Double-Crop Soybean Vegetative Growth, Seed Yield, and Yield Component Response to Agronomic Inputs in the Mid-Atlantic, USA

Kevin Alan Dillon

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David L. Holshouser

Wade E. Thomason

D. Ames Herbert, Jr.

Mark S. Reiter

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ABSTRACT

Maximizing productivity and profitability are the primary reasons for double-cropping soybean with small grain in the Mid-Atlantic, USA. Reduced double-crop yield can be attributed to: delayed planting that results in a shortened growing season and less vegetative growth; later-maturing cultivars that terminate main stem growth after flowering and have less growth and nodes; less soil moisture and plant-available nutrients due to small grain uptake; greater air and soil temperatures during vegetative stages that reduce early-season growth; and more favorable conditions for disease development during pod and seed formation. Field experiments were conducted in 2012 and 2013 in eastern Virginia to 1) evaluate cultivar stem growth habit, seeding rate, seed-applied inoculant, starter nitrogen (N) applied at planting, and foliar fungicide on soybean vegetative growth, total N uptake (TNU), seed yield and quality, and yield components; 2) determine the effect of starter N rate, applied with and without inoculant, on soybean vegetative growth, TNU, seed yield and quality, and yield components; and 3) evaluate the response of maturity group (MG) IV and V soybean cultivars to foliar fungicide.

Greater seeding rates, inoculant, N, and fungicide typically were not required together to increase yield. Although cultivar interacted with other factors, early-maturing indeterminate 95Y01 yielded more than late-maturing determinate 95Y20 at 4 of 6 locations. Seeding rate interacted with other factors, but the greater seeding rate increased MG IV yield at 1 of 6 locations and decreased MG V yield at 2 of 6 locations. Starter N increased seed yield by 6 kg ha^{-1} per kg N applied until yield plateaued at 16 kg

N ha^{-1}, which continued to 31 kg N ha^{-1}. When N rate was increased greater than 31 kg N ha^{-1}, yield decreased. Fungicide increased yield for MG IV and V cultivars at 4 of 6 and 3 of 6 locations, respectively and prevented yield loss via mid- to late-season disease control, delayed leaf drop, and greater seed size. Optimum fungicide timing depended on environment and disease development. These data assisted in understanding agronomic inputs' combined or individual effects on double-crop soybean growth, canopy, N uptake, seed yield, and yield components.

DEDICATION

I dedicate this dissertation to my lovely wife Mary Catherine Mills Dillon for dealing with my constant travel from 2011 to 2013, for understanding my limitations due to distance, and for showing me compassion and providing encouragement. Thank you Mary Catherine for helping me keep grinding through my doctoral degree and reminding me that there was light at the end of the tunnel. You make me a better man and I am blessed to call you my wife. I love you very much and look forward to our lives together after graduate school!

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CHAPTER I - INTRODUCTION

Soybean and Winter Wheat Production Significance

Soybean [*Glycine max* (L.) Merr.] and winter wheat (*Triticum aestivum* L.) production is crucial to the United States of America agricultural industry. Soybean accounts for 90% of the U.S. annual oilseed production and is therefore considered the most economically important oilseed crop grown in America (Ash, 2012). This production significance transcends to the global soybean market where, during 2012/2013 marketing year, the U.S. produced 82.6 million metric tons (mmt), which ranked first, followed by Brazil, Argentina, China, India, Paraguay, and Canada, who produced 82.0, 49.3, 13.0, 11.5, 8.3, and 5.1 mmt, respectively (FAS, 2014). The U.S. ranked second in both exports (seed, meal and oil) and crush (domestic) with 35.9 mmt exported and 46.0 mmt crushed. Brazil led the export market with 41.9 mmt followed by the U.S., Argentina, Paraguay, and Canada, who exported 35.9, 7.7, 5.3, and 3.5 mmt, respectively. China dominated the crush market in 2012/2013 with 64.9 mmt followed by the U.S., Brazil, Argentina, European Union, India, and Mexico, who crushed 46, 34.5, 33.6, 12.7, 9.7, and 3.6 mmt, respectively (FAS, 2014). Argentina was positioned with the most ending stocks at the marketing year end with 22.4 mmt, followed by Brazil, China, U.S., and India, who retained 15.9, 12.4, 3.8, and 0.4 mmt, respectively (FAS, 2014).

During 2013, approximately 31.2 million ha soybean were planted and over 89.5 billion kg produced in the U.S.; this production was valued at $41.8 billion with 2912 kg ha^{-1} observed mean yield and $0.47 kg^{-1} market price (five year mean) (NASS, 2014). The National Agricultural Statistics Services (NASS) estimates that 32.2 million ha will be planted in the U.S. in 2014, with 2912 kg ha^{-1} trendline yield.

Winter wheat production in 2013 in the U.S. accounted for 17.4 million ha planted, 13.1 million ha harvested, and 41.8 billion kg grown; this production resulted in $10.4 billion value, with $0.25 kg^{-1} market price (five year mean) (NASS, 2014). National winter wheat yields averaged 3188 kg ha^{-1} in 2013 and hectares are projected to drop slightly in 2014 with 16.9 million ha planted (NASS, 2014).

The Mid-Atlantic region of the U.S., which includes the states of Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, and Virginia, accounted for 1.3 million ha soybean and 793 thousand ha winter wheat in 2013 (NASS, 2014). When the regional acreage was broken down by state, the following estimates were reported: North Carolina (591,000 ha soybean and 401,000 ha winter wheat), Virginia (243,000 ha soybean and 129,000 ha winter wheat), Pennsylvania (218,000 ha soybean and 75,000 ha winter wheat), Maryland (194,000 ha soybean and 140,000 ha winter wheat), New Jersey (36,000 ha soybean and 14,000 ha winter wheat), and Delaware (67,000 ha soybean and 34,000 ha winter wheat) (NASS, 2014). Virginia's 242,800 ha soybean planted in 2013 resulted in 238,800 ha harvested, 2556 kg ha^{-1} mean yield, 610.3 million kg produced, and production valued at $287 million (NASS, 2014). During that same year, Virginia harvested 111,300 ha of winter wheat that averaged 4170 kg ha^{-1} and resulted in 464.1 million kg with $107.4 million total value (NASS, 2014). National Ag Statistics Service (2014) estimated that 129,500 ha winter wheat were planted in Virginia in fall 2013.

Mono-Crop and Double-Crop Systems

Mono-crop, defined as one crop grown land area^{-1} year $^{-1}$, produced during a long growing season is inefficient when compared to multiple cropping, which is widely adopted in differing environments (Egli, 2011). Double-crop is a form of relay cropping in which two monocultures are grown in sequence during one year (Loomis and Connor, 1992). Compared to mono-crop, double-crop more efficiently captures precipitation and photosynthetically active radiation and increases the productivity of the growing environment through the addition of crop residues to the soil, which benefits soil quality and provides an additional sink for atmospheric CO_2 (Caviglia and Andrade, 2010; Caviglia et al., 2004, 2011). Caviglia et al. (2011) recommended crop intensification to improve production settings' spatial and temporal diversity in South America as compared to systems that rely on fewer, dominant crops. Multiple cropping increases productivity by increasing the time year^{-1} devoted to seed filling by multiple seed fill periods (Egli, 2011). Increase in productivity due to multiple cropping adoption over mono-cropping was demonstrated in temperate environments including: wheat-soybean (Browning, 2011; Calvino et al., 2003; Caviglia et al., 2011; Heatherly and Elmore, 2004; Kyei-Boahen and Zhang, 2006; Nelson et al., 2011), wheat-grain sorghum (*Sorghum bicolor*) (Crabtree et al., 1990; Sanford et al., 1973; Sanford et al., 1986; Wesley et al., 1994), triticale (*Triticosecale*)-grain sorghum (Goff et al., 2010;), wheat-sunflower (*Helianthus annuus*) (Sanford et al., 1973; Sanford et al., 1986; Wesley et al., 1994), barley (*Hordeum vulgare* L.)-soybean (Browning, 2011; Groover et al., 1989), barley-grain sorghum (Camper et al., 1972), and barley-corn (*Zea mays* L.) (Camper et al., 1972). Double-crop has also been reported in tropical environments, with rice (*Oryza sativa*) production after winter wheat or multiple rice crops year^{-1} (Timsina and Conner, 2001; Yoshida, 1977). Wheat-soybean double-crop systems in Oklahoma, Kansas, Kentucky, Mississippi, and Virginia have demonstrated increased net returns as compared to mono-crop soybean (Farno et al., 2002; Kelley, 2003; Herbek and Bitzer, 1988; Kyei-Boahen and Zhang, 2006; Browning, 2011, respectively). Crop rotations involving small grains improved weed management, eliminated the need for tillage, increased water infiltration and soil organic matter, improved soil structure, trapped excess nitrogen (N), and reduced soil erosion from surface water runoff (Bernstein et al., 2011; Hartwig and Ammon, 2002; Kaspar et al., 2001; McMaster et al., 2000; Ruffo et al., 2004; Savabi and Stott, 1994).

Soybean yield potential is reduced as planting is delayed past the optimum date (Barreiro and Godsey, 2013; Bastidas et al., 2008; Chen and Wiatrak, 2010; De Bruin and Pedersen, 2008b; Egli and Cornelius, 2009). Research conducted in Ohio by Beuerlein (2001) determined every week after June 15th that soybean planting was delayed, soybean lost up to 470 kg ha^{-1} week^{-1}. The use of a double-crop system results in soybean planting that can be delayed past dates recommended for optimum yield potential (Wesley, 1999). Yield reduction for late-planted double-crop soybean was attributed to lack of sufficient vegetative growth (Ball et al., 2000b; Barreiro and Godsey, 2013; Boerma et al., 1982; Caviglia et al., 2011; Herbert and Litchfield, 1984; Jones et al., 2003), reductions in crop growth rate during the period when seed number (Egli and Bruening, 2000) and seed weight (Calvino et al., 2003) are defined, and reproductive phase duration (Egli, 2011). Board and Hall (1984) indicated that premature flowering induced by short photoperiod is a major yield limiting factor in July plantings between 30° and 32° 30’ N latitude. Increasing yield in late-planted soybean was correlated to increasing leaf area that maximizes light interception and subsequently increases biomass (Board and Harville, 1993; Board et al., 1992; Jones et al., 2003; Wells, 1991). Jones et al. (2003) attributed yield loss in a double-crop wheat-soybean system, compared to full-season soybean, to reduced amount of time to accumulate sufficient leaf area index (LAI) for maximum yield. In that study, the most influential factor on double-crop soybean LAI and seed yield was determined to be soil texture and associated plant-available water. The researchers recommended increasing plant population and decreasing row spacing to increase LAI.

In South America, Caviglia et al. (2011) reported that compared to mono-crop soybean, double-crop systems increased production by 58 to 82% and harvest residue by 91 to 143%. But, the yield of the soybean component of that system was critically influenced by early growing conditions that reduced biomass at the R1 developmental stage (beginning flower, Fehr and Caviness, 1977), which in-turn contributed to less assimilate supply during seed fill. The researchers determined that management of the cropping system to increase soybean biomass at R1 had the potential to enhance production and environmental benefits of double-crop in temperate environments. Reductions in double-crop soybean yield were also attributed to decreased seed number and weight seed^{-1} associated with short frost-free periods and decreased photoperiod and temperature (Calvino et al., 2003).

Brye et al. (2007) emphasized that wheat-residue management practices were critical to successful double-crop soybean establishment, but soybean growth and production were not negatively influenced by increasing wheat-residue levels due to advanced field implement and planting technology, which allows farmers to utilize alternative residue management. However, when soil water was limited due to previous depletion by the wheat crop, canopy closure was delayed or did not occur at all, reducing sunlight interception (Caviglia et al., 2011). Research demonstrated that higher plant populations were needed to maximize light interception and yield when soybean was planted past the optimum dates, especially if drought stress limited leaf area production (Ball et al., 2000a). Jones et al. (2003) also attributed reduced early season vegetative growth and leaf area development to moisture stress, especially on low plant-available water holding capacity soils. Therefore it stands to reason that a productive small grain crop with more growth (and residue) could reduce soil moisture available to the subsequent soybean crop, thereby inducing drought stress that may reduce vegetative growth and yield.

Soybean Seeding Rates and Plant Population

Seeding rate selection influences yield, lodging potential and economic return. The optimal seeding rate varies by field, desired plant population, planting date, soil type, seedbed condition, planting method (drill vs. planter), percent germination, and seed vigor (Walker et al., 2010). Soybean's unique ability to compensate for total, main stem and branch seed yield at reduced plant population has been documented (Board and Kahlon, 2013; Board et al., 1999; Carpenter and Board, 1997; Koger, 2009) and has been linked to cultivar selection and environmental conditions (Norsworthy and Frederick, 2002). Furthermore, soybean have responded to reduced seeding rates by producing more branches, biomass, pods, and seed plant^{-1} when compared to higher seeding rates (Egli, 1988; Carpenter and Board, 1997; Board, 2000; Egli and Bruening, 2006; Epler and Staggenberg, 2008; Cox et al., 2010).

Soybean seeding rate response varies based on cropping system, soil type, environmental conditions, and yield potential. Bowen and Schapaugh (1989) tested 128,000, 259,000 or 385,000 seeds ha^{-1} for full season soybean yield grown in Kansas and reported no response. Similar findings were reported by Grichar (2007) located in Texas Gulf Coast. Heatherly et al. (1999) and Heatherly and Elmore (2004) reported 200,000 to 300,000 uniformly distributed plants ha^{-1} maximized yield. Weber et al. (1966) worked with full-season soybean in Iowa and observed row spacing by seeding rate interactions that responded to higher seeding rates in narrow as opposed to wide rows. Boquet (1990) reported that 50-cm row spacing required higher plant densities to maximize irrigated soybean yields grown on clay soils in Louisiana as compared to 101-cm row spacing, whereas Timmons et al. (1967) worked in Minnesota clay loam soils and concluded that wider rows required higher seeding rates to maximize yield as compared to narrow rows. Bruns and Young (2012) tested irrigated, full-season soybean seeding rates ranging from 200,000 to 500,000 seed ha^{-1} in Mississippi and reported maximum yield (4,338 kg ha^{-1}) at 400,000 seed ha^{-1}. The 400,000 and 500,000 seed ha^{-1} increased yield by six and 4%, respectively when compared to 4,095 kg ha^{-1} yield observed with 200,000 seed ha^{-1}. Cox and Cherney (2011) demonstrated in New York silt loam soils, soybean yielded 7% more as seeding rates increased from 321,000 seed ha^{-1} to 420,000 seed ha^{-1} but declined by 4% for 469,000 seed ha^{-1}. More recently in New York, Orlowski et al. (2012) determined soybean farmers planting with a grain drill at 420,000 seed ha^{-1} could reduce seed cost but may increase weed control costs by switching to a row crop planter with seeding rate of 321,000 seed ha^{-1}.

Optimum yields have been obtained with relatively low final plant populations in Iowa silt loam and clay loam soils (De Bruin and Pedersen, 2008a), Kentucky silt loam and silty clay loam soils (Lee et al., 2008), and Tennessee non-irrigated silt loam soils (Walker et al., 2010). Reducing the minimal plant population needed for optimal yield has been (Ball et al., 2000; De Bruin and Pedersen, 2008a) and continues to be a critical soybean agronomic objective (Board and Kahlon, 2013), especially due to increased seed cost associated with biotech cultivars compared to conventional seed (Chen and Wiatrak, 2011b). Board and Kahlon (2013) determined the best strategy for Louisiana soybean farmers to minimize seeding cost without a yield reduction was to grow a soybean cultivar with low minimal optimal plant population, under optimal growing conditions. Lee et al. (2008) and De Bruin and Pedersen (2008a) reported due to high cost associated with soybean seed, economic seeding rates are often less than seeding rates that result in maximum yield. Chen and Wiatrak (2011a) examined full-season dryland soybean seeding rates ranging from 68,000 to 408,000 seed ha^{-1} produced in South Carolina coastal plain and determined the optimum MG V seeding rate to be 255,200 seed ha^{-1}. An economic analysis was conducted and the authors concluded optimum seeding rates differed based on maturity group (MG) selection. Specifically, seeding rates that produced maximum economic returns across study years were 136,000 and 208,600 to 252,600 seed ha^{-1} for MG IV and V, respectively.

Bertram and Pedersen (2004) reported in Wisconsin that increasing plant population density promoted rapid canopy closure of soybean grown on silt loam and loam soil and improved light interception and biomass production. Other researchers have reported the opposite, biomass increased with decreasing seeding rates. Carpenter and Board (1997) observed increased plant biomass when seeding rate decreased due to reduced intra-plant competition. Similarly, Cox et al. (2010) and Cox and Cherney (2011) reported biomass increased by 20% and 24% when seeding rate decreased from 580,000 to 358,000 and from 469,000 to 321,000 seed ha^{-1}, respectively. Aboveground biomass is a critical component of soybean seed yield (Shibles et al., 1965) due to its relationship with light interception, canopy closure, and translocation of nutrients from plant tissue to seed during pod-fill stages. Increasing plant population can increase competitive stress (Bowen and Schapaugh, 1989), plant height, plant mortality (Cooper and Lambert, 1971), and can result in greater yield loss via lodging (Weber and Fehr, 1966; Ethredge et al., 1989). Devlin et al. (1995) reported plant height responded to seeding rate. When soil moisture was adequate, increasing seeding rate increased plant height; however, when soil moisture was low, increasing seeding rate did not affect plant height. Ball et al. (2000) demonstrated in irrigated and non-irrigated Arkansas silty clay soils when photoperiod was shortened and temperature increased, vegetative growth duration and crop biomass decreased, which resulted in minimal optimal plant population being increased from 300,000 plants/ha to 600,000 plants/ha. Increasing seeding rates allowed LAI of 3.5 to 4.0 to be met even with the shortened growing season in double-crop production (Ball et al., 2000). Holshouser and Whittaker (2002) reaffirmed critical LAI value of 3.5 to 4.0 at R5 (beginning seed, Fehr and Caviness, 1977) for max light interception and yield of full season soybean produced in southeastern Virginia. Furthermore, also in Virginia, Malone et al. (2002) investigated double-crop soybean LAI with 15 manual defoliation experiments during a three year period and concluded that both full season and double-crop soybean decreased yield linearly when LAI values were below 3.5-4.0 at developmental stages R4 (full pod, Fehr and Caviness, 1977) to R5. In addition, yield for both cropping systems plateaued at higher LAI levels.

Chen and Wiatrak (2011b) examined MG and seeding rate's effect on full season, non-irrigated soybean plant stand, LAI and normalized difference vegetative index (NDVI) while grown in South Carolina coastal plain soils (loamy sand). Maturity group IV and V soybean were observed to have 74-87 and 59-78% emergence, respectively (Chen and Wiatrak, 2011b). Seeding rates ranged from 68,000 to 408,000 seed ha^{-1}. Leaf area index values 60 days after planting (DAP) were < 3.5 for MG IV and V all three years the study was conducted. The 90 DAP LAI values were > 3.5 for most MG, except MG IV due to the inability to achieve full canopy and improved adaptability in northern latitudes compared to study location. Maximum LAI values for MG IV were reached at 245,000 seed ha^{-1} at R5. The MG V cultivars required increased seed compared to MG IV to reach max LAI value at 260,000 to 285,000 seed ha^{-1} at R4 and was largely controlled by available soil moisture (Chen and Wiatrak, 2011b). Once NDVI values reached threshold or saturation level, further increased plant population did not increase NDVI. Optimum seeding rate for maximum NDVI was attained for MG IV and V at higher seeding rates compared to LAI. Specifically, MG IV max NDVI was attained at R5 at 350,000 seed ha^{-1} (NDVI: 0.856); MG V max NDVI at R4 with 315,000 (NDVI: 0.896) and

350,000 seed ha^{-1} (NDVI: 0.914) in 2008 and 2009, respectively. At 60 DAP NDVI was lower which demonstrated a positive linear relationship with seeding rate. Later in the growing season, at 90 DAP, NDVI was higher due to full canopy closure (except MG IV) and a quadratic and cubic relationship between seeding rate was observed. Chen and Wiatrak (2011b) emphasized there was an overall positive correlation between NDVI and LAI for each soybean MG. Chen and Wiatrak (2011b) concluded high seeding rates improved vegetative growth at vegetative and reproductive stages for 96-cm row soybean. Furthermore, increasing seeding rates above 272,000 seed ha^{-1} did not improve further late-season plant growth due to (i) LAI or NDVI no longer increased with seeding rate after saturation and (ii) reduced soil moisture available for plant uptake.

Although not the reason for greater seeding rate recommendations, soybean establishment may be difficult in double-crop wheat-soybean systems (De Bruin et al., 2005; Wagner-Riddle et al., 1994; Williams II et al., 2000). Walker et al. (2010) emphasized typical final full-season soybean stands range from 50 to 80% of planted seed. Double-crop soybean seedling emergence may be lower than full-season due to limited water available for the seed to germinate. Mid-Atlantic coastal plain soils can be drought prone and frequent drought exposure due to erratic precipitation and soils dominated by low-water holding capacity can result in soybean yield reduction (Frederick et al., 1998). Due to delayed planting date, potentially decreased nutrient availability, decreased seed to soil contact and poor emergence seeding rate recommendations are higher for double-crop than full-season. Soybean yield response to seeding rates is influenced by yield potential, which is determined by rainfall, soil type, irrigation availability and planting date (Devlin et al., 1995).

Walker et al. (2010) examined full season soybean seeding rates produced on non-irrigated, silt loam soils in Tennessee and reported reduced seed yield due to drought from over-relying on precipitation coinciding with sensitive reproductive developmental stages. Target plant population of 300,000 plants ha^{-1} (450,000 seed ha^{-1}) was recommended for optimal yield in most years (Walker et al., 2010). Devlin et al. (1995) examined soybean seeding rates ranging from 129,000 to 646,000 seed ha^{-1} with dryland conditions in Kansas, and concluded response depended on environmental conditions. Specifically, with high yield sites maximum yield was attained at 284,000 seed ha^{-1}; whereas when soil moisture was limited, 501,000 to 573,000 seed ha^{-1} were required to maximize yield. Holshouser and Whittaker (2002) observed varied drought stress levels in southeastern Virginia coastal plain soils (fine sandy loam and loam) while testing plant populations ranging from 103,000 to 850,000 plants ha^{-1}. With minimal drought stress, change in plant population did not affect yield. When soybean experienced brief moisture stress, 208,000 plants ha^{-1} were needed for maximum yield. Furthermore, if drought stress limited leaf area production, over 600,000 plants ha^{-1} were required to maximize seed yield. Similar research was conducted by Kratochvil et al. (2004) in Maryland coastal plain soils (sandy loam, silt loam and loamy sand) in full season and double-crop soybean production. When seeding rate was reduced by 40% (333,000 seed ha^{-1}), soybean consistently yielded less than the double-crop standard (555,750 seed ha^{-1}) during two years with different environmental conditions that included timely rainfall and moisture stress. Kratochvil et al. (2004) reported a 20% seeding rate reduction (445,000 seed ha^{-1}) produced equivalent yield to the double-crop standard seeding rate (555,750 seed ha^{-1}) and should be recommended to assist in reducing input costs in the Mid-Atlantic double-crop production system. However, with above average rainfall, MGIII cultivars increased full-season yield with 20% higher seeding rate (518,700 seed ha^{-1}). Norsworthy and

Frederick (2002) examined seeding rates for dryland, drilled soybean in South Carolina coastal plain soils (loamy sand) and determined rainfall influenced seed yield more than seeding rate or cultivar. In a drought stress dominated growing season, early MG V cultivar was negativity affected by reducing duration of vegetative growth stages. However, the following year, precipitation was above average and the early MG V yielded as well and in some cases, outperformed the later MG cultivars at both the recommended (620,000 seed ha^{-1}) and reduced seeding rates (370,000 seed ha^{-1}). Norsworthy and Frederick (2002) emphasized soybean seeding rates can be reduced while maintaining seed yield but only in drought stress free periods.

Cultivar Stem Growth Habit

Apical stem growth termination timing is divided into indeterminate and determinate categories (Ting, 1946). *Glycine soja*, wild soybean, is indeterminate in stem termination. The determinate trait was introduced over time due to wild soybean domestication (Tian et al., 2010). Specifically, artificial selection pressure on the *GmTFl1* gene encodes a single amino acid change that can be expressed as indeterminate or determinate stem termination (Tian et al., 2010). The stem and branch apical meristems maintain vegetative activity within indeterminate cultivars until vegetative dry matter ceases once seed translocation is initiated. Determinate cultivars' apical meristem vegetative dry matter activity ceases with photoperiod-induced floral induction and the meristems transition to reproductive inflorescences (Bernard, 1972). In summary, after anthesis initiation, soybean with indeterminate growth habit continue to grow in height while adding nodes, flowers and subsequent pods; soybean with determinate growth habit cease growth and flower at one time (Hoeft et al., 2000) progressing from the plant's lowest node to the top node. Stem termination has influenced plant height, flowering period, node production, maturity, water-use efficiency, and yield (Heatherly and Smith, 2004; Specht, 2001).

Most MG IV cultivars have an indeterminate stem growth habit, whereas most MG V cultivars are determinate. Cooper (1981) reported in a low-yield environment, where high temperature and drought stress reduced plant height, lodging, and yield, determinate cultivars yielded lower than indeterminate; in a high-yield environment, the indeterminate cultivar yielded less than determinate due to increased lodging. Graterol et al. (1996) demonstrated on Nebraska silt loam soils determinate and indeterminate cultivars yielded similarly in 76-cm wide rows but determinate cultivars yielded more than indeterminate cultivars in twin-row pattern. Beaver and Johnson (1981) examined soybean growth habit produced on Illinois silt loam soils and cautioned if drought stress typically dominated during vegetative stages, determinate cultivars should not be planted. Beuerlein (1988) determined semidwarf determinate cultivar had greater yield response to seeding rate than indeterminate cultivar.

Egli and Leggett (1973) investigated soybean stem growth habit in Kentucky by comparing indeterminate MG IV and determinate MG IV for stem growth and node production. Determinate MG IV reached > 80% final height and produced > 90% of final nod number by R1. Indeterminate MG IV reached < 50% of final height and < 60% of final node number by R1. Ouattara and Weaver (1994) planted soybean in Alabama during late-June to early-July and observed indeterminate lines were taller and increased main stem nodes at maturity compared to determinate lines. Kilgore-Norquest and Sneller (2000) contrasted stem growth habit in soybean planted during May and June in Arkansas and increased final height with indeterminate compared to determinate in both irrigated and dryland conditions.

Heatherly and Smith (2004) investigated stem growth habit effects on 50-cm-row irrigated soybean plant height and node production grown on Sharkey clay soil in Mississippi. The authors tested two mid-to-late MG IV indeterminate cultivars and two late MG V determinate cultivars. All cultivars increased plant height and node number between R1 and stem termination (ST). At R1, MG V determinate cultivars were taller and had increased nodes compared to MG IV indeterminate. The opposite was observed at ST; MG IV increased height and nodes between R1 and ST compared to MG Vs. More specifically, the duration between R1 and ST accounted for 78 and 33% of MG IV and V plant height, respectively, and 61 and 29% of MG IV and V node number, respectively. The MG IV indeterminate cultivars had increased final height and node number at ST date compared to MG V determinate cultivars. The determinate MG V cultivars did not grow as much as the indeterminate MG IV after R1, however, post-anthesis growth increase resulted in canopy closure by ST. Heatherly and Smith (2004) noted plant height differences between MG V determinate cultivars between R1 and ST and concluded genotypic variability for stem growth after R1 could be used by soybean breeders to ensure adequate plant stature. Heatherly and Smith (2004) concluded tall determinate and semi determinate MG V phenotypes would be preferred to conventional MG V determinate types in the ESPS due to increased plant height post-R1 and timely canopy closure.

Most branch development occurs from R1 to R5 in determinate cultivars (Board and Settimi, 1986) and changes little between R5 and R7 (beginning maturity, Fehr and Caviness, 1977) (Board and Kahlon, 2013). Similarly, Carpenter and Board (1997) found vegetative total dry matter was determined for both indeterminate and determinate soybean at R5. Determinate cultivars have been reported to have increased branch number (Beaver et al., 1985; Gai et al., 1984), branch dry matter (Beaver et al., 1985), and node (Gai et al., 1984) compared to indeterminate cultivars. Edwards and Purcell (2005) observed R1 to R5 duration to increase when moving from early to late maturing cultivars. Furthermore, Board and Kahlon (2013) provided insight into increased R1 to R5 duration. When cultivars are produced in the same environment, as MG increases, branch development will typically increase. Board and Kahlon (2013) tested MG IV to VIII for normalized branch dry matter to assist in making cultivar-specific recommendations for minimal optimal plant population. When the indeterminate MG IV and determinate MG V cultivars were compared, the ability to compensate for inadequate plant stand by producing increased branch matter was linked more to cultivar and genetic differences vs. growth habit. In addition, the MG V cultivars had 34% more variability within the range of normalized branch dry matter values compared to MG IVs. This can partially be explained by the sample size; almost three times the number of MG Vs were tested compared to MG IVs.

Due to latitude, the adopted management practices associated with the Early Soybean Production System (ESPS) developed in the Mid-South (Heatherly et al., 1999), and both full season and double-crop soybean production popularity in Virginia, both MG IV and V cultivars and subsequently both indeterminate and determinate growth habit are critical components of Mid-Atlantic soybean production systems. Cultivar selection is one of the most important agronomic decisions row-crop farmers make prior to planting. Furthermore, choosing the correct double-crop soybean cultivar is even more critical due to delayed planting date, reduced yield potential, and overall less than ideal growing conditions. Cultivar stem growth habit, i.e. choosing between indeterminate vs. determinate, may have a specific fit into the double-crop production setting by managing plant stress more efficiently throughout the shortened growing season.

Soybean Nitrogen Management

Soybean Nitrogen Requirements

Soybean has an extensive nutrient demand (Salvagiotti et al., 2009); as average yields increase, plant growth and seed yield may be limited by nutrients that were previously considered adequate. Sinclair and Horie, (1989) concluded that a large nitrogen requirement associated with high yielding crops is due to N being an elemental component of proteins and enzymes that make up the photosynthetic components in leaves. Soybean yield is closely correlated with N accumulated throughout the growing season (Lathwell and Evans, 1951). Specifically, Lathwell and Evans (1951) found seed yield to be correlated to pods retained plant^{-1}, which in turn were influenced by N amount available 40 to 65 DAP. Shibles et al. (1987) demonstrated that a large photosynthetic capacity is required during reproductive growth to maximize seed growth and subsequently, seed yield. During this reproductive growth period, the soybean plant uses N from the soil residual pool (if any remains) and plant tissue; however biological N_2 fixation rapidly decreases (Harper, 1987). Increases in N content in soybean seed were reported by Egli and Bruening (2007) and were attributed to N acquired during the seed-filling period rather than N mobilization from vegetative tissue. Duration of seed dry matter accumulation (filling) was not influenced by increasing seed N concentration (Egli and Bruening, 2007). The authors emphasized the negative relationship between seed protein concentration and yield could not be explained by individual seed level; rather, the whole plant controlled the assimilate supply to the seed and directly influenced yield (Egli and Bruening, 2007). Whereas, Zeiher et al. (1982) found that N accumulation in vegetative tissue is a resource that plants can use to satisfy demand for N if the N supply through biological N fixation is limited. Similarly, Harper (1987) determined that the soybean compensates for the reduction in biological fixed N by utilizing plant tissue N, once R6 (full seed, Fehr and Caviness, 1977) is reached. The N requirement for a 2570 kg ha^{-1} seed yield was reported by Weber (1966) to be

215 kg N ha^{-1}; the International Plant Nutrition Institute (IPNI) (2011) estimated the N requirement for 1680, 2688, 3696, and 4704 kg ha^{-1} seed yield to be 166, 251, 323, and 408 kg N ha^{-1}, respectively.

Biological N_2 Fixation and Inoculant Application

This need for N is met by the residual soil N pool and with symbiotic N_2 fixation from N fixing *Rhizobia* bacteria that convert N_2 gas to plant available N (Beuerlein, 2004; Bezdicek et al., 1978; Bhangoo and Albritton, 1976; Patterson and LaRue, 1983). The *Rhizobium* bacterial strain responsible for N_2 fixation in soybean is *Bradyrhizobium japonicum*. Soybean N demand can exceed 92 g kg^{-1} seed for optimum yield (Flannery, 1986). Salvagiotti et al. (2008) determined that approximately 80 kg N ha^{-1} are required to produce biomass that contains 1,000 kg ha^{-1} soybean seed and that 50 to 80% of this N requirement was met by N_2 fixation. Lindemann and Glover (2003) and Tien et al. (2002) reported that soybean can fix up to 280 kg N ha^{-1} through symbiotic N_2 fixation; this accounted for 70% of the total plant N requirement.

Effective inoculation with *Bradyrhizobia japonicum* bacteria is essential for N_2 fixation and economic yield production (Hiltbold et al., 1980). Biological N_2 fixation does not function from the onset of vegetative growth (Wani et al., 1995), rather the *Bradyrhizobia japonicum* bacteria actively start fixing N between the V2 (second fully-expanded trifoliate, Fehr and Caviness, 1977) and V3 (third fully-expanded trifoliate, Fehr and Caviness, 1977) soybean development stage. *Bradyrhizobium japonicum* populations were observed to be influenced by plant density, temperature, soil water content, organic matter, texture, and pH (Abendroth and Elmore, 2006; Albrecht et al., 1984; Bacanamwo and Purcell, 1999; Beuerlein, 2004; Graham, 1992; Seneviratne et al., 2000). Salvagiotti et al. (2008, 2009) reported that if N uptake is limited by an insufficient soil N supply or by declining biological N fixation during late seed fill, a less-than-optimal yield ceiling may be imposed upon the soybean crop. Mastrodomenico and Purcell (2012) showed under sufficient water conditions N_2 fixation provided 90% of the seed N content and continued into seedfill. The authors emphasized the need to identify and eliminate yield-limiting factors for later-maturing genotypes to take advantage of underused N while improving N dynamics for subsequent crop use. Mastrodomenico and Purcell (2012) demonstrated how soybean nutrition on soils with low organic matter and low N fertility is critically controlled by N_2 fixation. Due to the correlation of actively N-fixing bacteria with an increase in yield, inoculum material containing *Bradyrhizobia japonicum* bacteria were developed to apply as an in-furrow or on-seed treatment to increase N-fixing efficiency.

Inoculant use has become increasingly popular due to improved inoculant technology, relatively low product cost, ease of application, and increased input costs associated with nutrient management (De Bruin et al., 2010). Inoculants are unlikely to increase yield consistently in fields where soybean has previously been grown (Beuerlein, 2005; De Bruin et al., 2010; Furseth et al., 2012; Schulz and Thelen, 2008) and indigenous populations of *Bradyrhizobia japonicum* bacteria are present (Hiltbold et al., 1980). However, when soybean is grown on a soil not previously planted to soybean, inoculation is recommended to ensure symbiotic N_2 fixation and to encourage *Bradyrhizobia japonicum* bacteria population establishment (De Bruin et al., 2010; Furseth et al., 2012; Hiltbold et al., 1980; Schulz and Thelen, 2008). Thelen and Schulz (2009) determined that soybean grown on soils without a *Bradyrhizobia japonicum* bacteria population used available soil N in place of N_2 fixation and if soil N concentrations were low, N deficiency was observed. Inoculant should be applied if the field was flooded, has a non-optimal pH, is low in soil organic matter, or has a coarse textured soil (Abendroth and Elmore, 2006; Pedersen, 2004). Furseth et al. (2011) investigated previous growing season flooding effects on soil rhizobia and soybean production on fine sandy loam and silty clay loam soils in Wisconsin and reported no yield, oil or protein content response to *Bradyrhizobium japonicum* inoculation. Soil rhizobia populations were found to be adequate after extended flooding. Seed yield and protein content responded negatively, while oil content responded positively to initial rhizobia populations. Nitrate levels were high in the flooded locations and may have played a role in the negative response of rhizobia population on seed yield and quality. Furseth et al. (2011) concluded that seed inoculation may be required after flooding events if residual N is low or if large amounts of soil or residue from unknown origin are deposited in the field. In contrast, Furseth et al. (2012) demonstrated that rhizobia population level poorly predicted soybean response to inoculation at population levels typically observed in Wisconsin due to 13 of 15 of their nonresponsive environments being below the 11.4 natural log of rhizobia (89,300 cells g^{-1} soil), which was the established rhizobia population threshold for yield response to inoculant. Due to the inability to identify a rhizobia population threshold for preplant inoculation, Furseth et al. (2012) recommended applying inoculant if soybean had not been grown in five years or more on specific tract of land. Inoculation is a tool that can ensure proper nodulation and crucial N uptake in soybean plants, especially if rhizobia populations are low; however, yield response is not always observed.

Nitrogen Fertilization of Soybean

Soybean fertilization with N has gathered renewed interest in the U.S. due to the demand for high seed quality, large N requirements for seed fill, and the greater yield potential of modern soybean cultivars (Barker and Sawyer, 2005). Previous Research has examined the influence of pre-plant N fertilization on nodulation and soybean seed yield but mixed results were reported. Positive soybean yield response to N fertilization was reported by Ham et al. (1975), Purcell and

King (1996), Salvagiotti et al. (2008), and Wesley et al. (1998); whereas, some researchers did not observe yield increases (Gutierrez-Boem et al., 2004; Slater et al., 1991). Sorensen and Penas (1978) reported that soil temperature, moisture, and pH affected soybean response to applied N when grown on silty clay loam soils. Salvagiotti et al. (2009) evaluated surface- vs. deep-N application on silt loam soils; treatments included: (1) polymer-coated urea (ESN®, Agrium Advanced Technologies) deep-banded pre-plant between rows to 20-cm depth at 180 kg N ha^{-1}; (2) ammonium nitrate (AN) at 180 kg N ha^{-1}, 50% pre-plant broadcast and 50% broadcast at V6 (sixth fully-expanded trifoliate, Fehr and Caviness, 1977), with both applications incorporated; (3) AN top-dress hand-applied at R5 at 180 kg N ha^{-1} followed by sprinkler irrigation; and (4) untreated check. In this high soybean yield environment without N fertilization, soil N + natural biological N fixation accounted for approximately 90% of the N needed for maximum attainable seed yield; N fertilizer application was required to supply the remaining N. The authors further concluded that indigenous soil N fertility determines the degree of N-dependent yield gap in cereal crops; however, biological N fixation assists in closing that gap in yield in soybean. This study also determined that increased soybean seed yield with N fertilization was due to higher carbon assimilation rate during the seed fill period, as opposed to a longer seed fill period.

De Souza et al. (1997) found that when water stress occurs during seed fill, carbon and N can be remobilized from soybean leaf tissue and translocated to the seeds; the end result is a quicker reduction in photosynthetic rates. Decline in photosynthetic rates can result in premature senescence of leaves and yield loss through reduced seed size and number. Purcell and King (1996) concluded that N fertilizer alleviated N deficiency due to poor N fixation caused by reduced soil moisture. Starling et al. (1998) increased soybean yield grown on fine sandy loam soils in Alabama with starter N application; however, the authors emphasized the yield increase associated with N was the greatest when irrigation was available or precipitation occurred within 24 hours after N application.

Although soybean occasionally respond to pre-plant N fertilization, such fertilization may decrease the activity of *Bradyrhizobia*, reduce nodule growth and biological fixation, and increase the difference between N supply and demand (Bhangoo and Albritton, 1976; Ham et al., 1975; Yoneyama et al., 1985; Yoshida, 1979). Harper and Cooper (1971) demonstrated in a lab setting that N application increased nodule fresh weight but leghemoglobin content decreased, which resulted in reduced N_2 fixation. Weber (1966) observed with N application at seeding, nodule number, weight, and size decreased. Ham et al. (1971) attributed soybean response to N fertilization to poor nodulation or nodulation by poor N fixing strains of *Bradyrhizobia japonicum* bacteria. In contrast, relatively small fertilizer N amounts (46 kg ha^{-1}) applied in two split applications at seeding and flowering did not suppress soybean nodulation and N_2 fixation when grown on a Rhodustalf soil (Seneviratne et al., 2000). The inconsistent soybean response to N fertilization is due in large part to the residual NO_3-N content in the soil (Seneviratne et al., 2000); soybean responded to N fertilizer only when the soil NO_3-N was < 90 kg ha^{-1} in the top 0.6 m of soil (Lamb et al., 1990). Scharf and Wiebold (2003) concluded that out of 48 sites, response to N was observed if the following conditions were present: yields above 4000 kg ha^{-1}, fertilizer N application at the beginning pod growth stage, residual soil NO_3 less than 56 kg ha^{-1} in the top 61-cm, soil pH less than 7.5, and irrigation. The presence of NO_3-N in the soil was shown to interfere with the infection process and reduce or slow nodule formation, which can limit N_2 fixation (Weber, 1966). Research conducted in Minnesota (Ham et al., 1975) applied preplant broadcast N and increased soybean yield, seed weight, and seed protein, but had no effect on seed oil concentration. Slater et al. (1991) applied N preplant at a rate of 134 kg ha^{-1} on soybean grown on an irrigated silt loam soil in Nebraska and N application did not influence seed yield. Similar results were reported by Welch et al. (1973) on a silty clay loam in Illinois; N was applied preplant or as sidedress at rates ranging from 0 to 900 kg ha^{-1} and no yield response was observed. Yield response recorded in Michigan by Hesterman and Isleib (1991) varied by soil type. More specifically, the application of preplant N at 134 kg ha^{-1} on a Zilwaukee clay did not increase yield; whereas, the same application and rate increased yield by 460 kg ha^{-1} on a sandy loam soil.

Pre-Plant and Starter N Application

Hardy et al. (1971) reported that biological N fixation was initiated 14 days after planting only if plants were grown under ideal moisture and temperature conditions; the authors also stated that a small amount of N at planting benefited early soybean growth. Similar results were reported by Bergersen (1958) that N applied pre-plant benefited soybean due to nodules not being observed until nine days post emergence. Sij et al. (1979) applied N at soybean planting in Texas and reported no effect on leaf area, plant height, shoot fresh weight or yield. A yield response from broadcast N was not observed by Terman (1977) in Alabama; however, early vegetative growth was increased by 20%. Yoshida (1979) reported that N, applied at 30 to 90 kg ha^{-1} from soybean seedling emergence to R1, increased seed yields by 720 kg ha^{-1}. Reese and Buss (1992) found no soybean yield response to N applied at 56 kg or less N ha^{-1} near planting or at flowering on southeastern coastal plain soils. Shibles (1998) demonstrated that due to adequate levels of N from mineralization and residual N from previous years, the N requirement for the new soybean crop was initially met by most Midwestern soils; however, if a soil was low in organic matter, applying a preplant N fertilizer encouraged early season growth. Soybean research in South Dakota has reported that broadcast N, surface-applied at planting or at emergence increased yield, while N applied at mid-pod fill was not observed to increase yield (Bly et al., 1998; Riedell et al., 1998; Woodard et al., 1998).

Wilson et al. (2014) tested cultivar x N utilization interactions for 59 MGII cultivars planted in Minnesota and Wisconsin and 57 MGIII cultivars planted in Illinois and Indiana. Nitrogen was applied in a 2 way split with 224 kg N ha^{-1} at planting and 336 kg N ha^{-1} at V5 (fifth fully-expanded trifoliate, Fehr and Caviness, 1977) using an N source containing 50% urea and 50% polymer-coated urea. The authors reported yield was not affected by N application for the MGII cultivars and was attributed to high soil N and organic matter levels in Minnesota and Wisconsin, which likely supplied sufficient N in addition to N_2 fixation. The MGIII yield was affected by an interaction between N x release year and fertilized cultivars outperformed unfertilized cultivars by producing 27.4 and 22.8 kg ha^{-1} yr^{-1}, respectively. Nitrogen application increased MGIII yield by 12.4 and 16.3% in 1923 and 2007, respectively. Wilson et al. (2014) determined that the soil residual N and N_2 fixation did not meet the increasing yield demand and N fertilization was required. In Illinois and Indiana N_2 fixation contributed 61 and 59% of N needed for yield development, respectively (Wilson et al., 2014).

Starling et al. (1998) broadcast AN at 50 kg N ha^{-1} and incorporated prior to planting on fine sandy loam soils in Alabama. The authors increased R1 dry matter accumulation of both determinate and indeterminate stem-termination type near-isolines by 25% and increased soybean seed yield by 150 kg ha^{-1}(9%) when averaged across environment and genotype. Dry matter response to starter N at the R1 stage of growth was observed by Starling et al. (1998) to depend on growth habit and cultivar; both the indeterminate isolines responded positively to N application, whereas the determinate cultivar did not. Indeterminate isolines increased seed weight as compared to the determinate cultivar. The researchers concluded that an indeterminate genotype soybean combined with N application increased growth and yield in a late-planted, double-crop system.

Nitrogen applied in relatively small amounts at planting can be referred to as starter N and is intended to provide plant-available N to developing seedlings and may be a viable option for late-planted environments with shortened growing seasons. Osborne and Riedell (2006) examined the influence of starter N on soybean growth and yield in South Dakota by applying AN (34-0-0) and urea (46-0-0) at rates to supply 0, 8, 16, and 24 kg N ha^{-1} in conventional and no-tillage systems. In that study, all fertilizer was applied at planting in a band 5-cm below and 5-cm to the side of the seed furrow to soybean planted in 76-cm-rows. Seed yield increased with starter N application two of three years, with an average increase greater than 5% for the 16 kg N ha^{-1} rate compared to untreated control. The researchers attributed the increased soybean yield to increased early plant biomass and plant N concentration both at V3-V4 (fourth fully-expanded trifoliate, Fehr and Caviness, 1977) and R1. Starter N linearly influenced early plant biomass and plant N, however this increase was not maintained at R3 (beginning pod, Fehr and Caviness, 1977). They further reported the lack of response of starter N at R3 was due to the soybean utilizing N from translocation within the plant. Within the no-till system used in that study, urea increased seed yield by approximately 6% (2297 kg ha^{-1}) as compared to AN (2160 kg ha^{-1}) and untreated check. Yield differences were not observed in the conventional tillage system and were attributed to higher soil temperatures compared to the no-till system (Osborne and Riedell, 2006). In one of three years, starter N decreased oil concentration of soybean seed as rate was increased within the no-tillage system. This inconsistent response from applied starter N on seed quality was attributed to precipitation and temperature differences by Osborne and Riedell

(2006). These inconclusive results are similar to previous findings (Barker and Sawyer, 2005; Wesley et al., 1998).

Starling et al. (2000) reported in a corn-soybean rotation in southern Alabama, 15-cm-row soybean growth and seed yield were greater when 50 kg N ha^{-1} was applied at planting. Specifically, with starter N application, yield increased by 9%, R1 plant height increased by 5-cm, and plant N increased by 5%, all compared to the untreated check. Similarly, Pikul et al. (2001) increased soybean yield in 9 out of 11 years in the northern Great Plains with low starter N rates (<15 kg N ha^{-1}) when compared to no N application; starter N was applied at planting and placed 5-cm to the side and 5-cm below the seed. Taylor et al. (2005) broadcast applied AN at five rates (0, 25, 50, 75, and 100 kg N ha^{-1}) immediately after soybean planting in Alabama on Hartsells fine sandy loam, Norfolk fine sandy loam, and Malbis fine sandy loam. All three growing environments had < 8 kg NO_3-N ha^{-1}. Application of N at 60 to 70 kg ha^{-1} maximized yield and R1 dry matter accumulation, but reduced nodule number and mass; no effect of N application was reported on R1 plant height, mature plant height, or seed quality, protein and oil content. The researchers emphasized that while N application did not change plant height, greater early dry matter accumulation by N application was accomplished regardless of cultivar, planting date, or environment. It was further concluded that N applied at planting to late-planted soybean in the Deep South is warranted; however, the optimal economic rate depends on N fertilizer cost and soybean market value. For example, assuming \$0.30 kg^{-1} soybean market price and \$0.75 kg^{-1} N price, the optimal N rate was 59 kg ha^{-1} with 3310 kg ha^{-1} maximum economic soybean yield.

Fertilizer N Placement

Rehm and Lamb (2010) noted that due to the combination of agronomic and economic considerations with improved field equipment designed for liquid fertilizer application more-readily-available, current soybean farmers have shown increased interest in placement of fertilizer in close proximity to soybean seed. In their research, soybean was negatively affected when fluid fertilizers (10-15-0, 4-4.4-8.3, or 3-8-15, analysis of $N-P_2O_5-K$) were applied at 56 or 32 L ha^{-1} directly into the seed furrow on silt loam soils in Minnesota. When the same fluid fertilizers were applied at lower rates (28 or 16 L ha^{-1}), emergence was not reduced. It was determined that fertilizer grade, rate of application and placement inconsistently influenced plant weight, P concentration and uptake. Soybean yield was not affected at any location. Furthermore, soil test values for P and K were classified as very high (38-58 and 178-352 mg kg^{-1}, respectively) at all sites (Rehm and Lamb, 2010). Salvagiotti et al. (2009) demonstrated that, irrespective of N fertility status of a silt loam soil, deep banded polymer-coated urea at 180 kg N ha^{-1} maintained biological N fixation at levels similar to those observed in unfertilized control; however, soybean yield levels were lower for the deep banding application as compared to the surface application. Takahashi et al. (1991) demonstrated increased soybean seed yield and N uptake in response to N fertilization applied below the root nodulation zone; N fertilization did not negatively affect biological N_2 fixation.

Soybean Disease Management

In agricultural systems, there may be many plant diseases, many of which are fungal diseases. Foliar pathogens decrease the photosynthetic tissue area by reducing green leaf area, reduce the transfer of assimilates to grain production by diverting assimilates to fungal growth, weaken defense systems, and increase respiration (Agrios, 1997; Bassanezi et al., 2001; Shtienberg, 1992). Diseases share similar and sometimes identical characteristics, such as temperature ranges for disease development and means of inoculum dissemination (Li and Yang, 2009). Similarities and differences among different diseases and pathogens may result in spatial or temporal distribution patterns. For example, cool temperature diseases may tend to occur in the northern U.S., while diseases favoring warm temperatures may dominate in the south (Li and Yang, 2009). More specifically, Li and Yang (2009) reported the average optimal disease development temperature for soybean disease to be 25°C. A link between diseases can be established by utilizing comparative epidemiological approaches that examine similarities based upon disease attributes (Kranz, 2003; Legendre and Legendre, 1998; Li and Yang, 2009). Li and Yang (2009) defined ten variables that described characteristics of the diseases they examined: (1) optimal disease development temperature, (2) host range, (3) free moisture requirement, (4) major infected plant parts, (5) growth stage of infection, (6) secondary infection, (7) wind dispersal, (8) seed transmittable, (9) survival in host residue, and (10) long term survival in soil.

U.S. Soybean Disease Distribution

More than 30 fungal soybean diseases occur within the U.S. (Hartman et al., 1999; Li and Yang, 2009; McGee, 1992). Hartman et al. (1999) reported an extensive range and high disease prevalence with downy mildew (*Peronospora manshurica*), brown spot (*Septoria glycines*), frogeye leaf spot (*Cercospora sojina*), and Cercospora blight (*Cercospora kikuchii*) from the Gulf Coast to the northern U.S. Li and Yang (2009) indicated that wide spread occurrence of downy mildew, brown spot, frogeye leaf spot, and Cercospora blight was due in large part to their moderate optimal temperature needed for disease development and the capability of disease transmission through seed. The predominating foliar soybean diseases in the southern U.S. are Cercospora blight, frogeye leaf spot, aerial blight (*Rhizoctonia solani*), pod and stem blight (*Diaporthe phaseolorum* var. *sojae*), and anthracnose (*Colletotrichum truncatum*) (Schneider et al., 2007). Schneider et al. (2007) reported that Cercospora blight is the most prevalent and destructive soybean disease in the Mid-South. Wrather and Koenning (2006) indicated that foliar diseases including: bacterial blight (*Pseudomonas savastanoi* pv. *glycinea*), septoria brown spot, Cercospora blight, and frogeye leaf spot were present most years but did not significantly impact soybean yield in Iowa; only in 1 of 3 years did foliar diseases reduced yield by 9.5%. Li and Yang (2009) analyzed 34 soybean fungal pathogens including varieties and anastomosis groups that are known to cause 32 soybean diseases. They demonstrated a maximum similarity coefficient (how similar diseases are to each other based on their characteristics) between frogeye leaf spot and brown spot as well as rhizoctonia root rot (*Rhizoctonia solani*) and fusarium pod and collar rot (*Fusarium pallidoroseum*). Soybean rust was observed to be similar in infection occurrence to downy mildew and leptosphaerulina leaf spot (*Leptosphaerulina trifolii*). When cluster analysis was utilized, they grouped brown spot, frogeye leaf spot, phyllosticta leaf spot (*Phyllosticta sojicola*), purple seed stain, and downy mildew together. Analysis also placed brown stem rot (*Phialophora gregata*), southern blight (*Sclerotium rolfsii*), thielaviopsis root rot (*Thielaviopsis basicola*), charcoal rot (*Macrophomina phaseolina*), fusarium root rot (*Fusarium solani*), fusarium pod and collar rot, rhizoctonia root rot, fusarium wilt (*Fusarium oxysporum* f. sp. *tracheiphilum*), red crown rot (*Cylindrocladium crotalariae*), and sudden death syndrome (*Fusarium solani* f. sp. *glycines*) together in a cluster. Furthermore, the authors concluded that, with respect to soybean production in the U.S., soybean rust [*Phakospora pachyrhizi* (Sydow)] would be distributed geographically similarly to downy mildew, brown spot, frogeye leaf spot, and purple seed stain, however, occurrence would be limited on a regional scale. Still, Miles et al. (2007) emphasized that soybean rust could have a major impact on both the total soybean production and production costs in the U.S.

Soybean Disease in Virginia

Soybean in Virginia is susceptible to several diseases that can reduce yield (Phipps et al., 2010). Due to Virginia's geographical location, a mixture of diseases prevalent in northern or southern states can be present and potentially problematic. Due to this potentially diverse disease pressure, soybean farmers must rely on disease-resistant or tolerant cultivars (if available), field history, spray advisories, understanding weather x disease interactions, and foliar fungicide to minimize yield or quality loss from plant disease efficiently. Mehl and Phipps (2013) determined that Cercospora blight was the second most prevalent foliar disease of concern in soybean production in Virginia and caused a 1% yield loss in 2013.

Schneider et al. (2007) identified the most effective and economical method for disease management to be genetic resistance; however, agronomically acceptable, broad-spectrum disease resistant soybean cultivars are not generally available (Dorrance et al., 2004; Li and Yang, 2009). Soybean farmers have traditionally managed late-season diseases with fungicides (Levy, 2005; Miles et al., 2003, 2007; Patil and Anahosur, 1998; Sinclair and Hartman, 1995; Yorinori et al., 2005) and cultural practices (Schneider et al., 2007). Reasons for increased interest in preventative fungicide use in Midwest were attributed to yield loss prevention in the southern US (Wrather and Koenning, 2006) and the introduction of soybean rust into the U.S. (Swoboda and Pedersen, 2009). But, fungicide and application costs and potential yield losses due to improper application timing will incur new expenses to the soybean industry (Mueller et al., 2009).

Response and Economic Return with Foliar Fungicides

Soybean has responded inconsistently to the application of foliar fungicide. Foliar fungicide application has increased soybean yield in Ohio (Cruz et al., 2010), Paraguay and

Zimbabwe (Miles et al., 2007), Illinois, Florida, and Georgia (Mueller et al., 2006), and Virginia (Phipps et al., 2010). Other research has not reported such a response in Indiana (Hanna et al., 2006), North Dakota (Mueller et al., 2006), or Virginia (Phipps and Telenko, 2011). Researchers in Missouri (Bradley and Sweets, 2008), Illinois (Pataky and Lim, 1981), and Virginia (Phipps and Telenko, 2011) observed a reduction in disease severity when foliar fungicide was applied, but seed yield responses were inconsistent and were attributed to differences in disease development and weather during reproductive stages. Others reported a lack of yield response in absence of disease in Missouri (Bradley and Sweets, 2008) or Iowa (Swoboda and Pedersen, 2009).

Due to rising total input costs and narrowing profit margins, farmers desire to increase yield while limiting risk (Duffy and Smith, 2007; Swoboda and Pedersen, 2009). The economic return from fungicide application varies greatly based on the growth stage of the crop during disease introduction, disease pressure, crop yield potential, and product efficacy (Dorrance et al., 2007; Yang and Robertson, 2007). Bradley and Sweets (2008) found in the absence of disease pressure, fungicide applications were not economically justifiable in most years. Similarly, Swoboda and Pedersen (2009) concluded the fungicide application depended greatly on the geographical location and the disease amount present; economic loss resulted if application was not warranted due to lack of disease not being met. Yang and Robertson (2007) determined the fungicide application number to achieve appropriate soybean rust control depended on five main factors: (1) crop stage when the disease first appears, (2) disease severity, (3) current and forecasted weather pattern, (4) soybean market price, and (5) application cost. Dorrance et al. (2007) reported that soybean farmers in Brazil spent approximately $1 billion on soybean rust control with fungicide during 2003 and 2004. Alexander et al. (2005) estimated that economic losses due to soybean rust outbreak in the U.S. could reach \$2 billion year^{-1}; whereas, Livingston (2010) determined that, in 2006, 891,000 U.S. hectares were treated for soybean rust at a \$76.9 million fungicide cost. Dorrance et al. (2007) estimated the cost per fungicide application for soybean rust control to be from \$25 to \$86 ha^{-1}. Similarly, Swoboda and Pedersen (2009) demonstrated foliar fungicide application cost \$55 ha^{-1}.

Foliar Fungicide Spray Coverage and Damage

Successful control of late-season diseases in soybean is attributed to the delivery and subsequent penetration of effective fungicides into the middle and lower part of the crop canopy (Bradley and Sweets, 2008; Ozkan et al., 2007). Ozkan et al. (2007) determined that the level of uniformity and penetration into the canopy associated with fungicide application relies on nozzle type, spray pressure, application volume, and application speed. A very strong correlation between fungicide coverage and efficacy exists. Researchers have emphasized that in order to accomplish satisfactory fungicide efficacy, soybean farmers should choose the size and type of nozzle that provides high-fine to mid-medium (200 to 300 micron) size droplets, utilize appropriate amount of air pressure, keep spray volume at a minimum of 140 L ha^{-1} for ground application and 47 L ha^{-1} for aerial application, especially later in the season (Dorrance et al., 2007; Ozkan et al., 2007).

Fungicides are applied with self-propelled, pull type, or aerial spray applicators in the U.S. (Hanna et al., 2008). Holshouser and Taylor (2008) demonstrated that mechanical damage to 18 and 38-cm row soybean occurred when fungicides were applied at the R4 reproductive stages; ground application creates wheel tracks which can reduce yield when made during reproductive growth stages (Piper et al., 1989). Wilkens and Whigham (1986) observed a yield decrease for narrow row soybean when wheel damage reduced pods plant^{-1} and seed size.

Research has shown that compensation by soybean in rows adjacent to damaged rows can occur but is not typically enough to limit overall plot yield reduction (Piper et al., 1989; Stivers and Swearingin, 1980). Hanna et al. (2008) reported yield loss decreased with increasing boom width which limited wheel tracks by limiting soybean damage; yield was reduced by 4.9, 3.6, 3.2, and 3.2% for a 9, 18, 27, 36 m boom, respectively. Applicators should utilize the widest spray boom available during the reproductive growth stages of soybean to minimize the number of wheel track made in the field (Hanna et al., 2008).

