 738 096 810	45.38	24.20	0.38	6 125.00	861.33	0.39	3 515 139
Error (a)	6	7 286 604 062	10.27	4.18	0.07	1 108.13	396.98	259.22	1 883 991
B [cultivar]	9	15 219 234 511	12.58***	6.00	0.86	958.85	435.75*	7 695.38***	407 645
B x E	9	5 129 771 025	0.57	24.20*	0.31**	401.22	91.07*	230.48*	318 359
A x B	9	5 497 828 165	1.44	1.10	0.05	117.67	16.85	51.88	148 647
A x B x E	9	11 673 278 794	1.26	1.14	0.04	155.03	25.24	52.46	190 473
Error (b)	108	6 273 524 740	2.02	1.14	0.12	145.98	34.60	57.94	174 457

		Mean square									
SOV	df	PC	OC	LP	1S	2S	3S	4S	TS	TP	SP
Environment (E)	1	636.76***	41.54*	13.41	99.01*	588.61	3 808.80**	4.39	63 577.00**	9 608.63**	0.39
Rep (E)	6	3.48	1.03	690.52	4.60	25.33	121.68	0.28	2 079.94	320.79	0.02
A [drainage]	1	0.30	3.55	727.52	15.75	204.80	841.75*	0.41	14 967.00*	2 297.83*	0.03
A x E	1	0.20	1.02	3 324.98	0.61	42.05	5.00	0.34	10.69	8.29	0.06
Error (a)	6	1.18	0.76	2 227.45	3.83	9.53	33.00	0.55	528.57	83.29	0.01
B [cultivar]	9	5.66*	10.37**	2 940.24**	13.31	165.26*	45.68	0.92	1 449.85	349.15	0.17**
B x E	9	1.39*	1.55**	439.02	5.79	36.16	41.31	0.34	849.04	160.73	0.03
A x B	9	0.47	0.33	1 021.11*	2.43	12.32	29.61	0.12	326.40	42.68	0.03
A x B x E	9	0.37	0.27	273.98	1.99	18.21	28.36	0.21	483.74	79.43	0.01
Error (b)	108	0.47	0.26	776.83	3.90	17.17	30.74	0.19	526.75	87.47	0.02

* ** *** Significant at ($p \leq 0.05$), ($p \leq 0.01$), and ($p \leq 0.001$), respectively.

† SOV = source of variation, df =degrees of freedom, SC = stand count, EV = early vigor, LV = late vigor, IDC = iron deficiency chlorosis score, CC = canopy closure (at R 6), PH = plant height, TKW = thousand kernel weight, GY = grain yield, PC = protein content, OC = oil content, LP = lowest pod height, 1S to 4S = number of pods per plant with one to four seeds, TS = total seeds per plant, TP = total pods per plant, SP = average seeds per pod.