Classification of Foliar Fungicides

Tenuta et al. (2007) emphasized that each fungicide product is unique in regards to plant uptake, redistribution of active ingredient (a.i.) on or in host tissue, mode of action (MOA), efficacy, duration of residual activity, phytotoxicity, and potential for resistance. Fungicides have been observed to differ both in the range and degree of disease control efficacy (Schneider et al., 2007). Fungicides are classified as protective (functional only pre-infection) or curative (functional early post-infection) (Tenuta et al., 2007). Protectant fungicides prevent fungi from successfully penetrating host tissue. An example of a protectant fungicide is chlorothalonil, which is active only against spore germination; if chlorothalonil is applied after germination of spores, it is ineffective. The strobilurin (i.e. azoxystrobin, pyraclostrobin, trifloxystrobin, etc.) fungicide class stops both spore germination and host penetration, but has no efficacy once the fungus has penetrated plant tissue. Curative fungicides can inhibit or stop the development of infections and also have a level of anti-spore activity that can slow disease development; the triazoles are the only available fungicides observed to contain curative activity. If low levels of soybean rust are established in the field, the triazole fungicides are the application of choice;

however, triazoles do not have unlimited curative activity and efficacy is reduced once sporulation is initiated.

Some fungicides are classified as contact, are non-systemic protective, and remain on treated leaves but are not present on new growth that emerges following application. Chlorothalonil falls into this category by remaining on the leaf surface, is not actively taken up by the plant, and must be applied frequently as environmental conditions decrease residual activity (Tenuta et al., 2007). Most fungicides (including strobilurins and triazoles) labeled for soybean are either systemic or locally systemic; however, none are as highly systemic as some commonly used herbicides and insecticides (Tenuta et al., 2007). Reduced systemic action results in the increased need for proper coverage and canopy penetration when a foliar fungicide is applied. Adjuvant use has been observed to assist in fungicide efficacy by increasing the fungicide amount that reaches and stays on the leaf surface.

Chlorothalonil Fungicides

Chlorothalonil, a broad-spectrum fungicide, attacks multiple sites of fungal cells, inhibits enzymes that contain sulfur, and disrupts the production of energy within the fungus (Tenuta et al., 2007). Chlorothalonil and mancozeb are protectant fungicides that remain on the leaf surface and are most effective when utilized in a preventative nature (Miles et al., 2007). Chlorothalonil was extensively tested in the 1970’s and 1980’s; however, this fungicide is not very effective against most diseases and does not play a role in southern soybean disease management (Schneider et al., 2007).

Strobilurin Fungicides

Strobilurin fungicides have been observed to move into the plant, are locally systemic, but differ in systemic movement when products are compared (Tenuta et al., 2007). For example, pyraclostrobin is locally systemic and is taken up by the plant; however, it does not move far past the point of plant uptake. In contrast, another fungicide in the strobilurin family, azoxystrobin, is taken up by the plant, but has systemic properties that allow is to move somewhat further in distance beyond the point of uptake as compared to pyraclostrobin. Regardless of which strobilurin product is used, new leaves produced after application are not protected. The strobilurin family's MOA has been observed to inhibit fungal cellular respiration, which prevents energy production and results in rapid cell death (Bartlett et al., 2002; Tenuta et al., 2007). Strobilurin fungicides interfere with spore germination and germ tube development, are absorbed into the leaf tissue, and move in a translaminar manner (Bartlett et al., 2002; Karadimos et al., 2005; Koehle et al., 2002; Sauter et al., 1999). Strobilurin's MOA classifies it as quinone outside inhibitors (QoI) or Group 11 fungicides. Strobilurins have been observed to be most effective when applied prior to disease infection (Grossmann et al., 1999; Miles et al., 2007; Nelson et al., 2010).

Azoxystrobin was reported by Schneider et al. (2007) to be a core fungicide for Mid-South soybean farmers. Azoxystrobin is very efficacious on aerial blight, anthracnose, and pod and stem blight; suppresses Cercospora blight and frogeye leaf spot; however it is not very effective against soybean rust. This fungicide has been documented to be an excellent choice for tank-mix with a triazole fungicide. Pyraclostrobin is similar in efficacy to azoxystrobin, although it provides improved control of Cercospora blight and is very effective against soybean rust when applied pre-infection. Azoxystrobin and pyraclostrobin treated plots had 7 to 8 g kg^{-1} lower leaf N concentrations than untreated (Nelson et al., 2010). In contrast, when strobilurin fungicides were applied to small grains, N assimilation was observed (Koehle et al., 2002; Venencio et al., 2003). Nelson et al. (2010) reported that physiological differences between small grains and N-fixing plants like soybean could be responsible for the differing reaction to strobilurin fungicides. Pyraclostrobin has been reported to cause physiological changes in treated plants such as increased leaf greenness, chlorophyll content, photosynthetic rates, and water use efficiency as well as delayed senescence (Bryson et al., 2000; Grossmann and Retzlaff, 1997; Grossmann et al., 1999). Such changes may increase yield when pyracolstrobin is applied as compared to triazole use alone (Bryson et al., 2000).

Triazole Fungicides

Triazole fungicides have been documented (Tenuta et al., 2007) to have greater systemic activity, be absorbed more quickly within the leaf and have greater translocation to meristematic regions as compared to strobilurins; however, increased systemicity is not always directly correlated to increased efficacy. Triazoles are classified as demethylation inhibitors (DMI) or Group 3 fungicides; they inhibit sterol biosynthesis, which serves as an integral component of fungal cell membranes (Tenuta et al., 2007). Within the triazole family of fungicides, cyproconazole, flusilazole, flutriafol, metaconazole, myclobutanil, tebuconazole, and tetraconazole have been reported to be very effective against soybean rust; propiconazole's efficacy on soybean rust is reduced compared to other triazoles previously mentioned (Schneider et al., 2007). Triazole fungicides were observed to have no efficacy applied alone when trying to control brown spot (Cruz et al., 2010). Tenuta et al. (2007) concluded that strobilurin and triazole fungicides, applied at labeled rates, provided 14 to 28 days of protections whereas Chlorothalonil provided 7 to 14 days.

Combination of Strobilurins and Triazoles to Improve Efficacy

Tenuta et al. (2007) reported that both premixes and tank mixes of a strobilurin + triazole effectively controlled spore germination, host penetration, and initial colonization of plant tissue. Schneider et al. (2007) compared tank mixtures of triazoles and strobilurin fungicides and determined the following three mixtures provided the best option for managing soybean rust and other late-season soybean diseases in the Mid-South U.S.: (1) cyproconazole + azoxystrobin; (2) flusilazole + famoxadone; and (3) metconazole + pyraclostrobin. The mixtures of propiconazole + trifloxystrobin and propiconazole + azoxystrobin were not as effective at controlling soybean rust; however they can be used as a triazole + strobilurin combination for late-season soybean diseases. The mixture of tebuconazole + trifloxystrobin was rated and was not recommended (Schneider et al., 2007). Miles et al. (2007) demonstrated that mixtures of triazole + strobilurin consistently increased yield while simultaneously reducing defoliation and soybean rust severity. The triazole fungicides (tebuconazole and tetraconazole) were observed to have lower soybean rust severity but did not consistently increase seed yield; however the strobilurin fungicides (azoxystrobin, pyraclostrobin, and trifloxystrobin) tended to have higher disease incidence, yet yielded greater with reduced defoliation. Disease severity of brown spot was observed (Cruz et al., 2010) to decrease and yield increased with application of a strobilurin fungicide alone or in combination with a triazole applied at R3. Mueller et al. (2009) determined that tebuconazole and pyraclostrobin + tebuconazole generally resulted in the lowest soybean rust severity followed by pyraclostrobin. Increased levels of soybean rust severity was observed with azoxystrobin + propiconazole when compared to other fungicide treatments, although low yields were observed only when soybean rust severity was high (Mueller et al., 2009). Miles et al., (2007) concluded the products that effectively prevented the increase of disease severity of soybean rust when applied 20 or more days in advance of disease onset included tebuconazole and tetraconazole, followed by pyraclostrobin and pyraclostrobin + metconazole. Phipps et al. (2010) reported that Virginia soybean yield response under disease pressure was greatest with the following products and rates: Stratego® (mix of a.i. propiconazole and trifloxystrobin) at rate of 1457 mL ha^{-1} + surfactant; Stratego® at 730 mL ha^{-1} + Proline® (a.i. prothioconazole) at 73 mL ha^{-1}; Headline® (a.i. pyraclostrobin) at 438 mL ha^{-1}; Headline® at 343 mL ha^{-1} +TopGuard® (a.i. flutriafol) at 511 mL ha^{-1}; Headline® at 343 mL ha^{-1} + Proline® at 183 mL ha^{-1}.

Foliar Fungicide Application Timing

Fungicide application may decrease disease severity and increase soybean yield; however, delaying fungicide application until after disease is present has resulted in yield loss (Miles et al., 2003, 2007). Detection difficulties have led to improper fungicide application timing (Swoboda and Pedersen, 2009), which is critical for foliar soybean disease control (Mueller et al., 2009). Dorrance et al. (2007) emphasized that early treatment is needed for optimum fungicide performance. Application that is too early, too late, or too frequent may not be effective or needed to maximize yield (Mueller et al., 2009). Mueller et al. (2009) also concluded that the proper application timing can be altered by regional conditions and can include differences in disease intensity and stage of growth. Foliar fungicide effectiveness depends on the application during the early soybean rust development stages; specifically the application must be made pre-infection to less than 5% incidence on lower canopy leaves (Dorrance et al., 2007; Tenuta et al., 2007).

Fungicides were documented to be most effective when applied during early-flowering through seed fill; applications made prior to flowering tend to not increase yield in temperate climates (Cruz et al., 2010; Miles et al., 2007; Mueller et al., 2006, Padgett et al., 2006; Tenuta et al., 2007). Prior to soybean rust, the most common practice implemented by soybean farmers was to apply a single fungicide between R3 and R5 (Schneider et al., 2007). Pataky and Lim (1981) applied benomyl to soybean at R1, R3, and R6; disease severity was reduced when application occurred at the R3 or R1+R6 stages of growth, however, yield was increased by benomyl at only one of three locations. Miles et al. (2007) concluded fungicide application at R3 was more effective in reducing disease severity and increasing yield compared to application at R1 growth stage. Phipps and Telenko (2011) compared the foliar fungicide applications at R3, R5, and R3+R5. Foliar fungicide, regardless of the timing, decreased percent leaf, pod, and stem area of Cercospora blight, decreased the percent defoliation caused by Cercospora; and increased soybean seed weight. Hanna et al. (2008) applied foliar fungicide at R1, R3, R5, R3+R5, and R1+R3+R5, but no yield response to fungicide application timing was observed at any location. Similarly, Swoboda and Pedersen (2009) demonstrated that the application of a strobilurin or triazole alone or combined at R1, R3, or R5 did not affect soybean seed yield, seed moisture, lodging, leaf chlorophyll meter readings, or protein and oil content at harvest. These findings were similar to previous findings by Pedersen and Lauer (2004a, 2004b). Nelson et al. (2010) reported a yield increase from 230 to 360 kg ha^{-1} when fungicide was applied at R4; however no yield increase was observed when fungicide was applied at V4. Although brown spot and frogeye leaf spot severity differences at the two sites were < 2%, the combination of foliar diseases observed contributed to an overall reduction in yield up to 350 kg ha^{-1} when untreated (Nelson et al., 2010). Cruz et al. (2010) increased soybean seed yield by 184 to 490 kg ha^{-1} compared to the untreated check in three out of six site years in Ohio with fungicide application. In those studies, brown spot levels ranged from 1.7 to 21.2% and resulted in 2.5 to 9.5% yield loss if left untreated. Dorrance et al. (2010) also examined foliar fungicide in soybean produced in Ohio and increased yield 21% (6 out of 28 sites) with a foliar fungicide application at R3. Furthermore, three of the six significant responses yielded 282 kg ha^{-1} more compared to the untreated check.

Fungicide Resistance Management

Development of resistance in fungi has occurred in many fungi, especially when fungicides have been used intensively on crops (Bradley, 2007). Fungicide resistance development was linked to the placement of selection pressure on the fungal pathogen population; characteristics of both the fungicide and the pathogen influenced the selection pressure level and associated resistance risk. Strobilurin and triazole fungicides contain single MOA as compared to chlorothalonil, which has a multi-site MOA; therefore, the risk of resistance development in soybean disease is of greater concern for strobilurin (high) and triazole (medium) than chlorothalonil (Tenuta et al., 2007). Fungal pathogens that reproduce sexually have a greater probability to produce strains that are less sensitive to fungicidal properties due to increased genetic variability as compared to diseases that reproduce asexually (Bradley, 2007). Polycyclic diseases are more likely to develop resistance to fungicide than monocyclic disease partially due to the increased spore number produced within a growing season. The best fungicide resistance management program utilizes all available practices to prolong the efficacy and the life of fungicides. Bradley (2007) emphasized in order to reduce the risk of fungicide resistance, soybean farmers should apply a fungicide only when necessary, alternate differing fungicide MOA, utilize tank mixing of fungicides with different MOA, properly follow the label and abide by recommended rates and restrictions. If a fungicide is applied, the soybean crop should be closely monitored for disease signs which may indicate a resistance problem.

Focused Research Initiatives

Farmers utilize the wheat-soybean double-crop system in Virginia to maximize production and profitability. Even so, there is yield risk associated with double-crop soybean after wheat. Reduced double-crop soybean yield is due in large part to delayed planting in the summer (shorter growing season with reduced day length and light interception), less soil moisture after the wheat crop, lower plant-available nutrient levels due to wheat uptake, greater air and soil temperatures during vegetative development stages, and increased disease, insect, and weed pressure during pod and seed development.

The overall research goal is to determine management practices and inputs that maximize early vegetative growth and seed yield, while optimizing double-crop wheat-soybean production system productivity and profitability, while promoting farm sustainability and environmental stewardship. The next chapters focus on the following research objectives:

(1) Evaluate seeding rate, seed-applied inoculant, starter N applied at planting, cultivar growth habit, and foliar fungicide application on soybean vegetative response and seed yield produced in a wheat-soybean double-crop system in Mid-Atlantic USA.

(2) Evaluate soybean vegetative growth response and seed yield with starter N at planting with or without seed-applied *Bradyrhizobia japonicum* in a wheat-soybean double-crop system in Mid-Atlantic USA.

(3) Evaluate the response and specific interaction between MG IV and V soybean cultivars and foliar fungicide application in a wheat-soybean double-crop system in Mid-Atlantic USA.

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CHAPTER II - DOUBLE-CROP SOYBEAN RESPONSE TO SELECTED INPUTS I: YIELD AND AGRONOMIC CHARACTERISTICS

Abstract

Farmers can minimize environmental influence and increase double-crop soybean yield with agronomic inputs that accelerate early-season growth and canopy closure, while protecting limited leaf area from foliar disease. Field experiments were conducted in 2012 and 2013 to evaluate cultivar maturity and stem growth habit, seeding rate, seed-applied inoculant, nitrogen (N) applied at planting, and foliar fungicide on soybean vegetative response, total N uptake (TNU), and seed yield and quality in a wheat-soybean double-crop system. Measurements included plant height, TNU, normalized difference vegetative index (NDVI), and seed yield and quality. Although cultivar interacted with other factors, early-maturing indeterminate 95Y01 yielded more than late-maturing determinate 95Y20 by 153, 268, 277, and 215 kg ha^{-1} at 4 of 6 locations. Seeding rate interacted with other factors at some locations, but the greater seeding rate increased MG IV yield at 1 of 6 locations and decreased MG V yield at 2 of 6 locations. Inoculant assisted other factors to improve growth and yield, but was site-specific and difficult to predict. Starter N increased V4 plant height at 6 of 6 locations but response varied by cultivar. Soybean responded to N and produced greater yield compared to 0 N at 2 of 6 locations. For example, at 2012-Painter, N increased yield by 4% for late-maturing 95Y20. Fungicide positively influenced yield at 5 of 6 locations partially attributed to disease control when canopy closure was accomplished and soybean producing greater seed mass, also at 5 of 6 locations.

Abbreviations: N, nitrogen; TNU, total N uptake; NDVI, normalized difference vegetative index.

Introduction

The Mid-Atlantic region of the U.S., which includes the states of Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, and Virginia, accounted for 1.3 million ha soybean [*Glycine max* (L.) Merr.] and 793 thousand ha winter wheat (*Triticum aestivum* L.) in 2013 (NASS, 2014). Approximately 50% of the soybean produced in the Mid-Atlantic is grown in a double-crop system planted sequentially after a small grain, typically wheat or barley (*Hordeum vulgare* L.). Increased productivity with multiple cropping versus mono-cropping has been documented (Browning, 2011; Calvino et al., 2003; Caviglia et al., 2011; Heatherly and Elmore, 2004; Kyei-Boahen and Zhang, 2006; Nelson et al., 2011). Wheat-soybean double-crop systems in Oklahoma, Kansas, Kentucky, Mississippi, and Virginia have demonstrated increased net returns as compared to mono-crop soybean (Farno et al., 2002; Kelley, 2003; Herbek and Bitzer, 1988; Kyei-Boahen and Zhang, 2006; Browning, 2011, respectively). However, the use of a double-crop system results in soybean planting that is delayed past dates recommended for optimum yield potential (Wesley, 1999). Yield reduction for late-planted double-crop soybean was attributed to lack of sufficient vegetative growth (Ball et al., 2000; Barreiro and Godsey, 2013; Boerma et al., 1982; Caviglia et al., 2011; Herbert and Litchfield, 1984), reductions in crop growth rate during the period when seed number (Egli and Bruening, 2000) and seed weight (Calvino et al., 2003) are defined, and reproductive phase duration (Egli, 2011). Increasing yield in late-planted soybean was correlated to increasing leaf area that maximizes light interception and subsequently increases biomass (Board and Harville, 1993; Board et al., 1992; Jones et al., 2003; Wells, 1991). Reduced early season vegetative growth and leaf area development were attributed to moisture stress, especially on low plant-available water holding capacity soils (Jones et al., 2003). Malone et al. (2002) conducted 15 manual defoliation experiments during a three year period and concluded that both full season and double-crop soybean decreased yield linearly when LAI values were below 3.5-4.0 at developmental stages R4 to R5 (full pod and beginning seed, respectively, Fehr and Caviness, 1977). In addition, yield for both cropping systems plateaued at higher LAI levels.

Soybean's unique ability to compensate for total, main stem and branch seed yield at reduced plant population has been documented (Board and Kahlon, 2013; Board et al., 1999; Carpenter and Board, 1997) and linked to cultivar selection and environmental conditions (Norsworthy and Frederick, 2002). Soybean yield response to seeding rate is influenced by yield potential, which is determined by rainfall, soil type, irrigation availability and planting date (Devlin et al., 1995). Ball et al. (2000) demonstrated when photoperiod was shortened and temperature increased, vegetative growth duration and crop biomass decreased, which resulted in minimal optimal plant population being increased from 300,000 plants/ha to 600,000 plants/ha. Increasing seeding rates allowed LAI of 3.5 to 4.0 to be met even with the shortened growing season in double-crop production (Ball et al., 2000).

Double-crop soybean cultivar selection is important due to delayed planting date and overall less than ideal growing conditions that lead to reduced yields versus full-season systems. One method to extend the growing season for double-crop soybean is to plant later-maturing cultivars. However, the success of this strategy depends on whether the late-maturing cultivar can complete its life cycle before freezing temperatures terminate its growth. In Virginia and similar latitudes (36°40'1.86"N - 38°5'0.16"N), maturity group (MG) IV and V cultivars may be grown; therefore, a strategy for extending the growing season, and potentially increasing yield, may be to grow these later-maturing cultivars. However, unlike MG IV cultivars, MG V cultivars are usually classified as determinate in their growth habit.

Apical stem growth termination timing for soybean is categorized into either indeterminate or determinate (Ting, 1946). Bernard (1972) reported the stem and branch apical meristems maintain vegetative activity within indeterminate cultivars until vegetative dry matter ceases once seed translocation is initiated. But, determinate stem apical meristem vegetative activity ceases with photoperiod-induced floral induction and the meristems transition to reproductive inflorescences. Stem termination has influenced plant height (Egli and Leggett, 1973; Heatherly and Smith, 2004; Kilgore-Norquest and Sneller, 2000), reproductive stage duration (Board and Kahlon, 2013; Edwards and Purcell, 2005), node production (Egli and Leggett, 1973; Heatherly and Smith, 2004; Ouattara and Weaver, 1994), water-use efficiency (Specht, 2001), and yield (Beuerlein, 1988; Cooper, 1981; Graterol et al., 1996; Specht, 2001). An indeterminate stem growth habit coupled with a later-maturing cultivar may have a specific advantage in the Mid-Atlantic double-crop soybean by extending the growing season without the detrimental effect of terminating terminal main stem growth.

Although not the reason for greater seeding rate recommendations, soybean establishment may be difficult in double-crop wheat-soybean systems (De Bruin et al., 2005; Wagner-Riddle et al., 1994). Walker et al. (2010) emphasized typical final full-season soybean stands range from 50 to 80% of planted seed. Similarly, Chen and Wiatrak (2011b) observed full-season MG IV and V cultivars to have 74-87 and 59-78% emergence, respectively. Double-crop soybean seedling emergence may be less than full-season due to limited water available for the seed to germinate. Mid-Atlantic coastal plain soils can be drought prone and frequent drought exposure due to erratic precipitation and soils dominated by low-water holding capacity can result in soybean yield reduction (Frederick et al., 1998). Norsworthy and Frederick (2002) emphasized soybean seeding rates can be reduced while maintaining seed yield but only in drought stress-free periods. Holshouser and Whittaker (2002) reported change in plant population did not affect yield under conditions of minimum drought stress, 208,000 plants ha^{-1} were needed for maximum yield with brief moisture stress, and if drought stress limited leaf area production, over 600,000 plants ha^{-1} were required to maximize seed yield. Kratochvil et al. (2004) reported a 20% seeding rate reduction (445,000 seed ha^{-1}) produced yield equivalent to the standard double-crop seeding rate (555,750 seed ha^{-1}) and should be recommended to assist in reducing input costs. However, with above average rainfall, MG III cultivars increased full-season yield with 20% more seed (518,700 seed ha^{-1}) (Kratochvil et al., 2004). High seeding rates improved vegetative growth at vegetative and reproductive stages, however, optimum seeding rate varied by MG (Chen and Wiatrak, 2011a).

The International Plant Nutrition Institute (IPNI, 2011) estimated the nitrogen (N) requirement for 4704 kg ha^{-1} soybean seed yield to be 408 kg N ha^{-1}. This need for N is met by the residual soil N pool and with symbiotic N_2 fixation from N-fixing *Rhizobia* bacteria that convert N_2 gas to plant available N (Bhangoo and Albritton, 1976; Patterson and LaRue, 1983). Lindemann and Glover (2003), Salvagiotti et al. (2008), and Mastrodomenico and Purcell (2012) reported that 70%, 50 to 80%, and 90%, respectively, of the total plant N requirement was met by N_2 fixation. *Bradyrhizobium japonicum* populations were reported to be influenced by plant density, temperature, soil water content, organic matter, texture, and pH (Abendroth and Elmore, 2006; Albrecht et al., 1984; Bacanamwo and Purcell, 1999; Graham, 1992; Seneviratne et al., 2000). If N uptake is limited by an insufficient soil N supply or by declining N_2 fixation during late seed fill, a less than optimal yield ceiling may be imposed upon soybean (Salvagiotti et al., 2008, 2009). Inoculant use has become increasingly popular due to improved inoculant technology, relatively low product cost, ease of application, and increased input costs associated with nutrient management (De Bruin et al., 2010). However, inoculants are unlikely to increase yield consistently where soybean has previously been grown (Beuerlein, 2005; De Bruin et al., 2010; Furseth et al., 2011, 2012; Schulz and Thelen, 2008). Inoculant should be applied if the field was flooded, has a non-optimal pH, is low in soil organic matter, or has a coarse textured soil (Abendroth and Elmore, 2006; Pedersen, 2004). Mid-Atlantic coastal plain soils meet two of these four criteria; therefore a response should be more common in this region, even is soybean has been previously grown.

Soybean fertilization with N has gathered renewed interest in the U.S. due to the demand for high seed quality, N requirements, and the greater yield potential of modern soybean cultivars (Barker and Sawyer, 2005). The inconsistent soybean response to N fertilization is due in large part to the residual NO_3-N content in the soil (Seneviratne et al., 2000; Weber, 1966). Soybean responded to fertilizer N only when the soil NO_3-N was < 90 kg ha^{-1} (Lamb et al., 1990) or < 56 kg ha^{-1} in the top 61-cm (Scharf and Wiebold, 2003). Mid-Atlantic coastal plain soils generally meet these requirements. Nitrogen applied in relatively small amounts at planting can be referred to as starter N and is intended to provide plant-available N to developing seedlings. The need for starter N is questionable in environments with greater than 90 kg ha^{-1} soil N or where the previous season’s residue is decomposing. However, such an application may be a viable option for increasing early-season growth of soybean planted after wheat in a Mid-Atlantic coastal plain double-crop system where the preceding crop may have nearly depleted the soil of N and there is declining N_2 fixation. Furthermore, any additional early-season growth should benefit double-crop soybean that do not usually satisfy leaf area and node requirements for maximum yield potential.

Starling et al. (2000) applied 50 kg N ha^{-1} at planting on coastal plain soils, increased yield by 9%, increased R1 (beginning flower, Fehr and Caviness, 1977) plant height by 5-cm, and increased plant N by 5%,. Pikul et al. (2001) increased soybean yield in 9 out of 11 years with banded application (5-cm below and 5-cm to the side of the seed furrow) of low starter N rates with <15 kg N ha^{-1}. Taylor et al. (2005) broadcast applied NH_4 NO_3 at five rates (0, 25, 50, 75, and 100 kg N ha^{-1}) immediately after soybean planting on coastal plain soils and maximized yield and R1 dry matter accumulation with 60 to 70 kg N ha^{-1}, reduced nodule number and mass, but did not affect R1 or mature plant height, seed quality, or protein and oil content. Nitrate-N levels for that study were reported at < 8 kg ha^{-1}. The authors emphasized that while N application did not change plant height, it accomplished early dry matter accumulation regardless of cultivar, planting date, or environment. Osborne and Riedell (2006) banded starter N at 0, 8, 16, and 24 kg N ha^{-1}, increased seed yield more than 5% two of three years with 16 kg N ha^{-1} compared to untreated, and attributed the yield increase to increased early plant biomass and plant N concentration at V3-V4 (fourth fully-expanded trifoliate) and R1, but not R3 (beginning pod, Fehr and Caviness, 1977).

Even if certain practices allow for greater growth in double-crop soybean, the growth must be protected from foliar disease that could be more troublesome later in the season. The predominating foliar soybean diseases in the southern U.S. are Cercospora blight (*Cercospora kikuchii*), frogeye leaf spot (*Cercospora sojina*), aerial blight (*Rhizoctonia solani*), pod and stem blight (*Diaporthe phaseolorum* var. *sojae*), and anthracnose (*Colletotrichum truncatum*) (Schneider et al., 2007). Schneider et al. (2007) reported that Cercospora blight is the most prevalent and destructive soybean disease in the Mid-South. Soybean in Virginia is susceptible to several diseases that can reduce yield (Phipps et al., 2010). Due to Virginia's geographical location, a mixture of diseases prevalent in northern or southern states can be present and potentially problematic. Mehl and Phipps (2013) determined that Cercospora blight was the second most prevalent foliar disease of concern in soybean production in Virginia and caused a 1% yield loss in 2013.

Schneider et al. (2007) identified the most effective and economical method for disease management to be genetic resistance; however, agronomically acceptable, broad-spectrum disease resistant soybean cultivars are not generally available (Dorrance et al., 2004; Li and Yang, 2009). Soybean farmers have traditionally managed late-season diseases with fungicides (Levy, 2005; Miles et al., 2003, 2007; Patil and Anahosur, 1998; Sinclair and Hartman, 1995; Yorinori et al., 2005) and cultural practices (Schneider et al., 2007). Foliar fungicide application has increased soybean yield in Ohio (Cruz et al., 2010), Paraguay and Zimbabwe (Miles et al., 2003, 2007), Illinois, Florida, and Georgia (Mueller et al., 2006), and Virginia (Phipps et al., 2010). Other research has not reported such a response in Indiana (Hanna et al., 2006), North Dakota (Mueller et al., 2006), or Virginia (Phipps and Telenko, 2011). Researchers in Missouri (Bradley and Sweets, 2008), Illinois (Pataky and Lim, 1981), and Virginia (Phipps and Telenko, 2011) observed a reduction in disease severity when foliar fungicide was applied, but seed yield responses were inconsistent. Others reported a lack of yield response in absence of disease in Missouri (Bradley and Sweets, 2008) or Iowa (Swoboda and Pedersen, 2009).

Due to rising total input costs and narrowing profit margins, farmers desire to increase yield while limiting risk (Duffy and Smith, 2007; Swoboda and Pedersen, 2009). The economic return from fungicide application varies greatly based on the growth stage of the crop during disease introduction, disease pressure, crop yield potential, and product efficacy (Dorrance et al., 2007; Yang and Robertson, 2007). Bradley and Sweets (2008) found that in the absence of disease pressure, fungicide applications were not economically justifiable in most years. Swoboda and Pedersen (2009) demonstrated foliar fungicide application cost \$55 ha^{-1}. Fungicide application may decrease disease severity and increase soybean yield; however, delaying fungicide application until after disease is present has resulted in yield loss (Miles et al., 2003, 2007). Fungicides were documented to be most effective when applied during early-flowering through seed fill; applications made prior to flowering tend to not increase yield in temperate climates (Cruz et al., 2010; Miles et al., 2007; Mueller et al., 2006, Padgett et al., 2006; Tenuta et al., 2007).

The wheat-soybean double-crop system can maximize production and profitability. Even so, there is yield risk associated with double-crop soybean. Reduced double-crop soybean yield is due in large part to: delayed planting that results in a shortened growing season, later-maturing cultivars that terminate main stem growth after flowering and therefore have less growth and nodes; less soil moisture and plant-available nutrient levels due to wheat uptake; greater air and soil temperatures during vegetative development stages that reduce early-season growth; and increased disease during pod and seed development. Environmental factors that limit growth and yield for double-crop soybean cannot be as effectively managed without irrigation. To increase double-crop soybean yield, farmers can limit environmental influence by using agronomic inputs and management practices that increase early-season growth, accelerate canopy closure, and protect limited leaf area from foliar disease, We hypothesized that maximum input utilization (intensive management) would provide the greatest, but not necessarily the most consistent increase in early-season vegetative growth, seed yield, and seed quality, but any response would be influenced by environmental conditions and subsequent yield potential. Therefore the study objective was to evaluate cultivar stem growth habit, seeding rate, seed-applied inoculant, starter

N applied at planting and foliar fungicide application on soybean vegetative response, total N uptake (TNU), and seed yield and quality in a wheat-soybean double-crop system.

Materials and Methods

Site Description and Cultural Practices

Field experiments were conducted in 2012 and 2013 in a wheat-soybean double-crop system at six locations chosen to represent the major soybean producing regions of eastern Virginia and is dominated by coastal plain soils. Three locations in 2012 included Tidewater Agricultural Research and Extension Center (AREC) in Suffolk, VA (SUF12), Eastern Shore AREC in Painter, VA (PTR12), and Virginia Crop Improvement Association Foundation Seed Farm in Mt. Holly, VA (MTH12). Experiments in 2013 were located at Suffolk (SUF13), Painter (PTR13), and the Eastern Virginia AREC, in Warsaw, VA (WAR13). Refer to Table 2.1 for location soil type, texture, and classification, and coordinates. Experiments focused on soybean within wheat-soybean double-crop production settings typical of southeastern Virginia. Winter wheat management information for experiment locations can be found in Appendix A and were managed according to Extension recommendations (Alley et al., 2009; Anonymous, 2005; Hagood and Herbert, 2012). Locations all had soybean planted at least once within the previous four years (Appendix A). At planting, three random soil cores, 2.5-cm in diameter, were collected at the following depths (cm): 0-15; 15-30; 30-46. Soil samples were air dried, passed through a 2-mm sieve, and analyzed for selected soil chemical properties (soil extractable nutrient levels, soil pH, percent organic matter, and cation exchange capacity) (Appendix B). Soil pH and organic matter ranged from 5.9 to 6.5 and 1.0 to 1.6%, respectively. Soil P and K ranged from 25 to 145 mg P kg^{-1} and 71 to 123 mg K kg^{-1}, respectively. Background soil NH_4

concentrations (0-15-cm depth) were 1.0, 0.85, 1.0, 1.9, 0.96, and 9.8 kg ha^{-1}; whereas, soil NO_3 concentrations were 2.1, 0.09, 0.36, 1.1, 0.18, and 1.8 kg ha^{-1} for MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, respectively for both NH_4 and NO_3.

Experiments were no-till planted into wheat stubble immediately after wheat harvest in 38-cm rows (Table 2.2). Plots were ten rows wide and 7.3 m in length, but were end-trimmed to 5.2 m before harvest. The left five rows (rows 1 to 5) were used for growth, N uptake, and seed yield measurements (this chapter) and the right five rows (rows 6 to 10) were used for yield component sampling (Dillon et al. Chapter III). Plots were managed throughout the growing season according to Extension recommendations and insect and weed pests were maintained below economic injury levels.

Experimental Design

Experiments were conducted as a split-split plot design replicated four times. Five factors, each with two levels, were tested and included: 1) soybean cultivar growth habit (indeterminate or determinate); 2) seeding rate (593,000 or 725,000 seed ha^{-1}); 3) seed-applied liquid inoculant (untreated or with *Bradyrhizobia japonicum*); 4) starter N [0 or 31.4 kg N ha^{-1} 32% urea ammonium nitrate (UAN) solution application at planting (32-0-0 N-P-K, 320 g N kg fertilizer^{-1})]; and foliar fungicide (untreated or disease free management). Foliar fungicide defined the main plot to allow for application ease and accuracy, N application was chosen as the subplot to avoid application stoppage between plots within each replication, and sub-subplot was defined by a 2^3 factorial arrangement of cultivar, seeding rate, and inoculant. Pioneer (Pioneer Hi-Bred Int., Inc., Johnston, IA) 95Y01 indeterminate or 95Y20 determinate soybean cultivars were planted at the dates shown in Table 2.2. Both 95Y01 and 95Y20 cultivars were early MG V, reported to be close in maturity (relative maturity 5.0 versus 5.2, respectively) (additional cultivar characteristics are listed in Appendix B). For inoculant treatments, *Bradyrhizobia japonicum* (Optimize®, EMD Crop BioScience, Brookfield, WI) liquid inoculant was applied to the seed the day prior to planting. Seeding rates of 593,000 and 725,000 seed ha^{-1} were used to obtain a plant population of 445,000 and 545,000 soybean plants ha^{-1}, respectively (Holshouser, 2010). Nitrogen was applied during planting with a CO_2 spraying system, calibrated to supply 187 L ha^{-1} water volume at 32 PSI through sidedress 46-cm diameter coulters (Yetter Manufacturing, Colchester, IL), attached to the planter toolbar and centered between the planter units. A combination of dicyandiamide (DCD) + N-(n-butyl) thiophosphoric triamide (NBPT) (Agrotain Plus®, Koch Agronomic Services, LLC, Wichita, KS) was added to the UAN solution to reduce N loss from ammonia volatilization and nitrate loss pathways. Foliar fungicide, pre-mix of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively (Priaxor®, BASF Corporation, Research Triangle Park, NC) + non-ionic surfactant (Induce®, Helena Chemical Company, Collierville, TN) at 460 mL ha^{-1} (0.25% v/v) was applied by three point tractor sprayer in 187 L ha^{-1} water when soybean reached R3 and R5 developmental stages. Two fungicide applications were made in an attempt for complete fungal disease control.

Data Collection

Plant population was determined two weeks after planting (WAP) by stand counts and plant height was collected at V4 (Table 2.2). Normalized difference vegetative index (NDVI) is a calculation based on the red (R) (660 nm) and near infrared (NIR) (770 nm) light wavelengths and is calculated from the formula NDVI = [(NIR-R) / (NIR+R)]. The NDVI was measured with a GreenSeeker Sensor Model 505 (NTech Industries, Inc., Ukiah, CA) at V4 during the 2013 growing season (Table 2.2). One m of row was removed at V4 in three of four replications, oven-dried at 60°C until a constant weight was obtained (48 to 72 hr.), and weighed to determine total dry matter (TDM). Samples were ground through a Wiley mill fitted with a no. 40 (0.420-mm) screen. Total N concentration was determined by CNS dry combustion analysis (Elementar vario EL cube, Elementar Analysensysteme GmbH, Hanau, Germany). Total N uptake was calculated by multiplying TDM by percent N. When soybean reached R3 and R5, NDVI was measured with the GreenSeeker. Total aboveground biomass was collected at R5 with the same procedure used for V4 timing. To determine disease presence, leaflet samples were collected at R3 and R5 from untreated plots from all four replications by pulling ten leaflets per plot (five leaves from upper canopy; five leaves from lower canopy) and subjecting to incubation. Incubation method entailed the following steps: 1) place two paper towels in the bottom of plastic container; 2) soak towels with distilled water; 3) let excess water run out of container bottom; 4) place leaves top side up layered within box, with lower canopy leaves on left and upper canopy leaves on right; 5) place lid on top of container and ensure it is airtight; 6) incubate for five days minimum. After incubation, leaves were removed from the plastic container and examined for disease under high-power stereoscope. Disease incidence per leaf was recorded separately based on fungal pathogen presence and a percentage of leaves infected per treatment was reported.

Plant height and lodging were measured at R8 (full maturity, Fehr and Caviness, 1977). The middle three rows per plot were harvested at R8 (Table 2.2) with a Wintersteiger® small plot research combine and seed yield in kg ha^{-1} was adjusted to 130 g water kg^{-1}. Subsamples from each plot were collected to determine weight of 100 seed, percent purple seed stain, and seed quality. Oil and protein concentrations were determined with seed near NIR analysis (Foss Rapid Content Analyser XDS, Foss North America, Eden Prairie, MN) and were corrected for moisture.

Statistical Analysis

Statistical analysis used PROC MIXED (SAS, 2008) to test fixed effects and interactions among fixed effects. To evaluate the significance of treatment effects on growth, N uptake, yield and quality parameters, the agronomic inputs cultivar, seeding rate, inoculant, N, and foliar fungicide were considered fixed. For V4 and R5 TNU, only cultivar, inoculant and N were considered. In addition, to decrease TNU sample number, treatment combinations of cultivar, inoculant, and N were collected only at the low seeding rate factor and without the fungicide factor. Soybean growth, and V4 and R3 NDVI were collected prior to fungicide application and were therefore pooled across the fungicide factor when analyzed. Replicate of each treatment combination was considered a random variable in all analyses. Fisher's least significant difference test and least square means at $P < 0.05$ were used for mean separation. Location significantly affected all response parameters; therefore, each input's main effect and interaction between inputs response at different locations is discussed.

Results and Discussion

Environmental Conditions

The 2012 and 2013 growing season air temperatures were similar between locations and were close to the 29 year mean (Table 2.3). Rainfall in 2012 and 2013 differed by location and soybean yield was sometimes reduced due to limited water availability and subsequent moisture stress. Drought conditions in June and July at MTH12 severely reduced vegetative growth. Although mean precipitation from May to Nov. in 2012 was 26% less than the 29 year mean, adequate rainfall from August through November resulted in above average yields. Rainfall at PTR12 fell timely throughout the growing season, and was 25% more than the 29 year mean in

September. Soybean at PTR12 did not suffer from the lack of moisture, experienced good emergence, and rapid canopy closure. However, PTR12 suffered from rank growth that may have slightly reduced yield potential through lodging. Compared to the 29 year mean, 31% increased rainfall was observed at SUF12, resulting in little stress, accelerated canopy closure, and good yield. When the 2012 growing season is examined in entirety, SUF12 and PTR12 had considerably more soil moisture available for soybean uptake compared to MTH12, especially during the vegetative stages.

Rainfall events in June and July at WAR13 resulted in excellent soil moisture at planting and soybean emerged well and closed the canopy relatively quickly (Table 2.3). But, reduced rainfall during September may have limited yield potential. Excessive rainfall immediately after planting at PTR13 combined with poor seed-soil contact resulted in an average emergence of only 35%. Low emergence, plus lower-than-average rainfall in September likely limited yield potential. The SUF13 growing season experienced rainfall 5% above 29 year mean trend. Similar to observed conditions at PTR13, significant rainfall events occurred in June and soil moisture was adequate at planting. Timely rainfall events continued into August and soybean growth exceeded that normally experienced with double-crop soybean. Although rainfall during September at SUF13 was also below average, the greater water holding capacity of the Dragston fine sandy loam soil (Coarse-loamy, mixed, semiactive, thermic Aeric Endoaquults) likely prevented drought stress. The environment’s influence on soybean yield is well documented in coastal plain soils (Freeborn et al., 2001; Holshouser and Whittaker, 2002; Kratochvil et al., 2004; Norsworthy and Frederick, 2002).

Average plant population (plants ha^{-1}) for each location was as follows: MTH12 371,000, PTR12 422,000, SUF12 379,000, WAR13 432,000, PTR13 226,000, and SUF13 444,000. Even if PTR13 is excluded, emergence widely varied and ranged from as low as approximately 55 to as high as 75%. These conditions are typical in the soybean culture dominated by drought-stress prone soils (Chen and Wiatrak, 2011b; Walker et al., 2010).

Disease levels were higher in 2012 compared to 2013, however all locations (except MTH12) experienced close to or above mean rainfall, and increased soybean disease compared to what may be observed during drier growing conditions. Disease incidence (% of leaflets infected) for MTH12 at R3 included 24% downy mildew (DM), with light presence of Cercospora blight on upper leaves (CB-U), brown spot (BS), phyllosticta leaf spot (PLS) and anthracnose (AN). At R5, levels increased to 12% Cercospora blight on lower leaves (CB-L), 4% CB-U, 21% DM, and minimal BS, PLS, frogeye leaf spot (FLS), and alternaria leaf spot (ALS). At R3, 1% CB-L, 5% DM, 5% BS and minimal PLS was observed at PTR12. At R5, disease levels were 32% CB-L, 1% CB-U, 10% DM, 4% PLS, and slight AN, target spot (TS), and ALS. Disease levels at R3 for SUF12 were 2% CB-L, 25% DM, 4% PLS, with minimal BS and FLS. Disease levels at R5 were 32% CB-U, 2% CB-L, 17% DM, 6% BS, 8% PLS, with minimal AN. Soybean rust (*Phakopsora pachyrhizi*) was observed but had limited infection in SUF12 soybean. Disease levels at WAR13 at R3 included 2% FLS, with minimal DM. At R5, soybean had 16% CB-L, 14% CB-U, 20% DM, 4% FLS. At PTR13, 7% FLS and minimal DM were observed at R3 and 16% CB-L, 17% CB-U, 19% DM, 5% FLS at R5. At SUF13, R3 disease levels were 7% DM and minimal FLS and 12% DM, 2% FLS and 1% CB-L at R5. Disease levels would be lower during drier years that are more typical of Virginia; however, similar disease incidence has been documented in other years in southeastern Virginia (Phipps and Telenko, 2011).

Cultivar Stem Growth Habit

Although the maturity of the two cultivars chosen in these experiments was supposed to be within 2 days of each other, 95Y01 matured 7 to 10 days earlier than 95Y20. As a result, differences between maturity likely influenced results more than stem growth habit. Therefore, cultivars will be referred to as either early-maturing indeterminate or late-maturing determinate for 95Y01 and 95Y20, respectively. Please refer to Appendix B for all main effect and interaction P-values for response parameters discussed in this chapter.

When averaged across seeding rate, inoculant, N, and fungicide, plant populations (plants ha^{-1}) for 95Y01 vs. 95Y20 were 344,000 vs. 389,000, 407,000 vs. 438,000, 364,000 vs. 394,000, 428,000 vs. 437,000, 242,000 vs. 211,000, and 434,000 vs. 453,000 at MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, respectively (Appendix B). The desired plant populations and seed number counted prior to planting were the same for both cultivars, yet at three out of six locations (MTH12, PTR12, and SUF12) 95Y20 had significantly greater plants ha^{-1} compared to 95Y01. The remaining locations, WAR13 and SUF13 had similar plant populations between both cultivars; however, at PTR13, 95Y01 had a greater plant population compared to 95Y20. Soybean stand at PTR13 was less than ideal due to poor conditions at planting and poor emergence; however, we cannot explain why 95Y01 had greater plants ha^{-1} compared to the 95Y20. These differences in plant population are demonstrated by yield's response to the early- and later-maturing cultivars in combination with low and high seeding rate.

Cultivar and seeding rate interacted to affect seed yield at all locations in 2013, but did not influence yield at MTH12 or PTR12; however at SUF12, cultivar, seeding rate, inoculant and N affected yield and will be discussed later in this section. At the higher seeding rate, the earlier-maturing indeterminate 95Y01 produced 3400 kg ha^{-1} and increased WAR13 seed yield by 12 and 7%, compared to the later-maturing determinate 95Y20 at high and low seeding rates, respectively, but did not outperform 95Y01 at the low seeding rate (Table 2.5.1). Cultivar 95Y20 utilized the low seeding rate to increase yield compared to the higher seeding rate. Furthermore, partially attributed to the similar plant populations between cultivars at WAR13, 95Y20 produced similar yield compared to 95Y01 at the low seeding rate. At PTR13, 95Y01 with high seeding rate produced 3430 kg ha^{-1} seed and increased yield by 14% compared to the same cultivar at the low seeding rate (Table 2.5.1). In contrast, yield of 95Y20 did not respond to seeding rate due to the plant population already being approximately 30,000 plants ha^{-1} less than 95Y01. At SUF13, 95Y01 at the high seeding rate produced 5476 kg ha^{-1} and increased seed yield by 5% when compared to 95Y01 at the low seeding rate (Table 2.5.1). 95Y20 performed differently; increasing seeding rate decreased yields by 6% from 5263 to 4970 kg ha^{-1}. Furthermore, the seed yield obtained by 95Y20 at the low seeding rate was not different than 95Y01 at the high seeding rate. Plant population at SUF13 was similar for 95Y20 and 95Y01; therefore, when the yield obtained from 95Y20 at the low seeding rate was compared to 95Y01 at the same rate, yield values were similar. The trend of early-maturing cultivar 95Y01 increased seeding rate response at PTR13 and SUF13, but not at WAR13 can partially be attributed to the cultivar being better adapted to the northern latitude of WAR13 compared to PTR13 or SUF13. However, with the later-maturing determinate 95Y20, increasing the seeding rate past the recommended 593,000 seed ha^{-1} did not increase yield at PTR13 and resulted in less yield at WAR13 and SUF13. These data agree with earlier research (Jones et al., 2003) where later-maturing cultivars responded less to seeding rate than earlier-maturing cultivars in double-crop soybean.

Cultivar also interacted with seeding rate, inoculant, and N to influence the seed yield response at SUF12. As previously discussed, seeding rate response was expected to affect 95Y20 due to greater plant population compared to 95Y01 (394,000 vs. 364,000 plants ha^{-1}, respectively). Later-maturing 95Y20, at the high seeding rate yielded less when no inoculant or N was used (Table 2.5.2). Furthermore, yield with 95Y20 treated with N responded to lower seeding rate and inoculant. The combination of low seeding rate with inoculant resulted in 645 kg ha^{-1} significantly more yield than the high seeding rate and no inoculant. The only significant difference between treatments with 95Y01 was that when inoculant was used, N increased yield at the high seeding rate; however, N tended to increase yield with this cultivar regardless of seeding rate and inoculant, but differences were not significant. Treatment combination 95Y20/low seeding rate/inoculant/N produced 4658 kg ha^{-1} seed yield and was greater than 6 of the 16 observations (Table 2.5.2). Inoculant increased yield at only two observations from 3394 to 4417 kg ha^{-1} with application, compared to untreated, with the treatment combination 95Y20/high seeding rate/no N. Inoculant performed inconsistently with all other observations. This interaction can be attributed to 95Y20, without N, responded differently to inoculant based on seeding rate. At the low seeding rate, without inoculant yielded 4554 kg ha^{-1}, compared to 3394 kg ha^{-1} with the high seeding rate. When the later-maturing determinate 95Y20 was planted without N at the high seeding rate, inoculant was necessary to maintain soybean yield. Similar trend was observed at SUF12 with the same cultivar when N was applied, but it was not significant at P=0.05 (Table 2.5.2). Inoculant generally did not benefit the early-maturing indeterminate 95Y01.

At SUF12 and WAR13, fungicide and inoculant combined to affect the seed yield response with cultivar. At SUF12, the interaction was due to a greater yield increase with fungicide with 95Y01 when the seed was treated with inoculant versus a greater yield increase with fungicide with 95Y20 when not treated with inoculant (Table 2.5.3). Although not significantly different at P=0.05, fungicide increased 95Y01 yield by 418 and 158 kg ha^{-1} with and without inoculant, respectively. In a striking contrast, fungicide increased 95Y20 yield by 242 and 762 kg ha^{-1} with and without inoculant, respectively. While the addition of inoculant increased the yield response with fungicide for 95Y01, the same positive effect did not prevail with 95Y20. Instead, either fungicide or inoculant by themselves appeared to be critical to a yield increase with 95Y20 at SUF12. The response of the two cultivars to inoculant and fungicide were similar at WAR13, but differences were not as extreme for 95Y20. When fungicide was applied to 95Y01, yield increased by 406 and 153 kg ha^{-1} for with and without inoculant, respectively; however differences were significant at P=0.05 only for increased yield with inoculant and fungicide but not for without inoculant (Table 2.5.3). 95Y20 responded to fungicide differently by increasing yield by 75 and 346 kg ha^{-1} for with vs. without inoculant, respectively. Furthermore, differences between fungicide and no fungicide were significant when inoculant was not applied to the 95Y20 seed. 95Y01 generally responded to inoculant in combination with fungicide at WAR13; whereas, 95Y20 primarily increased yield independently with fungicide application, regardless of inoculant. At WAR13, 95Y01 outperformed 95Y20 when both inoculant and fungicide were used, while yields of the cultivars were similar at SUF12. Differences between cultivar may be attributed to better adaptability of the earlier-maturity to WAR13 versus SUF12.

Cultivars responded differently with yield based on with and without N treatment at PTR12. Without N, 95Y01 yielded 7% more than 95Y20 (4574 vs. 4243 kg ha^{-1}) (Table 2.5.4).

But, cultivar differences were not observed when N was applied because N increased 95Y20 yield by 4%.

Also at PTR12, fungicide interacted with cultivar to affect seed yield. Fungicide applied with 95Y01 and 95Y20 produced 4591 and 4566 kg ha^{-1} yield, respectively (Table 2.5.5). When differences within stem growth habit were examined, indeterminate 95Y01 increased yield by 4% compared to the same cultivar untreated; determinate 95Y20 increased yield by 10% compared to 95Y20 untreated. Foliar disease was observed to infect soybean at PTR12 around the beginning-pod reproductive stages (Dillon et al. Chapter V) which eliminates being able to attribute increased yield from fungicide for 95Y20 to disease pressure later in the season. Furthermore, even though disease infected soybean around R3, the early-maturing 95Y01 did not increase yield with fungicide more compared to 95Y20. Therefore, we attribute the yield increase from fungicide for 95Y20 to greater susceptibility to mid-season foliar disease, especially Cercospora blight.

Cultivars at PTR13 produced seed yield differently based on with or without inoculant. The combination of 95Y01 and no inoculant produced 3309 kg ha^{-1} and yielded 7% more than the same cultivar with inoculant (Table 2.5.6). In contrast, inoculant increased yield for 95Y20 by 176 kg ha^{-1}. Furthermore, 95Y01 out-yielded 95Y20 by 484 kg ha^{-1}, but only when inoculant was not applied. Plant population at PTR13 was greater with 95Y01 compared to 95Y20 and could partially explain increased yield when comparing both cultivars. Increased yield with 95Y01 can partially be attributed to drought stress during September, which limited 95Y20 yield potential, and 95Y01 being better adapted to the latitude at PTR13. In contrast, we previously discussed 95Y01’s tendency to increase yield with inoculant when combined with fungicide at SUF12 and WAR13. At PTR13, such a response was not observed with 95Y01; furthermore yield decreased with inoculant use. These data demonstrate how inoculant application is very site-specific and can be difficult to accurately predict.

Although affected by interactions with other factors previously discussed, the early-maturing indeterminate 95Y01 yielded 3, 8, 9, and 4% more than late-maturing determinate 95Y20 (4339 vs. 4492, 3074 vs. 3342, 2913 vs. 3190, and 5116 vs. 5331 kg ha^{-1}) for PTR12, WAR13, PTR13, and SUF13, respectively (Table 2.4). At PTR12 and all three locations in 2013, this can be explained by the earlier-maturing cultivar being farther advanced in development when drought stress occurred in September. However, if growth habit is considered, our results are similar to Boerma et al. (1982) and Cooper (1981), but differ from Beuerlein (1988) and Weaver et al. (1991). In Ohio where determinate cultivars are not usually grown, Cooper (1981) reported that determinate cultivars yielded lower than indeterminate cultivars in a low-yield environment where high temperature and drought stress reduced plant height, lodging, and yield. In Illinois where indeterminate cultivars dominate, Beaver and Johnson (1981) examined soybean growth habit produced on silt loam soils and cautioned if drought stress typically dominated during vegetative stages, determinate cultivars should not be planted. These studies are in contrast with MTH12 where plant height and growth were reduced, but there were no yield differences attributed only to cultivar. In addition, cultivar interacted with other inputs at MTH12 to affect yield and was already discussed. At SUF12, yield was not influenced by cultivar when examined alone (similar to MTH12) but responded to cultivar and seeding rate, inoculant, N, and fungicide. Lack of yield response attributed to the early-maturing 95Y01 at SUF12 may be because 95Y20 is better adapted to that location's latitude and rainfall. However, as mentioned previously, 95Y20 matured 7 to 10 days later than 95Y01, therefore direct comparisons between growth habits cannot be made. Typically, when the environmental conditions result in low-yield potential, later-maturing cultivars produce more stable yield, whereas the early-maturing cultivars decrease yield. Norsworthy and Frederick (2002) determined in a growing season dominated by drought stress, that the earlier maturing cultivar was negativity affected by reducing duration of vegetative growth stages. However, when precipitation was above average, the early MG V yielded as well or greater than later MG cultivars (Norsworthy and Frederick, 2002). In contrast, our data show the timing of rainfall or the lack thereof during critical pod-fill stages altered yield response to early- vs. later-maturing cultivars.

Measurements V4 plant height and V4 and R3 NDVI demonstrated the overall ability of 95Y01 to increase pre-pod stage parameters. General trend with V4 plant height was not as consistent as with V4 and R3 NDVI; however, cultivar or cultivar interactions affected plant height at all but the WAR13 site (Table 2.4). At SUF12, 95Y20 produced plant height that measured 39.1- and 39.7-cm for with and without N, respectively and was greater than 95Y01 without N (37.3-cm), but was similar in value to 95Y01 with N (38.9-cm). 95Y01 responded to N application, but 95Y20 did not.

Soybean at MTH12 and PTR12 differed in V4 plant height based on cultivar, seeding rate and N. At MTH12, 95Y01 produced similar height when N was applied with both seeding rates; however, without N, 95Y01 increased plant height by 6% with the low seeding rate, but was not significant at $P=0.05$ (Table 2.5.7). In contrast, 95Y20 responded to N by increasing V4 plant height by 8% with the low seeding rate; however, no differences were observed without N. Furthermore, 95Y20 had 8% greater height with N and the low seeding rate, compared to 95Y01 and the same treatment combination. 95Y20’s response to N at the low seeding rate could partially be attributed to greater plant population with 95Y20 at MTH12, which allowed the low seeding rate to respond to N better due to increased plants. Cultivars produced similar plant height at the high seeding rate due to the greater population for 95Y20, which allowed that cultivar to utilize N and produce atypical plant height that would normally be higher for 95Y01. The reduced plant population for 95Y01 limited the response to N, which resulted in similar V4 plant height when compared to 95Y20. Drought conditions controlled soybean emergence at MTH12, but we slightly reduced this influence on V4 plant height due to similar height between 95Y20 planted at the low and high seeding rates. If plant height was reduced for all high seeding rate observations then we could have partially linked decreased growth to decreased water due to increased uptake from more plants ha^{-1}. At PTR12, cultivars responded differently to seeding rate and N by increasing V4 plant height by 8% with N applied to 95Y20 at the low seeding rate compared to 95Y01 with the same combination (Table 2.5.7). When N was applied to the high seeding rate, 95Y01 increased plant height compared to 95Y20. Without N, 95Y01 produced greater plant height at the low seeding rate compared to 95Y20 at the same seeding rate (54.8- vs. 50.4-cm). In contrast, at the high seeding rate, without N, plant height differences were similar between cultivars. When differences within cultivars were examined, 95Y01 increased plant height by 13% with the high seeding rate with N but did not increase height without N. 95Y20 responded differently and increased V4 height with the low seeding rate, without N, but produced the same height between seeding rates when N was applied. The plant population for 95Y01 at PTR12 was approximately 30,000 plants ha^{-1} less than 95Y20; therefore, 95Y01 marginally responded greater to the combination of N and high seeding rate, but more importantly reduced V4 plant height with the low seeding rate, combined with N. However, when N was not applied, 95Y01 increased V4 plant height with the low seeding rate, compared to 95Y20. Starter N was generally more important and provided increased plant height for 95Y20 at the low seeding rate compared to 95Y01.

At PTR13, cultivar, inoculant, and N affected V4 plant height. When N was applied to 95Y01 in combination with inoculant, plant height did not differ between inoculant treatments; however, when N was removed, using inoculant decreased V4 plant height by 3.3-cm (Table 2.5.8). 95Y20 responded differently by producing similar plant height with N and with and without inoculant; however, plant height decreased (though not significantly at P=0.05) from 34.2- to 31.5-cm with no N/inoculant vs. no N/no inoculant, respectively. When N was not applied, inoculant proved more valuable to 95Y20 compared to 95Y01.

Also at PTR13, cultivar and seeding rate affected V4 plant height. Early-maturing 95Y01 had 9% greater plant height (36.0- vs. 32.7-cm) with the high seeding rate, compared to 95Y20 at the same seeding rate. However, at the low seeding rate, 95Y20 increased plant height compared to 95Y01 but was not significant at P=0.05. Furthermore, 95Y01 increased plant height by 9% with the high seeding rate compared to the same cultivar at low seeding rate. In contrast, changing the seeding rate did not influence plant height exhibited by 95Y20. 95Y01 had a greater plant population at PTR13 compared to 95Y20, yet the later-maturing determinate 95Y20 did not respond to increasing seeding rates. However, 95Y20 did demonstrate the ability to increase height at lower seeding rates by producing slightly greater plant height to 95Y01, while being limited by a plant population that had 30,000 less plants ha^{-1}. At SUF13, 95Y01 increased plant height by 7% (49.5- vs. 45.9-cm) with the high seeding rate compared to 95Y20 at the same rate. Plant height did not differ between seeding rates for 95Y20. In contrast, 95Y01 had 8% greater V4 plant height with the high seeding rate, compared to the low seeding rate.

Reduced plant height differences between 95Y01 and 95Y20 at SUF13 compared to PTR13 can partially be attributed to similar plant populations between cultivars at SUF13.

Also at SUF13, soybean height at V4 responded to cultivar and inoculant treatment combinations. 95Y20 with inoculant produced 48.1-cm-tall soybean and increased height by 6% compared to the same cultivar without inoculant (44.9-cm). 95Y01 slightly reduced plant height from 46.9- to 48.1-cm when inoculant was applied to the seed.

Canopy NDVI at V4 for all 2013 sites were greater with 95Y01 than 95Y20, but interactions with seeding rate at PTR13 and seeding rate or inoculant at SUF13 confounded these results. At PTR13, increasing the seeding rate increased 95Y01 V4 NDVI by 13% compared to the same cultivar at the low seeding rate (0.7165 vs. 0.6217, respectively). When the seeding rate was changed for 95Y20, NDVI values did not differ at P=0.05. In addition, 95Y01, planted at the high seeding rate, produced leaf area with 16% greater NDVI compared to 95Y20 at the high seeding rate. Increased NDVI with 95Y01 can partially be attributed to greater plant population at PTR13, compared to 95Y20. 95Y01 had more plants ha^{-1}, which resulted in greater V4 leaf area and increased NDVI. Cultivar and seeding rate also affected V4 NDVI at SUF13; however 95Y01 did not respond as great to increased seeding rates as observed at PTR13 due to similar plant population compared to 95Y20. 95Y01 did increase V4 NDVI by 8% with the high seeding rate. In addition, 95Y01 had 14% greater NDVI with the high seeding rate versus 95Y20 with the same rate. Even at a similar plant population, 95Y01 generally had greater NDVI values at SUF13 compared to 95Y20.

Also at SUF13, NDVI collected at V4 was influenced by cultivar and inoculant. 95Y01 increased NDVI by 6% with inoculant compared to 95Y20 with inoculant. Furthermore, when inoculant was not applied, NDVI values were 13% greater, increased from 0.7038 to 0.8093 for

95Y20 and 95Y01, respectively. Within both cultivars, inoculant addition or removal did not affect NDVI values at P=0.05. As mentioned previously, 95Y01 had a similar plant population at SUF13, yet still had greater V4 NDVI values compared to 95Y20. At WAR13, 95Y01 increased V4 NDVI from 0.8225 to 0.8382, compared to 95Y20 (Table 2.4). Even with a similar soybean population, the early-maturing indeterminate 95Y01 increased NDVI values at V4. Contrary to our early-season NDVI readings, Chen and Wiatrak (2011b) reported MG IV cultivars to have decreased NDVI compared to MG V.

Total N uptake at V4 was influenced by cultivar or interactions involving cultivar at 4 out of 6 locations. At MTH12 and WAR13, cultivar and inoculant did not significantly influence V4 TNU at P=0.05 (P=0.1405 and 0.1328, respectively); however this interaction helps explain how 95Y01 increased early-season plant productivity. 95Y01 at MTH12 did not need inoculant to increase TNU at V4. Specifically, 95Y01 without inoculant increased TNU by 10 kg N ha^{-1}, a 25% increase, compared to the same cultivar, with inoculant. In contrast 95Y20 increased TNU by 8 kg N ha^{-1}, a 20% increase, with inoculant. When inoculant was not applied, early-maturing indeterminate 95Y01 had 24% greater TNU (+11 kg N ha^{-1}) compared to the later-maturing determinate 95Y20. However, when inoculant was applied to both cultivars, determinate 95Y20 increased TNU by 7 kg N ha^{-1}, 18% increase compared to 95Y01. At WAR13, differences were similar, yet even greater in value between cultivar and inoculant and their effect on V4 TNU. When inoculant was not applied to 95Y01 seed, V4 TNU increased by 26 kg N ha^{-1}, 38% increase, compared to the same cultivar with inoculant. In contrast, later-maturing 95Y20, with inoculant, increased TNU by 11% (+6 kg N ha^{-1}), compared to no inoculant applied to 95Y20. When inoculant was withheld from both cultivars, early-maturing indeterminate 95Y01 exhibited 38% greater TNU (+26 kg N ha^{-1}) compared to later-maturing determinate 95Y20. Finally, when inoculant was applied to both cultivars, 95Y20 increased TNU by 11% (+5 kg N ha^{-1}) compared to 95Y01. At both MTH12 and WAR13, inoculant negatively affected 95Y01 TNU greater than it positively affected 95Y20 TNU. Early-maturing 95Y01 had a reduced plant population at MTH12 and similar plant population at WAR13, compared to 95Y20, but still managed to improve plant tissue N dynamics through greater TNU when inoculant was not used.

At SUF12, cultivars exhibited V4 TNU that differed by starter N treatments and responded similarly to N as observed with inoculant. 95Y01, without N, increased V4 TNU by 35% (+9 kg N ha^{-1}) compared to the same cultivar with N. In contrast, 95Y20 increased V4 TNU by 4 kg N ha^{-1} (+16%) with N compared to without. When N was withheld from both cultivars, 95Y01 increased V4 TNU by 29% (+8 kg N ha^{-1}); whereas, without N, 95Y20 increased TNU by 5 kg N ha^{-1} (+23%). Indeterminate 95Y01 did not require N to increase V4 TNU at SUF12 but determinate 95Y20 did. The following growing season at SUF13, cultivar marginally affected V4 TNU (P=0.0959) by independently increasing N uptake with 95Y01, from 61 to 82 kg N ha^{-1} (+25%), compared to 95Y20. At SUF13, V4 TNU was not influenced by the remaining factors - inoculant or N.

Cultivar 95Y01 had greater NDVI at R3 but differences were less and were observed only at WAR13 and PTR13, where interactions with N and inoculant (WAR13) and with N and seeding rate or inoculant (PTR13) affected differences. At WAR13, 95Y01 generally had greater NDVI values compared to 95Y20. However, 95Y01, with N/inoculant increased NDVI by only 1% compared to the same treatment combinations with 95Y20. Furthermore, 95Y01 no N/no inoculant increased NDVI by only 2% compared to 95Y20 with the same combinations. At PTR13, cultivar, seeding rate, and N affected R3 NDVI. Early-maturing 95Y01, with the high seeding rate increased NDVI by 3% for both with and without N, compared to the same N treatments combined with the low seeding rate (Table 2.5.7). In contrast, when N was applied to 95Y20, NDVI values were similar; however, when N was withheld, the low seeding rate increased R3 NDVI by 4%, vs. the high seeding rate. Also at PTR13, cultivar and inoculant affected R3 NDVI. 95Y01, without inoculant increased R3 NDVI by 3% compared to 95Y20 without inoculant. In addition, when inoculant treatments within 95Y01 were compared, differences were minimal; whereas, 95Y20 increased NDVI by 2% for with vs. without inoculant. At SUF13, the canopy had completely closed by R3 for both cultivars as indicated by NDVI readings of 0.95 or greater.

Mid-season measurements R5 NDVI and TNU demonstrated N uptake and growth differences between cultivars. Cultivar or interactions involving cultivar influenced R5 NDVI at all locations. Cultivar affected R5 NDVI differently due to an interaction with inoculant and N at PTR12 and SUF12, but both were not significant at $P=0.05$ ($P=0.1431$ and 0.1119, respectively). At PTR12, both 95Y01 and 95Y20 with both N and inoculant did not increase NDVI compared to no N/no inoculant for both cultivars. In addition, 95Y20 did slightly decrease NDVI (< 1%) at R5 when N was removed and inoculant was still used. Overall, at PTR12, NDVI values were generally greater with 95Y20; however, differences were minimal. At SUF12, R5 NDVI response to cultivar, inoculant, and N was very similar to PTR12. Neither 95Y01 nor 95Y20 increased NDVI values with both inoculant and N, when compared to without both factors. As observed with R5 NDVI at PTR12, when N was removed from 95Y20, and inoculant was still applied, NDVI values decreased but were < 1%.

Cultivar and inoculant combined to influence R5 NDVI at both MTH12 and PTR13. At MTH12, 95Y01 increased R5 NDVI values by 1% with inoculant compared to without (Table 2.5.6). In contrast, significant differences ($P=0.05$) between inoculant treatments were not observed with 95Y20. When cultivars were compared, 95Y01, with inoculant, produced leaf area that had similar NDVI values as 95Y20. However, when inoculant was withheld from the soybean seed, 95Y20 increased R5 NDVI by < 1%. At PTR13, R5 NDVI responded differently to cultivar and inoculant. Application of inoculant to 95Y01 did not improve NDVI values. However, 95Y20 increased R5 NDVI from 0.8447 to 0.8601 (+2%) when inoculant was applied, but was similar in value to both 95Y01 treatments (Table 2.5.6). The greater R5 NDVI differences with 95Y20 when inoculant was added at PTR13 could be attributed to decreased plant population. Early-maturing 95Y01 had approximately 32,000 more plants ha^{-1} at PTR13, compared to 95Y20 which may have increased inoculant response for later-maturing 95Y20. These data show R5 NDVI for treatment combinations that are close in value, which is primarily due to 95Y20's ability to increase leaf area mid-season and attain NDVI values similar to 95Y01; whereas earlier in the season 95Y01 exhibited greater NDVI.

Also at PTR13, cultivar and seeding rate influenced R5 NDVI. Early-maturing 95Y01 increased R5 NDVI from 0.8464 to 0.8620 with the low and high seeding rates, respectively (Table 2.5.1). In contrast, NDVI was slightly greater (< 1%) but not significant at P=0.05 with 95Y20 at the low vs. high seeding rate. This response at PTR13 is primarily due to a greater plant population with 95Y01 vs. 95Y20, which increased NDVI further with 95Y01 at the high seeding rate. However, even with a reduced plant population, 95Y20, at the low seeding rate produced leaf area with NDVI values that were similar to 95Y01 at the high seeding rate. These data demonstrate the ability of the later-maturing 95Y20 to increase mid-season leaf area and biomass, shows the early-maturing 95Y01's response to greater seeding rates, but does not negate the negative effects of reduced plant population on growth parameters and ultimately seed yield. Similar to our results, Chen and Wiatrak (2011b) demonstrated that MG V cultivars optimized NDVI at lower seeding rates than with MG IV cultivars. As mentioned previously, 95Y01 increased NDVI early-season; whereas, late-season, the later-maturing cultivar was able to attain similar and in some cases, greater NDVI. Part of our research objective was to increase early-season growth, which we accomplished with the early-maturing indeterminate 95Y01; however, it is also critical to maximize leaf area and light interception mid-season to ensure maximum seed yield. This presents us with the future challenge to select and manage cultivars that improve early-season growth while ensuring maximum canopy prior to pod-fill stages.

At SUF13, R5 NDVI responded to cultivar, seeding rate and fungicide. Later-maturing 95Y20 exhibited similar NDVI values at low/high seeding rates and with/no fungicide. Similarly, early-maturing 95Y01 maintained NDVI levels with the low seeding rate/fungicide, compared to the high seeding rate/fungicide. In contrast, 95Y01, at the low seeding rate decreased R5 NDVI by 2% when fungicide treatment was withheld compared to the same cultivar and seeding rate, but with fungicide. Furthermore, when fungicide was not applied to 95Y20 at the low seeding rate, NDVI increased by 2%, (0.8842 to 0.9011) compared to 95Y01, with the low seeding rate/no fungicide. However, 95Y20/high seeding rate/fungicide produced similar NDVI values as 95Y01/high seeding rate/fungicide (0.9023 vs. 0.8995, respectively). Cultivars had similar plant populations at SUF13 and assists in explaining this response. Greater seeding rates allowed 95Y01 to attain similar NDVI values compared to 95Y20; however, when the low seeding rate was used, 95Y01 NDVI values decreased.

Total N uptake at R5 was affected by an interaction between cultivar and inoculant at 1 out of 6 locations. At MTH12, cultivar and inoculant affected R5 TNU, but was not significant at P=0.05 (P=0.1547). Early-maturing indeterminate 95Y01 increased TNU by 23% (+32 kg N ha^{-1}) when inoculant was not used, compared to inoculant applied. Later-maturing determinate

95Y20 increased TNU by 26% (+33 kg N ha^{-1}) with inoculant compared to untreated. Our data showed that when inoculant was withheld from both cultivars, 95Y01 increased R5 TNU by 52 kg N ha^{-1} (+36%) compared to 95Y20. In contrast, when inoculant was applied to both 95Y01 and 95Y20 at MTH12, R5 TNU increased by 14 kg N ha^{-1} (+11%) for 95Y20 compared to 95Y01. Treating 95Y20 seed with inoculant was critical for R5 TNU exhibited by 95Y20 at MTH12, but negatively affected 95Y01 TNU. This response could partially be due to early-maturing 95Y01 being better adapted to the MTH12 location compared to the later-maturing 95Y20, which typically performed better at more southern locations (i.e. SUF). Also, 95Y01 matured 7 to 10 days earlier than 95Y20 and partially avoided drought stress that coincided with sensitive pod-fill stages for 95Y20, which may have reduced R5 TNU.

Seed weight was affected by cultivar or interactions involving cultivar at all locations. At MTH12, all five factors, cultivar, seeding rate, inoculant, N, and fungicide marginally influenced weight of 100 seed but was not significant at P=0.05 (P=0.1088). Although seed weight is not significant in this example, these data provide insight into yield formation. Early-maturing 95Y01 increased seed weight compared to all later-maturing 95Y20 observations at MTH12. 95Y01 with high seeding rate/inoculant/N/fungicide produced seed weight of 17.1 g 100 $seed^{-1}$, but was not different than the same cultivar at low seeding rate/no inoculant/no N/no fungicide, which weighed 16.9 g 100 $seed^{-1}$. When the low seeding rate was used with 95Y01 in combination with inoculant/N/fungicide, soybean produced 16.3 g 100 $seed^{-1}$, but was not different than the same cultivar at low seeding rate without inoculant/no N/no fungicide (16.2 g 100 $seed^{-1}$). However, 95Y01 at the high seeding rate, with all remaining factors (inoculant/N/fungicide) significantly increased (P=0.05) seed weight by 5%, compared to 95Y01 at the low seeding rate with untreated factors (17.1 vs. 16.2 g 100 $seed^{-1}$, respectively). In contrast, later-maturing 95Y20 at the high seeding rate with inoculant/N/fungicide yielded seed that weighed 14.6 g 100 seed^{-1}, but was not different than the same cultivar at high seeding rate with untreated factors (14.5 g), and was not different than the same cultivar at the low seeding rate with all treatments or with all factors untreated (both 14.2 g). Combining all factors did not increase seed weight for either 95Y01 or 95Y20 at MTH12. Furthermore, the high seeding rate generally increased seed weight for both cultivars compared to the low seeding rate. This seeding rate response could partially be attributed to decreased plant population with 95Y01 at MTH12, however 95Y20 also responded positively to the high seeding rate. Even with the reduced plant population, 95Y01 increased seed weight in all 32 observations compared to 95Y20. In addition, inoculant, N, and fungicide did not consistently increase seed weight when utilized in combination with either cultivar.

Seed weight at WAR13 was affected by a similar marginal interaction between all factors (P=0.1126), and while not significant at P=0.05, it provides insight into how cultivars produced different seed weight. Similar to MTH12, early-maturing 95Y01 produced greater seed weight than later-maturing 95Y20 at 32 out of 32 observations. Different from MTH12, fungicide increased seed weight for both cultivars 16 out of 16 observations at WAR13. The canopy never fully closed at MTH12; whereas, at WAR13, canopy closure was accelerated mid-season. General trends observed with these data also include cultivars did not increase seed weight consistently by changing the remaining factors - low vs. high seeding rate, with vs. without inoculant, or with vs. without N. Indeterminate 95Y01 produced 16.7 g 100 seed^{-1} at the high seeding rate, with all treatments, but was similar in value (P=0.05) to the same cultivar, with the same seeding rate, with untreated remaining factors (16.1 g). However, when 95Y01 was planted at the low seeding rate with all treated factors, 100 seed weighed 16.6 g, and was greater than (P=0.05) the same cultivar and seeding rate, but with untreated factors (15.6 g). Combining different factors with 95Y01 at the low seeding rate resulted in greater seed mass. Compared to MTH12, the plant population at WAR13 was similar between cultivars and did not limit 95Y01 at the low seeding rate from producing seed similar in weight to the high seeding rate. Later-maturing 95Y20, at the high seeding rate, with all factors treated, produced seed that weighed 14.5 g 100 seed^{-1}, and was greater than the same cultivar and seeding rate with untreated factors (13.6 g). However, when the low seeding rate was used with 95Y20, differences were not observed between all treated vs. untreated factors (14.4 vs. 14.0 g 100 seed^{-1}, respectively). Unlike 95Y01, combining agronomic inputs with 95Y20 at the high seeding rate improved seed weight. This response could be due to reduced adaptation of 95Y20 to WAR13 latitude. These data demonstrate how early-maturing 95Y01 increased seed yield at WAR13 through greater seed weight compared to later-maturing 95Y20.

Factors cultivar, seeding rate, inoculant, and fungicide marginally affected soybean seed mass at SUF13, but were not significant at P=0.05 (P=0.1004). Early-maturing 95Y01 increased seed mass for 16 out of 16 observations compared to later-maturing 95Y20. With 95Y01, fungicide increased seed weight at 3 of 8 observations compared to untreated. Specifically, 95Y01 at the high seeding rate, with all treated factors produced 18.1 g 100 seed^{-1} and was 3% greater than the same cultivar and seeding rate, but with untreated factors (17.5 g). When the low seeding rate was used, 95Y01, with all factors treated produced 100 seed that weighed 17.3 g but was not different (P=0.05) than the same cultivar at low seeding rate, without treated factors (16.7 g). General trend for 95Y01 at SUF13 was increased seed weight with fungicide, slightly greater weight with higher seeding rate, and inconsistent response from inoculant. Determinate 95Y20 at the high seeding rate produced 4% greater seed weight with all treated factors compared to the same cultivar and seeding rate, but with untreated factors (15.2 vs. 14.6, respectively), but was not significant at P=0.05. Once the low seeding rate was used, 95Y20, with all factors treated yielded seed that weighed 15.3 g 100 seed^{-1}, but was not greater than the same cultivar and seeding rate with untreated factors (15.0 g). Later-maturing 95Y20 at SUF13 did not respond as positively to the combination of inputs by increasing seed weight as observed with early-maturing 95Y01 and may be attributed to 95Y20 being better adapted to the SUF location. In addition, drought stress in September at SUF13 may have slightly reduced 95Y20 productivity during pod-fill stages and may have decreased seed production more compared to 95Y01.

At PTR12 and PTR13, cultivar, seeding rate, and N influenced seed weight. Early maturing 95Y01 produced greater seed weight compared to later-maturing 95Y20 at 8 out of 8 observations at PTR12 (Table 2.5.7). At the high seeding rate, 95Y01 with N, produced similar seed weight as high seeding rate/no N and low seeding rate/no N (18.8, 18.7, and 18.7 g 100 seed^{-1}, respectively). However, when 95Y01 was planted at the low seeding rate and N was applied, seed weight was 18.4 g 100 seed^{-1} and was less than all other 95Y01 observations. With 95Y20, there were no significant differences between treatments (P=0.05); however, lowering the seeding rate generally increased seed weight. Furthermore, N did not increase 95Y20 seed weight. The following season at PTR13, 95Y01 increased seed weight for 8 out of 8 observations, compared to 95Y20 (Table 2.5.7). 95Y01, with the low seeding rate and no N, produced seed that weighed 17.2 g 100 seed^{-1}, but was less than all other 95Y01 treatments. Nitrogen applied to the low seeding rate slightly increased seed weight; whereas, N was not required to increase weight with the high seeding rate. Significant differences were not observed with 95Y20; seed weight values and changing the seeding rate did not improve seed weight.

Nitrogen did increase 95Y20 seed weight regardless of the seeding rate at PTR13. Both cultivars responded differently to N application when PTR12 and PTR13 were compared but cannot be attributed to soil N differences due to soil at both locations having similar NH_4 and NO_3 values that were 0.85 and 0.09 kg ha^{-1} for PTR12 and 1.0 and 0.18 kg ha^{-1} for PTR13, respectively. However, in both examples, soil-N was very low and soybean response to N would be expected due to previous research by Scharf and Wiebold (2003) that showed when NO_3-N was < 56 kg ha^{-1} in the top 61-cm, soybean responded positively to N application.

Also at PTR13, cultivar, N and fungicide influenced 100 seed weight. Early-maturing 95Y01 increased seed weight by 19% when N was applied compared to 95Y20 (Table 2.5.9). When N was not applied, 95Y01 had 18% greater seed weight compared to 95Y20. The indeterminate responded to N only when fungicide was used. Furthermore, determinate 95Y20 did not respond to N, regardless of fungicide application.

The previous year at PTR12, seed weight responded to the combination of cultivar and inoculant treatments. Indeterminate 95Y01 produced greater seed weight compared to determinate 95Y20. However, 95Y01 responded to inoculant by increasing seed weight from 18.5 to 18.7 g 100 seed^{-1} with inoculant use. In contrast, 95Y20 reacted oppositely and decreased seed weight from 15.8 to 15.7 g 100 seed^{-1} when inoculant was applied.

Also in 2012, seed weight at SUF12 was independently affected by cultivar. Early-maturing 95Y01 produced 13% greater seed weight compared to later-maturing 95Y20 by increasing values from 15.7 to 18.0 g 100 seed^{-1} (Table 2.4). However, even with the increased seed weight, 95Y01 yielded less than 95Y20 at SUF12 due to a decreased plant population. If the plant population would have been similar, increasing seed weight would have improved 95Y01 seed yield and would have probably yielded greater than 95Y20 (as observed at all other locations). Excluding SUF12, seed yield increase associated with 95Y01 can partially be attributed to increased seed weight. Similar to our results, Starling et al. (1998) reported that indeterminate isolines increased seed weight as compared to determinate cultivars. Due to the influence of different maturity on our cultivars, we cannot attribute increased seed weight only to stem growth habit. In contrast, our research demonstrated the yield increase from 95Y01 was primarily attributed to earlier maturity, ability to avoid drought stress during critical pod-fill stages in September, 2013, and a positive response to generally atypical growing seasons that had timely and large rainfall events at most locations.

Seeding Rates

Seed yield responded to seeding rate or interactions involving seeding rate at 5 out of 6 locations. As previously discussed, different plant populations were observed at each location and controlled the yield response. Many of the interactions involving seeding rate's effect on yield have been discussed within the cultivar section; however there are interactions not yet mentioned. At SUF12, seeding rate, inoculant, N, and fungicide influenced seed yield. Seed yield at SUF12 ranged from 3169 to 4853 kg ha^{-1} and was generally greater with fungicide across both the low and high plant populations (Table 2.5.10). When N was applied to the low seeding rate, fungicide did not significantly increase yield ($P=0.05$). When the high seeding rate was used, in combination with N and inoculant, fungicide increased seed yield by 654 kg ha^{-1}, compared to no fungicide. Furthermore, when the inoculant was removed, yield increase attributed to fungicide was reduced to 295 kg ha^{-1}. When N was not applied, the low plant population did not result in increased fungicide yield response, regardless of inoculant. In contrast, when N was not applied, but the high seeding rate was planted without inoculant, fungicide increased yield by 1043 kg ha^{-1}, compared to no fungicide. Foliar fungicide was most effective at SUF12 when used in combination with the high seeding rate, inoculant, and N. However, when N was not applied, fungicide also increased yield with the high plant population, but inoculant was not required. The partial response to greater seeding rates regardless of N may be explained by plant populations that were reduced with the low seeding rate; therefore, increasing the seeding rate resulted in greater leaf area critical for plant productivity (Jones et al., 2003), which fungicide was effective in protecting.

Inoculant at MTH12 increased seed yield by 6% when combined with the high seeding rate, compared to no inoculant (3695 vs. 3459 kg ha^{-1}, respectively) (Table 2.5.11). When seeding rates and obtained plant populations were compared, inoculant at either the low or high seeding rate resulted in similar yield; however, when inoculant was not applied, the low seeding rate increased seed yield by 5% compared to the high seeding rate (3648 vs. 3459 kg ha^{-1}, respectively). Inoculant use at MTH12 provided greater yield when used at the high seeding rate but did not increase yield at the low seeding rate. Therefore, inoculant application was unnecessary at the low seeding rate. Plant populations at MTH12 obtained from the seeding rates 593,000 and 725,000 seed ha^{-1} were approximately 346,000 and 387,000 plants ha^{-1}, respectively. The high seeding rate resulted in only 40,000 plants ha^{-1} greater plant population compared to the low seeding rate. Our data shows inoculant response at the low plant population but no response at the high population; however, the high population we obtained at MTH12 and other locations is much less than we had intended. Inoculant response may be much different with soybean populations that are closer to our desired high plant population of 545,000 plants ha^{-1}. An inoculant response similar to MTH12 was also observed at SUF12 and was discussed previously with the more complex interaction involving seeding rate, inoculant, N, and fungicide. However, inoculant at SUF12 performed very similar to MTH12 and increased yield only at the high seeding rate and did not provide greater yield when in combination with the low seeding rate (Table 2.5.11).

Drought conditions were observed at MTH12 and the native *Bradyrhizobium* population may have been inhibited due to extreme moisture stress. When the low seeding rate was planted, the native *Bradyrhizobium* may have been adequate enough for N_2 fixation; whereas, with the increased seeding rate, *Bradyrhizobium* populations may have not been able to partially meet the soybean N demand. Growing conditions were much better at SUF12 compared to MTH12, yet a similar trend of removing inoculant from the high seeding rate resulting in decreased yield was observed. We did not collect nodule counts and this may have aided in quantifying the specific cause for response to inoculant. However, Furseth et al. (2012) recently demonstrated that rhizobia population level poorly predicted soybean response to inoculation.

As discussed earlier with cultivar, increasing seeding rate increased yield at some locations when in combination with early-maturing 95Y01. 95Y01's response to seeding rate varied due to plant populations that differed at MTH12, PTR12, SUF12, and PTR13, but were similar between cultivars at WAR13 and SUF13. At the 2012 locations, 95Y01 had decreased plant population compared to 95Y20 and responded to increased seeding rates. As we investigate seeding rate's effect on yield, we must maintain the context of how obtained plant populations were a controlling factor in seeding rate response, but also influenced response to inoculant, N, and fungicide. Early-maturing 95Y01 generally yielded greater at most locations due to overall atypical rainfall which promoted 95Y01 response to increased seeding rates. The overarching trend with later-maturing 95Y20 was the low seeding rate consistently maintained seed yield and additional seed ha^{-1} was not required. Again, plant populations were greater for 3 out of 6 locations for 95Y20, which may have overstated later-maturing 95Y20's response to low seeding rates. Norsworthy and Frederick (2002) emphasized in drought stress free periods, soybean seeding rates can be reduced while still maintaining seed yield.

Plant height at V4 responded to seeding rate or interaction involving seeding rate at all 6 locations. Similarly, Chen and Wiatrak (2011a) observed increased plant height response to increasing seeding rates in full season soybean for 2 out of 3 locations for MG IV and 3 out of 3 locations for MG V. Most of the interactions involving seeding rates have already been discussed in the cultivar section; however seeding rate, inoculant, and N affected V4 plant height at both MTH12 and WAR13. At MTH12, N application generally increased V4 plant height at both the low and high seeding rates regardless of inoculant (Table 2.5.12). However, the only significant difference observed was when N was not applied to the low seeding rate and inoculant was used. This combination resulted in decreased plant height by 8%, compared to no inoculant use. Similar response was not observed with the high seeding rate. Inoculant application was not as important to V4 plant height as was N. At WAR13, N increased V4 plant height for all observations, regardless of plant population. When N was applied to the high seeding rate/inoculant, plant height increased by 8%, from 46.5- to 50.5-cm, compared to no N/high seeding rate/no inoculant (Table 2.5.12). Furthermore, when N was applied to the high seeding rate/inoculant, V4 soybean produced 9% greater height compared to the same treatment combination, but with only N removed (50.5 vs. 46.0-cm, respectively). Without N, the high plant population (451,000 plants ha^{-1}) generally increased soybean height compared to the low plant population of 415,000 plants ha^{-1}. Application of N provided greater V4 plant height response at both MTH12 and WAR13 compared to inoculant.

At SUF12, seeding rate acted independently and affected V4 plant height. The high plant population at SUF12 was 402,000 plants ha^{-1} and increased V4 plant height by 4% compared to the low plant population of 356,000 plants ha^{-1} (39.5- vs. 38.0-cm, respectively) (Table 2.4). In comparison, Devlin et al. (1995) examined soybean seeding rates ranging from 129,000 to 646,000 seed ha^{-1} with dryland conditions in Kansas, and concluded when soil moisture was adequate, increasing seeding rate increased plant height; when soil moisture was low, increasing seeding rate did not affect plant height. Different from our observations, Cox and Cherney (2011) investigated seeding rates ranging from a low of 321,000 to a high of 469,000 seed ha^{-1} and reported that plant height did not respond to seeding rate.

Seeding rate or interactions involving seeding rate did not affect TNU collected at V4 at any of our locations. In contrast, canopy NDVI collected from V4 soybean responded to seeding rate or interactions involving seeding rate at all three locations in 2013. Interactions involving seeding rate and cultivar or inoculant were discussed earlier in the cultivar section; however V4 NDVI responded to seeding rate independently at WAR13. The high plant population of 451,000 plants ha^{-1} increased V4 NDVI from 0.8239 to 0.8369 (+2%), compared to the low soybean population of 415,000 plants ha^{-1} (Table 2.4). Substantial NDVI may have been lost at V4 due to not attaining our desired high population of 545,000 plants ha^{-1}. Greater early-season growth partially accomplished through increased seeding rates was a component to our objective and the author feels we did not adequately meet that due to plant populations that were almost 100,000 plants ha^{-1} lower than desired.

Canopy NDVI at R3 was influenced by seeding rate or interactions containing seeding rate at all three 2013 locations. Of the five interactions, four have previously been discussed in the cultivar section; however, at WAR13, R3 NDVI responded to the combination of seeding rate, inoculant, and N. At WAR13, R3 NDVI values did not vary greatly and ranged from 0.8693 to 0.8835 (Table 2.5.12). Generally, N application increased NDVI compared to no N.

The only significant difference between treatments was observed when no N/low seeding rate/no inoculant decreased R3 NDVI from 0.8802 to 0.8693, compared to the same treatment combination, but with inoculant. A similar response with N application was not observed. Inoculant benefited R3 NDVI only when the low seeding rate was planted without N.

Total N uptake at R5 acted similarly to TNU at V4 and did not respond to seeding rate or interactions involving seeding rate at any location in 2012 or 2013. Canopy NDVI at R5 was influenced by seeding rate or interaction containing seeding rate at all locations. Interactions involving seeding rate were previously discussed with cultivar; however, seeding rate interactions not containing cultivar at MTH12, PTR12, SUF12, WAR13, and PTR13 will now be discussed. Canopy NDVI at R5 responded to seeding rate and N at both PTR12 and PTR13. At PTR12, N applied to the high plant population of 445,000 plants ha^{-1} marginally increased NDVI values at R5, compared to no N, but was not significant at P=0.05 (P=0.1269) (Table 2.5.13). Nitrogen applied to the low plant population of 400,000 plants ha^{-1} marginally decreased R5 NDVI. The following year at PTR13, seeding rate and N also affected R5 NDVI. Both the low and high plant populations produced leaf area with similar R5 NDVI values when N was applied at planting (Table 2.5.13). However, when N was not applied at planting, the plant population of 242,000 plants ha^{-1} produced greater NDVI, compared to the low population of 211,000 plants ha^{-1}. Both plant populations at PTR13 were reduced due to poor emergence. Furthermore, the application of N at planting appeared to assist the low seeding rate; however, canopy closure was not consistently attained at PTR13 with either plant population.

Seeding rate and inoculant affected R5 NDVI at both SUF12 and WAR13. At SUF12, the low plant population of 356,000 plants ha^{-1} did not benefit from the addition of inoculant to seed at planting. In contrast, the high plant population, which contained 402,000 plants ha^{-1}

increased R5 NDVI values from 0.9087 to 0.9129 when inoculant was used (Table 2.5.11). The same factors influenced R5 NDVI at WAR13 where values ranged from 0.8883 to 0.8972 (Table 2.5.11). The low plant population, without inoculant, produced leaf area that had greater R5 NDVI values than the high plant population, without inoculant, but was not greater than either the low or high plant populations that received inoculant at WAR13. Inoculant benefited the high plant population at WAR13, but was not as critical to mid-season NDVI values with the low plant population.

At MTH12, R5 NDVI responded to seeding rate and fungicide. Application of fungicide to 346,000 plants ha^{-1} (low population) did not improve NDVI values at R5 compared to no fungicide (0.9179 vs. 0.9121, respectively) (Table 2.5.14). In contrast, applying fungicide to 387,000 plants ha^{-1} (high population) decreased NDVI from 0.9188 to 0.9106. These data demonstrate how fungicide did not improve seed yield at MTH12 due to the lack of canopy closure, expressed in this example as reduced NDVI.

Seed weight was affected by seeding rate or interactions involving seeding rate at all 6 locations. All but one of the interactions containing seeding rate have been discussed previously with cultivar. At PTR12, seeding rate, N, and fungicide influenced 100 seed weight. When N was withheld from both the low and high seeding rates at planting, seed weight values for the low and high plant populations (400,000 and 445,000 plants ha^{-1}, respectively) at harvest were similar. In contrast, when N was applied to the high plant population fungicide increased seed weight by 3%, from 16.9 to 17.5 g 100 seed^{-1}, respectively, compared to no fungicide (Table 2.5.15). However, when N was applied to the low seeding rate, differences between plant populations and fungicide treatments were not observed. Generally, at PTR12, plant populations or N were not responsible for increased seed weight, rather fungicide critically influenced seed mass, which is linked to seed yield (Pedersen and Lauer, 2004). The lack of seed weight differences at PTR12 for plant population can partially be attributed to both populations being less than desired. Specifically, our desired high soybean population was 545,000 plants ha^{-1} and we obtained 445,000 plants ha^{-1} at PTR12. Reducing our plant ha^{-1} weakened our overall ability to examine seeding rates and subsequent plant populations that are spaced 100,000 plants ha^{-1} apart and reduced our ability to properly investigate plant populations' effects on seed production.

Inoculant

Soybean yield responded to inoculant or interactions involving inoculant at 4 out of 6 locations. All but one interaction containing inoculant have been discussed with either cultivar or seeding rate. At PTR13, inoculant and fungicide influenced seed yield. When inoculant was applied to the seed prior to planting and sprayed with fungicide at PTR13, seed yield values were similar, compared to no fungicide (3002 vs. 3070 kg ha^{-1}, respectively) (Table 2.5.16). In contrast, when inoculant was not used, fungicide increased PTR13 seed yield by 252 kg ha^{-1} (+8%), compared to no fungicide. Fungicide application independently increased seed yield at PTR13. Overall, across locations, inoculant performed inconsistently, but was observed to provide a yield additive effect in limited instances.

Inoculant and interactions involving inoculant application affected pre-pod-fill stage measurements V4 plant height, TNU, and NDVI, and R3 NDVI at 4 of 6, 2 of 6, 1 of 3, and 2 of 3 locations. Inoculant did not independently influence pre-pod-fill measurements; rather interactions were responsible for effects and have been previously mentioned in the cultivar and seeding rate discussions. Mid-season measurements R5 TNU and NDVI were influenced by inoculant at 1 of 3 and 6 of 6 locations. Cultivar and inoculant influenced R5 TNU at MTH12 and was discussed with cultivar. Furthermore, all but one interaction containing inoculant affecting R5 NDVI have been discussed. At SUF13, inoculant and fungicide influenced canopy NDVI at R5. Values of NDVI ranged from 0.8934 to 0.9015 at SUF13 (Table 2.5.16). Generally, fungicide and inoculant increased NDVI together; however inoculant did not independently increase NDVI values. Fungicide increased NDVI with all observations at SUF13. Specifically, soybean treated with fungicide and inoculant exhibited NDVI values of 0.9015; when inoculant was removed, NDVI lowered to 0.8997 but was not significantly different at P=0.05. Soybean with fungicide/inoculant exhibited greater NDVI than the remaining two observations, no fungicide/no inoculant and no fungicide/inoculant. Fungicide improved R5 NDVI dynamics and was more critical than inoculant.

Seed weight responded to inoculant application or interactions containing inoculant at 4 of 6 locations and has been previously discussed in cultivar and seeding rate sections. Inoculant did not independently affect soybean growth, N uptake, or seed yield. In contrast, inoculant was observed to assist other factors in improving crop growth and yield, but was very site-specific and difficult to accurately predict. Seed quality was influenced by inoculant independently and by an interaction between inoculant and fungicide; however, in both cases, inoculant did not improve seed quality and differences were minimal. Previous research by Abendroth and Elmore (2006) and Pedersen (2004) recommended inoculant application if the field was flooded, had a non-optimal pH, was low in soil organic matter, or had a coarse textured soil. Our sandy coastal plain soils in the Mid-Atlantic account for at least two of those criteria - low soil organic matter and coarse texture. Similarly, Mastrodomenico and Purcell (2012) demonstrated that soybean nutrition on soils with low organic matter and low N fertility can be critically controlled by N_2 fixation. Furthermore, when soybean is grown on a soil not previously planted to soybean, inoculation is recommended to ensure symbiotic N_2 fixation and to encourage *Bradyrhizobia japonicum* bacteria population establishment (De Bruin et al., 2010; Furseth et al., 2012; Schulz and Thelen, 2008). However, as demonstrated in our experiments, inoculant response continues to be difficult to predict and needs to be validated in different soil moisture regimes that are utilized in double-crop soybean.

Starter N

Seed yield responded to N application at 2 of 6 locations, which included PTR12 and SUF12 and have been previously discussed with cultivar. Soil NH_4/NO_3 values were 0.85/0.09 and 1.0/0.36 kg ha^{-1} for PTR12 and SUF12, respectively (Appendix B). The soil-N values at PTR12 were the lowest of all locations, whereas SUF12 was the third lowest, after PTR12 and PTR13. Soybean yield response to N can partially be attributed to decreased soil-N and our locations all had relatively low soil-N values. Increased response to N would be expected at most locations due to relatively low soil-N values at all locations (Lamb et al., 1990; Scharf and Wiebold, 2003); however we observed response to N at only two locations. At PTR12, without N, 95Y01 yielded 7% more than 95Y20 without N; however N increased 95Y20 yield by 4%. At SUF12, N applied to the treatment combination 95Y20/low seeding rate/inoculant yielded 4658 kg ha^{-1} and was greater than 6 of the 16 observations. In comparison, Osborne and Riedell (2006) applied 16 kg N ha^{-1} and increased yield two of three years. Similarly, Pikul et al. (2001) increased soybean yield in 9 out of 11 years in the northern Great Plains with <15 kg N ha^{-1} applied as starter N. In southern Alabama, Starling et al. (2000) increased yield by 9% with 50 kg N ha^{-1} applied at planting. Also on coastal plain soils, Taylor et al. (2005) maximized soybean yield with 60 to 70 kg N ha^{-1} broadcast applied immediately after planting. Our yield response to N was limited but it did demonstrate that N may be applicable to double-crop soybean but is very site-specific and not predictive.

Pre-pod-fill measurements V4 plant height, TNU, and NDVI and R3 NDVI demonstrated N's ability to increase soybean growth and NDVI values by responding to N at 5 of 6, 2 of 6, 2 of 3, and 3 of 3 locations, respectively. Interactions involving N for V4 plant height and R3 NDVI have already been discussed with other factors; however, N independently affected both V4 TNU and NDVI. At WAR13, N application's effect on V4 TNU was not significant at P=0.05 (P=0.1177); however, N marginally affected TNU at V4 by producing 59 kg N ha^{-1} for soybean uptake and increased values by 27%, compared to no N (Table 2.4). Also at WAR13, N independently affected canopy health by increasing V4 NDVI values from 0.8166 to 0.8441 with N, compared to untreated (Table 2.4). At PTR13, N continued the trend of increasing V4 NDVI and values were 8% greater with N, compared to untreated (0.6655 vs. 0.6144, respectively) (Table 2.4). In comparison with our results, Osborne and Riedell (2006) attributed increased yield to increased early plant biomass and plant N concentration both at V3-V4. Furthermore, Ma et al. (2001) emphasized that plant NDVI during pod set was closely correlated with soybean yield.

Mid-season soybean measurement R5 TNU and NDVI were influenced by N application at 1 of 3 and 4 of 6 locations, respectively. Soybean R5 TNU at WAR13 was marginally affected by N, but was not significant at P=0.05 (P=0.2561). Total N uptake increased from 148 to 187 kg N ha^{-1} when N was applied, compared to untreated (Table 2.4). Starter N applied at WAR13 also positively affected V4 plant height, TNU, and NDVI, which were discussed previously. Soil-N at WAR13 was 1.9 and 1.1 kg ha^{-1} for NH_4 and NO_3, respectively, which could partially explain early-season soybean uptake response to N. In addition, soybean growth and canopy closure were accelerated at WAR due to large and timely rainfall events during June and July, which continued into August.

Starter N affected R5 NDVI by marginally interacting with fungicide at SUF13, but was not significant at P=0.05 (P=0.1118). When both N and fungicide were applied, R5 NDVI was 0.9002 and was similar to treatment combinations no N/fungicide (0.9010) and no N/no fungicide (0.8979). However, when fungicide was removed from both treated factors, NDVI decreased to 0.8920 and was significantly lower than the remaining three treatments. Therefore, at SUF13, fungicide was more critical to improve canopy NDVI at R5 compared to N. The remaining interactions involving N affecting R5 NDVI were previously discussed with cultivar, seeding rate, or inoculant.

Seed weight was influenced by N or interactions containing N at 6 of 6 locations. All interactions have already been discussed with the other agronomic factors. However, at SUF12, N independently affected 100 seed weight by increasing values from 16.7 to 17.0 g, compared to the untreated check (Table 2.4). Similarly, N increased seed yield at SUF12; these data demonstrate how yield increase with N at SUF12 was accomplished through increased seed mass. Applying N at planting generally increased early-season vegetative growth parameters and occasionally increased mid-season growth but did not consistently increase seed yield across locations.

Foliar Fungicide

Fungicide or interactions involving fungicide influenced soybean yield at 5 out of 6 locations. All interactions containing fungicide have been previously discussed with cultivar, seeding rate, inoculant, or N. One observation that has not been discussed is SUF13, where fungicide independently affected seed yield. Fungicide applied at R3 and R5 increased seed yield by 309 kg ha^{-1}, compared to no fungicide (5378 vs. 5069 kg ha^{-1}, respectively) (Table 2.4). At each location where fungicide influenced seed yield, a positive yield response was observed and can partially be attributed to soybean disease control. All five locations had considerable mid-to-late-season disease that limited yield in untreated soybean (Dillon et al. Chapter V). The one location where fungicide did not improve yield dynamics was MTH12, where fungal disease was present; however leaf area was not maximized and canopy never fully closed. Foliar fungicide was reported by Phipps et al. (2010) to increase soybean seed yield produced in southeastern Virginia. Fungicide generally increased yield for both 95Y01 and 95Y20; however the observed increase was controlled by maturity differences, cultivar adaptability to location, cultivar disease susceptibility, and rainfall timing during sensitive and critical pod-fill stages. Inoculant and N promoted yield increase associated with fungicide at specific sites, yet performed inconsistently when examined across locations.

Canopy R5 NDVI was affected by fungicide and interactions involving fungicide at 5 of 6 locations. All interactions containing fungicide's effect on R5 NDVI have previously been discussed; however, fungicide independently affected R5 NDVI at PTR12, SUF12, and WAR13. Fungicide marginally decreased R5 NDVI at both PTR12 and SUF12 from 0.9064 to 0.9038 and 0.9128 to 0.9106, respectively, compared to untreated, but were not significant at $P=0.05$ ($P=0.1153$ and 0.0915, respectively) (Table 2.4). These data are very similar in value and may be attributed to soybean canopy variability and full canopy closure at R5 for both PTR12 and SUF12. In contrast, at WAR13, fungicide increased R5 NDVI from 0.8880 to 0.8978, compared to no fungicide (Table 2.4).

Fungicide or interactions involving fungicide influenced seed weight at all locations. All fungicide interactions have been discussed previously; however at SUF12, fungicide independently affected seed weight. Fungicide increased seed weight by 3%, increasing values from 16.6 to 17.1 g 100 seed^{-1}, compared to no fungicide treatment (Table 2.4). In our experiments, fungicide was primarily responsible for increasing seed yield through increased seed mass. These data show that seed weight was not drastically increased at each location, but fungicide consistently improved seed yield through greater seed weight. Our experiments were conducted during growing seasons characterized as atypical for double-crop due to overall increased and timely rainfall at most locations. Furthermore, fungal disease infected the soybean canopy and accelerated through mid- into late-season and can partially explain greater seed weight associated with foliar fungicide application, which reduced disease severity and maintained leaf area for light interception, photosynthesis, and nutrient translocation for seed-fill.

Conclusion

Our experiments demonstrated that early-season growth and yield parameters were primarily controlled by rainfall and water availability. While results were site-specific, general trends were observed with these data. Early-maturing indeterminate 95Y01 matured 7 to 10 days earlier than later-maturing determinate 95Y20 and affected all growth and yield parameters due to the ability of early-maturing 95Y01 to outperform 95Y20 in high yield potential environments. In addition, the earlier-maturity allowed 95Y01 to avoid drought stress in September, 2013 that reduced 95Y20 pod-fill and yield. Early-maturing indeterminate 95Y01 increased TNU, mirrored in NDVI values and influenced seed yield with greater seed mass. Yield potential lost by 95Y20 can partially be attributed to decreased seed mass. However, 95Y20 was responsive to early season growth and dry matter production. Furthermore, later-maturing determinate cultivars are important to double-crop in Virginia due to increased leaf area and potentially stable yield across changing soil moisture regimes.

Later-maturing determinate 95Y20 consistently responded to the recommended seeding rate (593,000 seed ha^{-1}) with a stable, yet productive yield. We feel the partial objective of examining increased seeding rate's effect on growth and yield was not fully accomplished due to desired low, but especially high plant populations not being obtained. However, we were able to conclude that the current seeding rate recommendations need to be maintained and further research should investigate the unique ability of soybean to compensate with increased branches at reduced plant population in coastal plain soils.

When drought stress was prominent, starter N was not as important to growth or yield; rather, the application generally inhibited yield. If soil moisture was adequate at planting, positive early-season growth response was exhibited with plant height, TNU and NDVI. Overall, N's applicability to double-crop was more important early-season compared to mid- and late-season. If a cultivar was less adapted due to latitude and relative maturity, N application was observed to improve cultivar competiveness and productivity, expressed in yield. However in this example, if we had matched the relative maturity with location, N's usefulness may have been limited due to proper cultivar selection. Inoculant performance varied and was generally difficult to accurately predict.

Foliar fungicide was a valuable factor within our experiments and had the greatest potential to increase yield through seed mass and leaf area integrity if environmental conditions were ideal for soybean disease development. In contrast, fungicide did not consistently improve seed quality or reduce purple seed stain, primarily attributed to cultivar susceptibility (data not shown). Our research demonstrated that fungicide application did not always result in a positive return on investment. Cultivars were observed to interact with fungicide and at specific locations, did not respond similarly. Further research is needed to examine fungicide timing and specific interaction with soybean canopy and disease dynamics.

Producing double-crop soybean can be difficult due to typically reduced rainfall throughout the growing season, which inhibits photosynthesis and transpiration, through increased stomata closure. Due to the control rainfall places on our system, intensified management must be promoted to increase productivity and profitability. Excellent yield potential exists but in order to be achieved, double-crop soybean should be treated similar to full-season to maximize yield. Double-crop soybean vegetative growth and yield response to intensive management was achieved; however, our experiments demonstrated the greatest growth or yield response often occurred with single inputs or inputs combined that fit a site-specific need that did not require all inputs at once. Furthermore, the associated cost of adopting increased seeding rates, inoculant, N, and foliar fungicide in entirety is expensive and is not realistic to expect farmers to do so. Rather, site-specific management examining how seed yield is produced or compensated for at the plant and seed level is needed to assist farmers in making sound agronomic decisions in double-crop soybean production.

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Table 2.1 Site physical characteristics for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Site-Year	Soil Series and Texture †	Soil Classification †	Latitude	Longitude
MTH12	State fine sandy loam	Fine-loamy, mixed, semiactive, thermic Typic Hapludults	38°5'0.16"N	76°42'39.49"W
PTR12	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF12	Nansemond loamy fine sand	Fine-loamy, siliceous, semiactive, thermic Aquic Hapludults	36°40'1.86"N	76°43'41.61"W
WAR13	Kempsville loam	Fine-loamy, siliceous, subactive, thermic Typic Hapludults	37°59'24.22"N	76°46'29.48"W
PTR13	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF13	Dragston fine sandy loam	Coarse-loamy, mixed, semiactive, thermic Aeric Endoaquults	36°41'1.66"N	76°45'39.85"W

† USDA-NRCS web soil survey (WSS, 2014).

Table 2.2 Calendar dates for agronomic inputs, data collection, and developmental stages for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Site-Year					
Agronomic Input	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Planting	6/20	6/28	6/21	7/8	7/15	6/20
Stand counts	7/10	7/18	7/11	7/23	7/30	7/9
V4 plant height †	7/31	8/7	7/23	8/6	8/12	7/24
V4 plant tissue	7/31	8/7	7/23	8/6	8/12	7/24
V4 NDVI	-	-	-	8/6	8/12	7/24
R3 fungicide app.	8/24	8/29	8/21	8/27	9/6	8/20
R3 NDVI	-	-	-	8/27	9/6	8/21
R5 fungicide app.	9/5	9/10	9/6	9/17	9/24	9/4
R5 plant tissue	9/5	9/10	9/4	9/17	9/24	9/4
R5 NDVI	9/5	9/10	9/10	9/17	9/24	9/4
R8 plant height	-	-	-	12/4	11/25	10/17
Yield component	11/12	11/6	11/5	12/4	12/12	11/12
Harvest	11/20	11/29	11/28	12/4	12/17	12/3
Growth stage †						
V2	7/10	7/18	7/11	7/26	8/2	7/9
V3	7/19	7/25	7/16	7/30	8/5	7/16
V4	7/31	8/7	7/20	8/2	8/8	7/19
R2	8/14	8/20	8/8	8/20	8/28	8/9
R3	8/24	8/29	8/21	8/27	9/6	8/17
R4	8/30	9/3	8/30	9/8	9/13	8/23
R5	9/5	9/10	9/6	9/17	9/24	9/4
R6	9/20	9/25	9/19	9/26	10/2	9/18
R7	10/19	10/24	10/18	10/22	10/30	10/6
R8	11/12	11/6	11/5	11/25	11/25	10/24

† Soybean growth and development stages as described by Fehr and Caviness (1977).

Table 2.3 Air temperature and precipitation for 2012 and 2013 agronomic input experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Site-Year					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Temperature	--------------------------------°C----------------------------------					
May	21	21	21	20	19	19
June	23	23	23	24	24	24
July	28	28	27	26	26	26
August	26	25	25	23	23	24
September	21	22	21	20	21	20
October	16	17	16	16	17	17
November	7	8	7	8	9	9
Mean	20	21	20	20	20	20
May-Nov.	(20)†	(20)	(21)	(20)	(20)	(21)
Precipitation	---------------------------------mm---------------------------------					
May	67	64	204	55	42	91
June	13	103	157	194	179	206
July	30	123	120	158	84	88
August	141	246	204	95	100	164
September	69	55	92	26	46	51
October	191	252	208	76	96	115
November	12	21	18	75	61	88
Total	524	864	1003	679	608	803
May-Nov.	(710)†	(692)	(768)	(710)	(692)	(768)

† 29 year May-Nov. mean in parenthesis.

Table 2.4 Main effect cultivar (C), seeding rate (S), nitrogen (N), inoculant (I), and fungicide (F) influenced soybean growth and yield parameters for 2012 and 2013 agronomic input experiments.

	Site-Year					
	MTH12	**PTR12**	**SUF12**	**WAR13**	**PTR13**	**SUF13**
C £	----------Seed yield (kg ha^{-1})----------					
P95Y01	3651.5 a †	4491.7 a	4228.8 a	3342.5 a	3190.5 a	5331.5 a
P95Y20	3562.1 a	4339.4 b	4250.7 a	3074.1 b	2912.8 b	5116.4 b
S β						
593,000	3636.3 a	4378.7 a	4352.6 a	3222.2 a	2954.1 b	5224.9 a
725,000	3577.2 a	4452.5 a	4126.9 b	3194.3 a	3149.2 a	5223.0 a
N ‡						
With	3609.8 a	4423.0 a	4425.9 a	3196.9 a	3082.7 a	5170.8 a
Without	3603.8 a	4408.2 a	4053.6 b	3219.6 a	3020.6 a	5277.2 a
I §						
With	3660.0 a	4386.8 a	4347.0 a	3211.6 a	3036.3 a	5221.7 a
Without	3553.3 a	4444.4 a	4132.5 b	3204.9 a	3067.0 a	5226.2 a
F Φ						
With	3571.9 a	4578.7 a	4449.7 a	3330.7 a	3097.7 a	5378.5 a
Without	3641.7 a	4252.4 b	4029.7 b	3085.8 b	3005.6 a	5069.4 b
C £	----------V4 Plant height (cm)----------					
95Y01	30.4 a	55.0 a	38.1 b	47.4 a	34.3 a	47.5 a
95Y20	31.5 a	53.2 a	39.4 a	46.7 a	33.4 a	46.5 a
S β						
593,000	31.4 a	52.4 b	38.0 b	46.3 a	33.3 a	46.3 a
725,000	30.5 a	55.8 a	39.5 a	47.7 a	34.3 a	47.7 a
N ‡						
With	31.0 a	53.8 a	39.0 a	48.4 a	34.3 a	47.6 a
Without	31.0 a	54.4 a	38.5 a	45.6 b	33.3 a	46.4 a
I §						
With	30.7 a	54.3 a	38.4 a	47.1 a	33.7 a	47.5 a
Without	31.2 a	53.9 a	39.1 a	46.9 a	34.0 a	46.5 a
C £	----------V4 Total N uptake (kg ha^{-1})----------					
P95Y01	36.3 a	11.3 a	21.8 a	56.2 a	18.1 a	82.3 a
P95Y20	34.3 a	11.2 a	20.5 a	45.8 a	15.4 a	61.4 a
N ‡						
With	34.5 a	11.7 a	19.7 a	59.3 a	19.0 a	76.8 a
Without	36.1 a	10.8 a	22.5 a	42.7 a	14.5 a	66.8 a
I §						
With	34.6 a	11.2 a	21.4 a	45.9 a	16.8 a	76.4 a
Without	36.0 a	11.3 a	20.9 a	56.1 a	16.7 a	67.3 a
C £	----------V4 NDVI----------					
95Y01	- ¥	-	-	0.8382 a	0.6691 a	0.7970 a
95Y20	-	-	-	0.8225 b	0.6109 b	0.7200 b

S β	-	-	-			
593,000	-	-	-	0.8239 b	0.6195 b	0.7478 a
725,000	-	-	-	0.8369 a	0.6604 a	0.7692 a
N ‡	-	-	-			
With	-	-	-	0.8441 a	0.6655 a	0.7647 a
Without	-	-	-	0.8166 b	0.6144 b	0.7524 a
I §	-	-	-			
With	-	-	-	0.8293 a	0.6374 a	0.7605 a
Without	-	-	-	0.8315 a	0.6425 a	0.7565 a
C £	------------------------------------R3 NDVI------------------------------------					
95Y01	-	-	-	0.8828 a	0.8624 a	0.9559 a
95Y20	-	-	-	0.8717 b	0.8482 b	0.9549 a
S β	-	-	-			
593,000	-	-	-	0.8774 a	0.8459 b	0.9543 a
725,000	-	-	-	0.8770 a	0.8648 a	0.9565 a
N ‡	-	-	-			
With	-	-	-	0.8789 a	0.8589 a	0.9558 a
Without	-	-	-	0.8755 a	0.8517 a	0.9950 a
I §	-	-	-			
With	-	-	-	0.8787 a	0.8582 a	0.9552 a
Without	-	-	-	0.8757 a	0.8524 a	0.9556 a
C £	--------------------------R5 Total N uptake (kg ha^{-1})--------------------------					
P95Y01	126.6 a	46.5 a	189.0 a	177.0 a	200.2 a	258.8 a
P95Y20	107.8 a	44.5 a	148.3 a	156.3 a	186.5 a	250.6 a
N ‡						
With	115.0 a	44.8 a	176.4 a	186.7 a	184.9 a	261.8 a
Without	119.3 a	46.2 a	160.8 a	147.7 a	201.8 a	247.5 a
I §						
With	117.4 a	48.1 a	164.8 a	160.5 a	181.3 a	264.8 a
Without	117.0 a	42.9 a	172.5 a	172.8 a	205.4 a	244.5 a
C £	------------------------------------R5 NDVI------------------------------------					
95Y01	0.9142 a	0.9038 a	0.9125 a	0.8909 a	0.8542 a	0.8943 b
95Y20	0.9155 a	0.9065 a	0.9109 a	0.8949 a	0.8524 a	0.9012 a
S β						
593,000	0.9150 a	0.9048 a	0.9126 a	0.8949 a	0.8511 a	0.8965 a
725,000	0.9147 a	0.9054 a	0.9108 a	0.8909 a	0.8555 a	0.8991 a
N ‡						
With	0.9155 a	0.9051 a	0.9126 a	0.8951 a	0.8569 a	0.8961 b
Without	0.9142 a	0.9051 a	0.9108 a	0.8907 a	0.8497 a	0.8994 a
I §						
With	0.9157 a	0.9050 a	0.9125 a	0.8931 a	0.8560 a	0.8975 a
Without	0.9140 a	0.9053 a	0.9109 a	0.8928 a	0.8506 a	0.8981 a
F Φ						
With	0.9142 a	0.9038 a	0.9106 a	0.8978 a	0.8538 a	0.9006 a
Without	0.9155 a	0.9064 a	0.9128 a	0.8880 b	0.8528 a	0.8950 b

C £	-------------------------100 Seed weight (grams) -------------------------					
95Y01	16.6 a	18.6 a	18.0 a	16.2 a	17.6 a	17.3 a
95Y20	14.3 b	15.7 b	15.7 b	14.1 b	14.2 b	14.9 b
S β						
593,000	15.3 b	17.2 a	16.8 a	15.1 b	15.9 a	16.0 b
725,000	15.6 a	17.2 a	16.9 a	15.3 a	16.0 a	16.3 a
N ‡						
With	15.4 a	17.1 a	17.0 a	15.2 a	16.0 a	16.1 a
Without	15.4 a	17.3 a	16.7 b	15.2 a	15.9 a	16.2 a
I §						
With	15.4 a	17.2 a	16.9 a	15.2 a	15.9 a	16.2 a
Without	15.5 a	17.2 a	16.8 a	15.1 a	15.9 a	16.1 a
F Φ						
With	15.5 a	17.3 a	17.1 a	15.6 a	16.1 a	16.4 a
Without	15.3 b	17.1 b	16.6 b	14.8 b	15.8 b	15.9 b

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

¥ Data not collected in 2012.

β Seed ha^{-1}.

‡ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

† Means with different letter within parameter and column are significantly different based on Fisher’s Protected LSD at P (0.05).

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

Φ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

Table 2.5 Interaction between cultivar (C), seeding rate (S), inoculant (I), nitrogen (N), and fungicide (F) influenced growth and seed yield parameters for 2012 and 2013 agronomic input soybean experiments.

Table 2.5.1					Seed Yield			PTR13
					WAR13	PTR13	SUF13	R5 NDVI
C £	S β	I §	N ‡	F Φ	----------------kg ha^{-1}----------------			
P95Y01	593,000	-	-	-	3285.1 ab†	2950.6 b	5187.1 bc	0.8464 b
	725,000	-	-	-	3399.8 a	3430.3 a	5475.8 a	0.8620 a
P95Y20	593,000	-	-	-	3159.3 b	2957.5 b	5262.7 ab	0.8558 ab
	725,000	-	-	-	2988.8 c	2868.2 b	4970.2 c	0.8490 b

Table 2.5.2					SUF12
					Seed Yield
C £	S β	I §	N ‡	F Φ	---kg ha^{-1}---
P95Y01	593,000	With	With	-	4571.2 ab †
			Without	-	4013.4 bc
		Without	With	-	4476.9 abc
			Without	-	3999.1 bc
	725,000	With	With	-	4631.1 a
			Without	-	3939.5 cd
		Without	With	-	4212.5 abc
			Without	-	3986.9 bcd
P95Y20	593,000	With	With	-	4658.0 a
			Without	-	4124.8 abc
		Without	With	-	4423.4 abc
			Without	-	4553.9 ab
	725,000	With	With	-	4421.1 abc
			Without	-	4417.0 abc
		Without	With	-	4012.8 bc
			Without	-	3394.3 d

Table 2.5.3

					Seed Yield	
					SUF12	WAR13
C £	S β	I §	N ‡	F Φ	---------kg ha^{-1}---------	
P95Y01	-	With	-	With	4498.0 ab †	3540.7 a
	-		-	Without	4079.6 bc	3135.4 cd
	-	Without	-	With	4248.0 ab	3423.4 ab
	-		-	Without	4089.7 b	3270.5 bc
P95Y20	-	With	-	With	4526.0 a	3122.7 cd
	-		-	Without	4284.4 ab	3047.8 de
	-	Without	-	With	4526.9 a	3236.1 bcd
	-		-	Without	3665.3 c	2889.7 e

Table 2.5.4

					PTR12	WAR13
					Seed Yield	R3 NDVI
C £	S β	I §	N ‡	F Φ	--kg ha^{-1}--	
P95Y01	-	-	With	-	4409.6 ab †	0.8817 ab
	-	-	Without	-	4573.8 a	0.8838 a
P95Y20	-	-	With	-	4436.3 a	0.8762 b
	-	-	Without	-	4242.6 b	0.8672 c

Table 2.5.5

					PTR12	SUF13
					Seed Yield	R5 NDVI
C £	S β	I §	N ‡	F Φ	--kg ha^{-1}--	
P95Y01	-	-	-	With	4591.3 a †	0.8998 a
	-	-	-	Without	4392.2 b	0.8888 b
P95Y20	-	-	-	With	4566.1 ab	0.9014 a
	-	-	-	Without	4112.8 c	0.9011 a

Table 2.5.6

					PTR13	R5 NDVI	
					Seed Yield	MTH12	PTR13
C £	S β	I §	N ‡	F Φ	--kg ha^{-1}--		
P95Y01	-	With	-	-	3071.6 b †	0.9188 a †	0.8519 ab

	-	Without	-	-	3309.3 a	0.9095 b	0.8565 a
P95Y20	-	With	-	-	3000.9 bc	0.9126 ab	0.8601 a
	-	Without	-	-	2824.8 c	0.9184 a	0.8447 b

Table 2.5.7					V4 Plant Height		PTR13	100 Seed Weight	
					MTH12	PTR12	R3 NDVI	PTR12	PTR13
C £	S β	I §	N ‡	F Φ	------------cm------------			------g 100 seed^{-1}------	
P95Y01	593,000	-	With	-	30.2 b †	50.0 d	0.8488 b	18.2 b	17.7 a
		-	Without	-	31.5 ab	54.8 ab	0.8507 b	18.7 a	17.2 b
	725,000	-	With	-	30.5 ab	57.4 ab	0.8755 a	18.8 a	17.7 a
		-	Without	-	29.5 b	57.7 a	0.8745 a	18.7 a	17.9 a
P95Y20	593,000	-	With	-	32.8 a	54.3 abc	0.8606 ab	15.8 c	14.3 c
		-	Without	-	31.1 ab	50.4 cd	0.8223 c	15.8 c	14.2 c
	725,000	-	With	-	30.3 b	53.5 bcd	0.8506 b	15.6 c	14.3 c
		-	Without	-	31.8 ab	54.7 ab	0.8584 ab	15.8 c	14.1 c

Table 2.5.8					PTR13
					V4 Plant Height
C £	S β	I §	N ‡	F Φ	-----cm-----
P95Y01	-	With	With	-	34.5 ab †
	-		Without	-	32.2 bc
	-	Without	With	-	34.8 ab
	-		Without	-	35.5 a
P95Y20	-	With	With	-	34.0 abc
	-		Without	-	34.2 abc
	-	Without	With	-	34.0 abc
	-		Without	-	31.5 c

Table 2.5.9

					PTR13
					100 Seed Weight
C £	S β	I §	N ‡	F Φ	--g 100 seed^{-1}--
P95Y01	-	-	With	With	17.9 a †
	-	-		Without	17.4 b
	-	-	Without	With	17.5 b
	-	-		Without	17.6 ab
P95Y20	-	-	With	With	14.4 c
	-	-		Without	14.3 cd
	-	-	Without	With	14.4 c
	-	-		Without	13.9 d

Table 2.5.10

					SUF12
					Seed Yield
C £	S β	I §	N ‡	F Φ	--kg ha^{-1}--
-	593,000	With	With	With	4773.2 ab †
-				Without	4456.0 a-d
-			Without	With	4209.0 bcd
-				Without	3929.2 d
-		Without	With	With	4717.7 abc
-				Without	4182.6 bcd
-			Without	With	4359.6 a-d
-				Without	4193.3 bcd
-	725,000	With	With	With	4853.4 a
-				Without	4198.8 bcd
-			Without	With	4212.5 bcd
-				Without	4144.0 cd
-		Without	With	With	4260.0 a-d
-				Without	3965.3 d
-			Without	With	4212.4 bcd
-				Without	3168.7 e

Table 2.5.11					Seed Yield		R5 NDVI	
					MTH12	SUF12	SUF12	WAR13
C £	S β	I §	N ‡	F Φ	---------kg ha^{-1}---------			
-	593,000	With	-	-	3625.0 a †	4341.8 a	0.9121 ab †	0.8926 ab
-		Without	-	-	3647.7 a	4363.3 a	0.9131 a	0.8972 a
-	725,000	With	-	-	3695.0 a	4352.2 a	0.9129 a	0.8936 ab
-		Without	-	-	3459.5 b	3901.6 b	0.9087 b	0.8883 b

Table 2.5.12					V4 Plant Height		WAR13
					MTH12	WAR13	R3 NDVI
C £	S β	I §	N ‡	F Φ	------------cm-----------		
-	593,000	With	With	-	32.0 ab †	50.5 a	0.8768 ab
-			Without	-	30.1 bc	45.0 cd	0.8802 a
-		Without	With	-	31.0 abc	47.9 a-c	0.8835 a
-			Without	-	32.5 a	44.9 d	0.8693 b
-	725,000	With	With	-	29.3 c	46.9 b-d	0.8802 a
-			Without	-	31.3 abc	46.0 b-d	0.8777 ab
-		Without	With	-	31.5 abc	48.5 ab	0.8753 ab
-			Without	-	29.9 bc	46.5 b-d	0.8748 ab

Table 2.5.13					R5 NDVI	
C £	S β	I §	N ‡	F Φ	PTR12	PTR13
-	593,000	-	With	-	0.9036 a †	0.8589 a †
-		-	Without	-	0.9061 a	0.8432 b
-	725,000	-	With	-	0.9067 a	0.8548 a
-		-	Without	-	0.9042 a	0.8563 a

Table 2.5.14					MTH12
C £	S β	I §	N ‡	F Φ	R5 NDVI
-	593,000	-	-	With	0.9179 ab †
-		-	-	Without	0.9121 ab

-	725,000	-	-	With	0.9106 b
-		-	-	Without	0.9188 a

Table 2.5.15

					PTR12
					100 Seed Weight
C £	S β	I §	N ‡	F Φ	--g 100 seed^{-1}--
-	593,000	-	With	With	17.0 bc †
-		-		Without	17.1 bc
-		-	Without	With	17.3 ab
-		-		Without	17.2 abc
-	725,000	-	With	With	17.5 a
-		-		Without	16.9 c
-		-	Without	With	17.3 ab
-		-		Without	17.2 abc

Table 2.5.16

					PTR13	SUF13
					Seed Yield	R5 NDVI
C £	S β	I §	N ‡	F Φ	--kg ha^{-1}--	
-	-	With	-	With	3002.2 ab †	0.9015 a
-	-		-	Without	3070.4 ab	0.8934 c
-	-	Without	-	With	3193.2 a	0.8997 ab
-	-		-	Without	2940.9 b	0.8965 bc

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

β Seed ha^{-1}.

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

‡ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

Φ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within interaction and column are significantly different based on Fisher's Protected LSD at P (0.05).

CHAPTER III - DOUBLE-CROP SOYBEAN RESPONSE TO SELECTED INPUTS II: YIELD COMPONENTS

Abstract

Investigating soybean yield components can provide understanding to the effect of agronomic inputs on yield formation under different environments. Field experiments were conducted in 2012 and 2013 at locations across eastern Virginia to evaluate cultivar maturity and stem growth habit, seeding rate, seed-applied inoculant, nitrogen (N) applied at planting, and foliar fungicide on soybean yield components in a wheat-soybean double-crop system. Yield components included plant density; total dry matter (TDM); main stem and branch node, pod, and seed production; and harvest index (HI). Yield component parameters were significantly affected by environmental conditions that varied by location. The early-maturing indeterminate cultivar had greater seed yield, reproductive nodes, main stem pods and seed, and HI compared to the late-maturing determinate cultivar. The late-maturing determinate cultivar had greater branch pod, seed, and seed yield; and pods and seed per plant. Planting 593,000 seed ha^{-1} increased pods per plant from 24.8 to 29.5, compared to 725,000 seed ha^{-1}. Starter N increased reproductive nodes, pods, and TDM. Seed-applied inoculant performed inconsistently. Foliar fungicide affected several soybean yield components including nodes per plant, reproductive nodes, main stem pods and seed, branch and total seed yield, and TDM that when combined, positively influenced yield. These data have assisted in understanding yield components to more efficiently manage double-crop soybean yield potential that may be limited by the environment during critical early-to-mid-season growth and development.

Abbreviations: N, nitrogen; TDM, total dry matter; HI, harvest index.

Introduction

Approximately 50% of the soybean [*Glycine max* (L.) Merr.] produced in the Mid-Atlantic USA is grown in a double-crop system planted sequentially after a small grain, typically wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.). This results in soybean planting that is delayed past dates recommended for optimum yield potential (Wesley, 1999). Double-crop soybean yield reduction was partially attributed to reductions in crop growth rate during the period when seed number (Egli and Bruening, 2000) and seed weight (Calvino et al., 2003) are defined, and to reproductive phase duration (Egli, 2011). Rainfall, temperature, and other environmental influences on soybean production in coastal plain soils has been well documented by researchers in Maryland (Kratochvil et al., 2004), Virginia (Freeborn et al., 2001; Holshouser and Whittaker, 2002), and South Carolina (Chen and Wiatrak, 2010; Norsworthy and Frederick, 2002).

Yield components were reported by Egli (1998) as morphological characteristics whose formation was critical to yield production. Similarly, Kahlon et al. (2011) described yield components as the vehicle through which dry matter increases influence yield. Specifically, Loomis and Connor (1992) partially attributed yield to the percentage of dry matter transferred to the seed (harvest index). The effects of environmental factors on yield were partially controlled by growth dynamic x yield component interactions (Kahlon et al., 2011). Loomis and Connor (1992) summarized growth dynamic parameters as rates and levels of dry matter, leaf area, and light interception that characterized soybean’s seasonal growing pattern.

Board and Modali (2005) found that dry matter accumulation influenced yield by control of seed per m^2, pod per m^2, reproductive nodes per m^2, and node per m^2. In contrast, seed size, seed per pod, pods per reproductive node, and percent reproductive nodes did not directly affect yield formation (Board and Modali, 2005). Yield increases attributed to greater seed number were reported for Midwestern U.S. (DeBruin and Pedersen, 2009), Chinese (Liu et al., 2005), Indian (Lal and Haque, 1971), and Canadian cultivars (Morrison et al., 2000), while Specht and Williams (1984) and Cui and Yu (2005) reported greater importance of seed size (U.S. and Chinese cultivars, respectively). DeBruin and Pedersen (2009) found that seed per pod helped explain greater seed per m^2 in new vs. old Midwestern U.S. cultivars. Pod per plant was determined by Boerma (1979) and Frederick et al. (1991) to explain minimal yield improvement shown by southern and Midwestern U.S. cultivars, respectively. Kahlon et al. (2011) compared southern U.S. soybean germplasm and reported that yield was linearly correlated with seed per m^2 ($R^2 = 0.84$), pod per m^2 ($R^2 = 0.78$), reproductive node per m^2 ($R^2 = 0.53$), and node per m^2 ($R^2 = 0.46$). The authors also determined that seed size, seed per pod, pods per reproductive node, and percent reproductive node minimally affected yield formation. Kahlon et al. (2011) grouped yield components as primary, secondary, tertiary, and quaternary (Figure 3.1). In their analysis, the primary level included seed size and seed per m^2; whereas, seed per pod and pod per m^2 were considered within the secondary level. The tertiary level contained pods per reproductive node and reproductive nodes per m^2. The remaining level, quaternary consisted of nodes per m^2 and percent reproductive nodes. Robinson et al. (2013) examined herbicide drift on soybean yield components and determined that number of main stem nodes per m^2, main stem reproductive nodes per m^2, pods per m^2 and seed m^2 were most affected. Seed weight, seeds per pod, pods per reproductive node, and percent reproductive node were controlled more by cultivar genetics (Robinson et al., 2013).

Maturity group (MG) IV and MG V cultivars, and subsequently indeterminate and determinate growth habits, are used in the Early Soybean Production System developed in the

Mid-South (Heatherly et al., 1999) and in full-season and double-crop soybean systems in the Mid-Atlantic. Most MG IV cultivars are classified as indeterminate, where the main stem continues to grow into the reproductive stages. Most MG V cultivars are classified as determinate, where main stem growth is terminated soon after flower initiation. Time of cultivar stem termination influences reproductive stage duration (Edwards and Purcell, 2005) and main stem node production (Egli and Leggett, 1973). Ouattara and Weaver (1994) observed indeterminate lines were taller and increased main stem nodes at maturity compared to determinate lines of the same maturity. Heatherly and Smith (2004) reported late MG IV indeterminate cultivars had greater final height and node number at stem termination date compared to late MG V determinate cultivars. In contrast, determinate cultivars may have greater branch number (Beaver et al., 1985; Gai et al., 1984), branch dry matter (Beaver et al., 1985), and branch nodes (Gai et al., 1984) compared to indeterminate cultivars. Board and Kahlon (2013) determined that if cultivars were produced in the same environment, branch development typically increased with increasing maturity.

Soybean's unique ability to compensate for reduced plant population via increased yield plant^{-1} has been documented (Board and Kahlon, 2013; Board et al., 1999; Carpenter and Board, 1997) and linked to cultivar selection and environmental conditions (Norsworthy and Frederick, 2002). Chen and Wiatrak (2011) observed full-season MG IV and V cultivars to have 74-87 and 59-78% emergence, respectively. The sandy soils of the Mid-Atlantic coastal plain can be drought prone. Due to delayed planting and inadequate leaf area development that leads to reduced yield, seeding rate recommendations are greater for double-crop than full-season.

The ability to fix nitrogen (N) is critical on soils dominated by low organic matter and low N fertility (Mastrodomenico and Purcell, 2012). Inoculant use has become increasingly popular due to improved inoculant technology, relatively low product cost, ease of application, and increased input costs associated with nutrient management (De Bruin et al., 2010). However, inoculants have inconsistently affected yield where soybean was previously grown (De Bruin et al., 2010; Furseth et al., 2011, 2012; Schulz and Thelen, 2008). Similar to inoculant response, soybean response to N fertilization has been inconsistent and has been partially attributed to the residual NO_3-N content in the soil (Seneviratne et al., 2000; Weber, 1966). Starling et al. (2000) and Taylor et al. (2005) reported that starter N applied in relatively small amounts at planting may be a viable option for late-planted environments with shortened growing seasons.

Due to Virginia's geographical location, a mixture of diseases prevalent in northern or southern states can be present and potentially problematic. Soybean in Virginia is susceptible to several diseases that can reduce yield (Mehl and Phipps, 2013; Phipps et al., 2010). Soybean farmers have traditionally managed late-season diseases with fungicides (Levy, 2005; Miles et al., 2003, 2007; Yorinori et al., 2005) and cultural practices (Schneider et al., 2007). Swoboda and Pedersen (2009) applied a strobilurin fungicide to soybean in Iowa at R3 (beginning pod, Fehr and Caviness, 1977) and R5 (beginning seed, Fehr and Caviness, 1977) and reduced the number of nodes on soybean main stem by 0.6 and 0.9 nodes plant^{-1}, respectively. Whereas, Henry et al. (2011) demonstrated that pyraclostrobin fungicide did not affect seed per pod, pod per m^2, and nodes per plant when applied to soybean grown in Indiana. Kumudini et al. (2008) reported that soybean disease, if left untreated, reduced harvest index to levels lower than the untreated control and was attributed to defoliation expressed as reduced seed number and mass.

Maximizing production and profitability is the goal of wheat-soybean double-crop farmers. Even so, there is yield risk associated with double-crop soybean. Reduced double-crop soybean yield is primarily due to delayed planting that result in inadequate leaf area and shorter growth duration. In addition, less soil moisture after the wheat crop, lower plant-available nutrient levels due to wheat uptake, greater air and soil temperatures during vegetative development stages, and increased disease pressure during pod and seed development may also affect growth and yield. A single yield component is not usually solely responsible for seed yield; rather, multiple plant and seed parameters interact to affect yield. When environmental factors limit double-crop soybean yield, this is partially accomplished through influencing yield components' efficiency and potential. Therefore it is necessary to build on previous research conducted examining yield component in soybean but focus on how Mid-Atlantic farmers can manage double-crop soybean grown on drought-stressed dryland coastal plain soils and promote optimum yield component contribution to seed yield. We hypothesized that selected combination of inputs (intensive management) provide the greatest, but not necessarily the most consistent increase in yield component productivity, and that the response to these inputs are influenced by environmental conditions and subsequent yield potential. Therefore the study objective was to evaluate cultivar stem growth habit, seeding rate, seed-applied inoculant, starter N applied at planting, and foliar fungicide application on soybean yield components grown in a wheat-soybean double-crop system.

Materials and Methods

Site Description and Cultural Practices

Field experiments were conducted in 2012 and 2013 in a wheat-soybean double-crop system at locations chosen to represent the major soybean producing regions of eastern Virginia, which is dominated by sandy coastal plain soils (Table 3.1). Although soybean was the focus of this study, the winter wheat component of the system was grown in an intensively managed production setting typical of the Mid-Atlantic USA. Winter wheat management background information for study locations can be found in Appendix A and were managed according to Extension recommendations (Alley et al., 2009; Anonymous, 2005; Hagood and Herbert, 2012). Please refer to Dillon et al. (in press, Chapter II) for detailed information regarding soil sampling, soil nutrient levels, planting, plot size, and plot management information. Relevant agronomic events and measurements are listed in Table 3.2.

Experimental Design

Experiments were conducted as a split-split plot design replicated four times. Five factors, each with two levels, were tested and included: foliar fungicide (untreated or disease free management); soybean cultivar (indeterminate or determinate); seeding rate (593,000 or 725,000 seed ha^{-1}); seed-applied liquid inoculant (untreated or with *Bradyrhizobia japonicum*); and starter N [0 or 31.4 kg N ha^{-1} 32% urea ammonium nitrate (UAN) solution application at planting (32-0-0 N-P-K, 320 g N kg fertilizer^{-1})]. Foliar fungicide served as the main plot to allow for application ease and accuracy, starter N was chosen as the sub plot to avoid application stoppage between plots within each replication, and sub-sub plot was a 2^3 factorial arrangement of treatments consisting of the three remaining factors. Cultivars tested were Pioneer (Pioneer Hi-Bred Int., Inc., Johnston, IA) 95Y01 indeterminate or 95Y20 determinate soybean cultivars. The original goal was to compare a determinate vs. indeterminate cultivar of similar maturity. Cultivar 95Y01 is listed by the company as an indeterminate early-MG V, but matured 7 to 10 days earlier than 95Y20, which is also listed as determinate early-MG V. Therefore, 95Y01 and 95Y20 will hereafter be referred to as early- and late-maturing cultivars, respectively. Consult Appendix B for cultivar agronomic characteristics and Dillon et al (in press, Chapter II) for detailed timing, placement, and application descriptions of factors utilized.

Data Collection

Yield components were collected at R8 (full maturity, Fehr and Caviness, 1977) (Table 3.2). Whole soybean plants from 1 m of row were cut at the soil surface by hand from three replications and weighed to determine total fresh weight. Plants were counted and data converted to plants per m^2. Main stem length for each plant was measured from the base to the top of the plant, and the number of branches (with pods), nodes (starting at first node above unifoliate scars and ending at node at the top of the plant), and reproductive nodes (nodes with pods) were determined. Main stem and branch pods were counted, removed from the plant, and placed in separate bags for later processing and measurements. All biomass was oven-dried at 60°C for 48 to 72 h until a constant weight was obtained and weighed. Seed were removed from pods with a small-bundle thresher, weighed, and counted.

The following yield component parameters were calculated: % reproductive nodes per plant (reproductive node number / total node number); pods per reproductive node (total pods per plant / reproductive nodes per plant); main stem pods per m^2; branch pods per m^2; total pods per m^2; pods per plant (main stem pods + branch pods); main stem branch weight per m^2; main stem pod weight per m^2; branch pod weight per m^2; main stem seed per m^2; branch seed per m^2; total seed per m^2 (main stem seed + branch seed); seed per pod (total seed per m^2 / total pod per m^2); main stem seed yield (g per m^2); branch seed yield (g per m^2); total seed yield (g per m^2) (main stem seed yield + branch seed yield); total dry matter (TDM) per m^2 [(main stem and branch DM per m^2) + (main stem pod and branch pod DM per m^2) + seed yield]; seed size (seed per kg) (total seed per m^2 x 1,000) / total seed yield (g) per m^2); and harvest index (total seed yield per m^2 / TDM per m^2 x 100). For ease of discussion, we grouped our yield component parameters similar to Kahlon et al. (2011) as primary, secondary, tertiary, and quaternary, where: primary level included total seed per m^2, main stem seed per m^2, branch seed per m^2, total seed yield, main stem seed yield, branch seed yield, and seed size; secondary level included total pod per m^2, main stem pod per m^2, branch pod per m^2, and total seed per pod; tertiary level contained pods per reproductive node and reproductive nodes per m^2; and quaternary level consisted of nodes per m^2, percent reproductive nodes, and harvest index.

Statistical Analysis

Statistical analysis used PROC MIXED (SAS, 2008) to test fixed effects and interactions among fixed effects. To evaluate the significance of treatment effects on yield components, the agronomic inputs cultivar growth habit, seeding rate, inoculant, foliar fungicide, and N were considered fixed. Replicate of each treatment combination was considered a random variable in all analyses. Fisher's least significant difference test and least square means at $P < 0.05$ were used for mean separation. Location significantly affected all yield component parameters; therefore, each input's main effect and interaction between inputs response at different locations is discussed.

Results and Discussion

Environmental Conditions

During the 2012 and 2013, air temperature was close to the 29-year mean trend, whereas, rainfall varied from the mean depending on location (Table 3.3). At MTH12, rainfall was below average during June and July, which affected early-season growth and ultimately influenced seed yield due to reduced canopy closure. Increasing yield in late-planted soybean was correlated to increasing leaf area that maximizes light interception and subsequently increases biomass (Board and Harville, 1993; Wells, 1991). Furthermore, Jones et al. (2003) attributed double-crop soybean yield loss to reduced time to accumulate sufficient leaf area index, which was partially determined by soil texture and associated plant-available water. In contrast to MTH12, PTR12 and SUF12 experienced above-average rainfall throughout the 2012 growing season and the canopy quickly closed. All sites experienced near- or above-average rainfall from May through August in 2013. Timely rainfall events continued into July, resulting in good soybean growth and fast canopy closure. However, rainfall was below average during September. This dry period coincided with sensitive reproductive development stages (Table 3.2) and likely reduced yield. Lack of rainfall tends to be the limiting factor in dryland soybean production in coastal plain soils (Holshouser and Whittaker, 2002). Different locations provided different growing environments that proved valuable in this study.

Disease incidence samples were collected and examined for soybean leaf disease to better understand what pathogens were present in the soybean canopy when fungicide treatments were applied. Disease levels were greater in 2012 compared to 2013, however all locations (except MTH12) experienced close to or above mean rainfall, and subsequently increased soybean disease compared to what may be observed during drier growing conditions. For more specifics regarding disease incidence refer to Dillon et al. (in press, Chapter II). Disease levels would not be expected to be this high in drier years, however, Mehl and Phipps (2013) and Phipps and Telenko (2011) reported similar disease pressure for soybean grown in eastern Virginia.

Cultivar

Primary Level: Seed per m^2 and Seed Yield

Cultivar influenced total seed per m^2 (TS) for 3 of 6 locations (PTR12, SUF12, and PTR13). Determinate cultivar 95Y20 had 9, 13, and 17% more total seed than 95Y01, 2031 vs. 2231, 2554 vs. 2927, or 2301 vs. 2788 seed m^{-2} for PTR12, SUF12, or PTR13, respectively

(Table 3.4). Yield was significantly linearly correlated with seed per m^2 ($R^2 = 0.84$) by Kahlon et al. (2011), however our results found increased seed per m^2 with the lower-yielding 95Y20 (Table 3.4). Even with less total seed per m^2, 95Y01 yielded 200, 374, or 487 g m^{-2} more than 95Y20 at PTR12, SUF12, or PTR13, respectively. (Dillon et al. Chapter II)

Although the indeterminate 95Y01 cultivar produced less total seed, it had 23, 28, 21, 13, and 16% more main stem seed m^{-2} (MSS) than 95Y20 at MTH12, PTR12, WAR13, PTR13, and SUF13, respectively. Average seed number for 95Y20 vs. 95Y01 were 1378 vs. 1792, 1121 vs. 1562, 1324 vs. 1684, 1524 vs. 1747, and 2291 vs. 2716 seed m^{-2}, respectively. In contrast, determinate cultivar 95Y20 had 45 to 58% more branch seed m^{-2} (BRS) (364 vs. 837, 469 vs. 1110, 567 vs. 1035, 360 vs. 668, 554 vs. 1264, and 457 vs. 973 at MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, respectively).

At MTH12, seeding rate differed by cultivar by producing 979 BRS m^{-2} with 95Y20, at the low seeding rate, which was greater than all other treatment combinations (data not shown). Determinate 95Y20 responded to low seeding rate by increasing BRS by 29%, compared to the high seeding rate. Differences due to seeding rate with 95Y01 were not observed and values were less than 95Y20. Starter N and fungicide also interacted together with cultivar to affect BRS per m^2at MTH12 and SUF12. At MTH12, 95Y20 with no starter N and no fungicide produced 945 BRS m^{-2} and was greater than all other treatment combinations, except 95Y20-starter N-fungicide and 95Y20-no starter N-fungicide. When N was applied to 95Y20, fungicide slightly increased BRS; whereas, when N was not applied to the same cultivar, fungicide did not benefit BRS (data not shown). At SUF12, treatment combination no N/95Y20/no fungicide produced 1223 BRS m^{-2} and was greater than other treatments, except N/95Y20/fungicide. Cultivar 95Y20 with N increased BRS by 15% when fungicide was applied; when N was removed, and the same cultivar decreased BRS by 26% when fungicide was applied. Foliar fungicide was important to 95Y20 at MTH12 and SUF12 only when N was applied.

Treatments of N, cultivar, and inoculant also affected MTH12 BRS with combination no N/95Y20/inoculant producing 959 BRS m^{-2}, which was greater than all treatment combinations, but was no greater than N/95Y20/no inoculant (data not shown). When N was applied to 95Y20 and inoculant was used, BRS was reduced by 12% (compared to no inoculant); whereas, when N was not applied to 95Y20, and inoculant was used, BRS was increased by 19%, compared to no inoculant treatment. To maximize BRS at MTH12, either the application of N to 95Y20 that was not treated with inoculant, or inoculant was applied alone to 95Y20 seed and not treated with N was required.

Nitrogen, fungicide, cultivar, and inoculant affected PTR12 BRS. Treatment combination no N/95Y20/inoculant/fungicide produced 1435 BRS m^{-2} and was greater than 13 of the 16 treatment combinations. Indeterminate 95Y01 did not respond with increased BRS due to any factors within this interaction. The overall trend was that determinate 95Y20 responded minimally to fungicide; however, the interaction can partially be attributed to the no N-95Y20-inoculant treatment increasing BRS by 35% with fungicide application, compared to the same treatment without fungicide. Disease development accelerated during early pod stages at PTR12 and both early-maturing 95Y01 and late-maturing 95Y20 had Cercospora leaf blight. However, 95Y20 had increased leaf area, was more susceptible to disease, and had greater branches compared to 95Y01, which resulted in 95Y20 producing greater BRS that was protected with fungicide.

Starter N, cultivar, and seeding rate interacted at SUF12 by producing 1103 BRS m^{-2} from no N-95Y20-low seeding rate, which was greater than 5 of 8 treatment combinations.

When N was applied, 95Y01 had more BRS with the low seeding rate, whereas 95Y20 had more BRS with the high seeding rate. In contrast, when N was not applied, opposite response was observed and 95Y01 increased BRS with high seeding rate and 95Y20 increased BRS with the low seeding rate. Furthermore, 95Y01 with N had 37% more BRS than other treatment combinations when planted at the low seeding rate, compared to high seeding rate. Inputs fungicide, cultivar, and seeding rate affected SUF12 BRS. The treatment combination 95Y20/low seeding rate/no fungicide produced 1161 BRS m^{-2} and was greater than 5 of the 8 observations contained in this interaction. Indeterminate 95Y01 did not change fungicide response when seeding rates changed; whereas, determinate 95Y20 decreased BRS by 34% when fungicide was applied to soybean at the low seeding rate. In contrast, when fungicide was applied to 95Y20 at high seeding rates, BRS increased by 13%, compared to no fungicide application. Increased BRS with 95Y20 and the high plant population combined with fungicide at SUF12 can partially be attributed to the 95Y20 and the higher plant population producing greater leaf area which benefited from fungicide application compared to the low plant population. Branch seed was maximized with 95Y20 planted at the low seeding rate, yet fungicide proved valuable to 95Y20 when high plant population produced greater leaf area that was susceptible to Cercospora blight that developed high incidence at SUF12.

At WAR13, N, cultivar, seeding rate, and inoculant produced 888 BRS m^{-2} with N/95Y20/low seeding rate/inoculant, which was greater than 13 of 16 observations (data not shown). 95Y20 tended to dominate BRS increase, especially with N applied at low seeding rates. Application of N to 95Y01, at low seeding rate, with inoculant, increased values from 286 to 552 BRS m^{-2}, a 48% increase, compared to no inoculant.

Seed yield (g per m^2) (TSY per m^2) was influenced by cultivar at 2 of 6 locations (MTH12 and WAR13). Cultivar did not interact with any other factor at these two sites. Early-maturing indeterminate 95Y01 had 11 and 13% greater yield than 95Y20, from 298 to 335 and 243 to 279 g m^{-2} at MTH12 and WAR13, respectively (Table 3.4). Nitrogen interacted with cultivar at PTR13 TSY (P=0.0347). A starter N application produced 383 g m^{-2} with 95Y01, increasing yield by 14% compared to the same cultivar without nitrogen (Table 3.5.1). Cultivar 95Y20 did not respond to N application.

Early-maturing indeterminate 95Y01 yielded more on the main stem than 95Y20 at all 6 locations. Yield differences were 32, 39, 16, 30, 29, and 25% or 187 vs. 276, 168 vs. 278, 284 vs. 338, 164 vs. 233, 196 vs. 277, and 321 vs. 430 for MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, respectively. However, N interacted with cultivar at PTR13 (P=0.0284). Main stem seed yield (MSSY) was greatest with N applied to 95Y01 (295 g m^{-2}), and was greater than all other treatment combinations. Specifically, when N was not applied to 95Y01, MSSY decreased by 14%, compared to with N. Determinate 95Y20 did not respond to N application. At MTH12, N, fungicide, and cultivar interacted to affect MSSY. Treatment combination N/95Y01/fungicide produced 288 g m^{-2} and was greater than half of observations. Early-maturing indeterminate 95Y01 produced greater MSSY compared to later-maturing determinate 95Y20. With N, 95Y01 increased MSSY by 9% with fungicide; without N, 95Y01 decreased MSSY by 3%, compared to no fungicide. With N, 95Y20 decreased MSSY with fungicide; without N, fungicide applied to the same cultivar increased MSSY.

Later-maturing determinate 95Y20 had 46, 49, 35, 42, 47, and 48% greater branch seed yield m^{-2} (BSY per m^2) compared to early-maturing indeterminate 95Y01 (59 vs. 110, 84 vs.166, 100 vs.154, 46 vs.79, 80 vs.152, and 71 vs.137 g m^{-2}) for MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, respectively. However, seeding rate partially affected the cultivar response at MTH12. 95Y20 planted at the low seeding rate produced 129 g BSY m^{-2} and increased values compared to all other treatment combinations. In addition, 95Y20 at low seeding rate increased BSY by 29%, compared to the same cultivar at high seeding rate. 95Y01 did not respond to changes in seeding rate.

Treatment combinations of N, fungicide, and cultivar affected BSY at MTH12 and SUF12. At MTH12, no N/95Y20/no fungicide produced 125 g BSY m^{-2} and was greater than 5 of 8 observations. Cultivar 95Y20, with N, responded to fungicide application by increasing BSY, whereas, without N, fungicide application decreased BSY values. Similarly, SUF12 no N/95Y20/no fungicide produced 182 g BSY m^{-2} and was greater than all other treatments, except combination N/95Y20/fungicide. With N, 95Y20 increased BSY with fungicide. In contrast, without N, the same cultivar decreased BSY with a fungicide application.

At MTH12 inputs N, cultivar, and inoculant affected BSY. Treatment combination no N/95Y20/inoculant produced 128 g BSY m^{-2} and was greater than all other treatment combinations, except N/95Y20/no inoculant. With N, 95Y20 decreased BSY by 18% when inoculant was used, compared to no inoculant. In contrast, without N, 95Y20 increased BSY by 21% with inoculant application, compared to untreated. These data indicate that, under certain environments, starter N and inoculant may not be compatible (see Dillon et al. chapter IV for more detailed research).

Inputs N, fungicide, cultivar, and inoculant affected BSY at PTR12, WAR13, and PTR13. At PTR12, no N/95Y20/inoculant/fungicide produced 211 g BSY m^{-2}, which was greater than 13 of the 16 observations. When N was not applied to 95Y20 treated with inoculant, foliar fungicide increased BSY by 35%, compared to the same combination but no fungicide.

The WAR13 treatment combination N/95Y20/inoculant/no fungicide produced 105 g BSY m^{-2}, which was greater than 6 of the 8 observations. When N and inoculant were not applied, 95Y20 decreased branch seed yield and fungicide performance was somewhat diminished for 95Y20. At PTR13, N/95Y20/no inoculant/no fungicide produced 161 g BSY m^{-2} and was greater than half of the observations. The determinate cultivar 95Y20 generally increased BSY compared to indeterminate 95Y01. In addition, N tended to slightly increase BSY values for 95Y20, compared to no N. However, the interaction can be attributed to observed 110 g BSY m^{-2} from combination N/95Y01/inoculant/no fungicide. When N was applied, combined with inoculant and 95Y01, no fungicide increased BSY by 47%, compared to the same combination but with fungicide.

Nitrogen, cultivar, and seeding rate interacted to affect SUF12 BSY. No N/95Y20/low seeding rate produced 164 g BSY m^{-2}, which was greater than only 3 of 8 observations. When N was applied to 95Y01 at the low seeding rate, BSY values were the same as 95Y20 treatments. Similar response was not observed with the same combination but at high seeding rate.

At WAR13, BSY was influenced by an interaction between N, cultivar, seeding rate, and inoculant. Inputs N/95Y20/low seeding rate/inoculant produced 108 g BSY m^{-2} and was greater than 12 of the 16 observations. Cultivar 95Y20 maintained high BSY values with N and low seeding rate without the inoculant; however, N combined with inoculant to the high seeding rate resulted in branch seed yield comparable to the same cultivar as low seeding rates. In contrast, when inoculant was removed, N applied alone to the high seeding rate did not produce BSY comparable to the low seeding rate.

Cultivar 95Y20 had greater seed size (seed kg^{-1}) at 6 out of 6 locations, when averaged across other inputs (Table 3.4). Specifically, 95Y20 increased seed size by 13, 16, 12, 13, 19, and 14%, compared to 95Y01, at MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, respectively. When averaged across locations, later-maturing 95Y20 produced greater seed size by 1089 seed kg^{-1}, compared to 95Y01. Seed size typically provides insight into greater TSY; however, these data showed that 95Y01 had greater g per m^{2}, but exhibited less seed kg^{-1} compared to 95Y20. Cultivar 95Y01 had larger seed compared to 95Y20, which could be linked to increased seed yield (Dillon et al. Chapter II) through greater seed mass.

Seed mass was correlated to seed yield by Pedersen and Lauer (2004), whereas Board (1987) and Robinson et al. (2013) observed a weaker relationship between soybean yield and seed mass. In our experiments, the earlier-maturing indeterminate 95Y01 tended to increase yield compared to 95Y20; therefore, one may conclude that 95Y01 has a higher yield genetic yield potential than 95Y20. But one must also consider the 2012 and 2013 growing seasons, which were somewhat atypical for Virginia double-crop soybean due to above-average rainfall throughout the season in two of three sites in 2012 and above-average rainfall followed by below-average rainfall during the R5 and R6 (full seed, Fehr and Caviness, 1977) stages in September at all sites in 2013 (Table 3.3). Since 95Y01 matured 7 to 10 days earlier than 95Y20, it may have not been affected by drought to the same extent as 95Y20 since it was farther into the seed fill stages in September. In contrast, cultivar 95Y20's larger seed size indicates less effect of drought during seed fill. However, a seed-fill drought does not explain greater seed yield of 95Y01 at the MTH12 location; therefore 95Y01 could just be a genetically superior cultivar. Still, indeterminate 95Y01 performance could be limited in lower yielding environments that are more typical of double-crop soybean and seed yield results could then favor the later-maturing cultivar. If low yield potential dominated soybean vegetative and reproductive development, yield components would provide additional insight into how determinate later-maturing cultivars cope with moisture stress while simultaneously promoting canopy closure and seed fill. Furthermore, yield components may help explain seed yield parameters better in years dominated by a yield limits placed on double-crop soybean. Finally, although we could not directly compare the cultivars as indeterminate vs. determinate stem growth habits due to the maturity differences, there was more seed on the main stem and less on the branch stems for the indeterminate than the determinate cultivar. It is unknown if an indeterminate vs. determinate cultivar of the same maturity would respond the same way, but this trait could also have yield implications.

Secondary Level: Pod per m^2 and Seed per Pod

Cultivar 95Y20 had 9, 13, 19, 19, and 9%, more total pods m^{-2} (TP per m^2) (947 vs. 1037, 1076 vs. 1242, 1187 vs. 1471, 1047 vs. 1297, and 1483 vs. 1632 pods m^{-2}) compared to indeterminate 95Y01 at 5 of 6 locations (MTH12, PTR12, SUF12, PTR13, and SUF13) (Table 3.4). At WAR13, the treatment combination N/95Y01/with fungicide produced 1080 TP m^{-2}, which was greater than combinations N/95Y01/without fungicide and no N/95Y20/no fungicide (Table 3.6). Early-maturing 95Y01, with N increased TP per m^2 with fungicide, which protected greater leaf area partially increased with N application, from fungal disease that infected the soybean canopy mid-season and remained until leaf drop. In addition, 95Y01 was better adapted to WAR13 and matured earlier, which allowed 95Y01 to avoid drought stress in September that coincided more with 95Y20 pod-fill stages. However, without N, fungicide application to 95Y01 decreased TP per m^2. In contrast, determinate 95Y20, with N, decreased TP per m^2, whereas the same cultivar, without N, marginally increased TP per m^2 with fungicide.

Main stem pods per m^2 (MSP per m^2) were affected by cultivar at 5 of 6 locations in which indeterminate 95Y01 increased MSP compared to determinate 95Y20 (MTH12, PTR12, WAR13, PTR13, and SUF13) (data not shown). Indeterminate produced more total pods per m^2 and increased values by 18, 26, 20, 11, and 9%, from 635 to 775, 613 to 832, 641 to 799, 698 to 785, and 1131 to 1242 pods m^{-2}, respectively. Application of N to indeterminate 95Y01 increased PTR13 MSP per m^2 compared to all other treatment combinations (data not shown). In addition, N increased 95Y01 MSP per m^2 with application whereas no N decreased MSP m^{-2} by 12%. Determinate 95Y20 did not respond to N application. Agronomic inputs N, fungicide, cultivar, and inoculant affected MTH12 MSP per m^2 with N/95Y01/without inoculant/with fungicide producing 861 MSP m^{-2}, which was greater than 44% of interaction observations (data not shown). When N was applied to 95Y01, no response was observed; however when N was applied to 95Y20, inoculant application increased MSP per m^2, compared to no inoculant. In addition, when N was not applied, inoculant did not increase main stem pod production for either cultivar. Treatment combinations of N, fungicide, and cultivar at WAR13 affected MSP per m^2 (data not shown). With indeterminate 95Y01, N application increased MSP per m^2 compared to untreated. In contrast, determinate 95Y20 decreased MSP per m^2 when N was applied. Indeterminate soybean produced greater MSP per m^2 compared to determinate but differences within cultivar in combination with N were minimal.

Determinate 95Y20 produced greater branch pods per m^2 (BP per m^2) compared to 95Y01 at all locations in 2012 and 2013 (all $P<.0001$) by 57, 61, 47, 46, 56, and 52%, from 172 to 402, 244 to 629, 280 to 527, 176 to 317, 262 to 599, and 240 to 501 pod m^{-2} at MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, respectively (data not shown). At MTH12 inputs cultivar and seeding rate influenced BP per m^2 by producing 467 BP m^{-2} with determinate 95Y20, which was greater than all other treatments (data not shown). 95Y20 responded to change in low seeding rate by increased branch pod production, whereas changing seeding rate did not affect 95Y01. Three way interaction between N, fungicide, and cultivar affected BP at MTH12 and SUF12 (data not shown). At MTH12, no N/95Y20/without fungicide produced 452 BP m^{-2} and was greater than other combinations except with N/95Y20/with fungicide and no N/95Y20/with fungicide. 95Y20 tended to decrease BP without N compared to with N. Similarly, at SUF12, treatment combination no N/95Y20/without fungicide produced 608 BP m^{-2} and increased branch pod production compared to other treatments, except with N/95Y20/with fungicide. At both locations, fungicide was observed to increase BP only when N was applied to 95Y20, compared to no fungicide treatment.

Inputs N, cultivar and inoculant affected BP at MTH12 (data not shown). Treatment combination of no N/95Y20/with inoculant produced 458 BP m^{-2} and increased production compared to other treatments, but was not greater than with N/95Y20/without inoculant. When N was not applied to determinate 95Y20, but inoculant was used, BP m^{-2} increased by 22%, compared to no inoculant application. Similar response was not observed when N was applied.

At SUF12 inputs N, cultivar, and seeding rate affected BP (data not shown). 95Y20, regardless of N application increased BP per m^2 compared to 95Y01. In addition, N applied to 95Y01 increased BP by 34% with the low seeding rate, compared to the high seeding rate. Also at SUF12, inputs fungicide, cultivar and seeding rate produced 586 BP m^{-2} with 95Y20/high seeding rate/fungicide, but was not greater than 95Y20/low seeding rate/no fungicide and 95Y20/high seeding rate/no fungicide (data not shown). Early-maturing cultivar did not respond to changes in seeding rate or fungicide; whereas, later-maturing cultivar slightly increased BP at high seeding rate compared to the low seeding rate.

Kahlon et al. (2011) reported that pod per m^2 was a good indirect selection criterion across MG V-VIII soybean and was directly correlated with yield ($R^2 = 0.78$). Our results show overall increased total pod production with determinate 95Y20, yet seed yield results (Dillon et al. Chapter II) demonstrated early-maturing 95Y01 out-yielded later-maturing 95Y20, which was partially attributed to increased main stem pod and seed and total seed yield. The relationship between pod production area^{-1} and growing environmental is critical yet it is possible that seed mass, which is mostly determined by genetics (Robinson et al., 2013), is a more critically involved factor in yield formation when limited water availability and drought stress dominate soybean seed fill.

Total seed per pod (TSP) was shown to have limited involvement in yield formation (Kahlon et al., 2011) and was attributed mostly to genetic differences between cultivars (Robinson et al., 2013). However, our results demonstrated differences in pod per m^2 and seed per m^2 due to changes in agronomic inputs and this parameter provides further examination of how genetic x environment interactions influence double-crop soybean production. Indeterminate 95Y01 increased TSP compared to determinate 95Y20 at 5 of 6 locations (MTH12, PTR12, SUF12, PTR13, and SUF13) by 6, 5, 8, 3, and 6%, respectively (Table 3.4).

At PTR13 inputs cultivar and inoculant affected TSP by producing 2.22 TSP with 95Y01/inoculant, but was only greater than 95Y20/inoculant (Table 3.5.2). Inoculant application was not necessary for either cultivar, and furthermore, the determinate cultivar decreased TSP when inoculant was used. Inputs fungicide, cultivar, seeding rate, and inoculant affected SUF12 TSP (Table 3.7). Treatment combination 95Y01/high seeding rate/inoculant/fungicide produced 2.22 TSP and was greater than 69% of observations. 95Y01 at low seeding rate did not increase TSP with inoculant use. In contrast, 95Y01 at high seeding rate observed fungicide response when in combination with inoculant. When inoculant was removed from that combination, fungicide decreased TSP. When 95Y01 was planted with the low seeding rate, both inoculant and fungicide were not required; whereas, when planting changed to the increased rate of seed, both inputs were valuable in combination. At MTH12 inputs N, fungicide cultivar, and seeding rate interacted and produced 2.4 TSP with combination N/95Y01/low seeding rate/no fungicide, which was greater than 50% of observations (Table 3.8). Fungicide increased TSP 62% of observations. 95Y01 and 95Y20, across seeding rate, both increased TSP when N was not applied compared to with application. 95Y01 tended to have slightly higher TSP values compared to determinate 95Y20.

Tertiary Level: Pods per Reproductive Node and Reproductive Nodes per Plant

Determinate 95Y20 increased total pods per reproductive node (TPRN) at all locations (MTH12, PTR12, SUF12, WAR13, PTR13, SUF13) by 8, 12, 15, 18, 32, and 14%, respectively (Table 3.4). Inputs N, fungicide, and cultivar affected TPRN at MTH12 and SUF12 (Table 3.6). At MTH12, inputs no N/95Y20/no fungicide produced 2.5 TPRN, which was greater than 37% of observations. 95Y20, combined with N application, was more responsive and increased TPRN compared to 95Y01 with N. Without N, the difference between the two cultivars was negligible. Similarly, treatment combination no N/95Y20/no fungicide, at SUF12, produced 3.5 TPRN, which was greater than all other treatment combinations, except N/95Y20/fungicide. Specific to SUF12, when N was applied, fungicide increased TPRN compared to removal of N from the system.

Inputs N, cultivar, and seeding rate affected SUF12 TPRN. Two treatment combinations both produced 3.3 TPRN and included N/95Y20/high seeding rate and no N/95Y20/low seeding rate (Table 3.9). These combinations increased TPRN values greater than 37% of observations. Determinate 95Y20 produced greater TPRN values overall, however this interaction can be attributed to 95Y01, with N, at low seeding rate, increased TPRN by 16% compared to the high seeding rate.

At WAR13 inputs N, cultivar, seeding rate, and inoculant affected TPRN. The treatment combination of N/95Y20/low seeding rate/no inoculant produced 2.7 TPRN and was greater than 56% of observations (Table 3.10). 95Y20 tended to increase TPRN compared to 95Y01; however the interaction can be attributed to the observation where inoculant increased TPRN by 15%, compared to no inoculant, combined with low seeding rate, 95Y20, and no N. Care should be taken when extrapolating TPRN data; Kahlon et al. (2011) determined TPRN as a parameter not correlated to soybean yield.

Indeterminate 95Y01 increased reproductive nodes (RN) per plant at MTH12, PTR12, SUF12, and SUF13 by 11, 6, 12, and 10%, compared to determinate 95Y20 (Table 3.4). Inputs N, fungicide, and cultivar affected MTH12 RN per plant by producing 10.9 RN plant^{-1} with N/95Y01/no fungicide, and was greater than all other treatments except no N/95Y01/with and without fungicide (Table 3.6). The indeterminate cultivar responded to N application by increasing RN per plant compared to the determinate cultivar. Soybean canopy closure was not fully accomplished at MTH12; therefore fungicide response was not observed.

Treatment combinations of N, fungicide, cultivar, and inoculant affected RN per plant at SUF12 and WAR13. At SUF12, combination with N/95Y01/with inoculant/with fungicide produced 13.3 RN plant^{-1} and increased production over all treatments, but was not greater than combinations (1) with N/95Y01/with inoculant/no fungicide, (2) with N/95Y01/no inoculant/no fungicide, (3) no N/95Y01/with inoculant/no fungicide, and (4) no N/95Y01/no inoculant/with fungicide (Table 3.11). This interaction is due to fungicide's ability to increase RN per plant for determinate and indeterminate cultivars when inoculant was applied in combination with N.

When N was not applied the synergistic activity of the system disintegrated and RN production was not positively affected. At WAR13 the combination of inputs N, fungicide, cultivar, and inoculant that resulted in the lowest RN per plant were (1) with N/95Y01/no inoculant/no fungicide (8.9), (2) no N/95Y01/no inoculant/with fungicide (8.9), and (3) no N/95Y20/with inoculant/with fungicide (8.4) (Table 3.11). Fungicide performed inconsistently, determinate and indeterminate tended to be similar in RN production, and both inoculant and N tended to provide slight increase in RN per plant compared to untreated. Application of N was more critical to increase RN per plant at SUF12, compared to WAR13 and may be attributed to soil texture and soil N levels. Soil texture at SUF12 was loamy fine sand and was more prone to drought stress compared to the loam at WAR13 (Table 3.1). In addition, soil NH_4 and NO_3 were 1.0 and 0.36 kg ha^{-1} vs. 1.9 and 1.1 kg ha^{-1}, for SUF12 and WAR13, respectively (Appendix B). Although both locations were low in soil-N, approximately twice the NH_4 and three times the NO_3 were available for soybean uptake at WAR13 compared to SUF12. Kahlon et al. (2011) correlated reproductive node per m^2 to yield ($R^2 = 0.53$) and Robinson et al. (2013) concluded reproductive nodes per m^2 was a tertiary trait positively linked to secondary trait pods per m^2, which in turn affected primary trait seed per m^2, which was linked to seed yield. Among the yield components Kahlon et al. (2011) studied, RN per m^2 was the most accurate indirect selection criteria for increased yield during cultivar development. While our measurements involved RN per plant, positive trends observed with RN per m^2 should provide similarities to RN per plant, but at a narrower data range.

Quaternary Level: Node per Plant and Percent Reproductive Nodes

Determinate 95Y20 increased nodes per plant (NP) compared to 95Y01 by 10, 12, and 10%, from 14 to 15.6, 12.9 to 14.6, and 11.6 to 12.9 NP at PTR12, WAR13, and PTR13, respectively. At MTH12, interaction between N, fungicide, and cultivar affected nodes per plant. Treatment combination no N/95Y01/without fungicide produced 12.7 NP, which was reduced compared to all other treatment combinations, which produced similar values (data not shown). Cultivar 95Y20 continued the trend and increased NP, compared to 95Y01. In addition, N and fungicide promoted increased NP. Our results are similar to Gai et al. (1984), who reported increased nodes at maturity with determinate, compared to indeterminate growth habit. At low node levels, Egli (2013) found pods per m^2 were limited by node number but at higher node levels, there was no observed difference between nodes and pods.

Indeterminate 95Y01 increased percent reproductive nodes per plant (% RN) compared to determinate 95Y20 at all locations in 2012 and 2013 and ranged from 7 to 16% (Table 3.4). At MTH12, inputs fungicide and cultivar affected % RN by producing increased % RN with indeterminate 95Y01 compared to determinate 95Y20 (Table 3.5.3). Furthermore, fungicide application decreased % RN for each cultivar, compared to the same cultivar, untreated.

Indeterminate 95Y01 responded to inoculant by producing 76% RN at SUF12 and increased values by 3% compared to 95Y01 without inoculant (Table 3.5.2). Furthermore, 95Y20 decreased % RN compared to 95Y01 but exhibited no inoculant response. Also at SUF12, interaction between N, cultivar, and seeding rate affected % RN. When indeterminate was planted at the low seeding rate, N increased RN by 2% compared to no N (Table 3.9). At the high seeding rate, indeterminate decreased RN by 3% with N application, compared to untreated. Determinate cultivar, at low seeding rate decreased RN by 4% with N, compared to untreated. Furthermore, determinate at high seeding rate increased RN by 1% with N, compared to untreated.

Inputs N, fungicide, cultivar, and inoculant at WAR13 produced 76% RN with the treatment combination N/95Y01/no inoculant/with fungicide and had the greatest values for this interaction but was not greater than 50% of observations (Table 3.11). Both 95Y01 and 95Y20 slightly increased % RN with N application but the increase was slightly more for determinate 95Y20 (0.4 vs. 1.2%, respectively). Also at WAR13, inputs N, cultivar, seeding rate, and inoculant affected % RN by producing 79% with N/95Y01/low seeding rate/with inoculant and was greater than 75% of interaction observations (Table 3.10). General positive response to inoculant application was observed from this interaction. In addition, % RN increase was observed when N was applied with 95Y01 indeterminate cultivar and seeding rate changed. Values increased with the low seeding rate for 95Y01, with N, compared to the high seeding rate. Similar response was not observed with 95Y20 or without N. Robinson et al. (2013) determined % RN was controlled primarily by genetics. Kahlon et al. (2011) concluded that % RN was not correlated to yield and exhibited minimal involvement in yield formation. Reproductive node per plant is a more appropriate measure of soybean yield development.

Indeterminate 95Y01 increased harvest index (HI) at 5 of 6 locations compared to determinate 95Y20 by 4, 10, 4, 15, and 12% for MTH12, PTR12, SUF12, WAR13, and SUF13, respectively (Table 3.4). When averaged across all locations, 95Y01 increased HI by 4%. Loomis and Connor (1992) partially attributed soybean yield to harvest index. Egli (2011) determined that a final vegetative mass above a minimum level did not always result in increased seed yield. Specifically, the additional leaf area index associated with the larger vegetative mass did not increase light interception, canopy photosynthesis, or crop growth rate. Egli (2011) emphasized that these relationships cast light on the potential weakness of describing yield as a simple function of total biomass. We reported similar findings with the ability of N to increase soybean growth, while decreasing HI potential. Determinate, later-maturing 95Y20 accelerated growth and canopy closure quicker than indeterminate earlier-maturing 95Y01, but the end result was decreased HI observed with 95Y20. The overall goal would be to optimize harvest index by production-required photosynthetic material while simultaneously ensuring maximum seed production. Unfortunately, that goal can be difficult to obtain due to decreased yield potential typically observed in double-crop soybean production.

Seeding Rate

Primary Level: Seed per m^2 and Seed Yield

Changing seeding rate did not affect TS per m^2. When averaged across locations, the low seeding rate increased seed per m^2 by 3%, compared to the high seeding rate (Table 3.4). Main stem seed was not influenced by seeding rate; however an interaction between N, fungicide, seeding rate, and inoculant was observed at SUF12 but will be discussed in the fungicide input section. In contrast, the low seeding rate increased BRS per m^2 at MTH12, WAR13, and PTR13 by 22, 15, and 16%, from 525 to 675, 473 to 555, and 832 to 987 seed m^{-2}, respectively. Inputs fungicide and seeding rate affected MTH12 BRS by producing 723 BRS with the low seeding rate combined with no fungicide application and was greater than other treatment combinations, except low seeding rate with fungicide (data not shown). Fungicide application did not improve BRS for either seeding rates, however, there was a slight positive response to fungicide at the high seeding rate.

Total seed yield per m^2 was not influenced by seeding rate. When averaged across locations, the low seeding rate increased TSY by 3%, compared to the high seeding rate (Table 3.4). At SUF13, inputs fungicide and seeding rate produced 522 g m^{-2} with the low seeding rate/fungicide and was minimally higher in value compared to other treatments (Table 3.5.4). In addition, fungicide application at low seeding rate increased TSY by 13% compared to same seeding rate without fungicide. Fungicide slightly decreased TSY when applied to the high seeding rate.

Seeding rate did not influence MSSY per m^2, but when averaged across locations, the high seeding rate increased MSSY by 2%, compared to the low seeding rate (data not shown). Interaction involving seeding rate was observed at SUF12, but will be discussed with fungicide. The low seeding rate increased BSY m^{-2} by 22, 13, 20, and 17% at MTH12, PTR12, WAR13, and PTR13, respectively, compared to the high seeding rate (data not shown). Treatment combinations of fungicide, seeding rate, and inoculant affected BSY at SUF12 and PTR13. At SUF12, inputs no inoculant/low seeding rate/no fungicide produced 143 g BSY, but was only greater than combination no inoculant/low seeding rate/fungicide (12% of observations) (data not shown). Branch seed production with the combination no inoculant/low seeding rate/fungicide decreased g per m^2 by 37%, compared to the same combination but without fungicide (also highest value). At PTR13, the same inputs fungicide, seeding rate and inoculant produced 146 g BSY m^{-2} with the treatment combination no inoculant/low seeding rate/no fungicide, which was greater than 37% of observations (data not shown). Fungicide application increased BSY by 21%, when combined with no inoculant and the high seeding rate. Similar response was not observed at the low seeding rate. Fungicide application performance was not critical for BSY at SUF12, but was more important at PTR13 with the high seeding rate only.

Secondary Level: Pod per m^2 and Seed per Pod

When averaged across locations, the low seeding rate increased TP per m^2 by only 2%, compared to the high seeding rate (Table 3.4). Seeding rate did not influence TP; however interactions involving seeding rate were observed at PTR12 and WAR13. Inputs N, fungicide, seeding rate, and inoculant affected PTR12 TP by producing 1314 TP m^{-2} with the treatment combination no N/no fungicide/high seeding rate/no inoculant, which was highest of observed values but was greater than only 1 out of 16 observations (combination N/no fungicide/high seeding rate/no inoculant) (data not shown). Slight increase in TP was observed with the low seeding rate, N and inoculant performed inconsistently, and the intensive management package (N/fungicide/high seeding rate/inoculant) did not improve total pod dynamics. At WAR13, inputs N, fungicide, and seeding rate produced 1041 TP m^{-2} with the combination of N, high seeding rate, and fungicide, which was not greater than other treatment combinations (Table 3.12). Fungicide improved TP m^{-2} 75% of observations; the one exception where fungicide did not increase TP per m^2 was when N was not applied and soybean were planted at the high seeding rate.

Main stem pods per m^2 (MSP) was not influenced by seeding rate, but when averaged across locations, the low seeding rate decreased MSP by 2% (data not shown). At SUF12, inputs N, fungicide, seeding rate, and inoculant produced 1202 MSP m^{-2} with no N/high seeding rate/no inoculant/with fungicide and was greater than 81% of observations, but was not greater than without N/high seeding rate/with inoculant/no fungicide (1052 MSP m^{-2}) and with N/low seeding rate/with inoculant/with fungicide (1023 MSP m^{-2}) (data not shown). When N was not applied, the high seeding rate tended to increase MSP per m^2 compared to the low seeding rate. In contrast, with N application, the high seeding rate did not increase MSP compared to low seeding rate.

Branch pods per m^2 was increased by 21, 11, and 18% at 3 of 6 locations with the low seeding rate, compared to the high seeding rate at MTH12, PTR12, and PTR13, respectively (data not shown). At MTH12, inputs fungicide and seeding rate produced 342 BP m^{-2} with low seeding rate/no fungicide, but was not greater than low seeding rate/with fungicide (data not shown). Increased branch pods were produced with the low seeding rate compared to the high seeding rate; fungicide application was not needed to increase BP. Inputs fungicide, seeding rate, and inoculant affected PTR13 BP by producing 531 BP m^{-2} with the combination no inoculant/low seeding rate/no fungicide, which was greater than 50% of observations. As seeding rate was lowered and inoculant not applied, fungicide application decreased BP. At PTR12, inputs N, fungicide, seeding rate, and inoculant produced 554 BP m^{-2} with N/low seeding rate/without inoculant and fungicide and increased value compared to 38% of observations (data not shown). Soybean planted with the high seeding rate did not respond to N application and increase BP per m^2 when compared to low seeding rate with N. Fungicide increased BP per m^2 approximately 62% of observations.

Minimal differences averaged across locations were observed between TSP when seeding rate was examined (Table 3.4). However, interactions involving seeding rate were observed at different locations. Inputs N and seeding rate affected PTR12 TSP. Treatment combination of no N and low seeding rate produced 1.9 TSP and was greater than other treatment combinations, except N/high seeding rate (Table 3.5.5). When N was not used, the low seeding rate increased TSP values by 6%, compared to high seeding rate. No differences were observed between N applied and low and high seeding rates. At SUF12, N, seeding rate, and inoculant produced 2.1 TSP with N/low seeding rate/no inoculant, but was greater than only 37% of observations (Table 3.13). When N was not applied to the high seeding rate, changing inoculant treatments did not change TSP. When N was not applied to the low seeding rate, inoculant slightly increased TSP, compared to untreated; similar response was observed with N at the high seeding rate, with inoculant. With N, at low seeding rate, inoculant application decreased TSP, compared to untreated. At low seeding rate in combination with N, seed-applied inoculant was not required. WAR13 was affected by inputs N, fungicide, and seeding rate, where treatment combination N/low seeding rate/fungicide produced 2.3 TSP, but was only greater than 25% of interaction observations (Table 3.12). With N, low seeding rate increased TSP with fungicide application; without N, low seeding rate decreased TSP with fungicide. With N, high seeding rate did not promote TSP change; without N, high seeding rate increased TSP with fungicide application, compared to untreated. If low seeding rate was planted with N, fungicide performed well; if same rate was planted without N, fungicide was not necessary. If high seeding rate was planted with N, fungicide was not needed; if same rate was planted without N, fungicide improved TSP. At SUF13 TSP inputs fungicide, seeding rate, and inoculant affected TSP. Two treatment combinations produced the highest seed per pod levels and were inoculant/low seeding rate/fungicide and no N/low seeding rate/no fungicide, both observed at 2.12 TSP (Table 3.14). These values were greater than only 23% of observations. With inoculant, the low seeding rate increased TSP with fungicide; without inoculant, TSP values decreased. The high seeding rate, with inoculant, decreased TSP with fungicide application; same seeding rate, without inoculant slightly increased TSP.

Tertiary Level: Pods per Reproductive Node and Reproductive Nodes per Plant

The low seeding rate increased TPRN by 9, 14, and 16%, compared to the high seeding rate at MTH12, PTR12, and PTR13, respectively (Table 3.4). When averaged across locations, TPRN increased by 9% with the low seeding rate compared to the high seeding rate. At PTR13, inputs N, fungicide, and seeding rate produced 3.4 TPRN with N/low seeding rate/no fungicide and increased values compared to all other treatment combinations, except no N/low seeding rate/fungicide (Table 3.12). At high seeding rates, no response to N was observed. Application of N combined with low seeding rate increased TPRN without fungicide compared to untreated. In contrast, at low seeding rate, but without N, fungicide application slightly improved TPRN compared to no fungicide. At SUF13, inputs fungicide, seeding rate, and inoculant produced 3.1 TPRN with inoculant/low seeding rate/fungicide and was the highest value compared to other observations but was only greater than the treatment combination inoculant/high seeding rate/fungicide (Table 3.14). Utilizing the low seeding rate, combined with fungicide and inoculant increased TPRN by 19% compared to the high seeding rate and same fungicide and inoculant combination.

Planting the low seeding rate increased RN by 8, 10, 8, 9, and 10%, compared to the high seeding rate at MTH12, PTR12, WAR13, PTR13, and SUF13, respectively (Table 3.4). When averaged across locations, low seeding rate increased RN by 7% compared to high seeding rate. At MTH12, inputs fungicide and seeding rate affected RN per plant. Reproductive node per plant was highest at 10.6 with the combination low seeding rate/without fungicide and was greater than all other treatment combinations (Table 3.5.4). Planting at the low seeding rate maximized RN per plant at MTH12 and fungicide application was not required.

Inputs fungicide, seeding rate, and inoculant affected RN at SUF12 and PTR13. At SUF12, one treatment combination did not significantly differ from others; however, low seeding rate tended to increase RN production, fungicide increased RN per plant 50% of observations, and inoculant application slightly increased RN per plant (Table 3.14). Similarly at PTR13, treatment combinations with inoculant/high seeding rate/with fungicide and no inoculant/high seeding rate/no fungicide reduced RN per plant (Table 3.14). At both locations, RN was generally reduced when the high seeding rate was planted; and inoculant and fungicide were not the limiting factors. Inputs N, fungicide, seeding rate, and inoculant influenced WAR13 RN per plant. Treatment combinations (1 and 2) with N/low seeding rate/with inoculant/with and no fungicide, (3) with N/low seeding rate/no inoculant/with fungicide, and (4) no N/low seeding rate/no inoculant/no fungicide had the highest RN per plant values at 10.5, 11.3, 10.2, and 10.1, respectively (Table 3.15). The high seeding rate tended to decrease RN per plant and the low seeding rate favored N application to increase RN per plant, compared to untreated.

Quaternary Level: Node per Plant and Percent Reproductive Nodes

The low seeding rate increased NP by 7, 5, 6, 4, and 7%, compared to the high seeding rate at MTH12, PTR12, WAR13, PTR13, and SUF13, respectively (data not shown). When averaged across locations, low seeding rate increased NP by 5% compared to high seeding rate. At MTH12, inputs fungicide and seeding rate produced 14.4 NP with low seeding rate/no fungicide and was greater than high seeding rate/no fungicide, but was the same as low seeding rate/with fungicide and high seeding rate/with fungicide (data not shown). When fungicide was applied to soybean planted at the high seeding rate, NP increased by 7% compared to without fungicide application. Inputs fungicide, seeding rate, and inoculant influenced NP at SUF12 and PTR13. When inoculant was applied at SUF12, combined with low seeding rate and no fungicide, highest NP was observed at 16.8, which was no greater than all other treatment combinations, except with inoculant/high seeding rate/no fungicide and no inoculant/high seeding rate/with fungicide (data not shown). The higher seeding rate was responsible for reduced nodes per plant. Similarly, at PTR13, inputs with inoculant/low seeding rate/with fungicide produced 13.2 NP, which was greater than with inoculant/high seeding rate/with fungicide, no inoculant/low seeding rate/with fungicide, and no inoculant/high seeding rate/no fungicide. With inoculant the low seeding rate increased NP by 9% compared to the high seeding rate; when inoculant was removed from the system, the seeding rate response was negligible. Inoculant application was important for NP at both SUF12 and PTR13, but primarily in combination with the low seeding rate. Kahlon et al. (2011) reported yield was linearly correlated with node per m^2 ($R^2 = 0.46$). Low seeding rate generally increased NP in our experiments; furthermore, yield results (Dillon et al. Chapter II) demonstrated that seeding rates yielded the same when averaged across locations. However, at some locations, high seeding rate increased seed yield, even with fewer NP. These data show the importance of not relying solely on NP but also considering the yield component system in entirety.

Similar to the trend observed with NP, low seeding rate increased % RN by 5, 5, and 3% compared to high seeding rate at PTR12, PTR13, and SUF13, respectively (Table 3.4). When averaged across locations, low seeding rate increased % RN by 3% compared to high seeding rate (Table 3.4). At MTH12, inputs N and seeding rate produced 71% RN with both combinations N/low seeding rate and no N/high seeding rate, respectively, and increased RN by 5% compared to N/high seeding rate, but was not greater than no N/low seeding rate (Table 3.5.5). Application of N at low seeding rates produced equivalent % RN to without N applied at both low and high seeding rates. At WAR13, inputs N, fungicide, seeding rate, and inoculant produced 74% RN with treatment combination N/low seeding rate/with inoculant/no fungicide and was higher than 56% of interaction observations (Table 3.15). The N application, at the low seeding rate increased RN by 4% compared to the high seeding rate; without N, the low seeding rate increased RN by only 0.4%, compared to the high seeding rate.

Inoculant

Primary Level: Seed per m^2 and Seed Yield

Total seed per m^2 was not influenced by inoculant. When averaged across locations, inoculant application decreased TS by 2% (Table 3.4). At WAR13, inputs N, fungicide, and inoculant produced 2243 TS with N/no inoculant/fungicide, but was greater than only 1 out of 8 observations (Table 3.16). When N and inoculant were applied, fungicide did not increase TS; however, when N was applied without inoculant, fungicide slightly increased TS, compared to untreated. When N was removed, inoculant combined with fungicide increased TS by 7%, compared to no fungicide.

Main stem seed per m^2 responded to inoculant similar to TS. When averaged across locations, inoculant use decreased MSS by 1%. At SUF12, inputs N, fungicide, seeding rate, and inoculant produced 2440 MSS with no N/high seeding rate/no inoculant/fungicide and was greater than all other treatment combinations, except N/low seeding rate/no inoculant/fungicide and N/high seeding rate/no inoculant/fungicide (data not shown). When fungicide was applied, 75% positive response in MSS was observed, but only without inoculant. When inoculant was utilized, the response was not repeated. Fungicide application was more valuable to the intensive management system at SUF12 when the inoculant was not present.

Inoculant did not influence BRS; however interactions involving inoculant were observed and some have been discussed previously with cultivar and seeding rate inputs. When averaged across locations, with and without inoculant affected BRS similarly (data not shown). Inputs N, fungicide, and inoculant affected BRS at SUF12 and WAR13 (data not shown). At SUF12, inputs N/inoculant/fungicide produced 1029 BRS m^{-2}, which was greater than 50% of observations. When N was applied and inoculant was not used, BRS values decreased; without N and inoculant, BRS values slightly increased. Fungicide increased BRS when N and inoculant were used together, but did not repeat once the factors were changed. At WAR13, inputs N/inoculant/no fungicide produced 654 BRS m^{-2} and was greater than 37% of observations. When N was applied, and inoculant not used, fungicide increased BRS by 32%, compared to untreated. This increase was not observed from N and fungicide when inoculant was applied. At SUF12, inoculant was valuable to the system only in combination with N; furthermore, at WAR13, inoculant application did not benefit BRS.

When averaged across locations, inoculant decreased TSY by 1% with application (Table 3.4). At SUF12 inputs fungicide and inoculant affected TSY. Without inoculant application, combined with fungicide produced 467 g m^{-2}, which was only greater than no inoculant/no fungicide (Table 3.5.6). When inoculant was not utilized, fungicide increased total seed yield by 11%.

Inoculant increased MSSY with only one interaction observed (SUF12) which was previously discussed with seeding rate. When averaged across locations, inoculant did not benefit MSSY. Branch seed yield responded similarly to inoculant; however increased interactions with inoculant and other inputs were observed. Most of the interactions were discussed previously with other inputs. At SUF12, inputs N, fungicide, and inoculant produced 161 g BSY m^{-2} with N/inoculant/fungicide and was greater than 62% of observations (data not shown). When N and inoculant were both removed or inoculant applied alone, the addition of fungicide did not benefit BSY. Furthermore, fungicide increased BSY when both N and inoculant were applied, but did not benefit BSY when inoculant was removed from the N combination.

Secondary Level: Pod per m^2 and Seed per Pod

Inoculant, when applied alone did not increase TP at any experiment location (Table 3.4). When averaged across locations, inoculant application did not benefit TP (Table 3.4). Inputs fungicide and inoculant affected SUF12 by producing 1403 TP m^{-2} with no inoculant/with fungicide, but was not greater than other treatment combinations (Table 3.5.6). Without inoculant application, fungicide tended to increase TP m^{-2}; whereas, the opposite was observed when inoculant was utilized. At WAR13, inputs N, fungicide, and inoculant influenced TP. Treatment combination N/no inoculant/fungicide increased total pod production compared to the combinations N/no inoculant/no fungicide and no N/no inoculant/fungicide by producing 1079, 858, and 876 TP m^{-2}, respectively (Table 3.16). Inoculant was not needed in combination with both N and fungicide. Specifically, with N, inoculant application decreased TP m^{-2} by 13%, compared to without N, inoculant use increased TP m^{-2} by 13%.

Inoculant, applied alone, did not increase MSP per m^2; however interactions involving inoculant were observed. At WAR13, inputs N, fungicide, and inoculant affected MSP (data not shown). Specifically, MSP per m^2 values ranged from 665 to 780 and differences were minimal. When N was applied without inoculant, fungicide increased MSP; without N and with inoculant resulted in MSP response to fungicide application. Inoculant and N were not required together to increase main stem pod production with fungicide application.

Inoculant inconsistently affected BP per m^2 but was observed to interact with other inputs to benefit branch pod production (data not shown). Inputs N, fungicide, and inoculant influenced BP at SUF12 and WAR13 (data not shown). At SUF12, N/inoculant/fungicide produced 513 BP m^{-2} and increased production compared to all other treatment combinations but was not greater than without N/inoculant/no fungicide. With N, inoculant application increased BP, compared to untreated seed. Furthermore, fungicide improved BP when combined with N and inoculant; when inoculant was removed, fungicide did not increase branch pod production. At WAR13, inputs N/inoculant/no fungicide produced the highest value within this interaction at 304 BP m^{-2} and was greater than 37% of observations. When N was applied without inoculant, fungicide increased BP per m^2 but the same was not observed when inoculant and N were both utilized.

Inoculant application decreased TSP at 1 of 6 locations (MTH12) (Table 3.32). Furthermore, when averaged across locations, inoculant decreased TSP by 1% with application (Table 3.4). At PTR13, inputs fungicide and inoculant affected TSP. Without inoculant and with fungicide produced 2.2 TSP and was greater than inoculant/fungicide and no inoculant/no fungicide, but was not greater than inoculant/no fungicide (Table 3.5.6). When inoculant was not applied to the seed prior to planting, fungicide application increased TSP, compared to untreated. When inoculant was used, fungicide was not necessary.

Tertiary Level: Pods per Reproductive Node and Reproductive Nodes per Plant

Inoculant increased TPRN by 3% compared to untreated, when averaged across all 6 locations (Table 3.4). Inoculant, when examined alone, was not responsible for increased TPRN, but when in combination with other inputs, influenced TPRN. When averaged across locations, minimal response to inoculant was observed with reproductive nodes per plant (RN). However, similar to TPRN, inoculant application benefited RN in specific interactions with other inputs.

Quaternary Level: Node per Plant and Percent Reproductive Nodes

Nodes per plant did not respond to inoculant alone. Inoculant application, when averaged across locations slightly decreased NP, compared to untreated (data not shown). At WAR13, inputs N and inoculant produced 14.2 NP, which was greater than with N/no inoculant and no N/with inoculant, but was not different from untreated (13.9 NP, no N/no inoculant) (data not shown). When N was applied, inoculant was necessary to increase nodes per plant; when the inoculant was unpaired from the N treatment, NP decreased from 14.2 to 13.4. In certain situations, inputs may increase plant productivity together, compared to inputs applied alone; however, application of inputs simultaneously may not be greater than untreated and may not be economically viable. Percent reproductive nodes did not response to inoculant when applied alone (Table 3.4). Inoculant influenced % RN similarly to most yield component parameters, where response was characterized as inconsistent, site-specific, yet generally unpredictable.

Starter N

Primary Level: Seed per m^2 and Seed Yield

Starter N application inconsistently affected TS (Table 3.4), MSS (data not shown), and BRS (data not shown). When averaged across locations, N increased TS, MSS, and BRS by 2, 0.4, and 1%, respectively. Total seed yield responded similarly to N by increasing values by approximately 1% for TSY (Table 3.4), MSSY (data not shown), and BSY (data not shown). At SUF12, inputs N and fungicide produced 456 g m^{-2} with N and fungicide application and slightly increased TSY compared to other observations (Table 3.5.7). Fungicide application tended to benefit TSY when N was applied but was not observed without N. However, these values did not differ greatly and differences were minimal.

Secondary Level: Pod per m^2 and Seed per Pod

Starter N inconsistently affected TP independently (Table 3.4), MSP (data not shown), BP (data not shown) and TSP (Table 3.4). When averaged across locations, TP and BP increased with starter N by 2 and 1%, respectively; whereas, MSP and TSP were not influenced across locations. More importantly, as discussed previously, starter N was a component to interactions involving other inputs that increased soybean pod production. At PTR12, inputs N, fungicide, and inoculant produced 1.9 TSP with treatment combination no N/inoculant/fungicide and was greater than 50% of observations (Table 3.17). Highest values were observed with treatment combinations that did not use all three factors simultaneously. When N was applied, and combined with inoculant, fungicide application did not increase TSP; when N was removed but inoculant remained, fungicide increased TSP by 9%.

Tertiary Level: Pods per Reproductive Node and Reproductive Nodes per Plant

Starter N did not significantly influence TPRN; furthermore, when averaged across locations, N increased TPRN by 2% (Table 3.4). Response of TPRN to starter N applied alone was very site specific and minimal in value; however TPRN benefited from previously discussed interactions involving starter N. Reproductive nodes per plant was similar in response; however, at PTR13, starter N increased RN by 7% compared to untreated (Table 3.4). When averaged across locations, starter N increased RN by 2% (Table 3.4). Inputs N, fungicide, and inoculant affected RN at PTR12. Treatment combination with N/no inoculant/with fungicide produced 11 RN plant^{-1} and was highest compared to other treatment combinations but was not greater than no N/with inoculant/with fungicide and no N/no inoculant/with and without fungicide (Table 3.17). When N and inoculant were not applied, fungicide application was not critical; when N or inoculant was applied, fungicide tended to increase RN per plant. Inoculant and N combined to increase RN per plant; however N tended to be slightly more critical to the system compared to inoculant application.

Quaternary Level: Node per Plant and Percent Reproductive Nodes

Starter N increased NP by 4 and 6%, from 15.7 to 16.3 and 11.9 to 12.6 NP at SUF12 and PTR13, respectively (data not shown). When averaged across locations, N increased NP by 2%. Interactions involving NP response to starter N were previously discussed with other inputs. In addition, at SUF12, inputs N, fungicide, and inoculant produced 17 NP with treatment combination N/with inoculant/with fungicide and was greater than three treatment combinations, which included with N/no inoculant/with fungicide, no N/with inoculant/with fungicide, and no

N/no inoculant/no fungicide (P=0.0567) (data not shown). Fungicide did not perform consistently; whereas N and inoculant tended to increase NP in relatively small amounts. Percent RN decreased by 3% when starter N was applied to soybean at SUF13 (Table 3.4). Overall, % RN did not respond to N application and when averaged across locations response was minimal (Table 3.4). However, similar to NP, % RN responded to starter N when in combination with other inputs.

Foliar Fungicide

Primary Level: Seed per m^2 and Seed Yield

When applied alone foliar fungicide did not influence TSM, MSS, or BRS at all locations. Slight increase in TSM and MSS was observed with fungicide but was <1% (Table 3.4 and data not shown, respectively). However, at PTR13, inputs fungicide, seeding rate, and inoculant affected BRS. Treatment combination no inoculant/low seeding rate/no fungicide produced 1124 BRS m^{-2}, which was greater than 37% of observations. Fungicide tended to not increase BRS; however no inoculant/high seeding rate/fungicide increased BRS per m^2 by 22% compared to no fungicide application. Similar to other BRS interactions observed in our experiments, fungicide assisted other inputs to benefit pod production, primarily BRS.

Seed yield parameters were not significantly affected by fungicide that was applied alone; however when these data were examined closely, general trends were observed. Fungicide increased TSY, MSSY, and BSY all by approximately 2%, compared to untreated. While these values are marginal, they represent the yield additive effect observed with foliar fungicide application. Yield results demonstrated by Dillon et al. (In press, Chapter II) demonstrated seed yield increase from fungicide, which was mainly attributed to greater g per m^2. While yield component seed yield parameters may not demonstrate drastic increase in mass due to fungicide application, these data do provide insight into the larger scale associated with plot seed yield.

In addition, further interactions involving seed yield parameters were observed. At WAR13, inputs N, fungicide, and inoculant produced 294 g TSY m^{-2} with N/no inoculant/fungicide, which was greater than just 37% of observations (Table 3.16). Within this interaction, fungicide increased TSY across observations except for the combination no N/no inoculant/fungicide where fungicide application decreased TSY by 8%. At PTR12, inputs N, fungicide, seeding rate, and inoculant affected MSSY (data not shown). Treatment combination no N/high seeding rate/no inoculant/fungicide produced 402 g MSSY m^{-2} and was greater than 75% of interaction observations. Interestingly, 75% of the fungicide response was observed without inoculant and ranged from 12 to 30% positive response.

Secondary Level: Pod per m^2 and Seed per Pod

Total pod per m^2, MSP, BP, and TSP were inconsistently affected by fungicide. When fungicide was examined by itself, application did not consistently improve pod production at the whole plant, main stem, or branch level. Furthermore, fungicide did not improve TSP dynamics (Table 3.4). However, when used in combination with other inputs, at times fungicide provided a pod productivity additive effect.

Tertiary Level: Pods per Reproductive Node and Reproductive Nodes per Plant

Fungicide application did not influence TPRN at 2012 and 2013 locations (Table 3.4) when applied as a single input. Furthermore, when averaged across locations and all other inputs, fungicide decreased TPRN by 2% (Table 3.4). Our data demonstrated that foliar fungicide benefited TPRN when used in combination with other inputs in specific locations. For example, at SUF12, inputs N/inoculant/fungicide increased TPRN compared to all other treatments and produced 3.5 TPRN (Table 3.17). Fungicide improved TPRN; with the same N/inoculant combination, fungicide application increased TPRN by 18%, compared to no fungicide. Reproductive nodes per plant responded to fungicide at one location (PTR12) by increasing RN by 7%, compared to untreated (Table 3.4). When averaged across all locations, fungicide application increased RN by 1%. Foliar fungicide was observed to interact with cultivar, N, inoculant, and seeding rate to increase RN.

Quaternary Level: Node per Plant and Percent Reproductive Nodes

Fungicide application increased NP by 3 and 6%, from 13.6 to 14.0 and 14.3 to 15.3 NP at MTH12 and PTR12, respectively. When averaged across locations, fungicide increased NP by approximately 1%. Response was site-specific; in some experiments, application slightly decreased NP. Inputs N, fungicide, and inoculant affected PTR12 NP (data not shown). Inputs N/no inoculant/with fungicide produced 16.0 NP and was greater than other combinations, except no N/with inoculant/with fungicide and no N/no inoculant/with fungicide. Within this interaction, fungicide application consistently increased NP. The marginal increased NP observed with fungicide at MTH12 is interesting data due to reduced canopy closure observed at that location. Even without closed canopy, fungicide application somehow increased NP. Furthermore, yield response to fungicide was not observed at MTH12 (Dillon et al. Chapter II), yet node production was slightly improved as demonstrated by yield component parameters. While fungicide may have increased NP in limited situations, % RN did not increase with fungicide application (Table 3.4). When averaged across 6 locations and other inputs, fungicide slightly decreased % RN with application (Table 3.4).

Conclusion

Yield component results varied by location and in some instances response to agronomic inputs were site-specific. However, there are trends observed with each input that may aid in providing insight and summary to these large, intensive, and somewhat confusing data. The original objective with cultivar stem growth habit was to compare indeterminate and determinate function in double-crop soybean setting. Cultivar 95Y01, indeterminate in growth habit, matured 7 to 10 days earlier than determinate 95Y20, which affected our results due to 2012 and 2013 growing seasons experiencing atypical season long moisture and subsequently better yield potential for the early-maturing 95Y01. In addition, the short drought experienced during seed fill stages in September of 2013 likely enhances yield differences between the cultivars. However, depending on location, there were periods of moisture stress and in some cases prolonged drought stress throughout both growing seasons that can assist us in comparing these findings to a typical double-crop setting. Specifically, growth and yield was limited at MTH12 but soybean still yielded approximately 3600 kg ha^{-1}, which is greater than current double-crop or full-season soybean yield trends for Virginia. Yield data presented by Dillon et al. (Chapter II) discussed the lack of response to inputs at MTH12; however, yield component parameters were influenced by agronomic inputs but were not similarly expressed in seed yield at the field scale. While reduced rainfall inhibited early-season growth and canopy closure at MTH12, soybean still produced yield. Poor soybean stand was observed at PTR13 and was attributed to large rainfall events combined with poor weed control, but provides an opportunity to examine how these inputs function when plant population is reduced. Furthermore, reduced plant population is a common occurrence in double-crop soybean production.

The following yield component parameters were observed to favor the earlier-maturing indeterminate 95Y01 over the later-maturing determinate 95Y20: 6% more reproductive nodes per plant; 11% more reproductive nodes; 13% more main stem pods and main stem pods per plant (data not shown); 17% more main stem seed m^{-2}; 5% more total seed per pod; 28% more main stem seed yield; 7% more total seed yield; and 4% greater harvest index. In contrast, the following results summary was observed to be favorable for determinate 95Y20: 35% more branches plant^{-1} (data not shown); 6% more nodes plant^{-1}; 54% more branch pods m^{-2}; 51% more branch pods plant^{-1}; 12% more total pods m^{-2}; 11% more total pods plant^{-1}; 17% more total pod reproductive node^{-1}; 53% more branch seed m^{-2}; 7% more total seed m^{-2}; 45% more branch seed yield; 15% larger seed size; 2% more total dry matter (data not shown). Yield component results demonstrated how certain characteristics of either cultivar could be applicable to double-crop soybean by compensating for or taking advantage of certain environmental conditions influencing yield potential. Indeterminate cultivar increased seed yield through greater g per m^2 when compared to determinate cultivar, averaged across locations and other factors. Results were not as clear with yield component parameters but indeterminate 95Y01 slightly increased seed productivity, versus 95Y20, through increased main stem pod and seed no., main stem and total seed yield and harvest index. Indeterminate cultivars may have a fit in double-crop soybean, but will be influenced by early-maturity, other cultivar characteristics, and adaptation to specific locations and latitudes. Early-maturing cultivars (mostly indeterminate) typically perform better in environments with greater yield potential dominated by timely rainfall. Later-maturing (typically determinate) soybean produce stable yield across double-crop environments and may be the better choice in more typical growing seasons that are dominated by limited water availability in sandy coastal plain soils.

The objective with seeding rate was to determine seeding rates above the recommended was better for double-crop soybean, especially when other inputs are considered. We used

593,000 (recommended) vs. 725,000 seed ha^{-1} (intensive management) in these experiments in an attempt to obtain 450,000 and 550,000 plants ha^{-1}. Seeding rate varied by location but there were some trends observed for both levels. The following yield component parameters were observed with recommended (low) seeding rate, compared to the intensive (high) seeding rate: 15% increased branches plant^{-1} (data not shown); 5% more nodes plant^{-1}; 7% increased reproductive nodes plant^{-1}; 3% increased reproductive nodes; 6% increased main stem pod plant^{-1}; 12% increased branch pods m^{-2}; 27% increased branch pods plant^{-1} (data not shown); 2% increased total pods m^{-2}; 16% increased total pods plant^{-1} (data not shown); 9% increased total pods reproductive node^{-1}; 13% increased branch seed m^{-2}; 3% increased total seed m^{-2}; 13% increased branch seed yield; increased total seed yield by 3%; 2% increased total dry matter (data not shown); 0.4% increased HI (data not shown). In contrast, observations for the high seeding rate are much more concise, when compared to the low seeding rate: 2% increase in main stem pods m^{-2}; 2% increased main stem seed yield.

The seeding rate component of our growth and yield objectives (Dillon et al. Chapter II) was not efficiently met due to much less than desired plant populations at all locations for both the low, but especially the high seeding rate. Our obtained plant populations allowed us to adequately compare treatments but the ability to draw conclusions based on desired plant populations was greatly weakened. However, with the yield component analysis, we were able to avoid most of the variability with plant population at the field level and focus on the plant and seed response to agronomic input treatments. Furthermore, it would be interesting to examine similar seeding rates planted in growing environments with limited yield potential, due to moisture stress (i.e. MTH12). In addition it would be helpful in determining if the earlier-maturity and indeterminate growth habit, in our case 95Y01, has a fit in double-crop soybean, or were our results primarily influenced by improved yield potential. When compared with the seed yield results taken from the entire plot and not just 1 m of row (Dillon et al. Chapter II), yield component analysis shared a similar story; the low seeding rate maintained yield potential the same as increasing seeding rates. Specifically, the relative yield comparison for seeding rates when averaged across locations and other factors was 99.8 and 99.9% for low and high seeding rates, respectively (Dillon et al. Chapter II). The recommended seeding rate generally provided adequate plant population for yield components to develop seed yield; however, there were instances due to very poor emergence (i.e. PTR13) that increased seeding rate was necessary to maintain adequate yield potential. In general, the currently recommended seeding rate for double-crop soybean grown in Virginia is appropriate and should not be increased at this time. Future initiatives should build on previously conducted research by Holshouser and Whittaker (2002), Kratochvil et al. (2004), and Norsworthy and Frederick (2002) and examine how low in value can seeding rates be planted in double-crop soybean and still maintain yield potential in drought-stressed coastal plain soils.

Starter N applied at planting in the form of N tended to benefit the double-crop system, particularly with early-season growth that did not always result in increased yield but improved the soybean' ability to deal more efficiently with some of the yield-limiting factors during vegetative growth. Yield component parameters for N application, compared to untreated were as follows: 2% increased nodes plant^{-1}; 2% increased reproductive nodes plant^{-1}; 3% increased main stem pods plant^{-1} (data not shown); 1% increased branch pods m^{-2}; 4% increased branch pods plant^{-1} (data not shown); 2% increased total pods m^{-2}; 4% increased total pods plant^{-1} (data not shown); 1% increased total pods reproductive node^{-1}; 1% increased branch seed m^{-2}; 2% increased total seed m^{-2}; 1% increased main stem seed yield;1% increased total seed yield;

increased total dry matter by 2% (data not shown). The lack of N application was observed to increase harvest index by only 1%, compared to N application (data not shown). Application of starter N may improve yield component ability to produce soybean seed efficiently, but is site-specific and will ultimately be controlled by return on investment. When compared to the seed yield results using the entire plots for measurements and not just 1 m of row (Dillon et al. Chapter II), yield component parameters demonstrated a similar story. Soybean yield obtained from entire 1.1 x 5.1 m harvested plot areas exhibited 1.4% increase in yield with N, when averaged across locations and other factors. In some instances, N increased relative yield by almost 10%, whereas, decreased values were also observed, compared to the untreated control, but responses interacted with other factors and were very site-specific. The N component to the objectives was interesting to study due to the need to modify our planter to adequately meet this objective. Future work is needed examining the same concept, but N applied in 5-cm by 5-cm band to the side and below the seed furrow, which would more accurately represent production settings.

Seed-applied inoculant performed as expected and was unpredictable. Furthermore, it interacted in an unpredictable manner with the other tested factors. However, yield component trends were observed with inoculant, when compared to untreated: increased main stem pods per plant by 1%; 1% increased branch pods m^{-2}; 8% increased branch pods plant^{-1} (data not shown); no effect on total pods per m^{2}; 3% increased total pods plant^{-1} (data not shown); 3% increased total pods reproductive node^{-1}; 2% increased total seed m^{-2}. In contrast, the lack of inoculant was beneficial to some yield component parameters, compared to with inoculant: increased nodes plant^{-1} by 0.2%; increased reproductive nodes by 0.5%; 1% increased main stem pods m^{-2}; increased main stem seed yield by 2%; 1% increased total seed yield; increased total dry matter by 1% (data not shown). Inoculant has a site-specific fit in double-crop soybean and the yield component data, similar to seed yield data taken from harvesting entire plots (Dillon et al. Chapter II), demonstrated inoculant response to be variable and slightly improved plant productivity where soybean had been grown previously. The current recommendations are to apply inoculant if soybean has not been grown in the previous three years; the double-crop system may put increased stress on *Bradyrhizobium japonicum* populations due to reduced water availability and may require increased or more-timely inoculant application within intensified management.

Foliar fungicide consistently increased soybean seed yield (Dillon et al. Chapter II) but exhibited more elusive response with yield components. Fungicide application, when compared to untreated, was observed to: increase nodes plant^{-1} by 1%; increased reproductive nodes by 1%; 1% increased main stem pods; no effect on total pods plant^{-1} (data not shown); 1% increased main stem seed m^{-2}; 2% increased main stem seed yield; 2% increased branch seed yield; 2% increased total seed yield; increased total dry matter by 3% (data not shown). Without fungicide, yield component parameter observations were as follows: 2% increased main stem pod plant^{-1} (data not shown); 3% increased branch pods plant^{-1} (data not shown); 2% increased total pods plant^{-1} (data not shown); 2% increased total pods reproductive node^{-1}; increased seed size by 1%. Foliar fungicide did not provide one large increase for one specific yield component parameter; rather, application slightly increased numerous parameters, when combined, positively influenced yield. Seed yield results demonstrated (Dillon et al. Chapter II) fungicide to increase yield by 5%, when averaged across locations and other factors. Furthermore, fungicide performed the most consistently out of all agronomic inputs validated. The two growing seasons when our experiments were conducted exhibited increased disease incidence at most locations due to increased rainfall that promoted soybean disease development and fungicide response would be expected in such environments. Even when fungicide increased seed yield through more efficient seed production, the return on investment was not always positive (Dillon et al. Chapter II). Foliar fungicide can be effective but should be a single tool within a much larger management approach to soybean disease management.

Our experiments demonstrated the importance of promoting efficient soybean plant and seed productivity through wise agronomic practices and input management. Yield component parameters were significantly affected by environmental conditions that varied by location. Ideally, crop stress conditions would not be a limiting factor to ensure complete and accurate yield component analysis. However, the double-crop soybean growing environment varies by year and soybean can suffer from extreme moisture stress. It is crucial for researchers to understand yield component dynamics at the plant and seed level to more efficiently manage soybean yield potential partially determined by the environment and be able to assist farmers with agronomic decision making concerned with soybean productivity, ultimately determined through yield component parameters.

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Table 3.1 Site physical soil characteristics for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Site-Year	Soil Series and Texture †	Soil Classification †	Latitude	Longitude
MTH12	State fine sandy loam	Fine-loamy, mixed, semiactive, thermic Typic Hapludults	38° 5'0.16"N	76°42'39.49"W
PTR12	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF12	Nansemond loamy fine sand	Fine-loamy, siliceous, semiactive, thermic Aquic Hapludults	36°40'1.86"N	76°43'41.61"W
WAR13	Kempsville loam	Fine-loamy, siliceous, subactive, thermic Typic Hapludults	37°59'24.22"N	76°46'29.48"W
PTR13	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF13	Dragston fine sandy loam	Coarse-loamy, mixed, semiactive, thermic Aeric Endoaquults	36°41'1.66"N	76°45'39.85"W

† USDA-NRCS web soil survey (WSS, 2014).

Table 3.2 Calendar dates for agronomic inputs, data collection, and growth and developmental stages for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Agronomic Input	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Planting	6/20	6/28	6/21	7/8	7/15	6/20
Stand counts	7/10	7/18	7/11	7/23	7/30	7/9
V4 plant height †	7/31	8/7	7/23	8/6	8/12	7/24
V4 plant tissue	7/31	8/7	7/23	8/6	8/12	7/24
V4 NDVI	-	-	-	8/6	8/12	7/24
R3 fungicide app.	8/24	8/29	8/21	8/27	9/6	8/20
R3 NDVI	-	-	-	8/27	9/6	8/21
R5 fungicide app.	9/5	9/10	9/6	9/17	9/24	9/4
R5 plant tissue	9/5	9/10	9/4	9/17	9/24	9/4
R5 NDVI	9/5	9/10	9/10	9/17	9/24	9/4
R8 plant height	-	-	-	12/4	11/25	10/17
Yield component	11/12	11/6	11/5	12/4	12/12	11/12
Harvest	11/20	11/29	11/28	12/4	12/17	12/3
Growth stage †						
V2	7/10	7/18	7/11	7/26	8/2	7/9
V3	7/19	7/25	7/16	7/30	8/5	7/16
V4	7/31	8/7	7/20	8/2	8/8	7/19
R2	8/14	8/20	8/8	8/20	8/28	8/9
R3	8/24	8/29	8/21	8/27	9/6	8/17
R4	8/30	9/3	8/30	9/8	9/13	8/23
R5	9/5	9/10	9/6	9/17	9/24	9/4
R6	9/20	9/25	9/19	9/26	10/2	9/18
R7	10/19	10/24	10/18	10/22	10/30	10/6
R8	11/12	11/6	11/5	11/25	11/25	10/24

† Soybean growth and development stages as described by Fehr and Caviness (1977).

Table 3.3 Growing season air temperature and precipitation for the 2012 and 2013 agronomic input experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Site-Year					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Temperature	---------------------------------------°C---------------------------------------					
May	21	21	21	20	19	19
June	23	23	23	24	24	24
July	28	28	27	26	26	26
August	26	25	25	23	23	24
September	21	22	21	20	21	20
October	16	17	16	16	17	17
November	7	8	7	8	9	9
Mean	20	21	20	20	20	20
May-Nov.	(20)†	(20)	(21)	(20)	(20)	(21)
Precipitation	----------------------------------mm----------------------------------					
May	67	64	204	55	42	91
June	13	103	157	194	179	206
July	30	123	120	158	84	88
August	141	246	204	95	100	164
September	69	55	92	26	46	51
October	191	252	208	76	96	115
November	12	21	18	75	61	88
Total	524	864	1003	679	608	803
May-Nov.	(710)†	(692)	(768)	(710)	(692)	(768)

† 29 year May-Nov. mean in parenthesis.

Table 3.4 Main effect cultivar (C), seeding rate (S), nitrogen (N), inoculant (I), and fungicide (F) influenced soybean yield components for 2012 and 2013 agronomic input soybean experiments.

	Site-Year					
	MTH12	**PTR12**	**SUF12**	**WAR13**	**PTR13**	**SUF13**
C £	--------------------------Reproductive nodes per plant--------------------------					
95Y01	10.2 a †	10.5 a	12.0 a	9.4 a	9.5 a	11.4 a
95Y20	9.1 b	9.9 b	10.6 b	9.5 a	9.8 a	10.3 b
S β						
593,000	10.0 a	10.7 a	11.4 a	9.9 a	10.1 a	11.4 a
725,000	9.2 b	9.6 b	11.2 a	9.1 b	9.2 b	10.3 b
N ‡						
With	9.7 a	10.2 a	11.5 a	9.6 a	10.0 a	10.7 a
Without	9.5 a	10.1 a	11.1 a	9.3 a	9.3 b	11.1 a
I §						
With	9.6 a	10.0 a	11.5 a	9.6 a	9.8 a	10.8 a
Without	9.6 a	10.4 a	11.2 a	9.4 a	9.6 a	10.9 a
F Φ						
With	9.4 a	10.6 a	11.3 a	9.3 a	9.5 a	10.9 a
Without	9.8 a	9.8 b	11.3 a	9.7 a	9.9 a	10.9 a
C £	---------------------------Percent reproductive nodes---------------------------					
95Y01	74.5 a †	74.8 a	74.4 a	73.2 a	81.5 a	81.0 a
95Y20	64.9 b	63.1 b	66.7 b	65.3 b	76.1 b	70.5 b
S β						
593,000	70.2 a	70.7 a	70.9 a	70.3 a	81.0 a	76.7 a
725,000	69.2 a	67.2 b	70.2 a	68.2 a	76.6 b	74.7 a
N ‡						
With	69.2 a	68.6 a	70.2 a	69.7 a	79.6 a	74.6 b
Without	70.2 a	69.3 a	70.9 a	68.8 a	78.0 a	76.8 a
I §						
With	69.9 a	68.6 a	71.0 a	69.7 a	79.2 a	75.8 a
Without	69.5 a	69.3 a	70.1 a	68.8 a	78.4 a	75.7 a
F Φ						
With	67.3 b	69.2 a	71.2 a	68.6 a	77.7 a	75.1 a
Without	72.1 a	68.7 a	70.0 a	69.9 a	79.9 a	76.4 a
C £	---------------------------------Total pod per m^2---------------------------------					
95Y01	946.6 b †	1076.2 b	1187.1 b	974.6 a	1047.1 b	1482.6 a
95Y20	1037.0 a	1242.0 a	1470.6 a	958.2 a	1297.1 a	1632.2 a
S β						
593,000	1014.4 a	1191.1 a	1304.6 a	965.9 a	1202.9 a	1572.5 a
725,000	969.2 a	1127.1 a	1353.0 a	966.9 a	1141.3 a	1542.2 a
N ‡						
With	1102.0 a	1145.8 a	1311.2 a	983.3 a	1199.3 a	1553.1 a
Without	981.6 a	1172.4 a	1346.4 a	949.5 a	1144.8 a	1561.6 a

I §						
With	991.2 a	1154.2 a	1310.7 a	983.0 a	1161.3 a	1555.9 a
Without	992.4 a	1164.0 a	1346.9 a	949.8 a	1182.8 a	1558.8 a
F Φ						
With	1009.6 a	1157.9 a	1334.0 a	980.7 a	1135.8 a	1572.6 a
Without	974.0 a	1160.3 a	1323.6 a	952.0 a	1208.3 a	1542.1 a
C £	------------------------Total pods per reproductive node------------------------					
95Y01	2.20 b †	2.50 b	2.71 b	2.03 b	2.23 b	2.59 b
95Y20	2.40 a	2.85 a	3.19 a	2.49 a	3.26 a	3.03 a
S β						
593,000	2.41 a	2.87 a	3.01 a	2.30 a	2.99 a	2.88 a
725,000	2.19 b	2.47 b	2.89 a	2.23 a	2.50 b	2.73 a
N ‡						
With	2.32 a	2.63 a	3.01 a	2.32 a	2.80 a	2.75 a
Without	2.28 a	2.72 a	2.89 a	2.20 a	2.68 a	2.86 a
I §						
With	2.34 a	2.72 a	3.02 a	2.31 a	2.76 a	2.79 a
Without	2.26 a	2.63 a	2.88 a	2.22 a	2.73 a	2.82 a
F Φ						
With	2.26 a	2.69 a	2.91 a	2.24 a	2.67 a	2.77 a
Without	2.34 a	2.65 a	2.99 a	2.28 a	2.81 a	2.84 a
C £	----------------------------------Total seed per m^2----------------------------------					
95Y01	2155.4 a †	2031.0 b	2553.8 b	2044.2 a	2301.2 b	3172.7 a
95Y20	2214.9 a	2231.1 a	2927.3 a	1992.6 a	2788.4 a	3263.9 a
S β						
593,000	2255.6 a	2202.8 a	2714.3 a	2031.9 a	2601.6 a	3275.7 a
725,000	2114.7 a	2059.4 a	2766.8 a	2004.8 a	2488.0 a	3160.9 a
N ‡						
With	2195.5 a	2102.5 a	2729.4 a	2109.5 a	2604.3 a	3215.6 a
Without	2174.8 a	2159.6 a	2751.7 a	1927.3 a	2485.2 a	3221.0 a
I §						
With	2155.3 a	2110.4 a	2702.6 a	2021.6 a	2498.8 a	3218.5 a
Without	2215.1 a	2151.7 a	2778.5 a	2015.1 a	2590.8 a	3218.1 a
F Φ						
With	2228.1 a	2143.5 a	2756.0 a	2052.2 a	2481.4 a	3233.5 a
Without	2142.3 a	2118.6 a	2725.2 a	1984.6 a	2608.2 a	3203.1 a
C £	--------------------------------Total seed per pod--------------------------------					
95Y01	2.28 a †	1.89 a	2.16 a	2.10 a	2.21 a	2.14 a
95Y20	2.14 b	1.80 b	1.99 b	2.12 a	2.15 b	2.00 b
S β						
593,000	2.23 a	1.86 a	2.08 a	2.13 a	2.17 a	2.08 a
725,000	2.19 a	1.83 a	2.06 a	2.09 a	2.19 a	2.05 a
N ‡						
With	2.21 a	1.85 a	2.09 a	2.18 a	2.17 a	2.07 a
Without	2.22 a	1.85 a	2.06 a	2.04 a	2.18 a	2.07 a

I §						
With	2.18 b	1.84 a	2.07 a	2.08 a	2.16 a	2.07 a
Without	2.24 a	1.86 a	2.08 a	2.14 a	2.20 a	2.07 a
F Φ						
With	2.22 a	1.86 a	2.08 a	2.11 a	2.19 a	2.06 a
Without	2.20 a	1.83 a	2.07 a	2.11 a	2.17 a	2.08 a
C £	----------------------------Total seed yield (g m^{-2}) ----------------------------					
95Y01	335.0 a †	361.9 a	437.7 a	278.8 a	357.6 a	501.1 a
95Y20	297.7 b	334.2 a	438.5 a	243.0 b	348.6 a	458.2 a
S β						
593,000	326.5 a	358.9 a	430.0 a	262.2 a	359.2 a	488.0 a
725,000	306.2 a	337.3 a	446.2 a	259.6 a	347.0 a	471.3 a
N ‡						
With	314.3 a	343.4 a	432.4 a	270.6 a	363.2 a	484.9 a
Without	318.4 a	352.7 a	443.8 a	251.1 a	343.0 a	474.4 a
I §						
With	312.4 a	347.0 a	435.0 a	265.4 a	344.8 a	477.1 a
Without	320.3 a	349.2 a	441.2 a	256.4 a	361.4 a	482.2 a
F Φ						
With	319.6 a	351.2 a	445.5 a	269.7 a	345.7 a	487.3 a
Without	313.1 a	345.0 a	430.7 a	252.0 a	360.6 a	471.9 a
C £	------------------------------Seed size (seed per kg) ------------------------------					
P95Y01	6452.9 b †	5605.4 b	5884.3 b	7256.0 b	6471.5 b	6333.6 b
P95Y20	7458.3 a	6685.5 a	6677.8 a	8389.3 a	7993.7 a	7330.6 a
S β						
593,000	6971.4 a	6155.2 a	6352.4 a	7730.1 a	7245.1 a	6751.4 a
725,000	6939.8 a	6136.7 a	6209.6 a	7915.2 a	7220.1 a	6912.7 a
N ‡						
With	7045.6 a	6147.4 a	6349.2 a	7977.5 a	7233.2 a	6664.7 a
Without	6865.5 a	6144.6 a	6212.8 a	7667.8 a	7232.1 a	6999.5 a
I §						
With	6922.5 a	6120.1 a	6225.5 a	7611.1 a	7249.5 a	6973.7 a
Without	6988.7 a	6171.8 a	6336.5 a	8034.2 a	7215.8 a	6690.5 a
F Φ						
With	7041.7 a	6118.9 a	6194.4 a	7622.0 a	7191.9 a	6846.5 a
Without	6869.4 a	6173.1 a	6367.7 a	8023.3 a	7273.3 a	6817.7 a
C £	-----------------------------------Harvest index-----------------------------------					
95Y01	52.5 a †	52.4 a	53.0 a	44.7 a	54.2 a	55.2 a
95Y20	48.7 b	47.1 b	50.6 b	38.0 b	52.9 a	48.5 b
S β						
593,000	50.6 a	50.3 a	51.9 a	41.1 a	53.9 a	52.2 a
725,000	50.5 a	49.3 a	51.6 a	41.6 a	53.3 a	51.6 a
N ‡						
With	50.0 b	50.1 a	51.2 a	41.5 a	52.7 a	52.1 a
Without	51.2 a	49.5 a	52.4 a	41.3 a	54.4 a	51.7 a

I §						
With	50.5 a	49.9 a	52.3 a	41.0 a	53.5 a	52.2 a
Without	50.6 a	49.7 a	51.3 a	41.8 a	53.6 a	51.6 a
F Φ						
With	49.9 b	49.5 a	52.1 a	40.8 a	54.5 a	51.2 a
Without	51.3 a	50.1 a	51.5 a	41.9 a	52.7 a	52.6 a

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

β Seed ha^{-1}.

‡ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

Φ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

Table 3.5 Interaction between cultivar (C), seeding rate (S), inoculant (I), nitrogen (N), and fungicide (F) influenced soybean yield component parameters for 2012 and 2013 agronomic input experiments.

Table 3.5.1					PTR13
					Total seed yield
C £	S β	I §	N ‡	F Φ	----g per m^2----
P95Y01	-	-	With	-	382.7 a †
	-	-	Without	-	332.6 b
P95Y20	-	-	With	-	343.8 ab
	-	-	Without	-	353.4 ab

Table 3.5.2					SUF12	PTR13	Harvest index	
					Reproductive Nodes	Total Seed	PTR12	SUF13
C £	S β	I §	N ‡	F Φ	-------%-------	no. per pod	-------%-------	
P95Y01	-	With	-	-	76.1 a	2.22 a	53.4 a †	56.5 a
	-	Without	-	-	72.8 b	2.19 a	51.5 a	54.0 a
P95Y20	-	With	-	-	65.9 c	2.11 b	46.4 b	47.8 b
	-	Without	-	-	67.5 c	2.20 a	47.9 b	49.3 b

Table 3.5.3					MTH12	PTR13
					Reproductive Nodes	Harvest index
C £	S β	I §	N ‡	F Φ	-----------------%-----------------	
P95Y01	-	-	-	With	71.1 b †	53.1 ab
	-	-	-	Without	78.0 a	55.3 a
P95Y20	-	-	-	With	63.4 d	55.8 a
	-	-	-	Without	66.3 c	50.1 b

Table 3.5.4					MTH12		SUF13
					Reproductive Nodes	Pods	Total seed yield
C £	S β	I §	N ‡	F Φ	---------no. per plant---------		--g per m^2--
-	593,000	-	-	With	9.5 b †	22.2 b	522.3 a

-		-	-	Without	10.6 a	26.9 a	453.7 a
-	725,000	-	-	With	9.3 b	20.6 b	452.4 a
-		-	-	Without	9.1 b	19.8 b	490.2 a

Table 3.5.5

					MTH12	PTR12	SUF12
					Reproductive nodes	Total seed	Harvest index
C £	S β	I §	N ‡	F Φ	-------%-------	no. per pod	----%----
-	593,000	-	With	-	70.8 a †	1.82 bc	50.2 b
-		-	Without	-	69.6 ab	1.90 a	53.7 a
-	725,000	-	With	-	67.5 b	1.87 ab	52.2 ab
-		-	Without	-	70.8 a	1.79 c	51.1 ab

Table 3.5.6

					SUF12		PTR13
					Pods	Total seed yield	Total seed
C £	S β	I §	N ‡	F Φ	no. per m^2	----g per m^2----	no. per pod
-	-	With	-	With	1265.4 a †	424.3 ab	2.15 b
-	-		-	Without	1356.1 a	445.6 ab	2.17 ab
-	-	Without	-	With	1402.7 a	466.6 a	2.23 a
-	-		-	Without	1291.1 a	415.8 b	2.16 b

Table 3.5.7

					SUF12
					Total seed yield
C £	S β	I §	N ‡	F Φ	----g per m^2----
-	-	-	With	With	455.9 a †
-	-	-		Without	408.9 a
-	-	-	Without	With	435.0 a
-	-	-		Without	452.5 a

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

β Seed ha^{-1}.

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

‡ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

Φ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water at R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within interaction, parameter, and column are significantly different based on Fisher's Protected LSD at P (0.05).

Table 3.6 Interaction between N, cultivar, and fungicide influenced MTH12 reproductive (repro) node/plant, total pods/plant, total pods/reproductive node, SUF12 total pods/reproductive node, and WAR13 total pods/m^2 for agronomic input experiments.

			MTH12			SUF12	WAR13
N £	Cultivar ‡	Fungicide §	Repro. Node	Total Pod			
			---------no. plant^{-1}---------		-----no. repro. node^{-1}-----		--no. m^{-2}--
With	95Y01	With	9.8 bc †	20.7 b	2.11 b	2.86 cd	1080.5 a
		Without	10.9 a	25.8 a	2.33 ab	2.83 cd	896.5 b
	95Y20	With	9.1 bcd	22.7 ab	2.48 a	3.33 ab	957.1 ab
		Without	9.0 cd	21.9 ab	2.36 ab	3.01 bc	998.9 ab
Without	95Y01	With	10.1 ab	22.3 ab	2.21 b	2.57 d	918.0 ab
		Without	10.0 abc	21.7 ab	2.16 b	2.57 d	1013.3 ab
	95Y20	With	8.8 d	19.9 b	2.25 ab	2.89 cd	967.4 ab
		Without	9.4 bcd	24.0 ab	2.51 a	3.54 a	909.4 b

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

‡ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.7 Interaction between cultivar, seeding rate, inoculant, and fungicide influenced SUF12 total seed per pod and WAR13 harvest index for agronomic input experiments.

	Seeding			SUF12	WAR13
Cultivar ‡	Rate β	Inoculant Φ	Fungicide §	Total Seed	Harvest Index
				no. pod^{-1}	------%------
95Y01	593,000	With	With	2.13 b-f †	40.0 bcd
			Without	2.14 a-e	44.7 ab
		Without	With	2.19 abc	46.7 a
			Without	2.16 a-d	43.5 abc
	716,000	With	With	2.22 a	44.9 ab
			Without	2.10 d-g	44.5 ab
		Without	With	2.11 c-f	44.7 ab
			Without	2.20 ab	48.8 a
95Y20	593,000	With	With	2.04 f-i	40.0 bcd
			Without	1.97 hij	39.6 bcd
		Without	With	1.99 hij	37.3 d
			Without	2.05 e-h	37.0 d
	716,000	With	With	1.96 ij	34.5 d
			Without	2.01 g-j	39.5 bcd
		Without	With	1.97 hij	38.4 cd
			Without	1.94 j	37.6 cd

‡ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

β Seed ha^{-1}.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.8 Interaction between N, cultivar, seeding rate, and fungicide influenced MTH12 total seed per pod in agronomic input experiments.

N £	Cultivar ‡	Seeding Rate Φ	Fungicide §	MTH12 Total Seed
				no. pod^{-1}
With	95Y01	593,000	With	2.26 a-e †
			Without	2.36 a
		716,000	With	2.26 a-e
			Without	2.21 b-f
	95Y20	593,000	With	2.27 a-d
			Without	2.03 g
		716,000	With	2.09 fg
			Without	2.12 efg
Without	95Y01	593,000	With	2.33 ab
			Without	2.28 abc
		716,000	With	2.27 a-d
			Without	2.25 a-e
	95Y20	593,000	With	2.13 c-g
			Without	2.21 b-f
		716,000	With	2.15 c-g
			Without	2.13 d-g

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

‡ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

Φ Seed ha^{-1}.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.9 Interaction between N, cultivar, and seeding rate influenced SUF12 percent reproductive (repro) node, total pods per plant and total pods per reproductive node for agronomic input experiments.

		Seeding	SUF12		
N £	Cultivar ‡	Rate §	Repro. Node	Total Pod	
			-------%-------	no plant^{-1}	no. repro. node^{-1}
With	95Y01	593,000	75.8 a †	39.9 a	3.10 a
		716,000	72.9 ab	30.3 b	2.59 b
	95Y20	593,000	65.3 c	33.3 ab	3.07 a
		716,000	66.7 c	35.7 ab	3.27 a
Without	95Y01	593,000	73.5 a	30.7 b	2.58 b
		716,000	75.5 a	31.3 b	2.56 b
	95Y20	593,000	69.0 bc	35.5 ab	3.27 a
		716,000	65.7 c	31.7 b	3.16 a

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

‡ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

§ Seed ha^{-1}.

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.10 Interaction between N, cultivar, seeding rate and inoculant influenced WAR13 percent reproductive (repro) nodes, total pods per plant and total pods per reproductive node for agronomic input experiments.

		Seeding		WAR13		
N £	Cultivar Φ	Rate ‡	Inoculant §	Repro. Node	Total Pod	
				------%------	no. plant^{-1}	no. repro. node^{-1}
With	95Y01	593,000	With	79.5 a †	24.0 a-d	2.19 b-f
			Without	73.9 a-d	20.2 cde	2.05 def
		716,000	With	69.2 c-g	16.7 e	1.93 f
			Without	71.5 b-e	17.5 e	2.00 f
	95Y20	593,000	With	67.7 d-h	28.8 a	2.59 a
			Without	64.9 fgh	26.5 ab	2.72 a
		716,000	With	62.5 h	25.7 abc	2.69 a
			Without	68.3 c-h	22.2 b-e	2.41 a-d
Without	95Y01	593,000	With	72.0 b-e	19.0 de	2.01 ef
			Without	74.4 abc	21.4 b-e	2.09 c-f
		716,000	With	76.0 ab	19.6 cde	2.09 c-f
			Without	69.3 c-f	16.5 e	1.88 f
	95Y20	593,000	With	67.9 d-h	24.2 a-d	2.55 ab
			Without	61.9 h	20.0 cde	2.16 c-f
		716,000	With	67.7 gh	21.8 b-e	2.38 a-e
			Without	66.3 e-h	24.8 a-d	2.44 abc

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.
Φ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.
‡ Seed ha^{-1}.
§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.
† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.11 Interaction between N, fungicide, cultivar and inoculant influenced SUF12 reproductive (repro.) nodes per plant, WAR13 reproductive nodes per plant, and percent reproductive nodes for agronomic input experiments.

				SUF12	WAR13	
N £	Cultivar ‡	Inoculant Φ	Fungicide §	Repro. Node	Repro. Node	
				----------no. plant^{-1}----------		----%----
With	95Y01	With	With	13.3 a †	9.4 abc	75.0 ab
			Without	11.8 a-e	10.0 ab	73.7 abc
		Without	With	10.9 c-f	9.7 abc	75.8 a
			Without	12.3 abc	8.9 bc	69.7 a-d
	95Y20	With	With	11.4 b-f	9.9 ab	63.7 de
			Without	10.5 def	10.3 a	66.6 de
		Without	With	10.7 c-f	9.0 abc	63.7 de
			Without	10.7 c-f	9.87 abc	69.5 a-d
Without	95Y01	With	With	11.4 b-f	9.7 abc	74.3 abc
			Without	12.8 ab	9.1 abc	73.8 abc
		Without	With	12.1 a-d	8.9 bc	69.2 b-e
			Without	11.2 b-f	9.9 ab	74.5 ab
	95Y20	With	With	10.3 ef	8.4 c	62.8 e
			Without	10.0 f	9.87 abc	67.8 cde
		Without	With	10.6 c-f	9.3 abc	64.6 de
			Without	10.7 c-f	9.6 abc	63.6 de

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

‡ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.12 Interaction between N, seeding rate, and fungicide influenced WAR13 total pods per m^2 and total seed per pod, and PTR13 total pods per plant and total pods per reproductive (repro) node for agronomic input experiments.

N £	Seeding Rate Φ	Fungicide §	WAR13		PTR13	
			Total Pod	Total Seed	Total Pod	
			--no. m^{-2}--	-no. pod^{-1}-	no. plant^{-1}	no. repro. node^{-1}
With	593,000	With	996.7 a †	2.34 a	27.1 bc	2.67 bc
		Without	970.0 a	2.13 ab	38.3 a	3.43 a
	716,000	With	1040.9 a	2.07 ab	25.0 bc	2.55 c
		Without	925.4 a	2.18 ab	25.2 bc	2.57 c
Without	593,000	With	1000.2 a	1.90 b	30.6 b	3.16 ab
		Without	896.5 a	2.14 ab	26.6 bc	2.70 bc
	716,000	With	885.2 a	2.13 ab	20.6 c	2.31 c
		Without	1016.2 a	1.99 b	23.3 bc	2.56 c

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

Φ Seed ha^{-1}.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.13 Interaction between N, seeding rate, and inoculant influenced SUF12 total seed per pod for agronomic input experiments.

			SUF12
N £	Seeding Rate Φ	Inoculant §	Total Seed
			--no pod^{-1}--
With	593,000	With	2.03 b †
		Without	2.12 a
	716,000	With	2.11 a
		Without	2.08 ab
Without	593,000	With	2.11 a
		Without	2.08 ab
	716,000	With	2.03 b
		Without	2.03 b

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

Φ Seed ha^{-1}.

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.14 Interaction between inoculant, seeding rate, and fungicide influenced SUF12 reproductive (repro) nodes per plant, SUF13 total pods per reproductive node, total seed per pod, and PTR13 reproductive nodes per plant for agronomic input experiments.

			2012	2013		
	Seeding			Suffolk		Painter
Inoculant ‡	Rate Φ	Fungicide §	Repro. Node	Total Pod	Total Seed	Repro Node
			no. plant^{-1}	no. repro. node^{-1}	no. pod^{-1}	no. plant^{-1}
With	593,000	With	11.4 a †	3.08 a	2.12 a	10.5 a
		Without	11.8 a	2.74 ab	2.04 ab	10.3 a
	716,000	With	11.8 a	2.50 b	2.00 b	8.6 b
		Without	10.8 a	2.86 ab	2.11 a	9.7 ab
Without	593,000	With	11.4 a	2.71 ab	2.05 ab	9.3 ab
		Without	11.0 a	3.00 a	2.12 a	10.5 a
	716,000	With	10.7 a	2.80 ab	2.06 ab	9.6 ab
		Without	11.4 a	2.77 ab	2.04 ab	9.0 b

‡ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

Φ Seed ha^{-1}.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher’s Protected LSD at P (0.05) level.

Table 3.15 Interaction between N, fungicide, seeding rate and inoculant influenced WAR13 reproductive (repro) nodes per plant, and percent reproductive node for agronomic input experiments.

N £	Seeding Rate ‡	Inoculant Φ	Fungicide §	WAR13 Repro. Node	
				no. plant^{-1}	---%---
With	593,000	With	With	10.5 ab	72.7 ab
			Without	11.3 a	74.5 a
		Without	With	10.2 abc	72.3 abc
			Without	9.2 bcd	66.5 bcd
	716,000	With	With	8.9 cd	66.0 cd
			Without	9.0 cd	65.8 d
		Without	With	8.5 d	67.1 bcd
			Without	9.5 bcd	72.7 ab
Without	593,000	With	With	9.5 bcd	71.2 a-d
			Without	9.3 bcd	68.7 a-d
		Without	With	9.0 cd	67.0 bcd
			Without	10.1 abc	69.3 a-d
	716,000	With	With	8.7 d	65.9 cd
			Without	9.6 bcd	72.8 ab
		Without	With	9.2 bcd	66.8 bcd
			Without	9.3 bcd	68.9 a-d

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

‡ Seed ha^{-1}.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.16 Interaction between N, fungicide, and inoculant influenced WAR13 total pods per m^2, total seed per m^2, total seed yield per m^2, and SUF13 harvest index for agronomic input experiments.

			WAR13			SUF13
N £	Inoculant Φ	Fungicide §	Total Pod	Total Seed		Harvest Index
			------------no. m^{-2}------------		--g m^{-2}--	-------%-------
With	With	With	958.2 abc †	2166.0 ab	284.2 ab	53.7 a
		Without	1037.4 ab	2178.9 ab	278.2 ab	52.4 a
	Without	With	1079.4 a	2242.8 a	293.6 a	50.9 ab
		Without	858.0 c	1850.2 ab	226.6 c	51.4 ab
Without	With	With	1009.6 abc	1943.1 ab	259.8 abc	48.2 b
		Without	926.7 abc	1798.3 b	239.4 bc	54.4 a
	Without	With	875.8 bc	1856.7 ab	241.4 bc	52.1 ab
		Without	986.0 abc	2110.9 ab	263.9 abc	52.0 ab

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 3.17 Interaction between N, inoculant, and fungicide influenced PTR12 reproductive nodes per plant, total seed per pod, harvest index, SUF12 total pods per plant and total pods per reproductive (repro) node for agronomic input experiments.

			PTR12			SUF12	
N £	Inoculant Φ	Fungicide §	Repro Node	Total Seed	Harvest Index	Total Pod	
			-no. plant^{-1}-	-no. pod^{-1}-	------%------	no. plant^{-1}	no. repro. node^{-1}
With	With	With	10.0 bc †	1.76 d	48.2 bc	43.3 a	3.47 a
		Without	9.9 bc	1.86 abc	52.7 a	31.6 b	2.84 b
	Without	With	11.2 a	1.89 ab	49.8 abc	29.4 b	2.72 b
		Without	9.8 bc	1.87 abc	49.6 abc	34.9 b	3.00 b
Without	With	With	10.8 ab	1.95 a	51.1 ab	29.4 b	2.71 b
		Without	9.4 c	1.77 cd	47.6 c	34.7 b	3.05 b
	Without	With	10.2 abc	1.84 bcd	48.9 bc	31.3 b	2.74 b
		Without	10.2 abc	1.82 bcd	50.4 abc	33.8 b	3.07 b

£ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

§ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

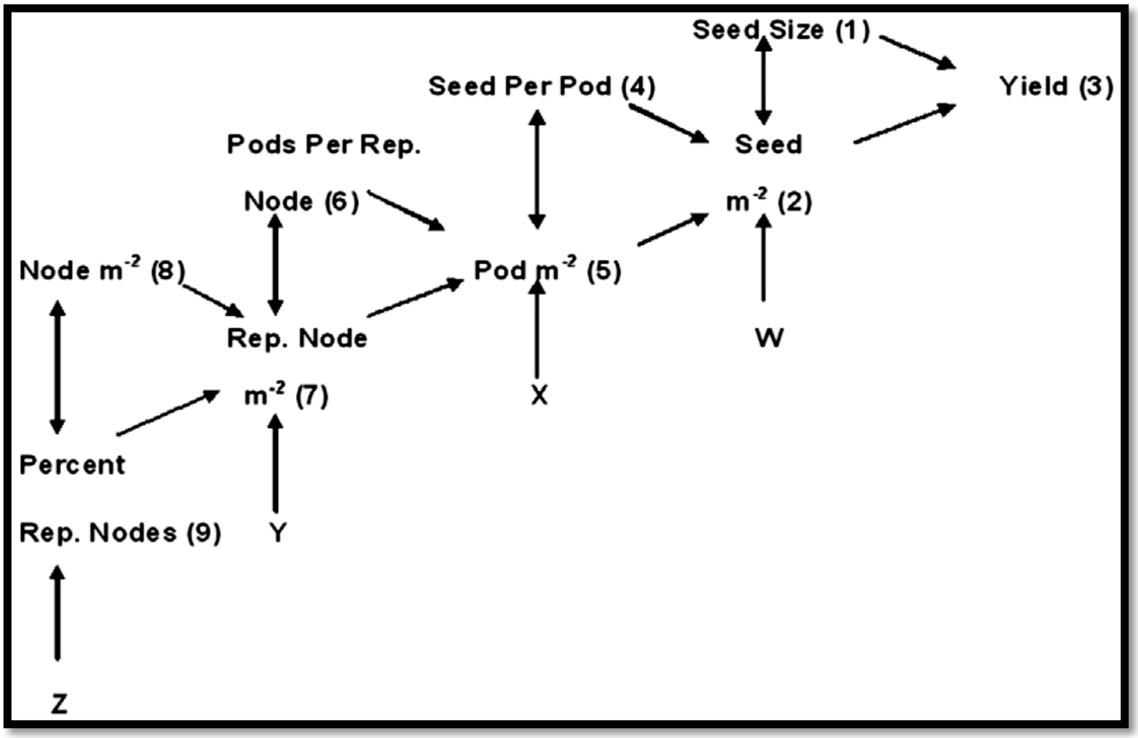

Figure 3.1 Path diagram demonstrating interactions between primary, secondary, tertiary, and quaternary level traits associated with soybean yield component analysis.

Primary level (traits 1, 2→3), secondary level (traits 4, 5→2), tertiary level (6, 7→5), and quaternary level (traits 8, 9→7). The W, X, Y, and Z represent residual effects, in the primary, secondary, tertiary, and quaternary levels, respectively. Adapted from “An analysis of yield component changes for new vs. old soybean cultivars.” by C.S. Kahlon, J.E. Board, and M.S. Kang, 2011, Agron. J., 103, p. 14. Copyright 2011 by the American Society of Agronomy. Adapted with permission.

CHAPTER IV - DOUBLE-CROP SOYBEAN GROWTH AND YIELD RESPONSE TO STARTER NITROGEN AND SEED-APPLIED INOCULANT

Abstract

Double-crop soybean typically exhibit reduced vegetative growth and decreased leaf area, which negatively influences seed production. Increasing early-season growth may improve photosynthetic efficiency, while conserving soil moisture through canopy closure. Field experiments were conducted in eastern Virginia in 2012 and 2013 to evaluate seed-applied inoculant combined with starter nitrogen (N) applied at planting on soybean vegetative response, total N uptake (TNU), seed yield and quality, and yield components produced in a wheat-soybean double-crop system. Measurements included plant height, TNU, normalized difference vegetative index (NDVI), seed yield and quality, and yield components. Canopy NDVI during early-pod fill was greater with starter N application. Node production was maximized at 47 kg N ha^{-1}. Starter N increased seed yield by 6 kg ha^{-1} per kg N applied until yield plateaued at 16 kg N ha^{-1}, which continued to 31 kg N ha^{-1}. When N rate was increased greater than 31 kg N ha^{-1}, yield decreased. Yield increased by 5% from 4055 to 4257 kg ha^{-1} with 16 kg N ha^{-1} and increased net profit by \$67 ha^{-1}, compared to 0 N. Total dry matter, pods per m^2 and seed weight per m^2 were greater with 16 kg N ha^{-1} and comparable to 63 kg N ha^{-1}. Seed size had a linear response to increasing N rates. Inoculant increased 100 seed weight and provided a return on investment of \$8 ha^{-1}. These data demonstrate that starter N is compatible with double-crop soybean, partially attributed to increased leaf, node, pod, and seed productivity.

Abbreviations: N, nitrogen; TNU, total N uptake; NDVI, normalized difference vegetative index.

Introduction

Yield reduction for late-planted double-crop soybean [*Glycine max* (L.) Merr.] is attributed to lack of sufficient vegetative growth (Ball et al., 2000), reductions in crop growth rate during the period when seed number (Egli and Bruening, 2000) and seed weight (Calvino et al., 2003) are defined, and reproductive phase duration (Egli, 2011). Increasing yield in late-planted soybean was correlated to increasing leaf area that maximizes light interception and subsequently increases biomass (Board and Harville, 1993; Jones et al., 2003; Wells, 1991). Approximately 50% of the soybean produced in Virginia is grown in a double-crop system planted sequentially after a small grain, typically wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.).

Soybean's need for nitrogen (N) is met by the residual soil N pool and with symbiotic N_2 fixation from *Bradyrhizobium japonicum* bacteria that convert N_2 gas to plant available N (Patterson and LaRue, 1983). Lindemann and Glover (2003), Salvagiotti et al. (2008), and Mastrodomenico and Purcell (2012) reported that 70%, 50 to 80%, and 90%, respectively of the total plant N requirement was met by N_2 fixation. *Bradyrhizobium japonicum* populations are influenced by plant density, temperature, soil water content, organic matter, texture, and pH (Abendroth and Elmore, 2006; Albrecht et al., 1984; Bacanamwo and Purcell, 1999; Graham, 1992; Seneviratne et al., 2000). If N uptake is limited by an insufficient soil N supply or by declining N_2 fixation during late seed fill, a less than optimal yield ceiling may be imposed upon soybean (Salvagiotti et al., 2009). Soybean nutrition on soils dominated by low organic matter and low N fertility is critically controlled by N_2 fixation (Mastrodomenico and Purcell, 2012). Inoculant use has become increasingly popular due to improved inoculant technology, relatively low product cost, ease of application, and increased input costs associated with nutrient management (De Bruin et al., 2010). However, inoculants are unlikely to increase yield consistently where soybean has previously been grown (De Bruin et al., 2010; Furseth et al., 2012).

Soybean fertilization with N has gathered renewed interest in the U.S. due to the demand for high seed quality, large N requirements for seed fill, and the greater yield potential of modern soybean cultivars (Barker and Sawyer, 2005). The inconsistent soybean response to N fertilization is due in large part to the residual NO_3-N content in the soil (Seneviratne et al., 2000; Weber, 1966). Soybean responded to fertilizer N only when the soil NO_3-N was < 90 kg ha^{-1} (Lamb et al., 1990) or < 56 kg ha^{-1} in the top 61-cm (Scharf and Wiebold, 2003). Nitrogen applied in relatively small amounts at planting can be referred to as starter N and is intended to provide plant-available N to developing seedlings and may be a viable option for late-planted environments with shortened growing seasons. Starling et al. (2000) applied 50 kg N ha^{-1} at planting on coastal plain soils, increased yield by 9%, increased R1 (beginning flower, Fehr and Caviness, 1977), plant height by 5-cm, and plant N by 5%, all compared to 0 N. Pikul et al. (2001) increased soybean yield 9 out of 11 years with banded application of low starter N rates with <15 kg N ha^{-1} when compared to no N application. Taylor et al. (2005) broadcast applied NH_4 NO_3 at five rates (0, 25, 50, 75, and 100 kg N ha^{-1}) immediately after soybean planting on sandy coastal plain soils and maximized yield and R1 dry matter accumulation with 60 to 70 kg N ha^{-1}, reduced nodule number and mass, but did not affect R1 or mature plant height, seed quality, or protein and oil content. In that study, NO_3-N levels were reported at < 8 kg ha^{-1}.

Double-crop soybean grown in the Mid-Atlantic USA typically exhibit reduced vegetative growth that results in decreased photosynthetic area, which negatively influences seed production. Soybean grown in double-crop can yield similarly to full-season if timely rainfall events are observed during sensitive reproductive developmental stages; however, typical weather trends observed with double-crop involve decreased rainfall events and reduced water to the crop. Water is one of the limiting factors that cannot be controlled by most Mid-Atlantic farmers; however early-season growth and subsequent increased leaf area and canopy closure can be improved by specific agronomic management. Increasing canopy closure would increase photosynthetic efficiency, while simultaneously conserving soil moisture and reducing weed competition. We hypothesized that starter N would improve early-season growth and N uptake, but that seed yield would not increase consistently with N or inoculant application. Therefore the study objective was to evaluate seed-applied inoculant combined with starter N applied at planting on soybean vegetative response, total N uptake (TNU), seed yield and quality, and yield components produced in a wheat-soybean double-crop system.

Materials and Methods

Site Description and Cultural Practices

Field experiments were conducted in 2012 and 2013 in a wheat-soybean double-crop system at locations chosen to represent the major soybean producing regions of eastern Virginia, which is dominated by sandy coastal plain soils (Table 4.1). Three locations in 2012 included Tidewater Agricultural Research and Extension Center (AREC) in Suffolk, VA (SUF12), Eastern Shore AREC in Painter, VA (PTR12), and Virginia Crop Improvement Association Foundation Seed Farm in Mt. Holly, VA (MTH12). Four locations in 2013 included Suffolk (SUF13), Painter (PTR13), Eastern Virginia AREC, in Warsaw, VA (WAR13), and Virginia Beach, VA (VB13).

Experiments focused on soybean within wheat-soybean double-crop production settings typical of southeastern Virginia. Winter wheat management information for study locations can be found in Appendix A and were managed according to Extension recommendations (Alley et al., 2009; Anonymous, 2005; Hagood and Herbert, 2012). All locations had soybean planted at least once within the previous four years (Appendix A). At planting, three random soil cores, 2.5-cm in diameter, were collected from each study replication at 0-15, 15-30, and 30-46-cm. Soil samples were air dried, passed through a 2-mm sieve, and analyzed for selected soil chemical properties (soil extractable nutrients, soil water pH, organic matter, and cation exchange capacity) (Appendix C). Soil pH ranged from 5.89 to 6.53. Organic matter ranged from 0.8 to 1.8%, with the exception of Virginia Beach, which was 5.1%. Background soil NH_4 concentrations were 1.0, 0.85, 1.0, 1.2, 0.92, 3.5, and 2.3 kg ha^{-1} for MTH12, PTR12, SUF12, WAR13, PTR13, SUF13, and VB13, respectively (0-15-cm depth). Soil NO_3 concentrations were 2.1, 0.09, 0.36, 0.76, 0.16, 0.51, and 1.8 kg ha^{-1} for MTH12, PTR12, SUF12, WAR13, PTR13, and SUF13, and VB13, respectively (0-15-cm depth). Soil P and K ranged from 24 to 140 mg P kg^{-1} and 73 to 137 mg K kg^{-1}, respectively.

Experiments were no-till planted into wheat stubble immediately after wheat harvest in 38-cm rows (Table 4.2). Cultivar 95Y01 (Pioneer Hi-Bred Int., Inc., Johnston, IA) (Appendix C) was planted at the recommended double-crop seeding rate of 593,000 seed ha^{-1} to obtain a plant population of 445,000 soybean ha^{-1} (Holshouser, 2010). Plots were ten rows wide and 7.3 m in length, but were end-trimmed to 5.2 m before harvest. The left five rows (rows 1 to 5) were used for growth, N uptake, and seed yield measurements and the right five rows (rows 6 to 10) were used for yield component sampling. Plots were managed throughout the growing season according to Extension recommendations and insect and weed pests were maintained below economic injury levels.

Experimental Design

Experiments were conducted as a split-plot design replicated four times. Two factors were tested and included seed-applied liquid inoculant (untreated or with *Bradyrhizobia japonicum*) and 32% urea ammonium nitrate (UAN) solution applied at planting [(0, 16, 31, 47, or 63 kg N ha^{-1}) (32-0-0 N-P-K, 320 g N kg fertilizer^{-1})]. Starter N application defined the main plot and inoculant was chosen as the subplot. For inoculant treatments, *Bradyrhizobia japonicum* (Optimize®, EMD Crop BioScience, Brookfield, WI) liquid inoculant was applied the day prior to planting. Nitrogen was applied during planting with a CO_2 spraying system, calibrated to supply 187 L ha^{-1} water volume at 32 PSI through sidedress 46-cm diameter coulters (Yetter Manufacturing, Colchester, IL), attached to the planter toolbar and centered between the planter units. A combination of dicyandiamide (DCD) + N-(n-butyl) thiophosphoric triamide (NBPT) (Agrotain Plus®, Koch Agronomic Services, LLC, Wichita, KS) was added to the UAN solution to reduce N loss from ammonia volatilization and nitrate loss mechanisms. We changed the water : N ratio to apply the correct N rates.

Data Collection

Plant population was determined two weeks after planting (WAP) by stand counts (Table 4.2). At V4 (fourth fully expanded trifoliate, Fehr and Caviness, 1977) plant height was collected. Normalized difference vegetative index (NDVI) is a calculation based on the red (R) (660 nm) and near infrared (NIR) (770 nm) light wavelengths and is calculated from the formula NDVI = [(NIR-R) / (NIR+R)]. Canopy NDVI was measured with a GreenSeeker Sensor Model 505 (NTech Industries, Inc., Ukiah, CA) at V4 during the 2013 growing season (Table 4.2). When soybean reached V4 1 m of row was removed in three of four replications, oven-dried at 60°C until a constant weight was obtained (48 to 72 hr.), and weighed to determine total dry matter (TDM). Samples were ground through a Wiley mill fitted with a no. 40 (0.420-mm) screen. Total N concentration was determined by CNS dry combustion analysis (Elementar vario EL cube, Elementar Analysensysteme GmbH, Hanau, Germany). Total N uptake was calculated by multiplying TDM by percent N. When soybean reached R3 and R5 (beginning pod and beginning seed, respectively, Fehr and Caviness, 1977), NDVI was measured in 2012 and 2013 (R3 not measured in 2013). Also at R5, total aboveground biomass was collected with the same procedure discussed previously.

Harvest measurements were divided into plot seed yield and yield components. Plant height and lodging were measured at R8 (full maturity, Fehr and Caviness, 1977). The middle three rows plot^{-1} were harvested at full maturity (Table 4.2) with a Wintersteiger® small plot research combine and seed yield was adjusted to 130 g water kg^{-1}. Subsamples from each plot were collected to determine weight of 100 seed, percent purple seed stain, and seed quality. Seed oil and protein concentrations were determined with NIR analysis (Foss Rapid Content Analyser XDS, Foss North America, Eden Prairie, MN) and were corrected for moisture.

Yield components were collected at R8 (Table 4.2). Whole soybean plants from 1 m of row were cut at the soil surface by hand from three replications and weighed to determine total fresh weight. Plants were counted and data converted to plants per m^2. Main stem length for each plant was measured from the base to the top of the plant, and the number of branches (with pods), nodes (starting at first node above unifoliate scars and ending at node at the top of the plant), and reproductive nodes (nodes with pods) were determined. Main stem and branch pods were counted, removed from the plant, and placed in separate bags for processing and measurements. All biomass was oven-dried at 60°C for 48 to 72 h until a constant weight was obtained and weighed. Seed were removed from pods with a small-bundle thresher, weighed, and counted.

The following yield component parameters were calculated: % reproductive nodes per plant (reproductive node number / total node number); pods per reproductive node (total pods per plant / reproductive nodes per plant); main stem pods per m^2; branch pods per m^2; total pods per m^2; pods per plant (main stem pods + branch pods); main stem branch weight per m^2; main stem pod weight per m^2; branch pod weight per m^2; main stem seed per m^2; branch seed per m^2; total seed per m^2 (main stem seed + branch seed); seed per pod (total seed per m^2 / total pod per m^2); main stem seed yield (g per m^2); branch seed yield (g per m^2); total seed yield (g per m^2) (main stem seed yield + branch seed yield); total dry matter (TDM) per m^2 [(main stem and branch DM per m^2) + (main stem pod and branch pod DM per m^2) + seed yield]; seed size (seed per kg) (total seed per m^2 x 1,000) / total seed yield (g) per m^2); and harvest index (total seed yield per m^2 / TDM per m^2 x 100). For ease of discussion, we grouped our yield component parameters similar to Kahlon et al. (2011) as primary, secondary, tertiary, and quaternary, where: primary level included total seed per m^2, main stem seed per m^2, branch seed per m^2, total seed yield, main stem seed yield, branch seed yield, and seed size; secondary level included total pod per m^2, main stem pod per m^2, branch pod per m^2, and total seed per pod; tertiary level contained pods per reproductive node and reproductive nodes per m^2; and quaternary level consisted of nodes per m^2, percent reproductive nodes, and harvest index.

Statistical Analysis

Statistical analysis used PROC MIXED (SAS, 2008) to test fixed effects and interactions among fixed effects. To evaluate the significance of treatment effects on growth, N uptake, NDVI, seed yield, and yield component parameters, inoculant, N, and location were considered fixed. Replicate of each treatment combination was considered a random variable in all analyses. Fisher's least significant difference test and least square means at $P < 0.05$ were used for mean separation. Orthogonal polynomial trend contrasts were constructed to analyze for and describe the relationship between N rate and response parameters.

Results and Discussion

Environmental Conditions

The air temperatures during 2012 and 2013 growing seasons were similar between locations and were close to the 29 year mean (Table 4.3). Rainfall differed greatly between locations. Drought conditions in June and July at MTH12 resulted in reduced soil moisture at planting and poor soybean growth. However, rainfall resumed in August and soybean yield was generally above average. Except for September, rainfall was above average at PTR12. At SUF12, rainfall was at or above average for all months. Other than September, rainfall was near or above average at all locations in 2013. The environment's influence on soybean yield is well documented in coastal plain soils (Freeborn et al., 2001; Holshouser and Whittaker, 2002; Kratochvil et al., 2004; Norsworthy and Frederick, 2002). Rainfall was near or above average at 6 of 7 locations, resulting in very good growth that was atypical of double-crop soybean. Still, intermittent moisture stress limited soybean growth and yield at some locations. Therefore, these data provide the opportunity to validate starter N and seed-applied inoculant across differing environments.

Soybean populations ranged from 202,000 to 435,000 plants ha^{-1} across locations and exhibited 34 to 73% emergence based on a seeding rate of 593,000 seed ha^{-1} (Table 4.4.1). Soybean emergence at MTH12 was limited (57%) due to inadequate soil moisture. Emergence at PTR12 was adequate (70%), but SUF12 emergence resulted in 290,000 plants ha^{-1}, which is much less than the recommended 450,000 soybean ha^{-1} for double-crop. Soybean population at PTR13 was only 202,000 plants ha^{-1} (34% emergence) due to wet soils and residue, and poor weed control that prevented good seed-to-soil contact at planting. With the exception of PTR13, plant populations at the remaining 2013 locations were adequate for good yield potential (Table 4.4.1 and 4.4.2).

Seed Yield and Vegetative Growth

Seed yield varied across locations but location did not interact with other factors (Table 4.5). Soybean yielded 3710, 5099, 4613, 3942, 3844, 2757, and 4572 kg ha^{-1} for MTH12, PTR12, SUF12, VB13, WAR13, PTR13, and SUF13, respectively (Table 4.4.2). Inoculant did not affect yield and did not interact with N; however, starter N significantly affected seed yield. Using orthogonal polynomial trend analysis, yield increased slightly (approximately 50 kg ha^{-1}) to a maximum at 20 to 25 kg N ha^{-1}, then decreased with further N rate increases (Figure 4.1). Starter N increased seed yield by 6 kg ha^{-1} for every kg N ha applied until yield plateaued at 16 kg N ha^{-1}, which continued to 31 kg N ha^{-1}; when the N rate was increased greater than 31 kg N ha^{-1}, yield decreased with N rates 47 and 63 kg ha^{-1} (Table 4.9). However, mean separation indicated that 16 kg N ha^{-1} resulted in the greatest yield versus the other rates tested and increased yield by 5%, from 4055 to 4257 kg ha^{-1}, compared to 0 N (Table 4.6). Similarly, Pikul et al. (2001) applied <15 kg N ha^{-1} and increased soybean yield 9 out of 11 years. Starling et al. (2000) applied 50 kg N ha^{-1} at planting on coastal plain soils and increased yield by 9% compared to 0 N. Taylor et al. (2005) maximized yield with 60 to 70 kg N ha^{-1} on coastal plain soils. In contrast, inoculant did not affect soybean yield in our experiments (Table 4.6).

Starter N application did not affect 100 seed weight of the harvested plot, but inoculant increased 100 seed weight from 17.6 to 17.8 g (1%) (Table 4.6). While this only represented a

1% increase, it indicated that inoculant might contribute to yield through greater seed mass. Seed yield (g per m^2) was collected for comparison with harvested plot yield and 100 seed weight, but will be discussed later with yield components. Weight of 100 seed was the only growth and plot yield parameter influenced by inoculant (Table 4.5); these data show inoculant inconsistently affected soybean and was not predictable. De Bruin et al. (2010) and Schulz and Thelen (2008) both concluded that inoculants are unlikely to increase yield consistently where soybean has previously been grown.

Plant height at V4 differed by location (data not shown) but was not affected by N rate or inoculant, or interactions containing either factor (Table 4.5). Canopy NDVI at V4 was different at 2013 locations and was greatest at WAR13, followed by VB13, SUF13, and PTR13 (Table 4.4.1). However, no V4 NDVI differences were attributed to N rate or inoculant (Table 4.5). Early-season canopy measurements did not respond to N; however as the season progressed and the demand for N increased with crop growth, uptake, and eventual translocation, treatment differences became easier to distinguish (Table 4.7.1). Location affected the response of R3 NDVI to inoculant and N (Table 4.5) and regression analysis showed no significant R3 NDVI response to N rate with or without inoculant at SUF13 and VB13 (Table 4.10). However, N rate, without inoculant, had a cubic effect on R3 NDVI at PTR13 (Figure 4.2). Canopy NDVI increased with 16 kg N ha^{-1}, compared to 0 N, decreased in value when 31 and 47 kg N ha^{-1} were applied, but re-established greater NDVI values with the high N rate of 63 kg ha^{-1}; however at the 63 kg N ha^{-1} rate, NDVI was less than values obtained with 16 kg N ha^{-1}. Specifically, NDVI increased by 0.0045 for each kg N until 16 kg N ha^{-1} was applied. When inoculant was combined with N rates, R3 NDVI at PTR13 had a cubic response and maximized canopy NDVI with 31, 47, and 63 kg N ha^{-1} rates. At WAR13, soybean exhibited a linear response to N rates with and without inoculant (Table 4.10 and Figure 4.3). When inoculant was not applied, N increased R3 NDVI by 0.0002 with each kg N applied; with inoculant, N decreased NDVI values by a similar amount. The reduced soybean response to N with R3 NDVI when combined with inoculant can partially be attributed to greater NDVI values that ranged from 0.94 to 0.95 for N rates with inoculant.

Canopy NDVI at R5 differed by location and ranged from 0.8571 to 0.9121 (Table 4.4.1). More importantly, R5 NDVI increased linearly with starter N (Table 4.9 and Figure 4.4). All N rates increased NDVI compared to 0 N, but values were similar between N rates and N increased NDVI by only 0.00008 per kg N ha^{-1} (Table 4.7.1). The NDVI values obtained in this study may not be as applicable in full-season soybean where canopy is fully closed; however, in double-crop where yield is partially limited by reduced leaf area (Jones et al., 2003), greater NDVI during the most critical stages of seed development is important in yield formation and may partially explain increased yield with starter N.

Total N uptake at V4 differed between locations (Table 4.5). Although the location x N rate x inoculant interaction was not significant at P=0.05 (P=0.0613) (Table 4.5), it provides insight into soybean leaf N dynamics early-season. At PTR13 and SUF13, V4 TNU differences were not observed. In contrast, soybean at V4 increased TNU linearly when N was applied without inoculant at WAR13 (Table 4.10). In addition, the high N rate, without inoculant maximized V4 TNU compared to all other treatments (Figure 4.5). Starter N without inoculant increased V4 TNU by 0.82 kg N ha^{-1} per kg N ha^{-1} applied. When inoculant was applied to the seed, starter N did not improve early-season N uptake and each kg N ha^{-1} applied decreased TNU by 0.275 kg N ha^{-1}. Furthermore, when inoculant was combined with 63 kg N ha^{-1} TNU decreased from approximately 120 to 60 kg N ha^{-1}, compared to the same N rate, but without inoculant. Total N uptake values were similar between N rates and with and without inoculant at 16, 31, and 47 kg N ha^{-1}; however at the 0 N and high N rate, inoculant either increased or decreased V4 TNU.

Total N uptake at seed-fill (R5) responded to N rate, which acted independently and did not interact with inoculant (Table 4.5). Soybean exhibited a cubic response to N rates by decreasing R5 TNU by 2.4 kg N ha^{-1} maintained through the 16 kg N ha^{-1} rate, compared to 0 N; however, the 47 kg N ha^{-1} rate maximized R5 TNU, which decreased when the high rate of 63 kg N ha^{-1} was applied (Table 4.9 and Figure 4.6). Furthermore, when compared to 0 N, the high N rate decreased R5 TNU by 24 kg N ha^{-1} (Table 4.7.1).

Nitrogen and inoculant influenced seed quality in our experiments; however, these data showed that seed quality was rated excellent to very good (<1.8); therefore was not considered relevant (Table 4.8). Seed oil was not affected by N or inoculant. In contrast, seed protein was marginally affected by N ($P=0.0521$). Still no trend between protein and N rate could be distinguished (Tables 4.6 and 4.9). In comparison, Taylor et al. (2005) reported that N applied at planting on coastal plain soils did not affect seed quality or protein and oil content.

Yield Components

Kahlon et al. (2011) grouped yield components as primary (seed size and seed per m^2), secondary (seed per pod and pods per m^2), tertiary (pods per reproductive node and reproductive nodes per m^2), and quaternary (nodes per m^2 and percent reproductive nodes). Our yield component analyses demonstrate N's overall influence on seed yield formation, shown by 7 of 12 parameters being affected by N compared to just 1 of 12 responding to inoculant. Starter N increased seed yield (seed weight per m^2) by 14, 10, 12, and 15%, when comparing 16, 31, 47, and 63 kg N ha^{-1} to 0 N (Table 4.7.2). Our regression analyses demonstrated that seed weight per m^2 responded linearly to starter N and increasing N contributed to yield formation with greater seed weight per m^2 (Table 4.9 and Figure 4.7). Seed weight increased by 0.76 g m^{-2} per kg N ha^{-1} applied. Although regression indicated a linear response, 16 kg N ha^{-1} produced seed weight similar in value to that observed with the high rate of 63 kg N ha^{-1}, and was greater than 0, 31, and 47 kg N ha^{-1}, according to mean separation.

Primary level parameters seed per m^2 was influenced by starter N, but seed size was not significant at P=0.05 (P=0.0645) (Table 4.5). Although linear, quadratic, or cubic trends for N rate with seed m^{-2} could not be distinguished (Table 4.9), 16 kg N ha^{-1} resulted in 2892 seed m^{-2}, which was 12% greater than 0 N (Table 4.5 and 4.7.2). Increased seed yield with 16 kg N ha^{-1} can partially be attributed to increased seed per m^2 with the same rate. Similarly, Kahlon et al. (2011) reported that yield was linearly correlated with seed per m^2 ($R^2 = 0.84$). While seed size was not significant at P=0.05, regression showed a linear response to increasing N rate (Table 4.9). Seed size increased by 0.01 g 100 $seed^{-1}$ per kg N per ha applied (Table 4.7.2 and Figure 4.8). Specifically, 0 N produced 14.68 g 100 $seed^{-1}$, which was 5% smaller than the highest N rate.

Secondary yield component parameter pods per m^2 was influenced by N rate and an interaction between inoculant and N rate (Table 4.5). Soybean exhibited a linear response to N rate with and without inoculant that affected pod production (Table 4.10). Pods per m^2 were not influenced by N rate when in combination with inoculant (Figure 4.9). Pod production was less variable when inoculant was applied to the seed prior to planting and combined with starter N. In contrast, when inoculant was not applied, increasing N rates increased pod production by three pods m^{-2} with each kg N ha^{-1} applied. Furthermore, 16 kg N ha^{-1} contributed to pod production at similar levels compared to 63 kg N ha^{-1}, both without inoculant. When the highest N rate was applied, inoculant decreased pod production. When 16, 47, or 63 kg N ha^{-1} was applied, inoculant was not necessary to improve pod dynamics; however with 0 N or 31 kg N ha^{-1}, inoculant contributed to soybean producing greater pods per m^2. Kahlon et al. (2011) linearly correlated yield with pod per m^2 ($R^2 = 0.78$). Our data shows a response to starter N for both pod and seed production. Seed per pod was not affected by starter N (Table 4.5), which is similar to Robinson et al. (2013), who reported seed per pod to be attributed more to differences in cultivar.

Soybean exhibited a cubic response to N rate with tertiary parameter pods per reproductive node (Table 4.9). Starter N decreased pods per reproductive node by 0.02, maintained with 16 and 31 kg N ha^{-1} applied; however, the 47 kg N ha^{-1} rate increased pods per reproductive node (Figure 4.10). Furthermore, increasing N rate greater than 47 kg N ha^{-1} decreased pod production. Without N, untreated soybean produced 2.5 pods per reproductive node, was greater than the high N rate (2.3), but was not greater than other N rates (Table 4.7.3).

Node production per plant had a cubic response to N rate; when N rates were increased from 0 to 31 kg N ha^{-1} node number did not change (Table 4.9 and Figure 4.11). However, when 47 kg N ha^{-1} was applied, node production was maximized at 14.6 nodes $plant^{-1}$ and increased by 4, 5, 4, and 7%, compared to 0, 16, 31, and 63 kg N ha^{-1}, respectively (Table 4.7.3). When the high N rate of 63 kg N ha^{-1} was applied node production decreased by one node per plant. Kahlon et al. (2011) linearly correlated yield with reproductive node per m^2 ($R^2 = 0.53$), and node per m^2 ($R^2 = 0.46$). In addition, the authors concluded reproductive node per m^2 was the most accurate and practical potential indirect selection criteria for increased yield during cultivar development. While differences were minimal, our data did not focus on cultivar; rather, we showed that 47 kg N ha^{-1} applied as starter N maximized node dynamics. In contrast, reproductive nodes per plant and percent reproductive node were not consistently increased by starter N (Table 4.5). Similarly, Board and Modali (2005) and Kahlon et al. (2011) determined percent reproductive node to be minimally involved in yield formation.

Yield is a function of sunlight intercepted by the crop, the dry matter produced from light, and the percentage of this dry matter transferred to the seed, referred to as harvest index [(g of seed yield) / (g of total dry matter)] (Loomis and Connor, 1992). Total dry matter in our experiments was affected by N rate and soybean had a linear response that increased TDM by 1.6 g m^{-2} per kg N applied (Tables 4.7.2 and 4.9). Similar to pods per m^2 and seed weight per m^2 (Figures 4.9 and 4.7, respectively), 16 kg N ha^{-1} produced similar TDM compared to 63 kg N ha^{-1} (Figure 4.12). Total dry matter levels were 13, 10, 13, and 15% greater with 16, 31, 47, and 63 kg N ha^{-1} rates, compared to 0 N. Similarly, Osborne and Riedell (2006) increased seed yield by more than 5% at two of three years with 16 kg N ha^{-1} compared to 0 N, and partially attributed the yield increase to greater early plant biomass. Our data partially explains how starter N affected seed yield through increased biomass accumulated throughout the growing season. Similarly, Kahlon et al. (2011) emphasized that yield components are the vehicle through which dry matter increases affect yield. Furthermore, Board and Modali (2005) reported dry matter accumulation affected yield through control of seed per m^2, pod per m^2, reproductive nodes per m^2, and nodes per m^2.

Starter N or inoculant did not affect harvest index (Table 4.5 and Table 4.7.2). The partial goal of this research was to increase early-season vegetative growth and leaf area to maximize yield potential. Total dry matter demonstrates that we increased biomass with starter N, but did not negatively impact harvest index.

Starter N and Inoculant Return on Investment

Seed yield was utilized for simple economic analysis to determine return on investment for starter N and inoculant. Input values utilized were as follows: inoculant: \$0.20 kg seed^{-1}; 32-0-0 UAN: \$1.35 kg N^{-1}. Mean commodity price the previous five years (2009-2013) for Virginia soybean (\$0.44 kg^{-1}) was used to calculate the return on investment (NASS, 2014). Inoculant cost \$20.70 ha^{-1} (95Y01 at 593,000 seed ha^{-1}); whereas, N cost \$21.60, \$41.85, \$63.45, and \$85.05 for 16, 31, 47, and 63 kg N ha^{-1}, respectively. When examined solely on N rate, seed yield increased by 202 kg ha^{-1} with the 16 kg N ha^{-1} application, compared to 0 N, which increased gross income by \$88.88 ha^{-1} (Table 4.6). Application of N at 16 kg N ha^{-1} provided a positive return on investment and increased net profit by \$67.28 ha^{-1}. All other N rates negatively affected yield and decreased net profit. The combination of N + inoculant cost \$42.32 for the 16 kg N rate + inoculant. When observed yield with N rate x inoculant is examined, 16 kg N ha^{-1} + inoculant increased yield by 239.5 kg ha^{-1} compared to 0 N/no inoculant. Gross income increased by \$105.38, which resulted in positive return on investment and net profit of \$63.06 with 16 kg N ha^{-1} with inoculant, compared to 0 N/no inoculant. When inoculant was removed from the low N rate, yield increased by 189.9 kg ha^{-1}, compared to 0 N/no inoculant, which increased gross income and net profit by \$83.56 and \$41.24 ha^{-1}, respectively. Increased value was observed with applying both the low N rate and seed-applied inoculant; however, inoculant performance in our experiments was difficult to predict and its use in double-crop may be limited to specific fields where soybean have not been previously grown or have not been included in the rotation during the previous three to five years. In addition, *Bradyrhizobium japonicum* populations N_2 fixation efficiency may be limited due to decreased soil water, which can be problematic during early vegetative growth in double-crop soybean.

Conclusion

Increasing plant biomass accumulation with starter N provided greater soybean yield and greater profit at 16 kg N ha^{-1}. Early-season growth, as measured by NDVI, was not influenced to the same extent as mid-to-late-season growth when the effect of N became more apparent. Specifically, NDVI during early-pod fill stages was greater with starter N application. Therefore, increased photosynthetic material was available for the soybean to utilize for yield formation. Inoculant did not affect vegetative growth parameters but did increase weight of 100 seed. Yield component parameters provided insight into yield formation and starter N effects on node, pod and seed production. Node production was maximized at 47 kg N ha^{-1}. In contrast, reproductive node parameters were not influenced by starter N or inoculant. Starter N increased pod production when inoculant was not applied. Yield component parameters seed weight per m^2 and seed size had a linear response to starter N. Yield increased by 5% with starter N applied at 16 kg N ha^{-1}, but further yield increases were not realized with greater N rates. Pods per m^2, seed weight per m^2, and TDM all were greater with 16 kg N ha^{-1} and were comparable to 63 kg N ha^{-1}. Starter N did not negatively influence harvest index.

These data demonstrate that starter N may be compatible with double-crop soybean, partially attributed to increased leaf, node, pod, and seed productivity. In contrast, inoculant showed little benefit. Current Extension recommendations should be maintained that encourage inoculant application only in specific conditions where soybean have not been previously grown or included in the rotation within the previous three to five years, or N_2 fixing ability of bacteria are limited due to decreased water. Further research should examine transitioning away from the row middle and placing N in a starter band in closer proximity to the seed. Investigating banding N at planting will allow treatments to be more appropriately compared to production settings where starter bands are commonly used; however, narrow row planter or drill modifications will be necessary to ensure proper placement of liquid fertilizer in proximity to the seed.

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Table 4.1 Site physical characteristics for 2012 and 2013 N rate x inoculant soybean experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Site-Year	Soil Series and Texture †	Soil Classification †	Latitude	Longitude
MTH12	State fine sandy loam	Fine-loamy, mixed, semiactive, thermic Typic Hapludults	38° 5'0.16"N	76°42'39.49"W
PTR12	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF12	Nansemond loamy fine sand	Fine-loamy, siliceous, semiactive, thermic Aquic Hapludults	36°40'1.86"N	76°43'41.61"W
VB13	Nimmo loam	Coarse-loamy, mixed, semiactive, thermic Typic Endoaquults	36°38'43.20"N	76° 6'21.54"W
WAR13	Kempsville loam	Fine-loamy, siliceous, subactive, thermic Typic Hapludults	37°59'24.22"N	76°46'29.48"W
PTR13	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF13	Dragston fine sandy loam	Coarse-loamy, mixed, semiactive, thermic Aeric Endoaquults	36°41'1.66"N	76°45'39.85"W

† USDA-NRCS web soil survey (WSS, 2014).

Table 4.2 Calendar dates for agronomic inputs, data collection, and growth and developmental stages for 2012 and 2013 N rate x inoculant soybean experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Agronomic Input	MTH12	PTR12	SUF12	VB13	WAR13	PTR13	SUF13
Planting	6/20	6/28	6/21	6/24	7/8	7/15	6/20
Stand counts	7/10	7/18	7/11	7/11	7/23	7/30	7/9
V4 plant height †	7/31	8/7	7/23	7/22	8/6	8/12	7/24
V4 NDVI	- §	-	-	7/22	8/6	8/12	7/24
V4 plant tissue	7/31	8/7	7/23	7/22	8/6	8/12	7/24
R3 fungicide applic.	8/16	8/22	8/17	8/20	8/27	9/6	8/13
R3 NDVI	-	-	-	8/20	8/27	9/6	8/13
R5 plant tissue	9/5	9/10	8/30	9/4	9/17	9/24	8/29
R5 NDVI	9/5	9/10	8/30	9/4	9/17	9/24	8/29
R8 plant height	11/12	11/6	11/5	10/21	11/25	11/25	10/17
Yield component	11/12	11/6	11/5	10/21	11/19	11/19	10/24
Harvest	11/19	11/29	11/28	10/31	12/4	1/9 ‡	11/1
Growth stage †							
V2	7/10	7/18	7/11	7/11	7/26	8/2	7/9
V3	7/19	7/25	7/16	7/17	7/30	8/5	7/16
V4	7/31	8/7	7/20	7/22	8/2	8/8	7/19
R2	8/2	8/7	7/30	8/1	8/14	8/28	7/29
R3	8/16	8/22	8/17	8/15	8/23	9/6	8/13
R4	8/23	8/29	8/23	8/23	9/3	9/13	8/21
R5	9/5	9/10	8/30	9/4	9/17	9/19	8/31
R6	9/12	9/17	9/9	9/17	9/26	10/2	9/13
R7	10/8	10/14	10/6	10/6	10/22	10/30	10/4
R8	11/7	11/4	11/3	10/21	11/19	11/19	10/16

† Soybean growth and development stages as described by Fehr and Caviness (1977).

§ Data not collected.

‡ 2014.

Table 4.3 Growing season air temperature and precipitation for 2012 and 2013 N rate x inoculant experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Site-Year						
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13	VB13
Temperature	--------------------------------------°C--------------------------------------						
May	21	21	21	20	19	19	22
June	23	23	23	24	24	24	26
July	28	28	27	26	26	26	29
August	26	25	25	23	23	24	26
September	21	22	21	20	21	20	23
October	16	17	16	16	17	17	20
November	7	8	7	8	9	9	12
Mean	20	21	20	20	20	20	23
May-Nov.	(20)†	(20)	(21)	(20)	(20)	(21)	(21)
Precipitation	--------------------------------------mm--------------------------------------						
May	67	64	204	55	42	91	152
June	13	103	157	194	179	206	56
July	30	123	120	158	84	88	165
August	141	246	204	95	100	164	129
September	69	55	92	26	46	51	47
October	191	252	208	76	96	115	159
November	12	21	18	75	61	88	77
Total	524	864	1003	679	608	803	784
May-Nov.	(710)†	(692)	(768)	(710)	(692)	(768)	(712)

† 29 year May-Nov. mean in parenthesis.

Table 4.4 Location influenced soybean population, N uptake, NDVI, and seed yield and quality for 2012 and 2013 N rate x inoculant experiments.

Table 4.4.1

Site-Year	Population	R5 TNU £	V4 NDVI Φ §	R5 NDVI
	-plants ha^{-1}-	kg N ha^{-1}		
MTH12	338,978 c †	140.9 c	- ‡	0.9084 a
PTR12	411,524 ab	229.2 ab	-	0.9121 a
SUF12	289,725 d	170.2 c	-	0.9006 b
VB13	434,975 a	260.6 a	0.7662 b	0.8853 c
WAR13	407,918 b	225.5 b	0.8248 a	0.8877 c
PTR13	201,797 e	241.8 ab	0.5454 d	0.8571 d
SUF13	360,198 c	239.5 ab	0.7251 c	0.9009 b

Table 4.4.2

	Seed				
	Yield	Weight	Quality	Oil	Protein
	--kg ha^{-1}--	g 100 sd^{-1}		----------%----------	
MTH12	3710 d †	17.4 c	1.96 b	19.6 e	41.3 b
PTR12	5099 a	18.8 a	1.47 c	19.9 d	43.3 a
SUF12	4613 b	18.0 b	1.94 b	20.9 a	43.0 a
VB13	3942 c	17.9 b	1.87 b	20.5 b	40.6 c
WAR13	3844 cd	17.0 d	1.06 d	20.1 c	41.5 b
PTR13	2757 e	17.9 b	1.01 d	20.0 cd	41.4 b
SUF13	4572 b	16.8 d	2.65 a	21.1 a	41.6 b

† Means with different letter within parameter and column are significantly different based on Fisher's Protected LSD at P (0.05) level.

£ Total N uptake.

Φ V4, fourth fully expanded trifoliate, Fehr and Caviness, 1977.

§ Normalized difference vegetative index.

‡ Data collected only at 2013 site-years.

¥ Incomplete site-year analysis.

Table 4.5 Test of fixed effects and interactions for soybean population, growth, N uptake, NDVI, seed yield and quality, and yield components for 2012 and 2013 N rate x inoculant experiments.

Attribute	Location (L) ¥	N Rate (N) §	Inoculant (I) Φ	L*N	L*I	N*I	L*N*I
	--	--	-----Pr > F-----	--	--	--	--
Plant population	<.0001 †	0.9054	0.8712	0.1308	0.2325	0.7399	0.8318
V4 plant height §	<.0001	0.2631	0.1958	0.0810	0.9948	0.5907	0.9679
V4 TNU £	<.0001	0.1283	0.4555	0.2597	0.9851	0.3827	0.0613
V4 NDVI ‡	<.0001	0.7654	0.5903	0.6989	0.6188	0.9829	0.9704
R3 NDVI ‡	<.0001	0.2169	0.2946	0.2671	0.6656	0.0434	0.0429
R5 TNU	<.0001	0.0436	0.1510	0.2616	0.9759	0.5568	0.2625
R5 NDVI	<.0001	0.0454	0.2943	0.1409	0.5198	0.8537	0.9630
Seed yield	<.0001	0.0129	0.2554	0.1377	0.9254	0.9609	0.8050
Seed weight	<.0001	0.5652	0.0403	0.8834	0.5556	0.9402	0.8801
Seed quality	<.0001	0.2095	0.9365	0.6695	0.2832	0.0439	0.9160
PSS δ	<.0001	0.9697	0.6557	0.6798	0.9495	0.3431	0.6320
Oil	<.0001	0.4371	0.7972	0.3142	0.6066	0.1130	0.8738
Protein	<.0001	0.0521	0.5213	0.7596	0.1984	0.2323	0.9122
Nodes plant^{-1}	<.0001	0.0226	0.5637	0.8483	0.8494	0.8148	0.6783
RN plant^{-1} β	<.0001	0.0916	0.2232	0.7072	0.6933	0.9844	0.6426
% RN	<.0001	0.7135	0.1941	0.6190	0.3555	0.7685	0.1632
Pods m^{-2}	<.0001	0.0555	0.5521	0.5257	0.4604	0.0271	0.9618
Pods plant^{-1}	<.0001	0.0419	0.1390	0.4602	0.4678	0.9091	0.5839
Pods RN^{-1}	<.0001	0.0272	0.0965	0.2551	0.3905	0.6735	0.7652
Seed m^{-2}	<.0001	0.0453	0.5961	0.4856	0.8100	0.2385	0.9702
Seed pod^{-1}	<.0001	0.2246	0.8432	0.6991	0.4701	0.1589	0.5320
Seed weight m^{-2}	<.0001	0.0110	0.6310	0.5158	0.7540	0.1767	0.9745
TDM μ	<.0001	0.0055	0.8826	0.5809	0.7383	0.0774	0.7726
Seed size	<.0001	0.0645	0.9608	0.9675	0.9874	0.9596	0.9969
Harvest index	<.0001	0.6946	0.1818	0.1646	0.2041	0.9212	0.3307

¥ 7 site-years in 2012 and 2013

§ 32% urea ammonium nitrate solution applied at 16, 31, 47 and 63 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

† P (0.05) level significance.

§ V4, fourth fully expanded trifoliate, Fehr and Caviness, 1977.
£ Total N uptake.
‡ Collected only in 2013.
δ Purple seed stain.
β Reproductive node.
μ Total dry matter.

Table 4.6 Main effect N rate and inoculant influenced soybean seed yield, weight, quality, oil and protein for 2012 and 2013 N rate x inoculant experiments.

	Seed		
N rate §	Yield	Weight	Protein
	--kg ha^{-1}--	g 100 sd^{-1}	%
0	4055.5 b †	17.7 a	41.7 ab
16	4257.5 a	17.6 a	41.8 ab
31	4056.7 b	17.6 a	42.1 a
47	4076.6 b	17.8 a	41.5 b
63	3936.7 b	17.7 a	42.0 a
Inoculant ‡			
With	4108.9 a	17.8 a	41.9 a
Without	4044.3 a	17.6 b	41.8 a

§ kg N ha^{-1} of 32% urea ammonium nitrate solution at planting, 5.1 cm deep, between rows.

‡ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

† Means with different letter within main effect, parameter and column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 4.7 Main effect N rate influenced soybean population, growth, N uptake, NDVI, and yield components for 2012 and 2013 N rate x inoculant experiments.

Table 4.7.1	Population	V4 Plant Height δ	V4 TNU £	R5 TNU	V4 NDVI β ‡	R3 NDVI ‡	R5 NDVI
N rate §	--plants ha^{-1}--	-----cm-----	------kg N ha^{-1}------				
0	349,763 a †	40.2 ab	45.6 b	218.9 ab	0.7080 a	0.9067 b	0.8880 b
16	352,026 a	40.8 ab	45.7 b	215.3 ab	0.7274 a	0.9088 ab	0.8937 a
31	345,878 a	40.2 ab	47.6 ab	211.5 ab	0.7133 a	0.9147 a	0.8954 a
47	353,563 a	41.1 a	54.0 a	236.7 a	0.7114 a	0.9115 ab	0.8939 a
63	345,280 a	39.3 b	52.5 ab	194.5 b	0.7168 a	0.9125 ab	0.8948 a

Table 4.7.2	Seed			TDM µ	Seed size	HI Φ
	--no m^{-2}--	no pod^{-1}	---------g m^{-2}---------		g 100 sd^{-1}	---%---
0	2529.9 b †	2.29 a	368.2 b	714.2 b	14.68 d	51.3 a
16	2891.1 a	2.35 a	427.3 a	822.2 a	14.93 c	52.0 a
31	2704.5 ab	2.30 a	409.1 a	791.3 a	15.09 bc	51.6 a
47	2791.9 a	2.35 a	419.7 a	820.1 a	15.18 b	51.3 a
63	2819.8 a	2.26 a	431.1 a	839.0 a	15.44 a	51.2 a

Table 4.7.3	Nodes	Reproductive nodes		Pods		
	-----no. $plant^{-1}$------		---%---	-no. m^{-2}-	no. $plant^{-1}$	no. RN^{-1}
0	14.0 b †	10.8 ab	77.3 a	1088.3 b	28.0 a	2.55 a
16	13.9 b	10.9 ab	77.9 a	1216.2 a	27.2 ab	2.44 ab
31	14.0 b	10.7 ab	76.3 a	1166.8 ab	26.7 ab	2.46 ab
47	14.6 a	11.3 a	77.7 a	1172.7 ab	29.5 a	2.56 a
63	13.6 b	10.4 b	76.4 a	1224.7 a	24.4 b	2.31 b

§ kg N ha^{-1} of 32% urea ammonium nitrate solution at planting, 5.1 cm deep, between rows.

† Means with different letter within parameter and column are significantly different with Fisher's Protected LSD at P (0.05) level.

δ V4, fourth fully expanded trifoliate, Fehr and Caviness, 1977.

£ Total N uptake.

β Normalized difference vegetative index.

‡ Data collected only at 2013 site-years.

µ Total dry matter.

Φ Harvest index.

Table 4.8 Interaction between N rate and inoculant influenced soybean seed yield, weight, quality, oil, and protein, and pods per m^2 and total dry matter (TDM) for 2012 and 2013 N rate x inoculant experiments.

		Seed			
N rate §	Inoculant Φ	Quality	Oil	Pod	TDM
			%	---no. m^{-2}---	--g m^{-2}--
0	With	1.67 abc †	20.3 ab	1146.5 bcd †	739.5 cd
	Without	1.71 abc	20.1 b	1030.1 d	688.9 d
16	With	1.55 c	20.2 ab	1196.6 abc	803.3 abc
	Without	1.70 abc	20.3 a	1235.8 ab	841.1 ab
31	With	1.78 a	20.4 a	1238.6 ab	837.0 abc
	Without	1.76 ab	20.2 ab	1095.0 cd	745.7 bcd
47	With	1.73 abc	20.2 ab	1183.0 abc	825.6 abc
	Without	1.80 a	20.4 a	1162.3 a-d	814.6 abc
63	With	1.84 a	20.4 a	1151.0 bcd	789.8 abc
	Without	1.57 bc	20.4 a	1298.5 a	888.1 a

§ kg N ha^{-1} of 32% urea ammonium nitrate solution at planting, 5.1 cm deep, between rows.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

† Means with different letter within parameter and column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Table 4.9 Regression analyses summary for N rate effect on soybean N uptake, NDVI, seed yield and protein, and yield components for 2012 and 2013 N rate x inoculant experiments.

Attribute	Linear	Quadratic	Cubic	a	b_1	b_2	b_3	R^2
	------------------	Pr > F	------------------					
R5 TNU ‡	0.3638 †	0.1801	0.0284	219.4	-2.4526	0.1273	-0.0015	0.82
R5 NDVI ¥	0.0217	0.0718	0.2837	0.8904	8×10^{-5}	-	-	0.52
Seed yield	0.0374	0.0521	0.2252	4087.1	6.0114	-0.1331	-	0.62
Protein	0.5880	0.8988	0.0723	-	-	-	-	-
Nodes plant^{-1}	0.9940	0.0837	0.0124	13.996	-0.0493	0.0029	-3×10^{-5}	0.82
Pods RN^{-1} §	0.0506	0.4260	0.0144	2.5603	-0.0204	0.0009	-1×10^{-5}	0.95
Seed m^{-2}	0.0856	0.2338	0.0807	-	-	-	-	-
Seed weight m^{-2}	0.0075	0.1993	0.0748	387.37	0.7561	-	-	0.55
TDM £	0.0024	0.2123	0.1097	747.7	1.5821	-	-	0.63
Seed size	0.0034	0.9182	0.6500	14.71	0.0113	-	-	0.98

† P (0.05) level significance.

‡ Total N uptake.

¥ Normalized difference vegetative index.

§ Pods per reproductive node.

£ Total dry matter.

Table 4.10 Regression analyses for N rate (N) effect on soybean V4 total N uptake and R3 NDVI with or without inoculant (I) at 2013 locations and N rate effect on pods per m^2 as affected by inoculant averaged across 2012 and 2013 N rate x inoculant experiments.

Attribute	Linear	Quadratic	Cubic	a	b_1	b_2	b_3	R^2
V4 TNU §	------------------	Pr > F	------------------					
WAR13-Overall N*I	0.0348 †	0.4162	0.1333					
WAR13-Inoc ‡	0.4095	0.5537	0.2227	81.179	-0.275	-	-	0.24
WAR13-No Inoc	0.0274	0.0936	0.3463	48.171	0.8232	-	-	0.59
PTR13-Overall N*I	0.6813	0.8428	0.8849					
PTR13-Inoc	0.6168	0.7060	0.7400	-	-	-	-	-
PTR13-No Inoc	0.1666	0.4128	0.5576	-	-	-	-	-
SUF13-Overall N*I	0.4690	0.4085	0.1287					
SUF13-Inoc	0.6268	0.0583	0.9714	-	-	-	-	-
SUF13-No Inoc	0.1342	0.4087	0.0270	-	-	-	-	-
R3 NDVI ¥								
VB13-Overall N*I	0.9158	0.0891	0.7945					
VB13-Inoc	0.5685	0.2650	0.5392	-	-	-	-	-
VB13-No Inoc	0.6733	0.1864	0.3291	-	-	-	-	-
WAR13-Overall N*I	0.0428	0.2963	0.5328					
WAR13-Inoc	0.1432	0.0771	0.6987	0.8962	-0.0002	-	-	0.22
WAR13-No Inoc	0.1456	0.7424	0.6194	0.8772	0.0002	-	-	0.70
PTR13-Overall N*I	0.4263	0.9747	0.0083					
PTR13-Inoc	0.0484	0.2707	0.2206	0.8567	-0.0005	6 x 10^{-5}	-8 x 10^{-7}	0.81
PTR13-No Inoc	0.3664	0.2522	0.0101	0.8495	0.0045	-0.0002	2 x 10^{-6}	0.99
SUF13-Overall N*I	0.4518	0.1147	0.5910					
SUF13-Inoc	0.3598	0.8485	0.9728	-	-	-	-	-
SUF13-No Inoc	0.8833	0.0441	0.4688	-	-	-	-	-
Pods per m^2								
Overall N*I	0.0375	0.2114	0.0872					
Inoc.	0.9766	0.1621	0.8405	1184.4	-0.0394	-	-	0.001
No Inoc.	0.0038	0.7117	0.0093	1070.8	2.9808	-	-	0.48

† P (0.05) level significance.

§ Total N uptake.

‡ Inoculant, *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

¥ Normalized difference vegetative index.

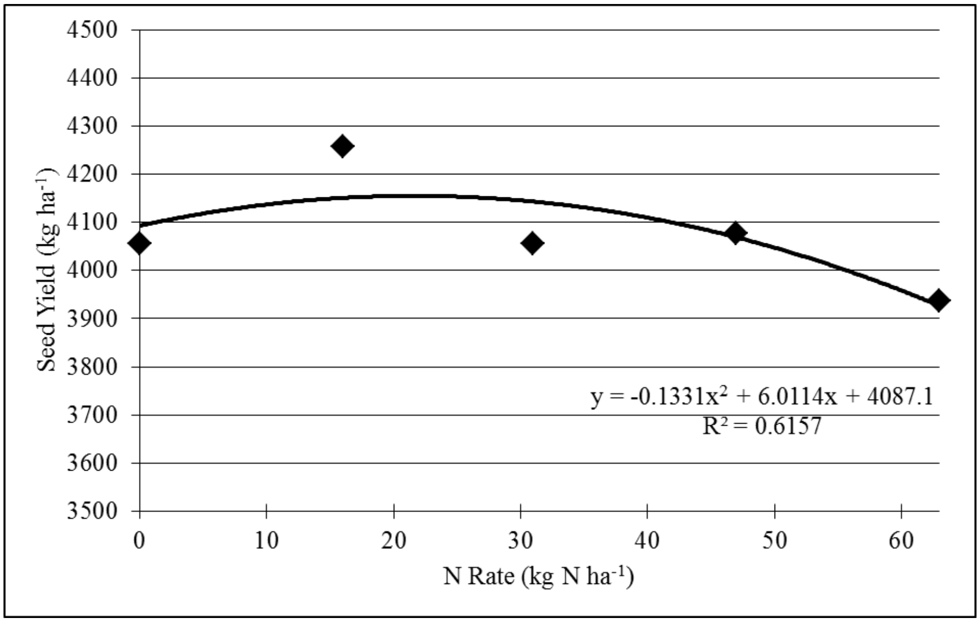

Figure 4.1 Soybean seed yield responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

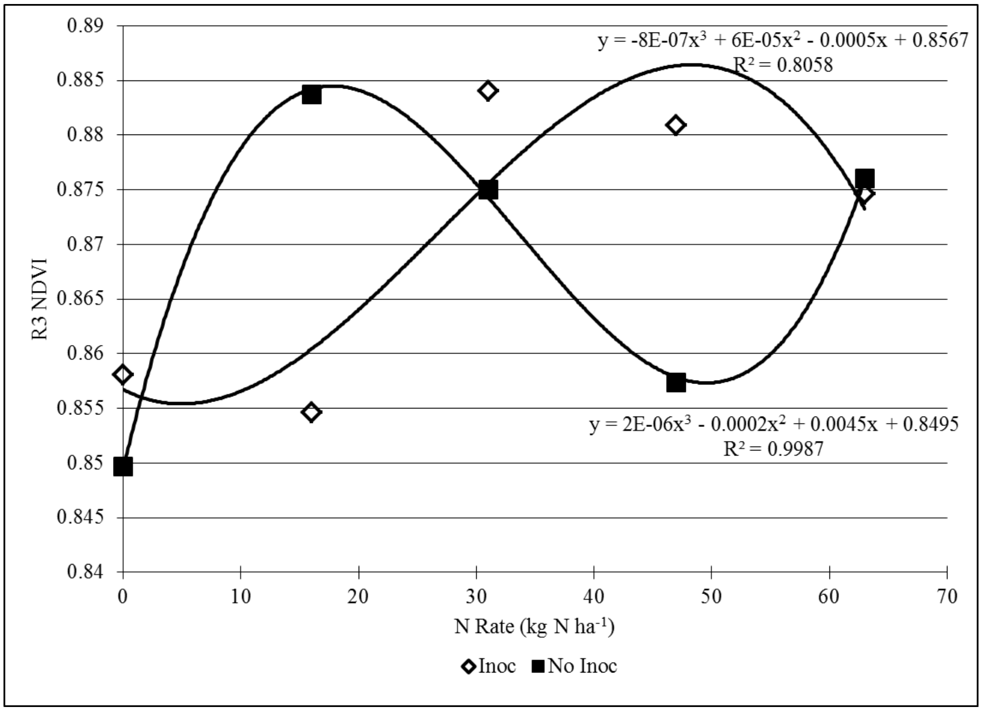

Figure 4.2 Canopy NDVI at R3 responded to N rate with and without inoculant for PTR13 N rate x inoculant experiment.

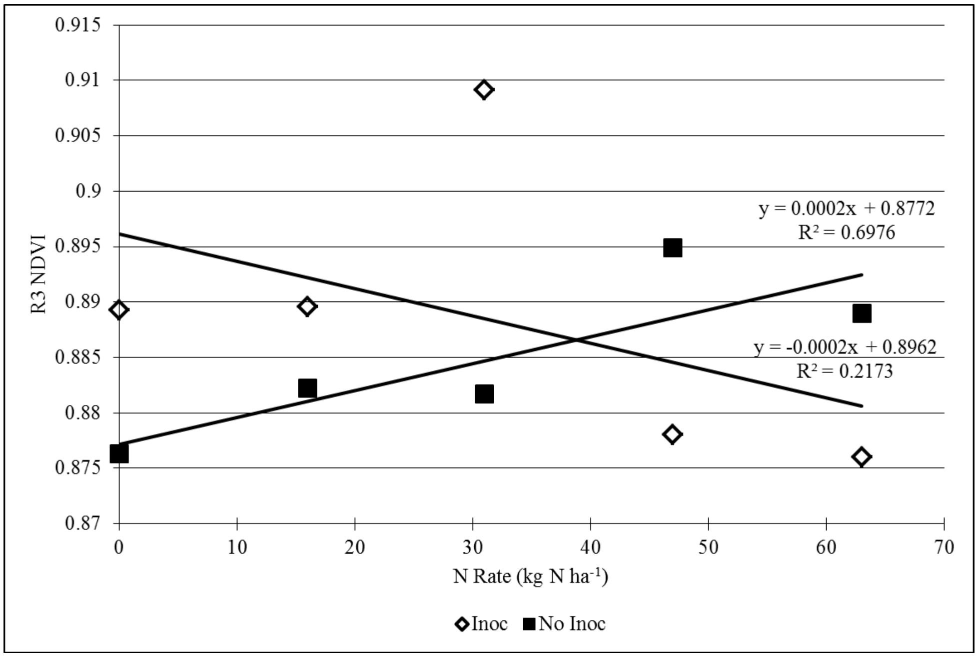

Figure 4.3 Canopy NDVI at R3 responded to N rate with and without inoculant for WAR13 N rate x inoculant experiment.

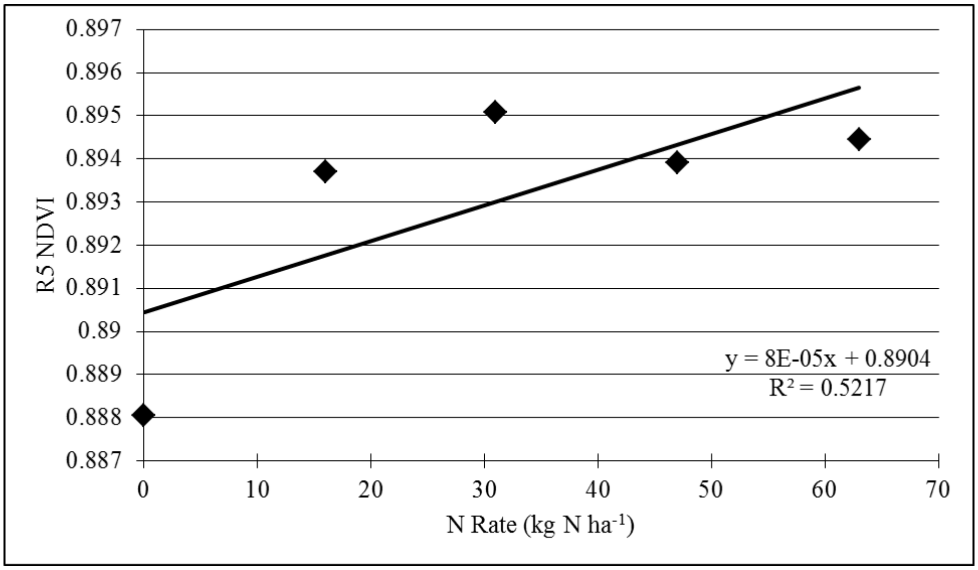

Figure 4.4 Soybean R5 NDVI responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

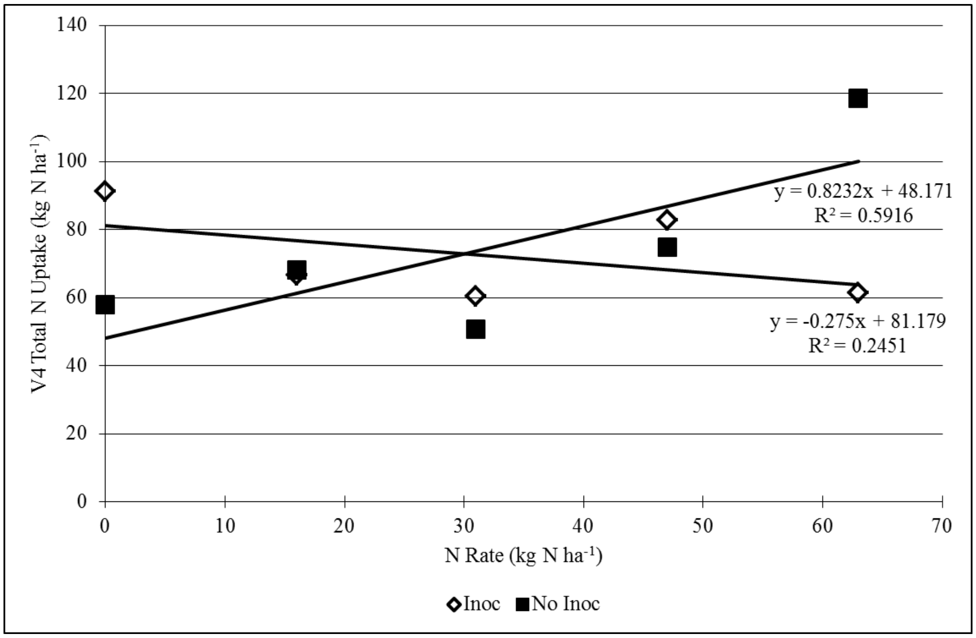

Figure 4.5 Soybean total N uptake at V4 responded to N rate with and without inoculant for WAR13 N rate x inoculant experiment.

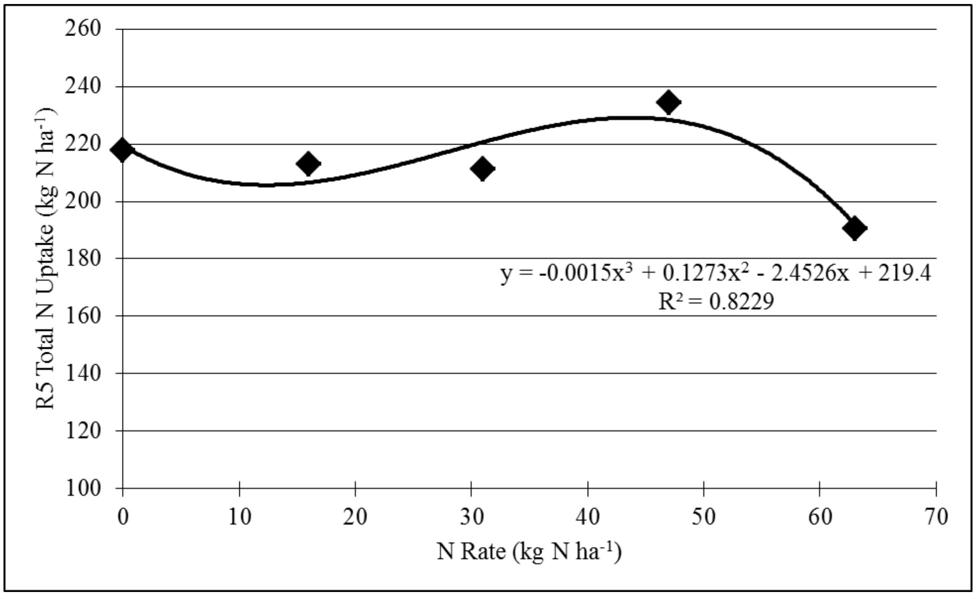

Figure 4.6 Soybean R5 total N uptake responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

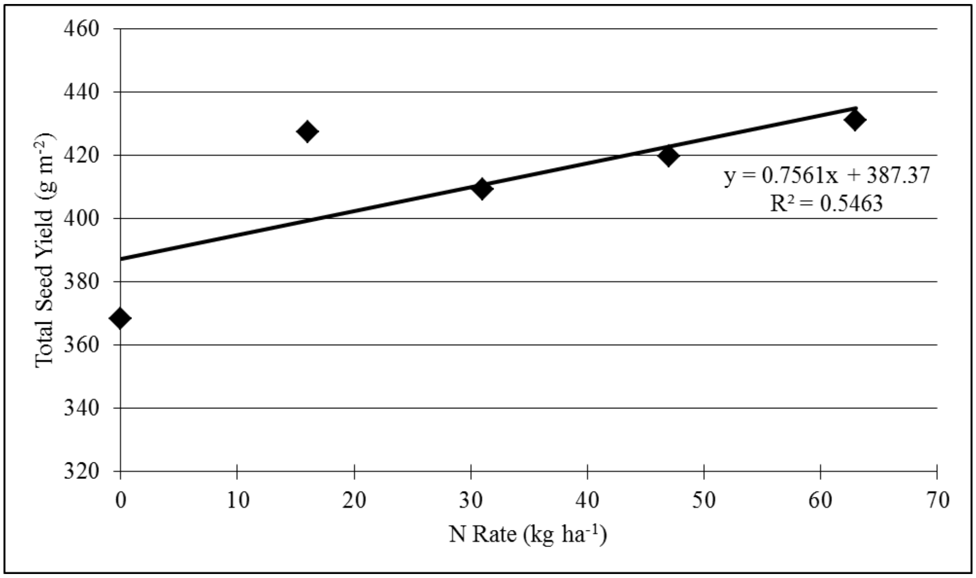

Figure 4.7 Soybean seed yield (g per m^2) responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

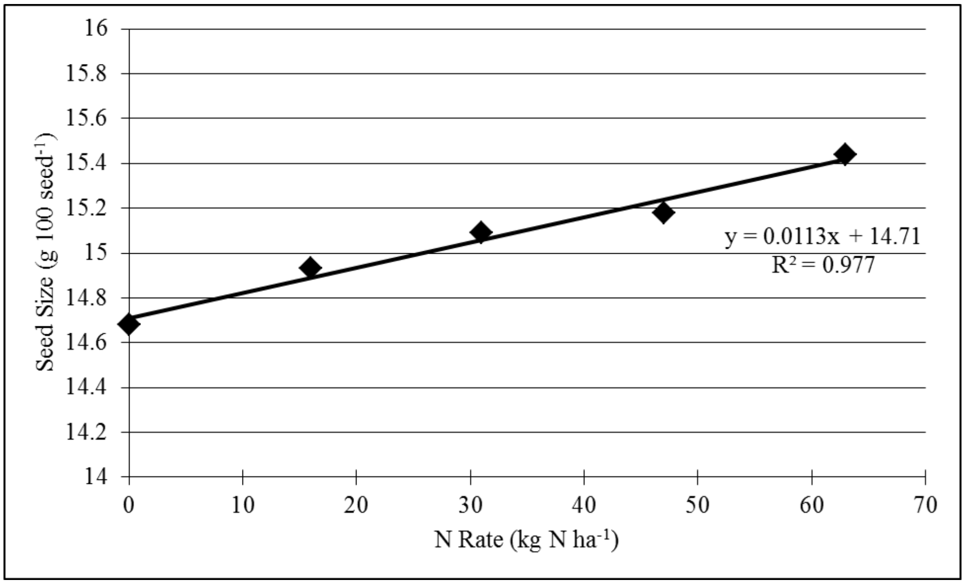

Figure 4.8 Soybean seed size responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

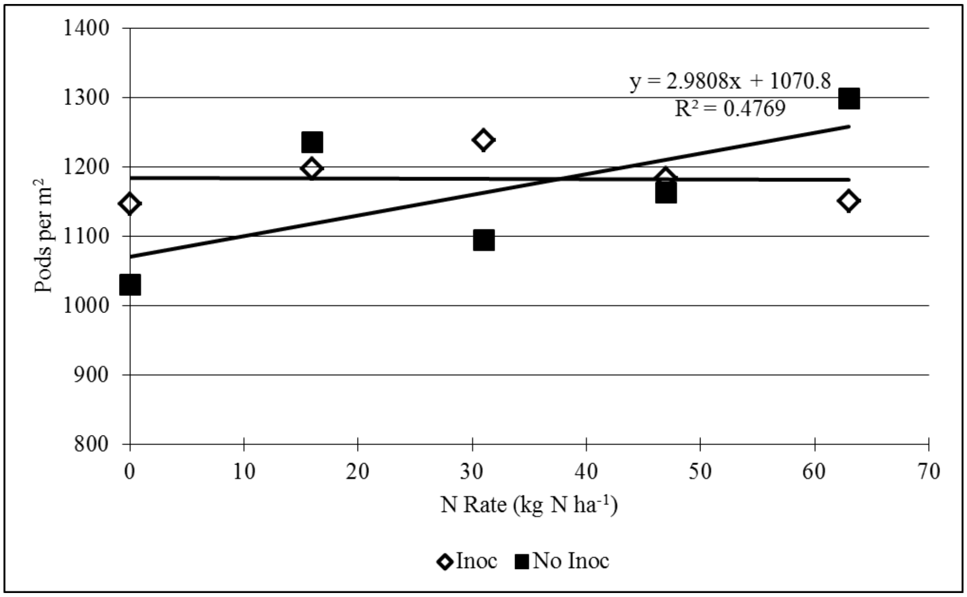

Figure 4.9 Soybean pods per m^2 responded to N rate with and without inoculant, averaged across location for 2012 and 2013 N rate x inoculant experiments.

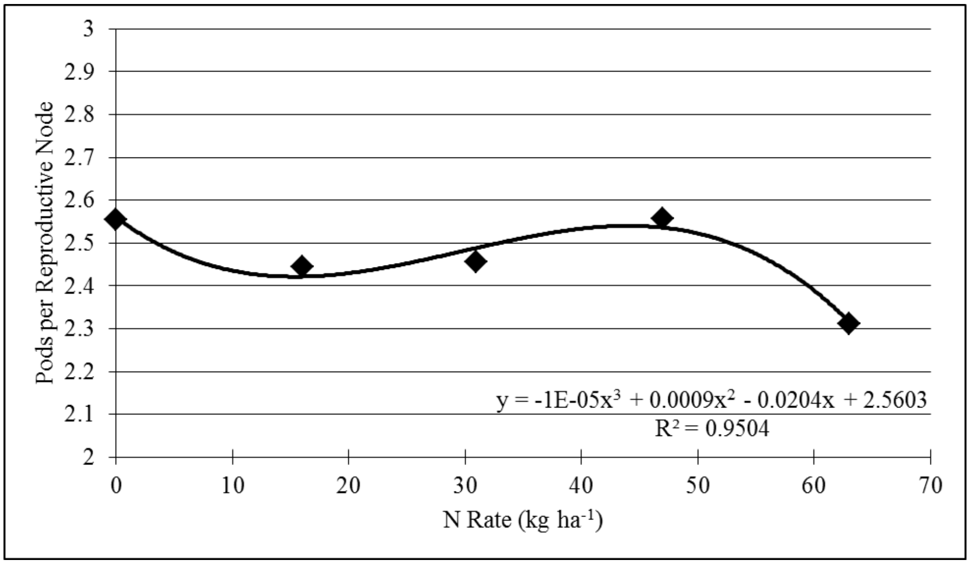

Figure 4.10 Soybean pods per reproductive node responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

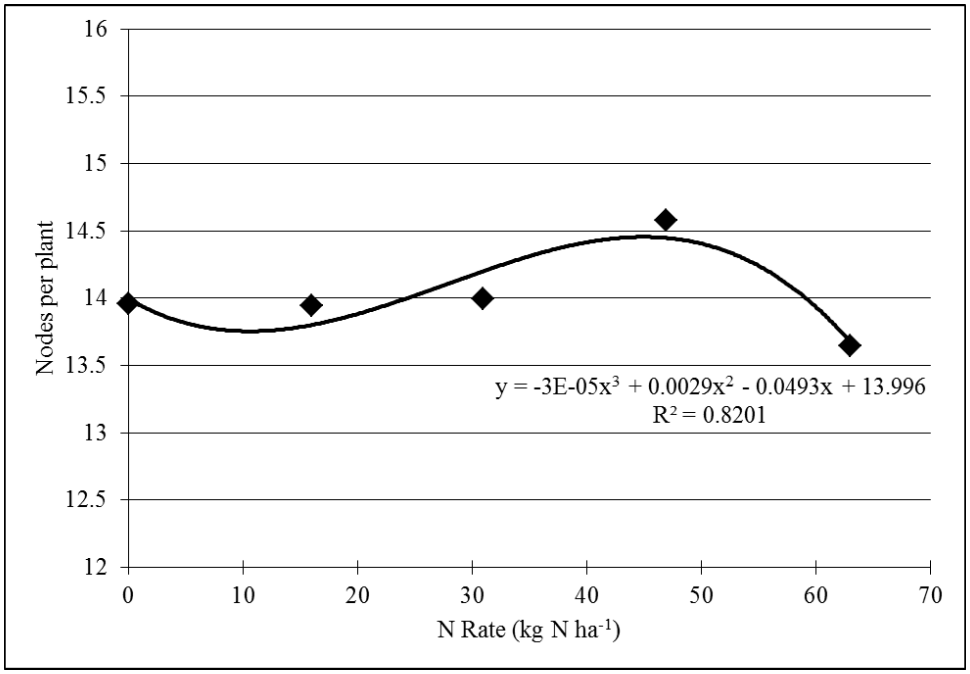

Figure 4.11 Soybean nodes per plant responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

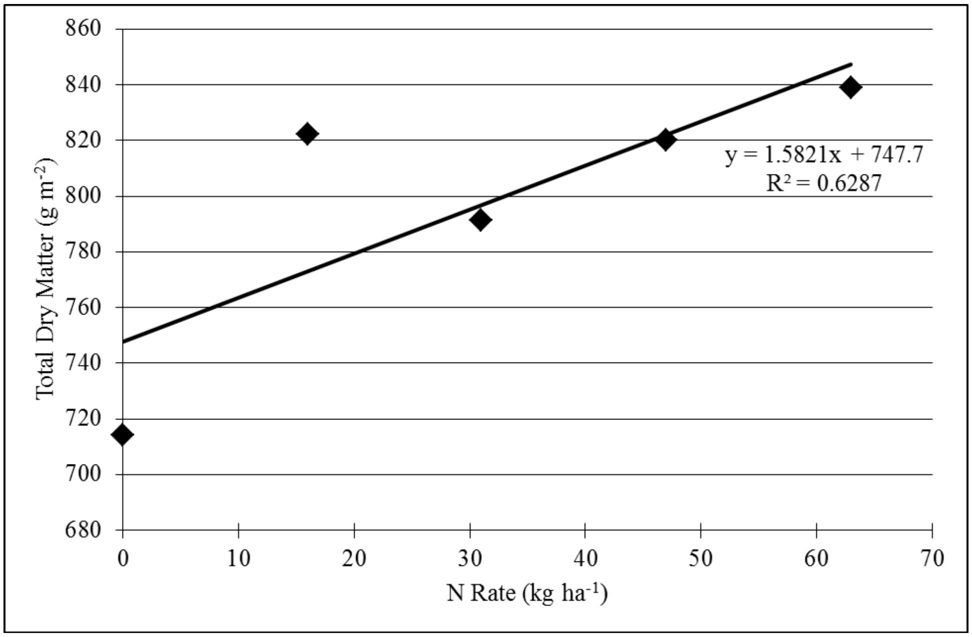

Figure 4.12 Soybean total dry matter responded to N rate, averaged across location and inoculant for 2012 and 2013 N rate x inoculant experiments.

CHAPTER V - DOUBLE-CROP SOYBEAN YIELD RESPONSE TO FOLIAR FUNGICIDE

Abstract

Foliar applied fungicides may provide an opportunity for greater yields in double-crop soybean when environmental conditions are conducive for disease development. However, cultivars may have varying levels of disease tolerance and respond differently to fungicide application. Field experiments were conducted in eastern Virginia in 2012 and 2013 to evaluate disease and yield response of maturity group (MG) IV and V soybean cultivars to foliar applied fungicide application in a wheat-soybean double-crop system. Measurements included normalized difference vegetative index (NDVI), cercospora leaf and stem blight ratings, leaf drop, seed yield and yield response, purple seed stain (PSS), and seed weight and quality. Fungicide application increased yield at 4 of 6 and 3 of 6 locations for MG IV and MG V cultivars, respectively. Fungicide increased seed weight at 5 of 6 locations. Canopy closure and leaf area were limiting factors in yield increase attributed to fungicide. Cercospora blight was generally controlled by foliar fungicide; however, improved disease control did not always increase yield. Optimum fungicide timing depended on soybean growth, environmental conditions, and disease intensity, and rate of disease development. These results should assist research and Extension personnel, crop consultants, industry representatives, and farmers in making agronomic and plant pathology decisions in double-crop soybean production.

Abbreviations: MG, maturity group; NDVI, normalized difference vegetative index; PSS, purple seed stain.

Introduction

Soybean [*Glycine max* (L.) Merr.] is a host to greater than 30 fungal diseases that occur in the U.S. (Hartman et al., 1999). Li and Yang (2009) primarily attributed wide spread occurrence of downy mildew (*Peronospora manshurica*), brown spot (*Septoria glycines*), frogeye leaf spot (*Cercospora sojina*), and Cercospora blight (*Cercospora kikuchii*) to moderate optimal temperature needed for disease development and the capability to transmit disease through seed. The predominating foliar soybean diseases in the southern U.S. are Cercospora blight, frogeye leaf spot, aerial blight (*Rhizoctonia solani*), pod and stem blight (*Diaporthe phaseolorum* var. *sojae*), and anthracnose (*Colletotrichum truncatum*) (Schneider et al., 2007). Schneider et al. (2007) also reported that Cercospora blight is the most prevalent and destructive soybean disease in the Mid-South.

Soybean in Virginia is host to several diseases that can reduce yield (Phipps et al., 2010). Due to Virginia's geographical location, a mixture of diseases prevalent in northern or southern states can be present and potentially problematic. This potentially diverse disease pressure causes soybean farmers to rely on disease-resistant or tolerant cultivars (if available), field history, spray advisories, understanding weather x disease trends, and foliar fungicide to minimize yield or quality loss from plant disease. Mehl and Phipps (2013) determined that Cercospora blight was the second most prevalent foliar disease of concern in soybean production in Virginia.

Schneider et al. (2007) identified the most effective and economical method for disease management to be genetic resistance; however, agronomically acceptable, broad-spectrum disease resistant soybean cultivars are typically not available (Dorrance et al., 2004; Li and Yang, 2009). Soybean farmers have traditionally managed late-season disease with fungicides

(Levy, 2005; Miles et al., 2007; Sinclair and Hartman, 1995; Yorinori et al., 2005) and cultural practices (Schneider et al., 2007). Reasons for increased interest in preventative fungicide use in the Midwest were attributed to yield loss prevention in the southern U.S. (Wrather and Koenning, 2006) and the introduction of soybean rust (*Phakopsora pachyrhizi*) into the U.S. (Swoboda and Pedersen, 2009).

Foliar fungicide has increased soybean yield in Ohio (Cruz et al., 2010), Paraguay and Zimbabwe (Miles et al., 2003, 2007), Illinois, Florida, and Georgia (Mueller et al., 2006), and Virginia (Phipps et al., 2010). In contrast, such a response was not reported in Indiana (Hanna et al., 2006), North Dakota (Mueller et al., 2006), or Virginia (Phipps and Telenko, 2011). Reduction in disease severity with foliar fungicide was observed, but seed yield response was inconsistent in Missouri (Bradley and Sweets, 2008), Illinois (Pataky and Lim, 1981), and Virginia (Phipps and Telenko, 2011). Lack of yield response to fungicide in absence of disease was reported in Missouri (Bradley and Sweets, 2008) and Iowa (Swoboda and Pedersen, 2009).

Due to rising total input costs and narrowing profit margins, farmers desire to increase yield while limiting risk (Duffy and Smith, 2007; Swoboda and Pedersen, 2009). The economic return from fungicide varies based on the crop growth stage during disease introduction, disease pressure, yield potential, and product efficacy (Dorrance et al., 2007; Yang and Robertson, 2007). Bradley and Sweets (2008) found in disease absence, fungicide applications were not economically justifiable in most years. Similarly, Swoboda and Pedersen (2009) concluded fungicide depended greatly on the geographical location and the disease amount present; economic loss resulted if application was not warranted due to lack of disease. Dorrance et al. (2007) estimated the cost per fungicide application for soybean rust control to be from $25 to

\$86 ha^{-1}. Similarly, Swoboda and Pedersen (2009) reported foliar fungicide application cost of \$55 ha^{-1}.

Fungicides are applied with self-propelled, pull type, or aerial spray applicators in the U.S. (Hanna et al., 2008); however, in the Mid-Atlantic, airplane and helicopter sprayers are not commonly used due to the smaller field size compared to the Midwest and Mid-South. Holshouser and Taylor (2008) demonstrated that mechanical damage to 18 and 38-cm row soybean occurred when fungicides were applied at the R4 (full pod, Fehr and Caviness, 1977) reproductive stages; ground application creates wheel tracks which can reduce yield when made during reproductive growth stages (Piper et al., 1989). Wilkens and Whigham (1986) observed a yield decrease for narrow row soybean when wheel damage reduced pods per plant and seed size. Research has shown that compensation by soybean in rows adjacent to damaged rows can occur but is not typically enough to limit overall plot yield reduction (Piper et al., 1989). Optimum fungicide application timing is critical to maximize yield while also minimizing the trip number and crop damage within the field.

Mueller et al. (2009) concluded that the proper application timing can be altered by regional conditions and can include differences in disease intensity and growth stage. Fungicides were documented to be most effective when applied during early-flowering through seed fill; applications made prior to flowering did not increase yield in temperate climates (Cruz et al., 2010; Miles et al., 2007; Mueller et al., 2006, Padgett et al., 2006; Tenuta et al., 2007). Prior to soybean rust, the most common practice implemented by soybean farmers was to apply a single fungicide between R3 (beginning pod, Fehr and Caviness, 1977) and R5 (beginning seed, Fehr and Caviness, 1977) (Schneider et al., 2007). Pataky and Lim (1981) applied benomyl to soybean at R1 (beginning flower, Fehr and Caviness, 1977), R3, and R6 (full seed, Fehr and

Caviness, 1977) and reduced disease severity with application at R3 or R1+R6 growth stages; however, yield increased at only one of three locations. Miles et al. (2007) concluded fungicide at R3 more effectively reduced disease severity and increased yield compared to R1 application. Phipps and Telenko (2011) compared fungicide applied at R3, R5, and R3+R5 and regardless of the timing, decreased percent leaf, pod, and stem area of Cercospora blight, decreased the percent defoliation caused by Cercospora blight; and increased soybean seed weight. Hanna et al. (2008) applied fungicide at R1, R3, R5, R3+R5, and R1+R3+R5, but did not observe a yield response to timing at any location. Similarly, Swoboda and Pedersen (2009) demonstrated that fungicide at R1, R3, or R5 did not affect soybean seed yield, seed moisture, lodging, leaf chlorophyll meter readings, or protein and oil content at harvest. Nelson et al. (2010) increased yield from 230 to 360 kg ha^{-1} when fungicide was applied at R4; however yield was not increased when fungicide was applied at V4 (fourth fully-expanded trifoliate, Fehr and Caviness, 1977). Although brown spot and frogeye leaf spot severity were < 2%, the combination of foliar diseases reduced yield by 350 kg ha^{-1} when left untreated (Nelson et al., 2010). Cruz et al. (2010) increased seed yield with fungicide by 184 to 490 kg ha^{-1} compared to untreated in three out of six locations in Ohio. In those studies, brown spot levels ranged from 2 to 21% and resulted in 2 to 9% yield loss when left untreated. Dorrance et al. (2010) increased yield 21% (6 out of 28 sites) with fungicide applied at R3. Furthermore, three of the six significant responses yielded 282 kg ha^{-1} more compared to the untreated check.

Late-planted double-crop soybean yield reduction is attributed to lack of sufficient vegetative growth (Ball et al., 2000), reductions in crop growth rate during the period when seed number (Egli and Bruening, 2000) and seed weight (Calvino et al., 2003) are defined, and reproductive phase duration (Egli, 2011). Increasing yield in late-planted soybean is correlated to increasing leaf area that maximizes light interception and subsequently increases biomass (Jones et al., 2003). Malone et al. (2002) conducted 15 manual defoliation experiments during a three year period and concluded that both full season and double-crop soybean decreased yield linearly when LAI values were below 3.5-4.0 at developmental stages R4 to R5. In addition, yield for both cropping systems plateaued at higher LAI levels. Foliar pathogens decrease the photosynthetic tissue area by reducing green leaf area, reduce assimilate transfer to grain production by diverting assimilates to fungal growth, weaken defense systems, and increase respiration (Agrios, 1997; Bassanezi et al., 2001; Shtienberg, 1992). Current soybean research initiatives in eastern Virginia are investigating applying agronomic inputs designed to increase vegetative growth and canopy closure. Improved canopy closure would provide increased habitat for fungal disease to utilize and develop within double-crop soybean. Due to latitude, the adopted management practices associated with the Early Soybean Production System (ESPS) developed in the Mid-South (Heatherly et al., 1999), and both full season and double-crop soybean popularity in Virginia, both maturity group (MG) IV and V cultivars are critical components of Mid-Atlantic soybean production. Therefore, our objective was to evaluate the response and specific interaction between MG IV and V soybean cultivars and foliar fungicide application in a wheat-soybean double-crop system.

Materials and Methods

Site Description and Cultural Practices

Field experiments were conducted in 2012 and 2013 in a wheat-soybean double-crop system at locations chosen to represent the major soybean producing regions of eastern Virginia, (Table 5.1). Three locations in 2012 included Tidewater Agricultural Research and Extension Center (AREC) in Suffolk, VA (SUF12), Eastern Shore AREC in Painter, VA (PTR12), and

Virginia Crop Improvement Association Foundation Seed Farm in Mt. Holly, VA (MTH12). Three locations in 2013 included Suffolk (SUF13), Painter (PTR13), and Eastern Virginia AREC, in Warsaw, VA (WAR13). Refer to Table 5.1 for location soil type, texture and classification, and coordinates. Experiments focused on soybean within wheat-soybean double-crop production settings typical of eastern Virginia. Winter wheat management information for study locations can be found in Appendix A and wheat was managed according to Extension recommendations (Alley et al., 2009; Anonymous, 2005; Hagood and Herbert, 2012). Soybean was grown at least once within the previous four years at all locations (Appendix A). Soybean was no-till planted into wheat stubble immediately after wheat harvest in 38-cm rows at the recommended double-crop seeding rate of 593,000 seed ha^{-1} (Holshouser, 2010) (Table 5.2 and 5.3). Plots were five rows wide and 7.3 m in length, but were end-trimmed to 5.2 m before harvest. Plots were managed throughout the growing season according to Extension recommendations and insect and weed pests were maintained below economic injury levels.

Experimental Design

Two adjacent experiments, one containing MG IV and one containing MG V cultivars, were conducted as a strip-plot design replicated four times. Two factors were tested and included cultivar (ten MG IV or ten MG V cultivars) and foliar fungicide timing (untreated or application at R3, R5, or both R3 and R5). Cultivars defined the vertical plots and were planted down the field in strips. Soybean differed in disease resistance; for more information refer to Appendix D. Ten MG IV, ranging from 4.2 to 4.9 relative maturity or ten MG V ranging from 5.1 to 5.6 relative maturity (Table 5.4) were chosen based on purple seed stain ratings obtained in 2011 (D.L. Holshouser, unpublished data). Fungicide was chosen as the horizontal plot to avoid spraying with a CO_2 backpack and to ensure accurate and even application across cultivars. Both cultivar and fungicide were re-randomized by replication. Foliar fungicide, pre-mix of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively (Priaxor®, BASF Corporation, Research Triangle Park, NC) + non-ionic surfactant (Induce®, Helena Chemical Company, Collierville, TN) at 460 mL ha^{-1} (0.25% v/v) was applied by three point tractor sprayer in 187 L ha^{-1} water at the R3, R5, or at both R3 and R5 soybean developmental stages (Fehr and Caviness, 1977) (Table 5.2 and 5.3). The sprayer was driven within the experiment alleys during application, which negated the possibility of yield loss attributed to wheel-traffic damage.

Data Collection

Plant population and plant height were determined two and four weeks after planting (WAP), respectively (Table 5.2 and 5.3). Normalized difference vegetative index (NDVI) was measured at R5 with a GreenSeeker Sensor Model 505 (NTech Industries, Inc., Ukiah, CA). The GreenSeeker collects NDVI by using the red (R) (660 nm) and near infrared (NIR) (770 nm) and is calculated from the formula NDVI = [(NIR-R) / (NIR+R)]. Disease incidence samples were collected at R3 and R5 from untreated plots from all four replications by pulling ten leaves per plot (five leaves from upper canopy; five leaves from lower canopy) and subjecting to incubation. Incubation method entailed the following steps: 1) place two paper towels in the bottom of plastic container; 2) soak towels with distilled water; 3) let excess water run out of container bottom; 4) place leaves top side up layered within box, with lower canopy leaves on left and upper canopy leaves on right; 5) place lid on top of container and ensure it is airtight; 6) incubate for five days minimum. After incubation, leaves were removed from the plastic container and examined for disease under high-power stereoscope. Disease incidence per leaf was recorded separately based on fungal pathogen presence and leaf percentage infected per treatment was reported.

Starting at R6 and continuing until R8 (full maturity), weekly visual ratings examined Cercospora blight on soybean leaves and stem (rated separately), percent of leaf area exhibiting yellowing, and percent leaf drop. In addition, NDVI reading were collected weekly. Weekly disease ratings allowed us to use the following formula for area under the disease progress curve (AUDPC) (Campbell and Madden, 1990):

(Equation 5.1) $$\text{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2} \right) (t_{i+1} - t_i)$$

Where "t" is time in days of each reading, "y" is the percentage of affected foliage at each reading and "n" is the number of readings. We reported AUDPC separately for Cercospora blight on leaves vs. stems. Weekly leaf drop ratings were utilized to calculate relative leaf drop in percent form for each treatment by the formula: relative leaf drop = (leaf drop measurement 1 + 2 + 3 + 4 + 5) / number of data collection timings. For example, if six weekly measurements were collected, all leaf drop measurement timings were added together and divided by 6. Reporting leaf drop as relative leaf drop allows us to examine canopy dynamics throughout the mid- and late-season reproductive stages, but limits us from comparing leaf drop values between treatments for a specific timing.

Plant height and lodging were measured at R8, the middle three rows per plot were harvested at R8 with a Wintersteiger® small plot research combine, and seed yield in kg per ha was adjusted to 130 g water kg^{-1} (Table 5.2 and 5.3). Yield differences between varieties were normalized by subtracting the untreated control yield (same cultivar and replication) from each cultivar x fungicide timing treatment's seed yield, and is referred to as yield response to fungicide. Subsamples from each plot determined 100 seed weight, percent purple seed stain

(PSS), and seed quality. Seed oil and protein concentrations were determined with NIR analysis (Foss Rapid Content Analyser XDS, Foss North America, Eden Prairie, MN) and were corrected for moisture.

Statistical Analysis

Statistical analysis used PROC MIXED (SAS, 2008) to test for fixed effects and interactions. To evaluate the significance of treatment effects on canopy dynamics, disease and leaf drop ratings, and seed yield and quality parameters, cultivar, fungicide and location within year were considered fixed. Replicate of each treatment combination was considered a random variable in all analyses. Fisher's least significant difference test and least square means at $P < 0.05$ were used for mean separation. Data were analyzed separately by year due to two MG IV cultivars and one MG V cultivar not being available in 2013 vs. 2012. Cultivars with the same relative maturity from the same company were substituted to maintain ten cultivars for each MG.

Results and Discussion

Environmental Conditions

The air temperatures in 2012 and 2013 were similar between locations and the 29 year mean, but near or above-average rainfall occurred at 5 of 6 locations in 2012. This was somewhat atypical of double-crop soybean in that the canopy was fully closed by the mid-reproductive stages; therefore, the environment was ideal for fungal disease development. The exception was MTH12, which experienced drought conditions in June and July, which reduced soil moisture at planting, emergence, canopy closure, and yield. Soybean emerged quickly at PTR12 and SUF12, closed the canopy quickly, and experienced little water stress throughout the season. In 2013, rainfall was near or above average through August at all locations, resulting in good vegetative growth. However, drought conditions in September may have reduced disease development and yield potential. Environment's influence on fungal disease spread and severity is well documented; specifically, rainfall is largely responsible for disseminating fungal spores throughout the crop canopy (Sinclair and Hartman, 1999).

Soybean populations ranged from 329,000 to 415,000 plants ha^{-1} when averaged across all locations. Emergence was slightly greater in 2012, compared to 2013, with 385,000 vs. 367,000 plants ha^{-1}. In addition, emergence ranged from approximately 55 to 70%. These emergence levels are typical in the soybean culture dominated by soils prone to drought-stress (Chen and Wiatrak, 2011; Walker et al., 2010).

Disease levels were greater in 2012 compared to 2013, and can partially be attributed to more rainfall during August, September and November. Still, disease incidence was similar between locations. Specifically, fungal pathogens Cercospora blight, downy mildew, brown spot, phyllosticta leaf spot (*Phyllosticta sojicola*), frogeye leaf spot, anthracnose, and target spot (*Corynespora cassiicola*) were present on soybean leaves collected from experimental plots. Furthermore, Cercospora blight and downy mildew both consistently infected the most leaves in 2012 and 2013 locations. Disease levels would be lower where canopy is not fully closed, which is more typical of double-crop soybean production; however, disease incidence similar to our observations has been documented in southeastern Virginia (Mehl and Phipps, 2013: Phipps and Telenko, 2011). Due to differences in canopy development, yield potential, and disease levels that changed across locations and influenced results, location within year was considered to be fixed to properly compare treatments. These data are site-specific due to changing disease levels; however, general trends can be observed while keeping results in the context of rainfall, disease, and yield potential at each location. Even with above or close to normal rainfall, soybean exhibited drought stress in some of our experiments and provided insight into how fungicide application timing can fit into double-crop soybean that is typically controlled by limited leaf area. I will discuss the MG IV and V experiments separately to promote clarity and help explain trends observed for each MG.

MG IV Cultivars x Fungicide

Cultivar and location interacted to influence AUDPC for Cercospora blight on leaves (CBL) and stems (CBS) (Tables 5.6). In general, CBL was greater at SUF12 than at PTR12, which was sometimes but not always greater than MTH12 (Table 5.7.1). The exception was cultivar V01-1022, where CBL levels did not differ between locations. In contrast, no such pattern could be discerned with CBS levels. Some cultivars experienced more stem disease at MTH12 than at the other locations. Location-dependent cultivar response was expected due to Cercospora levels differing by location. The effect of fungicide on AUDPC-CBL and CBS was also influenced by location (Table 5.6). At MTH12, no fungicide resulted in 193 %-days CBL and 519 %-days CBS and was greater than all fungicide treatments (Table 5.7.2). In addition, the R5 timing decreased CBL more than the R3 and R3+R5 timings and decreased CBS more than the R3 timing. Locations PTR12 and SUF12 performed similarly with the greatest AUDPC for CBL and CBS with the untreated control and the R3+R5 timing decreased CBL and CBS the greatest compared to fungicide applied alone at R3 or R5 (Table 5.7.2). Mueller et al. (2009) concluded that application too early, too late, or too frequent might not be effective or needed to maximize yield.

In 2013, Cercospora was less compared to 2012 and AUDPC demonstrated that fungicide, applied without high disease levels, did not provide consistent control (Table 5.8.2). At WAR13, fungicide did not reduce CBL compared to untreated; whereas, fungicide decreased

CBS at R3 or R3+R5, but not R5. At PTR13, CBL was not affected by fungicide treatments, but all three fungicide timings reduced CBS compared to untreated. At SUF13, fungicide applied at R5 provided the greatest decrease in CBL and CBS, compared to no fungicide. In addition, applying fungicide only at R3 resulted in disease levels greater than untreated. We attribute decreased Cercospora levels associated with the R5 timing to increased rainfall in August that encouraged disease development at SUF13, compared to WAR13 or PTR13 (Table 5.5) and coincided more with R5 than R3 reproductive stages (Table 5.2).

Similar to AUDPC, relative leaf drop responded differently to cultivar depending on location (Table 5.6), which was partially attributed to disease and environment, but was largely controlled by relative maturity. As relative maturity increased, relative leaf drop generally decreased (Table 5.7.1 and 5.8.1).

Location also affected leaf drop response to fungicide (Table 5.6). At all locations in 2012, relative leaf drop was less compared to no fungicide, regardless of applications timing (Tables 5.7.2 and 5.8.2). Fungicide reduced leaf drop by to 4.2 to 6.1%, 2.5 to 3.6%, and 5.1 to 7.3% at MTH12, PTR12, and SUF12, respectively (Table 5.7.1). Only at SUF12 were differences between fungicide timing, where the R3+R5 application decreased leaf drop by 2.2% more than the R5 application. Similarly, Phipps and Telenko (2011) extended leaf drop caused by Cercospora blight with fungicide application in eastern Virginia. In contrast, fungicide applied at R5 at WAR13 and PTR13 did not reduce leaf drop values (Table 5.8.2). But the R3 timing decreased relative leaf drop by 5% compared to no fungicide treatment. In contrast, similar reductions in leaf drop were observed with all applications at SUF13. These data revealed that relative leaf drop decreased more with fungicide application in environments more conducive for disease. Therefore, these data indicate that decreased leaf drop is primarily due to disease control with fungicide and not to a physiological response of soybean to the strobilurin fungicide. Leaf drop measurements provided helpful insight into how fungicide affected yield through maintaining leaf area integrity. Board et al. (2007) evaluated defoliation during seed fill (R5) and reported 40 to 50% yield reduction when plants had 66% defoliation during the first three weeks of seed fill and less loss when defoliation occurred during later seed fill stages. Furthermore, Hartman et al. (1991) calculated green leaf area and attributed 52 to 85% of the yield loss in research to leaf severity and defoliation. Board and Harville (1998) and Haile et al. (1998) both reported that defoliation alone during the reproductive growth stages without soybean rust can decrease yields.

In 2012 and 2013, location affected yield response to cultivar (Table 5.6). This observation was expected due to genetic differences between cultivars and differing adaptability at locations differing in latitude. In 2012, seed yield was greatest at Suffolk, followed by Painter and Mt. Holly (Table 5.7.1). In 2013, Suffolk MG IV cultivars yielded greater than Warsaw and Painter (Table 5.8.1). Seed yield for each location mirrored rainfall trends for both years (Table 5.5).

We hypothesized that cultivars would interact with fungicide timing to influence yield, but such a response was not exhibited (Table 5.6). In 2012, yield responded similarly to fungicide across locations (Table 5.6). Fungicide applied at R3 increased yield across cultivars by 9%, from 4068 to 4488 kg ha^{-1} compared to untreated, but yielded no more than when applied at R5 or R3+R5 (Table 5.7.5). In contrast to our results, Dorrance et al. (2007) emphasized that early fungicide treatment was needed for optimum fungicide performance. The response to fungicide observed in our experiments was not maximized only at R3 or R5; rather the timing of disease entering the soybean canopy was responsible for increased fungicide efficacy at R3, R5 or R3+R5. General trends for fungicide timing performance were observed, but they were more importantly linked to disease infection and severity. Swoboda and Pedersen (2009) concluded that fungicide response partially depended on the amount of disease present and economic loss resulted if application was not warranted due to economic threshold not being met. Furthermore, although some disease differences did not result in different yields, these data indicate that applying fungicides at specific soybean stages (as promoted by most fungicide labels and some Extension recommendations) instead of when disease is most abundant may not be the best fungicide management strategy.

In 2013, fungicide's effect on yield depended on location (Table 5.6). Yield at PTR13 did not increase with fungicide; rather the greatest yield was attained with the untreated control at 3211 kg ha^{-1} (Table 5.8.2). In contrast, fungicide applied at R3 produced 5178 kg ha^{-1} at SUF13 and increased yield by 3%, compared to untreated, but yielded no more than other application timings. At WAR13, the R3 and R3+R5 applications produced the greatest yields (3696 and 3770 kg ha^{-1}, respectively) (Table 5.8.2). Delaying the application until R5 decreased yield by 308 and 234 kg ha^{-1}, when compared to R3+R5 and R3, respectively. Yield was reduced by 537, 463, and 229 kg ha^{-1}, when fungicide was not applied at WAR13, compared to R3+R5, R3, and R5, respectively. Similarly, Miles et al. (2003) and (2007) reported that fungicide may increase soybean yield but delaying application until after disease was present resulted in yield loss.

Yield response data, calculated as the kg per ha increase or decrease compared to the untreated control from the same cultivar and replication, further examined the differences between fungicide timings and more fully evaluated differences between cultivars to fungicide. Neither cultivar nor fungicide timing influenced yield response in 2012 (Table 5.6), however all three locations had a positive yield response when averaged across fungicide timings that ranged from 52 to 412 kg ha^{-1} (Table 5.7.3). This analysis reiterates that one fungicide application at either R3 or R5 increased yields, but there was no advantage for two applications at MTH12, PTR12 and SUF12. Interestingly, under conditions suitable for high levels of disease, all cultivars responded similarly to fungicide applications.

In contrast, cultivar yield response differed between locations in 2013 (Table 5.6). Soybean cultivars at WAR13 responded to fungicide by increasing yield for all 10 cultivars (Table 5.8.1). The MG IV cultivars were adapted to WAR13 and all but one performed well in high yield potential environment characterized by full canopy closure. Only cultivar V04-1022 responded less than all other cultivars to fungicide (63 kg ha^{-1}). Otherwise, yield response ranged from 248 to 675 kg ha^{-1}. Cultivar V04-1022 was listed as a 4.9 relative maturity but matured considerably later than predicted when compared to the other cultivars of similar relative maturity. In contrast, soybean cultivars at PTR13 responded negatively to fungicide in all 10 observations and yield response ranged from -62 to -535 kg ha^{-1} (Table 5.8.1). Negative yield response at PTR13 can partially be attributed to decreased leaf area and incomplete canopy closure with MG IV experiments. Soybean at SUF13 responded positively to fungicide in 8 of 10 observations; however, no specific trend regarding relative maturity was identified (Table 5.8.1). Cultivars that were 4.8 or 4.9 relative maturity (U74B81R and V04-1022) responded positively to fungicide. However, P94Y23 and SS4700R2 were 4.2 and 4.7 relative maturity, respectively and increased yield by 316 and 330 kg ha^{-1}, respectively, which demonstrated the inconsistent yield increase when comparing early- vs. late-maturing cultivars.

Application timing did not interact with cultivar or location in 2013, but influenced soybean yield response to fungicide (Table 5.6). When averaged across locations, yield increased by 155 and 123 kg ha^{-1}, and decreased by 54 kg ha^{-1}, for R3, R3+R5, and R5 application timings, respectively, when compared to untreated. Nelson et al. (2010) reported a yield increase of 230 to 360 kg ha^{-1} when fungicide was applied at R4.

Yield increase from fungicide can largely be attributed to increased seed weight. In 2012, when averaged across cultivars and locations, fungicide increased seed weight by 1.2 to 1.4 g 100 $seed^{-1}$ (Table 5.6 and 5.7.5). In 2013, fungicide increased seed weight at WAR13 and SUF13 at all application timings, but only at the R3 timing at PTR13 (0.3 g 100 $seed^{-1}$) (Table 5.6 and 5.8.2). At WAR13, the R3 timing increased seed weight 0.3 or 0.6 g 100 $seed^{-1}$ more than the untreated or R5 timing, respectively, but was similar to the R3+R5 timing. At SUF13, seed weight increased with all fungicide timings by 0.2 to 0.3 g 100 $seed^{-1}$. Phipps and Telenko (2011) reported similar results that soybean seed weights were increased with the use of fungicide.

In 2012 and 2013, both seed quality and PSS were influenced by cultivars that responded differently based on location (Table 5.6). Fungicide did not improve seed quality in 2012. Fungicide slightly improved seed quality in 2013 by 6 and 10% with R3 and R3+R5 timings when compared to untreated, but seed quality was generally good (averaging 2.0 in a 1 to 5 scale rating) (Table 5.8.3). Purple seed stain was not affected by fungicide in 2012, but percent of seed infected decreased at 2 of 3 locations in 2013 when fungicide was applied (Table 5.6 and 5.8.2). Cultivar marginally interacted with fungicide (P=0.0987) (Table 5.6). The interaction can primarily be attributed to differences between cultivar susceptibility; therefore, cultivar x fungicide data is not presented. Values ranged from 1.25 to 5.25% infected seed; however, 8 of 10 cultivars did not respond to different fungicide timings. At WAR13 and PTR13, the R3+R5 timing decreased PSS from 3.5 to 1.9 or 2.6 to 1.0% infected seed, respectively, compared to no fungicide (Table 5.8.2). In contrast, fungicide application at R5 or R3+R5 increased the number of infected seed by 0.9 and 1.5% at SUF13. Although differences were observed between treatments, there was relatively little PSS with the MG IV experiments in 2012 and 2013.

Seed oil and protein did not vary between cultivar in 2012; however, in 2013, location x cultivar influenced seed oil and protein concentrations (Table 5.6). Seed oil ranged from 19.1 to 20.2, from 19.6 to 20.9 and from 20.2 to 20.7% at WAR13, PTR13, and SUF13, respectively (Table 5.8.1). At WAR13, as cultivar relative maturity increased, seed oil generally decreased; whereas, at PTR13, no relative maturity trend was established. Seed oil values at SUF13 were similar between cultivars. Seed protein ranged from 38.9 to 41.9, from 40.6 to 42.6, and from 38.3 to 40.7% at WAR13, PTR13, and SUF13, respectively (Table 5.8.1). Unlike seed oil, cultivars at WAR13 and PTR13 did not have seed protein trends that were linked to relative maturity. The only trend observed from these data is that SUF13 cultivars generally reduced variability with seed protein values between cultivars.

Seed oil and protein concentrations responded to fungicide in 2012, whereas, only protein responded in 2013 (Table 5.6). Fungicide increased seed oil at only 1 of 3 locations (PTR12) in 2012 by yielding 19.7% oil with the R5 timing, which was greater than R3+R5 and untreated by approximately 1 and 3%, but was no different than the R3 timing (Table 5.7.2). Similar to seed oil, seed protein increased by all fungicide application timings from 2.8 to 5.45% at PTR12 with untreated producing the lowest protein at 37% and R3 exhibiting the greatest protein concentration with 43% (Table 5.7.2). Although protein was affected by fungicide in 2013, levels were not greater with fungicide. Interestingly, protein levels declined by 0.5% with the R3+R5 applications, but were not different than the R3 application (Table 5.8.3).

Canopy NDVI was influenced by fungicide but not cultivar and differed by location in 2012 (Table 5.6). At MTH12 and SUF12, R5 NDVI was not affected by fungicide and ranged from 0.8870 to 0.9117 and from 0.9033 to 0.9085, respectively. However, at PTR12, lack of fungicide decreased NDVI by 12%, compared to fungicide at R3 and values ranged from 0.7941 to 0.9082. The canopy never fully closed and there was no yield response at MTH12; therefore, there was little leaf area for fungicide to protect. The minimal NDVI response to fungicide at SUF12 could be attributed to excessive canopy and overall growth with all plots, regardless of cultivar or fungicide.

Similar to 2012, fungicide protected leaf area by increasing NDVI at only 1 of 3 locations in 2013 (Table 5.6). At PTR13 and SUF13, NDVI was no greater with fungicide compared to untreated; values ranged from 0.8868 to 0.8931 and from 0.8987 to 0.9047, respectively. In contrast, WAR13 NDVI increased from 0.8895 to 0.9102 with fungicide at R3, compared to untreated. The MG IV soybean produced greater leaf area which was protected by fungicide and expressed in NDVI values partially attributed to complete canopy closure and disease that infected the canopy by the R3 stage. In summary, fungicide increased NDVI at 2 of 6 locations. Ma et al. (2001) reported plant NDVI during pod set to be closely correlated with soybean yield. In contrast, our R5 NDVI values did not consistently relate increased NDVI to fungicide application as observed with fungicide’s effect on seed yield. Chen and Wiatrak (2011) examined NDVI values from soybean grown on coastal plain soils in South Carolina and concluded that at full canopy closure, NDVI was saturated and lost sensitivity. Use of R5 NDVI may not the best choice to validate fungicide’s influence on canopy dynamics.

We cannot conclude that a specific relative maturity is better suited to fungicide. But as leaf area increases with later maturing cultivars, the microenvironment should theoretically be more conducive for disease formation; therefore fungicide should be more effective. However, as leaf area decreases with early-maturing cultivars, fungicide would be increasingly critical to protect limited photosynthetic area. This paradox could possibly explain the limited differences between relative maturities. Regardless, it is difficult to predict fungicide response based on cultivar relative maturity and is more likely attributed to disease susceptibility. The two cultivars that responded negatively to fungicide at SUF13 were AG4732 and U74A79R and we partially attributed their responses to better disease resistance characteristics compared to the other eight cultivars. Although fungicide application at PTR13 was not linked to the greatest seed yield (Table 5.8.1), cultivars differed in their response to fungicide. Lack of fungicide response by the MG IV cultivars at PTR13 is likely due to mid- and late-season drought stress, which may not have been as conducive for fungal disease development. Similar to our observations, Bradley and Sweets (2008) determined that fungicide increased yield only when applied in a year with precipitation during reproductive growth stages.

MG V Cultivars x Fungicide

Cercospora blight levels, expressed at AUDPC-CBL, were influenced by interactions between location and cultivar, location and fungicide, or fungicide and cultivar in 2012 (Table 5.9). At MTH12, PTR12, and SUF12, cultivar CBL values ranged from 83 to 258, 168 to 365, and 172 to 338%-days, respectively (Table 5.10.1). The AUDPC-CBL was less for all MG V cultivars when fungicide was applied, regardless of timing (Table 5.10.3). However, only 4 of 10 or 5 of 10 MG V cultivars had more CBL with the R3 or R5 timing, respectively, compared to the R3+R5 application. Furthermore, no differences in CBL existed between the R3 and R5 application timings. Trends due to relative maturity were not observed, but variability between cultivars' response to fungicide was more likely attributed to disease susceptibility. In addition, fungicide influenced CBL values differently depending on location (Table 5.9). Compared to the untreated, applying fungicide at R3+R5 decreased CBL by 34, 63, and 56% at MTH12, PTR12, and SUF12, respectively (Table 5.10.2). Differences between CBL values for R3 vs. R5 were minimal at MTH12. But at PTR12, applying fungicide at R5 decreased AUDPC CBL values by 14%-days more than the R3 timing. In contrast, fungicide at R3 decreased CBL by 17% more than the R5 timing at SUF12. Furthermore, at PTR12 and SUF12, disease persisted through reproductive stages and maturity and the R3+R5 timing reduced CBL the greatest and provided the most critical leaf area protection compared to all other treatments. These data reiterate that the optimal fungicide timing coincides with the greatest disease pressure and reduced CBL.

Cercospora blight on the stems responded similarly in 2012 to the AUDPC-CBL data (Table 5.9). Cultivar interacted with location to influenced CBS values. At MTH12, PTR12, and SUF12, CBS values for cultivars ranged from 127 to 605, from 91 to 345, and from 242 to 478%-days, respectively (Table 5.10.1). Similar to CBL, cultivars differed in susceptibility to CBS, which provides insight into the lack of cultivar x fungicide timing effect on seed yield. Cultivar also interacted with fungicide to affect CBS. Similar to CBL, all MG V cultivars decreased CBS with fungicide application and there were no differences between the R3 and R5 application timings (Table 5.10.3). The R3+R5 fungicide timing was greater than R3 or R5 timing with 4 of 10 or 6 of 10 cultivars, respectively. Finally, location affected CBS response to fungicide. At MH12, the R3 or R5 timing did not lower CBS, but the R3+R5 timing reduced CBS by 111, 86, or 83 %-days versus no fungicide, R3 timing, or R5 timing, respectively. At PTR12, the R3, R5, or R3+R5 reduced CBS by 109, 109, or 162 %-days, respectively. At SUF12, the R3, R5, or R3+R5 reduced CBS by 292, 270, or 363 %-days, respectively.

In 2013, cultivar, fungicide, and location interacted to affect AUDPC CBL (Table 5.9). In general, AUDPC CBL was greatest at SUF13, followed by PTR13 and WAR13. Specifically, CBL values ranged from only 23 to 173%-days for all treatment combinations (Table 5.12). Cultivars responded differently to fungicide treatments, but the degree of response varied by location. Furthermore, no trend was observed that showed increased or decreased CBL for cultivars when fungicide timing was changed. Cruz et al. (2010) provided insight into cultivar x fungicide interactions by emphasizing that fungicide application was intended to reduce the overall level of disease but the observed response was greatly influenced by cultivar susceptibility. Due to the relatively low CBL at WAR13, fungicide performed well with all three timings and decreased CBL compared to the untreated. In contrast, CBL levels at SUF13 or PTR13 were unaffected by fungicide, regardless of application timing.

Although there was no three-way interaction, location affected the AUDPC-CBS response to cultivar and to fungicide in 2013 (Table 5.9). At WAR13, PTR13 and SUF13, CBS levels ranged from 56 to 88, from 45 to 63, and from 49 to 80%-days, respectively (Table 5.11.1). Interestingly, CBS levels were greatest at WAR13, but the same location had the least CBL compared to PTR13 and SUF13. All three locations had increased AUDPC CBS levels when fungicide was not applied compared to all fungicide timings. Specifically, at WAR13, fungicide applied at R3, R5, and R3+R5 decreased CBS levels by 21, 11, and 23%, compared to untreated (Table 5.11.2). Soybean at PTR13 responded similarly between fungicide timings and decreased CBS levels by 23, 21, and 27% for R3, R5, and R3+R5, respectively (Table 5.11.2). At SUF13, fungicide applied to soybean decreased CBS levels by 11, 17, and 18% for R3, R5, and R3+R5 timings (Table 5.11.2). Furthermore, fungicide applied at R3+R5 decreased CBS greater than fungicide applied just at R3.

In addition, there was a marginal cultivar x fungicide interaction that affected CBS (P=0.660). The R3+R5 fungicide timing decreased CBS with all cultivars (Table 5.11.3). The R3 timing reduced CBS in all but cultivars except S56-G6 and the R5 timing reduced CBS in seven cultivars but not with P5610RY, 95Y60, or S56-G6. There were no differences in control of CBS between the R3 and R3+R5 applications, but the R5 application gave less control than R3+R5 for AG5632, 95Y60, and P5655RY. Cercospora blight on the stems was greater in 2012 than 2013, however in both years, the R3+R5 fungicide timing consistently provided efficacious control of CBS for different cultivars ranging from 5.1 to 5.6 relative maturities.

Cultivar affected relative leaf drop in both years, but cultivar rankings changed depending on location; however, fungicide did not affect the cultivar response (Table 5.9). Leaf drop at MTH12, PTR12, and SUF12 ranged from 35.1 to 49.0, from 26.9 to 54.6, and from 37.4 to 50.6, respectively (Table 5.10.1). The least leaf drop was observed at MTH12, which also had the least disease incidence, compared to PTR12 and SUF12, which had similar disease levels. Leaf drop, when averaged across 2013 MG V cultivars ranged from 42 to 70.3%, from 45.5 to 69.5%, and from 62.5 to 72.6% for WAR13, PTR13, and SUF13, respectively (Table 5.11.1). Cultivars responded differently with leaf drop at different locations attributed to both disease and relative maturity; however, general trends cannot be determined from these data.

Location affected relative leaf drop response to fungicide in 2012, but not in 2013. At MTH12, leaf drop did not differ between fungicide treatments, but all fungicide application timings delayed leaf drop at PTR12 and SUF12 (Table 5.10.2). In addition, the R3+R5 timing decreased relative leaf drop by 20 and 26%, from 42.1 to 35.0% and 48.2 to 38.3% at PTR12 and SUF12, respectively, compared to untreated. Also, relative leaf drop for the R3 and R5 timings was greater than R3+R5 at both PTR12 and SUF12, but were less than the untreated. In 2013, fungicide applied at R3+R5 resulted in 56% relative leaf drop, which was 1, 3, and 4% less than R5, R3, and untreated, respectively (Table 5.11.5).

Location, cultivar, and fungicide affected soybean yield in both years (Table 5.9). As discussed previously with MG IV's, yield was expected to fluctuate between locations due to environment, yield potential, and relative maturity differences (Table 5.10.1 and 5.11.1). Interestingly however, cultivar responded similarly to fungicide application (no cultivar x fungicide interaction). In 2012, fungicide increased yield at 2 of 3 locations (PTR12 and SUF12) (Table 5.10.2). Yield response to fungicide was not expected at MTH12 due to early-season drought stress that reduced soybean growth and canopy closure, resulting in less than favorable environment for disease development. The environment was more favorable for disease development at SUF12, but fungicide did not increase yield when analyzed together with other locations. However, when SUF12 yield was further investigated and analyzed independently, fungicide at R3 and R3+R5 contributed to greater yield with 4802 and 4781 kg ha^{-1}, respectively, and was significantly greater than the untreated (4542 kg ha^{-1}), but was no different than R5 timing (4709 kg ha^{-1}) ($P=0.0427$) (Table 5.10.7). At PTR12, fungicide increased yield at all application timings. Soybean yielded 4718 to 4880 kg ha^{-1} at PTR12 when fungicide was applied, resulting in 17 to 21% yield increase compared to untreated, (Table 5.10.2). Similar to these data, field evaluations by Phipps et al. (2010) of fungicides in Virginia demonstrated a yield response ranging from a few kg per ha in low disease pressure to as high as 20 kg ha^{-1} in moderate to high disease pressure.

In 2013, dry conditions in September (Table 5.5) resulted in much less disease, averaging 53%-days versus 255%-days for 2012 (Tables 5.10 and 5.11). As a result, fungicide increased yield at only 1 of 3 locations (Table 5.11.2). Fungicide increased yield with the R5 or R3+R5, but not the R3 application timing at PTR13. Fungicide applied at R3+R5 increased yield by 10, 15, and 18%, compared to R5, R3, and untreated, respectively. Disease was observed to infect soybean later in the season at PTR13; therefore, the R3 fungicide application did not last long enough to adequately protect soybean from the late disease infection. Furthermore, there appeared to be a positive combination effect from two fungicide applications. Alone, the R3 and R5 timings increased yield by 189 and 274 kg ha^{-1}, which totals to a 463 kg ha^{-1} yield benefit. But together, the applications increased yield by 767 kg ha^{-1}. It is intriguing how fungicide applied at R3+R5 provided a greater effect in 2013, but in 2012, when disease levels were higher, the R3+R5 combination did not perform in such a manner.

Cultivars did not differ in their response to fungicide in 2012; yield response differed only by location (Table 5.9). Yield response to fungicide in 2012, averaged across the three timings varied by location and was 222, 173, and -54 kg ha^{-1} at SUF12, PTR12, and MTH12, respectively (Table 5.10.4). These data are similar to seed yield which showed fungicide increased yield at Painter and Suffolk in 2012 but not at Mt. Holly.

In contrast to 2012, cultivars did respond differently to fungicide application in 2013. Averaged over locations, the yield response ranged from -26 to 251 kg ha^{-1}. This indicates that under low disease pressure, certain cultivars may differ in their response to foliar fungicides. We observed inconsistent response by MG V cultivars to specific fungicide timings, partially attributed to cultivars differing greatly in susceptibility to CBL, regardless of fungicide. Differences between fungicide application timing depended on location and disease development. The AUDPC CBL and CBS values for 2012 demonstrate that disease control does not always increase yield in soybean. In contrast, the 2013 CBS values decreased with R3+R5 fungicide, which matches our yield results. However, Cercospora blight values decreased greater with R3 vs. R5; but when compared to yield results, the R3 fungicide timing did not yield greater than R5 at any location in 2013. Leaf drop at PTR12 was lowest with R3+R5, which matched the yield results where R3+R5 yielded the greatest. However, delayed leaf drop in 2013 partially attributed to fungicide only contributed to yield at PTR13. Kumudini et al. (2008) demonstrated that a reduction in harvest index due to defoliation was expressed as reduced seed number and mass, which are partially responsible for yield formation.

As revealed with the yield data, there were no differences in yield response between application timings at WAR13 (Table 5.11.2). However, at SUF13, the R3+R5 timing resulted in 199 and 184 kg ha^{-1} more yield than the R3 and R5 applications, respectively. Nevertheless, as stated previously, the R3+R5 application did not increase yield over the untreated. At PTR13, fungicide applied at R3+R5 produced 666, 579, and 392 kg ha^{-1} greater yield compared to untreated, R3 and R5, respectively (Table 5.11.2). When return on investment is examined at PTR13, yield increase attributed to fungicide provided a positive return on investment for R3+R5 (+\$194 ha^{-1}) and R5 (+\$43 ha^{-1}), but resulted in net loss with the R3 timing (-\$39 ha^{-1}).

Cultivar affected seed weight across all locations in 2012, but the response to fungicide depended on location (Table 5.9). Yield at MTH12 did not vary by fungicide timing and the same was observed with 100 seed weight (Table 5.10.2). However seed weight differences mirrored yield responses at PTR12, indicating that larger seed played a role in the observed yield increases. Similarly, Henry et al. (2011) applied pyraclostrobin and increased seed mass from 13.9 to 14.3 g 100 seed^{-1} compared to untreated. In contrast, fungicide did not affect seed weight at SUF12.

Location affected seed weight response to cultivar in 2013 (Tables 5.9). Cultivars' seed weight ranged from 13 to 15.9, from 12.7 to 16.7, and from 14.5 to 18.4 g 100 seed^{-1} at WAR13, PTR13, and SUF13, respectively (Table 5.11.1). All cultivars at SUF13 produced heavier seed, compared to cultivars at PTR13 and WAR13. Furthermore, out of the 10 MG V cultivars investigated, six had the second greater seed weight at PTR13, with an average relative maturity of 5.5, compared to WAR13, where four cultivars had the second greater seed weight and averaged 5.4 relative maturity. Differences in seed weight between cultivars at different locations may be partially attributed to relative maturity and cultivar adaptability. Location did not affect seed weight response to fungicide, but seed weight was 0.4 and 1.5 g 100 seed^{-1} greater vs. untreated when fungicide was applied at R5 and R3+R5, respectively (Table 5.9 and 5.11.5). As in 2012, seed weight likely contributed to greater seed yield at PTR13, but this increase did not translate into yield at the other two locations.

Cultivars differed in seed quality in 2012 and 2013, but the relative response depended on location in 2013. In 2012, seed quality differed by location and values were 1.9, 1.6, and 1.4 for SUF12, MTH12, and PTR12, respectively. Seed quality at SUF12 was significantly greater than MTH12 or PTR12. Furthermore, MTH12 cultivars' seed quality was greater than PTR12 cultivars. Seed quality at PTR12 was the best of all three locations. Cultivars' seed quality ranged from 1.5 to 1.8 in 2012 and relative maturity trend was not identified. Seed quality at WAR13, PTR13, and SUF13 ranged from 1.0 to 1.4, from 1.0 to 1.1, and from 1.2 to 2.7, respectively. At SUF13, as relative maturity increased, seed quality generally improved; in contrast, at WAR13, as relative maturity increased, seed quality was generally worse. Relative maturity did not provide a consistent trend at PTR13, which can partially be attributed to minimal differences between cultivars. Only at SUF13 did fungicide improve seed quality (Tables 5.9 and 5.11.2). Fungicide applied at R3+R5 and at R5 at SUF13 improved seed quality by 25 and 22%, respectively, compared to the untreated control (Table 5.11.2).

In 2012, cultivars had different PSS ratings that varied by location (Table 5.9), but ranged from only 0 to 0.3% infection. Specifically, PSS values were slightly greater at SUF12, followed by MTH12 and PTR12. In 2013, a three-way interaction of location, cultivar, and fungicide was present for PSS. Purple seed stain values ranged from 0 to 10.5% and varied by cultivar, as observed in 2012. More importantly, PSS ranged from 0 to 2.5%, from 0 to 1.0%, and from 0 to 10.5% for WAR13, PTR13, and SUF13, respectively. Cultivars treated with fungicide at both WAR13 and PTR13 generally had similar PSS ratings compared to untreated soybean. In contrast, at SUF13, PSS was generally greater and specific cultivars benefited from fungicide, whereas, other did not. For example, P5655RY rated 10.5% PSS without fungicide, compared to 6.5, 4.7, and 3.0% for R3+R5, R3, and R5 timings, respectively. Furthermore, P5655RY untreated PSS values were significantly greater than the same cultivar PSS vs. all fungicide timings. In addition, with P5655RY, PSS significantly improved with R5 > R3 > R3+R5. Therefore, fungicide applied at both R3+R5 did not improve PSS in this example at SUF13 and an independent application at R5 reduced PSS the most. Purple seed stain dynamics were ultimately controlled by cultivar susceptibility; however, fungicide did improve PSS for specific cultivars. Purple seed stain was much greater in 2013 compared to 2012, even though Cercospora blight was reduced in 2013 compared to the previous year. Schuh (1999) reported that resistance for purple seed stain and Cercospora leaf blight may be controlled by separate genetics. In comparison to our results, Phipps and Telenko (2011) applied fungicide with the same active ingredient and at the same timings that we utilized but did not improve PSS dynamics with fungicide.

Seed protein and oil content varied with cultivar in 2012 (Table 5.9). Fungicide also increased seed oil by approximately 4% with all three timings compared to untreated (Table 5.9

and 5.10.6). At 1 of 3 locations (PTR12), fungicide increased seed protein by 4.7 to 5.1% (Table 5.10.2). In 2013, location affected the protein and oil content response to cultivar (Table 5.9). Seed oil ranged from 18.1 to 19.3%, from 18.5 to 19.6%, and from 20.0 to 21.5% for cultivars at WAR13, PTR13, and SUF13, respectively. Seed protein at WAR13, PTR13, and SUF13 ranged from 37.0 to 41.7%, from 40.1 to 42.3%, and from 40.7 to 44.5%, respectively. Trends for either oil or protein associated with MG V cultivar differences explained by relative maturity were not identified at any location. Fungicide minimally affected oil content across all locations equally, but location interacted with fungicide with protein (Table 5.9). Oil content was the same at 19.6% for the untreated and R3 application, which was 0.1 or 0.2% greater than the R5 or R3+R5 application. At WAR13, protein content of the untreated control was 0.6% greater than when fungicide was applied at R3 or R5, but did not differ significantly from the R3+R5 application (Table 5.11.2). Protein content was not affected by fungicide at PTR13, but the R5 application resulted in 0.6 or 0.9% greater protein content than the R3 or R3+R5 application; however, the R5 application did not differ from the untreated. Less rainfall during September, which resulted in less disease in 2013, likely contributed to reduced oil and protein response to fungicide. Inconsistent fungicide effect on seed oil and protein was also reported by Swoboda and Pedersen (2009), who demonstrated that fungicide applied independently at R1, R3, or R5 or a combined application at R1+R3+R5 did not affect seed oil or protein content at harvest.

Fungicide increased R5 NDVI at only 1 of 3 locations in 2012 (PTR12) (Table 5.9). Canopy NDVI values increased from 0.7970 to 0.9082 when untreated was compared to the R3 timing. The NDVI values demonstrated partial yield contribution by fungicide at PTR12. Values of R5 NDVI did not differ between untreated and fungicide at MTH12 or SUF12. In comparison, significant yield differences at MTH12 were not observed, which matches the R5

NDVI values, but does not apply to SUF12, where soybean increased yield with fungicide. In 2013, R3 fungicide did not increase NDVI values at any location. Canopy R5 NDVI values at WAR13, PTR13, and SUF13 ranged from 0.8619 to 0.9004, from 0.8632 to 0.8844, and from 0.8900 to 0.9139, respectively. Soybean at WAR13 had greater NDVI differences between cultivars compared to PTR13 or SUF13 and may partially be attributed to foliar disease that entered the canopy early at WAR13 and infected cultivars differently based on susceptibility, which was expressed in leaf area and measured by NDVI. Canopy NDVI at R5 was greatest at SUF13 and can partially be attributed to environment which accelerated canopy closure. Relative maturity differences were minimal and did not help explain R5 NDVI differences at any location in 2013.

Conclusion

During the 2012 and 2013 growing seasons, 3 of 6 locations received atypical rainfall that resulted in above average vegetative growth and ideal conditions for disease development. These conditions allowed us to investigate how foliar fungicide and soybean cultivars affect growth, disease, and yield parameters when the environment is conducive for disease development. Our data showed that MG IV and V cultivars and fungicide did not interact to affect seed yield. We partially attribute no cultivar x fungicide yield response to the lack of resistance to Cercospora blight, the primary disease occurring in our experiments. However, cultivars did occasionally respond differently to fungicide, as evidenced by yield response that removed the cultivar yield bias from the data. Furthermore, cultivars did not consistently respond to specific timings, but response was related more to environmental conditions that affected disease development at the time of application. Cultivar and fungicide combined to affect other soybean-related parameters including purple seed stain and Cercospora blight on leaves and stems that influenced seed yield directly through photosynthetic efficiency and indirectly through seed quality. While we did not optimize fungicide timing with cultivar, these data demonstrated how critical fungicide can be for double-crop soybean when disease resistant varieties are not available.

Many of our results were site-specific; however general trends can be gleaned from our data and may assist in understanding how our research can be applied. Fungicide application increased seed yield at 4 of 6 and 3 of 6 locations for the MG IV and MG V cultivars, respectively. Yield increase observed at 67% for MG IV and 50% for MG V is relatively high compared to the literature which is typically dominated by 20 to 50% yield response to fungicide (Bradley and Sweets, 2008; Dorrance et al., 2010; Nelson et al., 2010; Pataky and Lim, 1981; Wrather and Koenning, 2006). But, most of that research was conducted under full-season and not double-crop soybean systems. Double-crop soybean matures later in the year when conditions may be more conducive to disease development due to cooler temperatures. Still, if experiments were conducted during growing seasons with more typical rainfall that may limit vegetative growth, results may be closer to those experienced by others.

We attribute increased soybean yield with fungicide partially to increased seed weight. Within both the MG IV and V experiments, seed weight was greater with fungicide at the same locations where soybean increased yield with fungicide. Canopy never fully closed at MTH12 due to drought stress; however, yield responded to fungicide, but did not differ by fungicide timing. Even with limited canopy closure, Cercospora blight still infected soybean at MTH12. These data demonstrate that improved disease control attributed to different fungicide timings does not always result in a yield increase, especially when canopy development is limited. In addition to visual observations and NDVI, leaf drop and AUDPC for Cercospora blight on soybean leaves and stems quantified canopy's importance to disease development and seed yield. Fungicide decreased leaf drop for all six MG IV experiments and for 5 of 6 MG V experiments and contributed to yield through improved leaf area retention. Cercospora blight on soybean leaves and stems was partially controlled by fungicide, but control was not always complete, even with two applications. Improved disease control did not always translate to greater seed yield.

Our research was not designed to test which MG was better-suited for eastern Virginia but rather to investigate if fungicide timing affected MG IV's and V's differently. When averaged across all locations and fungicide timings, MG IV and MG V experiments yielded similarly in 2012 (4409 vs. 4402 kg ha^{-1}, respectively). In contrast, in 2013 MG IV cultivars in our experiments yielded 3873 kg ha^{-1} compared to 3685 kg ha^{-1} observed with the MG V's. The yield difference in 2013 can partially be attributed to MG IV's being in an advanced developmental stage during September when drought stress coincided with MG V cultivars' critical reproductive stages. The optimum fungicide timing changed by location and disease development; however, R3 and R3+R5 performed the most consistently for the MG IV's and MG V's, respectively. We attribute decreased yield response to R5 applications to fungicide not applied until after disease infection. Still, the R5 timing was observed to increase yield in some experiments and the response was occasionally greater than when fungicides were applied at R3. However, the risk of delaying fungicide until R5 could be great and tended to result in lower yields compared to the R3 application. In summary, efficacy was ultimately controlled by when disease infected the canopy.

Double-crop soybean vegetative growth is typically lower than full-season and can partially be attributed to decreased water available during early-season. Therefore, research initiatives need to focus on increasing early-season growth with agronomic inputs designed to accelerate seedling growth, and ultimately close the canopy faster and more efficiently. Historically, double-crop soybean does not develop adequate leaf area and close the canopy as frequently as full-season. Under these conditions, fungal disease infection may not develop as rapidly due to the canopy being exposed to increased sunlight, wind, and higher temperatures. However, with increased and improved canopy closure and architecture being a priority in double-crop soybean research initiatives, fungal disease populations may shift even more into double-crop soybean canopy due to cooler conditions during the pod and seed fill stages that are more conducive to disease development. This would increase the need for appropriate fungicide application timings combined with disease forecasting and modeling, designed to provide mid-to-late-season soybean disease efficacy while optimizing and protecting seed yield. In conclusion, these data have assisted research and Extension personnel, crop consultants, industry representatives, and farmers in making agronomic and plant pathology decisions in double-crop soybean production.

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Table 5.1 Site physical characteristics for 2012 and 2013 maturity group IV and V soybean x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Site-Year	Soil Series and Texture †	Soil Classification †	Latitude	Longitude
MTH12	State fine sandy loam	Fine-loamy, mixed, semiactive, thermic Typic Hapludults	38° 5'0.16"N	76°42'39.49"W
PTR12	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF12	Rains fine sandy loam	Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults	36°40'56.20"N	76°45'55.76"W
WAR13	Kempsville loam	Fine-loamy, siliceous, subactive, thermic Typic Hapludults	37°59'24.22"N	76°46'29.48"W
PTR13	Bojac sandy loam	Coarse-loamy, mixed, semiactive, thermic Typic Hapludults	37°35'9.82"N	75°49'29.58"W
SUF13	Rains fine sandy loam	Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults	36°40'57.61"N	76°46'2.89"W

† USDA-NRCS web soil survey (WSS, 2014).

Table 5.2 Calendar dates for agronomic inputs, data collection and growth and developmental stages for 2012 and 2013 maturity group IV soybean x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Agronomic Input	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Planting	6/19	6/28	6/18	7/8	7/10	6/17
Stand counts	7/10	7/18	7/11	7/23	7/30	7/9
V4 plant height †	7/31	8/7	7/23	8/6	8/12	7/24
R3 fungicide applic.	8/16	8/22	8/13	8/27	9/6	8/13
R5 fungicide applic.	9/5	9/10	8/30	9/17	9/16	8/30
R8 plant height	11/12	11/6	11/5	12/4	11/25	10/17
Harvest	11/19	11/29	11/5	12/4	1/9 ‡	11/22
Growth stage †						
V2 †	7/10	7/18	7/11	7/26	7/30	7/9
V3	7/19	7/25	7/16	7/30	8/2	7/12
V4	7/31	8/7	7/20	8/2	8/5	7/16
R2	8/9	8/7	7/30	8/17	8/27	7/29
R3	8/16	8/22	8/13	8/27	9/4	8/13
R4	8/30	8/29	8/21	9/3	9/9	8/20
R5	9/5	9/10	8/30	9/17	9/16	8/28
R6	9/19	9/17	9/9	9/23	9/24	9/12
R7	10/11	10/10	10/2	10/15	10/22	9/30
R8	10/18	10/24	10/12	10/31	11/13	10/8

† Soybean growth and development stages as described by Fehr and Caviness (1977).

‡ 2014.

Table 5.3 Calendar dates for agronomic inputs, data collection and growth and developmental stages for 2012 and 2013 maturity group V soybean x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Agronomic Input	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Planting	6/19	6/28	6/18	7/8	7/10	6/18
Stand counts	7/10	7/18	7/11	7/23	7/30	7/9
V4 plant height †	7/31	8/7	7/23	8/6	8/12	7/24
R3 fungicide applic.	8/24	8/29	8/21	9/5	9/6	8/20
R5 fungicide applic.	9/12	9/17	9/6	9/23	9/24	9/4
R8 plant height	11/12	11/6	11/5	12/4	11/25	11/21
Harvest	11/19	11/29	11/5	12/4	12/17	12/19
Growth stage †						
V2	7/10	7/18	7/11	7/26	7/30	7/9
V3	7/19	7/25	7/16	7/30	8/2	7/12
V4	7/31	8/7	7/20	8/2	8/5	7/16
R2	8/14	8/22	8/8	8/27	8/30	8/10
R3	8/24	8/29	8/21	9/5	9/6	8/19
R4	9/5	9/10	8/30	9/14	9/13	8/26
R5	9/12	9/17	9/9	9/23	9/24	9/4
R6	10/18	10/10	9/19	10/8	10/5	9/18
R7	10/25	10/24	10/20	10/31	11/2	10/16
R8	11/12	11/6	11/5	11/25	11/25	11/14

† Soybean growth and development stages as described by Fehr and Caviness (1977).

Table 5.4 Soybean cultivars utilized in 2012 and 2013 maturity group IV and V x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Year	Company	Cultivar	RM †
2012, 2013	Asgrow	4632	4.6
2012, 2013	Asgrow	4732	4.7
2012, 2013	Asgrow	5332	5.3
2012, 2013	Asgrow	5632	5.6
2012	NK	S51-J3	5.1
2013	NK	S51-H9	5.1
2012, 2013	NK	S56-G6	5.6
2012	Pioneer Hi-Bred	94Y22	4.2
2013	Pioneer Hi-Bred	94Y23	4.2
2012, 2013	Pioneer Hi-Bred	94Y70	4.7
2012, 2013	Pioneer Hi-Bred	95Y40	5.4
2012, 2013	Pioneer Hi-Bred	95Y60	5.6
2012	Progeny	4811RY	4.8
2013	Progeny	4850RY	4.8
2012, 2013	Progeny	5610RY	5.6
2012, 2013	Progeny	5655RY	5.6
2012, 2013	Public VA	V041022	4.9
2012, 2013	Southern States	4700R2	4.7
2012, 2013	Southern States	4711NR2	4.7
2012, 2013	Southern States	5112NR2	5.1
2012, 2013	Southern States	5510NR2	5.5
2012, 2013	USG	74A79R	4.7
2012, 2013	USG	74B81R	4.8

† Relative Maturity.

Table 5.5 Growing season air temperature and precipitation for 2012 and 2013 maturity group IV and V soybean x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Site-Year					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Temperature	----------------------------------°C----------------------------------					
May	21	21	21	20	19	19
June	23	23	23	24	24	24
July	28	28	27	26	26	26
August	26	25	25	23	23	24
September	21	22	21	20	21	20
October	16	17	16	16	17	17
November	7	8	7	8	9	9
Mean	20	21	20	20	20	20
May-Nov.	(20)†	(20)	(21)	(20)	(20)	(21)
Precipitation	------------------------------------mm------------------------------------					
May	67	64	204	55	42	91
June	13	103	157	194	179	206
July	30	123	120	158	84	88
August	141	246	204	95	100	164
September	69	55	92	26	46	51
October	191	252	208	76	96	115
November	12	21	18	75	61	88
Total	524	864	1003	679	608	803
May-Nov.	(710)†	(692)	(768)	(710)	(692)	(768)

† 29 year May-Nov. mean in parenthesis.

Table 5.6 Test of fixed effects and interactions for soybean growth, disease, and seed yield and quality parameters for 2012 and 2013 maturity group IV x foliar fungicide experiments.

Attribute	Year	Location (L)	Cultivar (C)§	Fungicide (F)Φ	L*C	L*F	C*F	L*C*F
		--		Pr >--				
R5 NDVI £	2012	0.0043 †	0.6548	0.0127	0.8750	0.0245	0.6578	0.9747
	2013	<.0001	<.0001	<.0001	<.0001	<.0001	0.4569	0.6144
AUDPC-CBL ‡	2012	<.0001	<.0001	<.0001	<.0001	<.0001	0.9508	0.8342
	2013	<.0001	0.3473	0.0332	0.0690	0.0003	0.9976	1.0
AUDPC-CBS ‡	2012	<.0001	<.0001	<.0001	<.0001	<.0001	0.6858	0.9950
	2013	<.0001	0.0001	0.0004	<.0001	<.0001	0.9050	0.9996
Leaf drop	2012	<.0001	<.0001	<.0001	<.0001	0.0105	0.9687	1.0
	2013	<.0001	<.0001	<.0001	<.0001	0.0059	0.9357	1.0
Seed yield	2012	<.0001	0.0019	<.0001	0.0173	0.1371	0.8879	0.9672
	2013	<.0001	<.0001	<.0001	<.0001	<.0001	0.9439	0.9961
Yield response	2012	<.0001	0.8678	0.5590	0.1054	0.7413	0.8212	0.9264
	2013	<.0001	0.2096	0.0016	0.0028	0.5067	0.9918	1.0
Seed weight	2012	<.0001	0.0002	<.0001	0.1817	0.1998	0.7198	0.9735
	2013	<.0001	<.0001	<.0001	<.0001	<.0001	0.7222	0.9264
Seed quality	2012	<.0001	<.0001	0.4477	0.0016	0.5268	0.9949	0.9998
	2013	<.0001	<.0001	0.0239	<.0001	0.3502	0.9265	0.9891
Purple seed stain	2012	<.0001	<.0001	0.4256	<.0001	0.6460	0.9991	1.0
	2013	<.0001	<.0001	0.0241	<.0001	<.0001	0.0987	0.8253
Seed oil	2012	<.0001	0.2848	0.0313	0.7096	0.0183	0.5353	0.9928
	2013	<.0001	<.0001	0.1984	0.0002	0.1828	0.3807	0.6132
Seed protein	2012	0.0241	0.3631	0.0099	0.6113	0.0369	0.6652	0.9818
	2013	<.0001	<.0001	0.0127	0.0475	0.9274	0.9574	0.9950

§ Ten MG IV cultivars ranging from 4.2 to 4.9 relative maturities.

Φ Foliar application of pyraclostrobin + fluxapyroxad at R3 (beginning pod), R5 (beginning seed), and R3+R5 stages (Fehr and Caviness, 1977).

† P (0.05) level significance.

£ Normalized difference vegetative index.

‡ Area under disease progress curve for cercospora blight on soybean leaves (CBL) and stems (CBS).

Table 5.7 Location, cultivar, and fungicide main effects and interactions influenced soybean yield, seed quality, purple seed stain, cercospora blight leaf and stem ratings, relative leaf drop, seed oil and protein concentrations, seed weight, and yield response for 2012 maturity group IV x foliar fungicide experiments.

Table 5.7.1			Seed			AUDPC ‡		Relative
Cultivar	Location	Fungicide	Yield	Quality	PSS δ	CBL	CBS	leaf drop
			--kg ha^{-1}--		---%---	------%-days------		----%----
AG4632	MTH12	-	3726 ij †	2.1 b-d	0.2 hi	122.6 mn	228.1 f-i	67.9 e-h
	PTR12	-	4982 a-c	1.6 f-i	0.7 d-i	198.0 gh	179.7 i-l	71.5 b-d
	SUF12	-	5025 a-c	2.0 c-e	2.1 c	297.2 b-d	311.7 b-d	67.0 g-i
AG4732	MTH12	-	3596 ij	2.1 b-d	0.1 hi	118.6 mn	296.3 b-e	69.3 d-g
	PTR12	-	4823 a-e	1.6 f-i	0.5 g-i	185.7 hi	240.7 e-i	67.5 f-h
	SUF12	-	4922 a-d	1.8 d-g	1.9 c	292.0 b-e	280.7 c-g	64.3 i-l
94Y22	MTH12	-	3669 ij	2.4 ab	1.9 c	141.1 k-n	504.4 a	77.1 a
	PTR12	-	4295 f-h	1.7 e-i	1.8 c	165.4 h-k	236.0 e-i	74.2 ab
	SUF12	-	4703 b-f	2.6 a	8.3 a	313.3 b	318.1 bc	69.8 d-g
94Y70	MTH12	-	3740 ij	2.1 b-d	0.3 hi	112.7 n	286.2 c-f	73.6 bc
	PTR12	-	4683 b-f	1.5 g-i	0.37 hi	142.6 j-n	219.6 g-j	70.2 d-f
	SUF12	-	4662 b-f	2.2 bc	3.2 b	263.2 d-f	351.5 b	67.7 e-h
P4811RY	MTH12	-	3552 ij	2.4 ab	0.2 hi	125.4 l-n	307.4 b-d	65.7 h-j
	PTR12	-	3965 g-i	1.3 i	0.3 hi	164.8 h-l	236.0 e-i	68.1 e-h
	SUF12	-	4815 a-f	1.9 c-f	1.6 c-f	314.7 b	265.8 c-h	63.2 j-m
SS4700R2	MTH12	-	3411 j	1.4 i	0 i	111.4 n	211.2 h-j	67.1 g-i
	PTR12	-	4424 d-g	1.44 hi	0.7 d-i	166.0 h-k	156.0 j-l	61.2 m
	SUF12	-	5254 a	1.5 hi	1.1 c-h	271.6 c-f	253.0 d-h	61.8 lm
SS4711R2	MTH12	-	3494 ij	1.6 e-i	0.06 i	123.4 mn	277.4 c-g	66.8 g-i
	PTR12	-	4356 e-h	1.6 f-i	0.3 hi	169.8 h-k	221.6 g-i	69.4 d-g
	SUF12	-	4644 c-f	1.8 d-h	1.75 cd	282.1 b-e	266.5 c-h	62.7 k-m
U74A79R	MTH12	-	3684 ij	2.1 b-d	0.4 g-i	155.3 i-m	311.4 b-d	70.6 c-e
	PTR12	-	4800 a-f	1.5 hi	0.69 e-i	180.7 h-j	185.3 i-k	66.9 g-i
	SUF12	-	4973 a-c	1.9 c-g	1.4 c-g	371.1 a	315.1 b-d	65.5 h-k
U74B81R	MTH12	-	3746 ij	1.8 d-h	0.2 hi	166.8 h-k	288.5 c-f	70.3 d-f
	PTR12	-	5170 ab	1.5 g-i	0.6 f-i	174.7 h-k	238.8 e-i	69.5 d-g

	SUF12	-	4723 b-f	1.8 d-h	1.7 cde	305.0 bc	279.4 c-g	63.6 j-m
V04-1022	MTH12	-	3645 ij	1.3 i	0.5 g-i	254.8 ef	562.4 a	47.1 o
	PTR12	-	3888 h-j	1.3 i	0.3 hi	235.3 fg	143.2 kl	48.5 o
	SUF12	-	4612 c-f	1.6 f-i	0.5 g-i	233.1 fg	117.2 l	53.5 n

Table 5.7.2			AUDPC		Relative	Seed	
			CBL	CBS	leaf drop	Oil	Protein
Cultivar	Location	Fungicide	-------%-days-------		-----%-----	-----------%-----------	
-	MTH12	Untreated	193.0 de	519.4 a	71.4 a	19.0 bc	39.3 cd
-		R3	140.4 gh	297.6 bc	67.2 bc	19.4 a-c	40.1 c
-		R5	105.4 i	231.3 de	65.3 cd	19.3 a-c	39.9 c
-		R3+R5	134.1 h	261.0 cd	66.3 c	19.3 a-c	39.9 c
-	PTR12	Untreated	260.5 c	336.6 b	69.1 b	17.2 d	37.3 d
-		R3	162.7 fg	172.3 fg	65.5 c	19.4 a-c	42.7 a
-		R5	172.6 ef	186.7 fg	66.6 c	19.7 ab	42.6 ab
-		R3+R5	117.3 hi	127.1 h	65.7 c	18.6 c	40.1 bc
-	SUF12	Untreated	444.6 a	517.9 a	68.7 b	20.2 a	41.2 a-c
-		R3	243.2 c	205.9 ef	62.1 ef	19.9 ab	41.6 a-c
-		R5	291.8 b	231.1 de	63.6 de	20.1 a	41.6 a-c
-		R3+R5	197.6 d	148.7 gh	61.4 f	20.1 a	41.7 a-c

Table 5.7.3			Seed	
			Yield Response	Weight
Cultivar	Location	Fungicide	---kg ha^{-1}---	g 100 $seed^{-1}$
-	MTH12	-	71 b	15.6 c
-	PTR12	-	52 b	17.0 b
-	SUF12	-	412 a	17.8 a

Table 5.7.4

Cultivar	Location	Fungicide	Seed weight
			----g 100 seed^{-1}----
AG4632	-	-	16.6 cd
AG4732	-	-	17.4 a-c
94Y22	-	-	17.7 a
94Y70	-	-	16.8 b-d
P4811RY	-	-	16.4 de
SS4700R2	-	-	16.4 de
SS4711R2	-	-	16.8 b-d
U74A79R	-	-	17.6 ab
U74B81R	-	-	17.0 a-d
V04-1022	-	-	15.6 e

Table 5.7.5

Cultivar	Location	Fungicide	Seed Yield	Seed Weight
			kg ha^{-1}	g 100 seed^{-1}
-	-	Untreated	4060 b	15.9 b
-	-	R3	4488 a	17.3 a
-	-	R5	4439 a	17.1 a
-	-	R3+R5	4343 a	17.0 a

† Means with different letter within interaction, parameter, and column are significantly different based on Fisher's Protected Fisher's Protected LSD at P (0.05) level.

δ Purple seed stain ratings.

‡ Area under disease progress curve for cercospora blight on soybean leaves (CBL) and stems (CBS).

Table 5.8 Location, cultivar, and fungicide main effects and interactions influenced soybean yield, yield response, seed weight, quality, oil and protein, leaf drop, purple seed stain, and cercospora blight leaf and stem ratings for 2013 maturity group IV x foliar fungicide experiments.

Table 5.8.1			Seed						Relative
Cultivar	Location	Fungicide	Yield	Yield Resp.¥	Weight	Quality	Oil	Protein	leaf drop
			---------kg ha^{-1}---------		g 100 $seed^{-1}$		-----------%-----------		----%----
AG4632	WAR13	-	3667 hi †	551 ab	15.0 j-m	1.6 g-i	19.7 j-m	39.7 m-o	80.9 b-d
	PTR13	-	2865 op	-412 lm	14.8 k-m	2.2 e	20.3 c-g	41.0 f-j	81.3 b
	SUF13	-	5271 a-c	194 b-h	15.4 f-h	3.1 a	20.4 b-g	40.0 k-m	70.7 h
AG4732	WAR13	-	3938 g	248 b-g	15.2 h-j	1.19 k-m	19.7 j-m	39.7 m-o	80.8 b-d
	PTR13	-	2955 no	-122 g-l	15.0 i-l	2.0 ef	20.9 a	41.5 b-f	82.0 ab
	SUF13	-	5299 ab	-420 lm	16.9 b	3.0 a-c	20.4 b-g	40.0 k-m	74.6 g
94Y23	WAR13	-	3727 gh	518 a-c	15.3 g-i	1.9 fg	20.1 g-k	38.9 op	83.9 a
	PTR13	-	3183 k-n	-445 lm	16.1 de	2.2 e	20.9 a	41.1 e-i	81.1 bc
	SUF13	-	4967 de	316 a-f	17.4 a	2.8 b-d	20.4 b-g	38.3 p	78.7 de
94Y70	WAR13	-	3565 hi	430 a-d	14.6 mn	1.2 j-m	19.7 i-m	39.7 m-o	79.8 b-e
	PTR13	-	3090 l-o	-192 i-m	14.6 mn	1.6 g-i	20.6 a-f	40.6 f-m	81.3 b
	SUF13	-	4767 ef	149 c-i	16.4 cd	3.3 a	20.69 a-d	40.0 k-n	75.7 fg
P4850RY	WAR13	-	3652 hi	675 a	14.7 l-n	1.1 lm	19.4 lm	40.8 f-k	76.2 fg
	PTR13	-	3242 k-m	-535 m	14.9 j-m	1.5 h-j	19.8 h-l	42.3 ab	74.4 g
	SUF13	-	5493 a	155 c-i	16.6 bc	2.7 cd	20.29 d-g	40.7 f-l	60.8 k
SS4700R2	WAR13	-	3538 h-j	339 a-e	15.67 eg	1.1 lm	19.67 k-m	41.9 a-e	78.8 c-e
	PTR13	-	3064 l-o	-259 j-m	15.8 ef	1.69 gh	19.6 k-m	42.6 a	77.5 ef
	SUF13	-	5398 a	330 a-f	16.4 cd	2.8 b-d	20.6 a-e	40.5 g-m	68.1 i
SS4711R2	WAR13	-	3421 i-k	459 a-c	15.1 i-k	1.3 i-l	20.16 f-i	40.2 i-m	81.5 b
	PTR13	-	2864 op	-160 h-m	15.2 h-k	1.7 f-h	20.86 ab	42.2 a-c	79.9 b-d
	SUF13	-	4692 f	22 e-k	16.2 d	3.06 ab	20.7 a-c	40.4 g-m	69.9 hi
U74A79R	WAR13	-	3300 j-l	325 a-f	15.7 e-g	1.3 i-l	19.36 m	40.5 g-m	80.9 b-d
	PTR13	-	3034 l-o	-523 m	15.8 ef	2.0 ef	20.13 f-j	41.3 c-g	80.5 b-d
	SUF13	-	5085 b-d	-104 g-l	17.4 a	3.2 a	20.5 a-f	40.4 h-m	68.6 hi
U74B81R	WAR13	-	3632 hi	481 a-c	15.6 fg	1.4 i-k	20.15 f-i	41.3 d-h	80.3 b-d
	PTR13	-	2865 op	-322 k-m	15.4 f-i	1.9 fg	20.5 a-g	42.17 a-d	79.9 b-d

	SUF13	-	4892 d-f	235 b-g	16.4 cd	2.69 d	20.3 c-g	40.77 f-l	69.6 hi
V04-1022	WAR13	-	2962 no	63 d-j	14.0 o	1.0 m	19.5 lm	39.1 n-p	57.2 l
	PTR13	-	2688 p	-62 f-l	14.3 no	1.1 lm	19.7 i-m	40.9 f-k	64.6 j
	SUF13	-	5024 c-e	295 a-f	15.66 fg	2.7 cd	20.2 e-h	39.9 l-n	60.6 k

Table 5.8.2

				Seed		AUDPC ‡		Relative
			Yield	Weight	PSS δ	CBL	CBS	leaf drop
Cultivar	Location	Fungicide	-kg ha^{-1}-	g 100 seed^{-1}	--%--	-------%-days-------		----%----
-	WAR13	Untreated	3233 e	14.6 f	3.5 a	51.4 b	86.7 a	80.1 a
-		R3	3696 c	15.5 c	3.0 ab	45.7 b-e	76.1 bc	75.9 d
-		R5	3462 d	14.9 e	2.0 de	49.3 bc	80.5 ab	79.0 ab
-		R3+R5	3770 c	15.3 cd	1.9 d-f	45.1 b-f	77.9 b	77.1 cd
-	PTR13	Untreated	3211 e	15.2 d	2.6 b-d	34.9 d-f	63.1 de	78.8 ab
-		R3	3038 f	15.5 c	1.1 fg	33.3 f	45.1 f	77.0 cd
-		R5	2773 g	14.9 e	1.5 e-f	36.8 d-f	51.8 f	78.8 ab
-		R3+R5	2918 fg	15.1 de	1.0 g	33.9 ef	49.8 f	78.3 bc
-	SUF13	Untreated	4998 b	16.3 b	2.0 de	55.3 b	69.8 cd	71.6 e
-		R3	5178 a	16.6 a	2.2 c-e	73.3 a	82.4 ab	69.5 f
-		R5	5050 ab	16.5 a	2.9 a-c	38.9 c-f	60.6 e	68.9 f
-		R3+R5	5129 ab	16.6 a	3.5 a	47.0 b-d	65.6 de	68.9 f

Table 5.8.3

				Seed	
			Yield Response	Quality	Protein
Cultivar	Location	Fungicide	--kg ha^{-1}--		-----%-----
-	-	Untreated	-	2.1 a	40.8 a
-	-	R3	155 a	1.9 b	40.6 ab
-	-	R5	-54 b	2.0 ab	40.8 a
-	-	R3+R5	123 a	1.98 b	40.3 b

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† Means with different letter within interaction, parameter, and column are significantly different based on Fisher's Protected LSD P(0.05).

¥ Yield response.

δ Purple seed stain ratings.

‡ Area under disease progress curve for cercospora blight on soybean leaves (CBL) and stems (CBS).

Table 5.9 Test of fixed effects and interactions for soybean growth, disease, and seed yield and quality parameters for 2012 and 2013 maturity group V x foliar fungicide experiments.

Attribute	Year	Location (L)	Cultivar (C)§	Fungicide (F)Φ	L*C	L*F	C*F	L*C*F
		--Pr > F--						
R5 NDVI £	2012	<.0001 †	0.5592	0.0021	0.9107	<.0001	0.9688	0.9952
	2013	<.0001	<.0001	0.0444	0.0009	0.5885	0.9928	0.8701
AUDPC-CBL ‡	2012	<.0001	<.0001	<.0001	<.0001	<.0001	0.0448	0.7371
	2013	0.0011	<.0001	<.0001	<.0001	0.0032	0.4767	0.0424
AUDPC-CBS ‡	2012	<.0001	<.0001	<.0001	<.0001	<.0001	0.0033	0.7005
	2013	<.0001	<.0001	<.0001	<.0001	0.0008	0.0660	0.4690
Leaf drop	2012	<.0001	<.0001	<.0001	<.0001	<.0001	0.8066	0.9930
	2013	<.0001	<.0001	<.0001	<.0001	0.4763	0.9845	1.0
Seed yield	2012	<.0001	0.3065	0.0006	0.0372	0.0008	0.9980	0.9860
	2013	<.0001	<.0001	<.0001	<.0001	0.0002	0.9826	1.0
Yield response	2012	0.0002	0.1957	0.8927	0.3372	0.3905	0.9876	0.9186
	2013	<.0001	0.0279	<.0001	0.3208	0.0086	0.9348	0.9988
Seed weight	2012	0.1093	<.0001	<.0001	0.1147	0.0006	0.9126	0.9884
	2013	<.0001	<.0001	<.0001	<.0001	0.1940	0.9442	0.9035
Seed quality	2012	<.0001	<.0001	0.6800	0.0839	0.4253	0.7274	0.9963
	2013	<.0001	<.0001	0.0047	<.0001	0.0001	0.8509	0.9752
Purple seed stain	2012	0.0013	0.0010	0.3264	0.0115	0.2152	0.3624	0.9703
	2013	<.0001	<.0001	<.0001	<.0001	<.0001	0.0189	<.0001
Seed oil	2012	<.0001	0.0170	0.0540	0.1534	0.1109	0.8879	0.9993
	2013	<.0001	<.0001	0.0106	<.0001	0.4001	0.8018	0.8366
Seed protein	2012	<.0001	0.0473	0.0217	0.1075	0.0200	0.8880	0.9995
	2013	<.0001	<.0001	0.0477	<.0001	0.0339	0.2073	0.8588

§ Ten MG V cultivars ranging from 4.2 to 4.9 relative maturities.

Φ Foliar application of pyraclostrobin + fluxapyroxad at R3 (beginning pod), R5 (beginning seed), and R3+R5 stages (Fehr and Caviness, 1977).

† P (0.05) level significance.

£ Normalized difference vegetative index.

‡ Area under disease progress curve for cercospora blight on soybean leaves (CBL) and stems (CBS).

Table 5.10 Location, cultivar, and fungicide main effects and interactions influenced soybean yield, cercospora blight leaf and stem ratings, leaf drop, seed weight, oil and protein, and yield response for 2012 maturity group V x foliar fungicide experiments.

Table 5.10.1

				AUDPC ‡		
Cultivar	Location	Fungicide	Seed Yield	CBL	CBS	Relative leaf drop
			---kg ha^{-1}---	-----------%-days-----------		----%----
AG5332	MTH12	-	3850 gh †	207.1 j-l	488.9 b	50.9 ab
	PTR12	-	4463 c-e	364.9 a	168.7 k-m	40.9 g-j
	SUF12	-	4509 b-e	337.8 ab	397.8 c	42.7 f-h
AG5632	MTH12	-	3567 hi	256.5 e-h	213.0 i-k	35.1 m-p
	PTR12	-	4958 a-c	223.9 h-l	115.7 m-o	32.2 o-q
	SUF12	-	5062 a	267.7 de	332.3 d-f	37.4 j-n
S51-J3	MTH12	-	3866 f-h	224.9 g-l	605.2 a	46.7 c-e
	PTR12	-	4572 a-e	325.7 bc	344.9 c-f	54.6 a
	SUF12	-	4602 a-e	326.9 bc	478.5 b	50.6 b
S56-G6	MTH12	-	3571 hi	95.3 p	127.5 l-o	36.8 l-n
	PTR12	-	4704 a-e	199.1 l-n	90.8 no	30.6 q
	SUF12	-	4996 ab	172.3 m-o	292.4 f-h	40.5 g-k
95Y40	MTH12	-	3809 g-i	233.2 f-k	252.2 g-i	44.1 e-g
	PTR12	-	4739 a-e	266.7 d-f	146.4 l-n	40.6 g-j
	SUF12	-	4805 a-d	263.3 ef	241.7 hi	42.1 f-h
95Y60	MTH12	-	3598 hi	146.9 o	233.4 h-j	36.9 k-n
	PTR12	-	4358 d-f	299.8 cd	139.1 l-o	34.1 n-q
	SUF12	-	4848 a-d	271.1 de	288.2 f-h	35.7 m-o
P5610RY	MTH12	-	3311 i	206.9 j-m	268.4 g-i	38.2 i-m
	PTR12	-	5041 a	168.1 no	81.2 o	26.9 r
	SUF12	-	4683 a-e	200.5 k-n	310.4 e-g	39.8 h-l
P5655RY	MTH12	-	3881 f-h	219.2 i-l	375.4 cd	41.5 g-i
	PTR12	-	4245 e-g	208.9 j-l	157.1 k-m	31.5 pq
	SUF12	-	4666 a-e	240.2 e-j	333.9 d-f	39.7 h-l
SS5112NR2	MTH12	-	3607 hi	258.5 e-g	485.8 b	48.8 b-d
	PTR12	-	4382 de	319.7 bc	209.9 i-k	49.7 bc
	SUF12	-	4475 c-e	313.3 bc	353.7 c-e	49.0 b-d

SS5510NR2	MTH12	-	3584 hi	83.5 p	180.2 j-l	44.0 e-g
	PTR12	-	4692 a-e	225.0 g-l	125.5 l-o	45.7 d-f
	SUF12	-	4438 de	247.7 e-i	290.2 f-h	42.5 f-h

Table 5.10.2

			Seed			AUDPC		Relative leaf drop
			Yield	Weight	Protein	CBL	CBS	
Cultivar	Location	Fungicide	-kg ha^{-1}-	g 100 seed^{-1}	---%---	-----%-days-----		----%----
-	MTH12	Untreated	3705 d	15.5 b	38.1 bc	246.6 c	363.7 b	42.3 bc
-		R3	3622 d	15.6 b	38.9 bc	182.8 de	338.9 b	42.7 b
-		R5	3742 cd	15.5 b	38.9 bc	181.8 de	336.2 b	43.1 b
-		R3+R5	3589 d	15.7 ab	39.8 ab	161.6 e	253.3 d	41.0 b-d
-	PTR12	Untreated	4028 c	13.9 c	36.8 c	365.2 b	252.9 d	42.1 bc
-		R3	4835 ab	15.8 ab	41.5 a	245.3 c	143.5 f	38.1 e
-		R5	4718 ab	15.9 ab	41.9 a	231.1 c	144.4 f	39.5 de
-		R3+R5	4880 a	16.3 a	41.8 a	199.2 d	90.9 g	35.0 f
-	SUF12	Untreated	4542 b	15.5 b	42.2 a	398.9 a	562.6 a	48.2 a
-		R3	4802 ab	16.0 ab	41.9 a	231.9 c	271.1 cd	40.2 c-e
-		R5	4709 ab	15.9 ab	41.8 a	248.6 c	292.8 c	41.3 b-d
-		R3+R5	4781 ab	16.1 ab	41.6 a	176.9 e	201.1 e	38.3 e

Table 5.10.3

			AUDPC	
			CBL	CBS
Cultivar	Location	Fungicide	--------%-days--------	
AG5332	-	Untreated	430.0 a	546.6 b
	-	R3	286.1 ef	323.1 de
	-	R5	264.2 e-h	304.4 d-f
	-	R3+R5	232.9 h-k	233.2 h-m
AG5632	-	Untreated	332.8 cd	303.0 d-h
	-	R3	223.3 i-l	185.3 l-p
	-	R5	252.2 f-j	229.5 j-n
	-	R3+R5	189.1 l-o	163.6 n-r
S51-J3	-	Untreated	391.4 ab	678.4 a
	-	R3	300.5 de	451.1 c

	-	R5	279.1 ef	423.9 c
	-	R3+R5	199.0 k-o	351.4 d
S56-G6	-	Untreated	250.2 f-j	294.0 d-j
	-	R3	130.8 qr	145.9 o-r
	-	R5	119.7 r	142.6 p-r
	-	R3+R5	121.5 r	98.4 r
95Y40	-	Untreated	351.7 bc	303.3 d-g
	-	R3	221.5 i-l	194.6 l-p
	-	R5	235.7 g-k	214.0 k-o
	-	R3+R5	208.7 k-n	140.8 p-r
95Y60	-	Untreated	338.7 cd	301.1 d-i
	-	R3	214.3 j-m	199.1 l-p
	-	R5	214.2 j-m	230.9 j-n
	-	R3+R5	189.9 l-o	149.8 o-r
P5610RY	-	Untreated	264.6 e-h	277.0 e-k
	-	R3	180.2 m-o	230.5 i-n
	-	R5	188.8 l-o	234.3 g-m
	-	R3+R5	133.7 p-r	138.2 p-r
P5655RY	-	Untreated	338.0 cd	433.3 c
	-	R3	198.8 k-o	242.6 f-l
	-	R5	191.5 l-o	274.1 e-k
	-	R3+R5	162.8 o-q	205.2 l-p
SS5112NR2	-	Untreated	412.6 a	481.9 bc
	-	R3	274.2 e-g	333.8 de
	-	R5	281.2 ef	353.4 d
	-	R3+R5	220.6 i-l	230.1 j-n
SS5510NR2	-	Untreated	258.6 f-i	312.1 de
	-	R3	170.4 n-p	204.6 l-p
	-	R5	178.4 n-o	171.0 m-q
	-	R3+R5	134.1 p-r	106.7 qr

Table 5.10.4

			Seed	
			Yield Response	Oil
Cultivar	Location	Fungicide	----kg ha^{-1}----	---%---
-	MTH12	-	-54 b	18.5 b
-	PTR12	-	173 a	18.4 b
-	SUF12	-	222 a	19.8 a

Table 5.10.5

			Seed		
			Weight	Oil	Protein
Cultivar	Location	Fungicide	g 100 seed^{-1}	----------%----------	
AG5332	-	-	15.8 c	18.7 bc	40.3 a-d
AG5632	-	-	14.8 d	18.8 b	40.2 a-d
S51-J3	-	-	15.9 c	18.7 bc	39.5 cd
S56-G6	-	-	14.1 e	19.2 ab	41.87 ab
95Y40	-	-	15.8 c	19.5 ab	41.9 a
95Y60	-	-	14.5 de	18.8 b	39.6 b-d
P5610RY	-	-	18.0 a	17.7 c	38.4 d
P5655RY	-	-	15.7 c	18.9 ab	40.0 a-d
SS5112NR2	-	-	15.0 d	19.9 a	40.8 a-c
SS5510NR2	-	-	16.7 b	18.9 ab	41.6 a-c

Table 5.10.6

			Seed	
			Weight	Oil
Cultivar	Location	Fungicide	g 100 seed^{-1}	---%---
-	-	Untreated	15.0 b	18.3 b
-	-	R3	15.8 a	19.1 a
-	-	R5	15.7 a	19.1 a
-	-	R3+R5	16.0 a	19.2 a

Table 5.10.7

Cultivar	Location	Fungicide	Seed Yield
			-kg ha^{-1}-
-	SUF12 ¥	Untreated	4542 b
-		R3	4802 a
-		R5	4709 ab
-		R3+R5	4781 a

† Means with different letter within interaction, parameter, and column are significantly different based on Fisher's Protected LSD at P (0.05) level.

‡ Area under disease progress curve for cercospora blight on soybean leaves (CBL) and stems (CBS).

¥ Independent site-year analysis to help explain yield dynamics.

Table 5.11 Location, cultivar, and fungicide main effects and interactions influenced soybean yield, seed weight, cercospora blight stem ratings, leaf drop, yield response, and seed quality, oil and protein for 2013 maturity group V x foliar fungicide experiments.

Table 5.11.1			Seed			
Cultivar	Location	Fungicide	Yield	Weight	AUDPC-CBS ‡	Rel. leaf drop
			---kg ha^{-1}---	g 100 seed^{-1}	-----%-days-----	----%----
AG5332	WAR13	-	3288 i-k †	15.1 e-h	71.0 c	70.3 a-c
	PTR13	-	3722 gh	14.2 kl	50.2 i-m	69.5 bc
	SUF13	-	4964 c	15.4 d-f	67.8 c-e	72.5 a
AG5632	WAR13	-	3202 jk	13.0 no	68.1 c-e	47.5 lm
	PTR13	-	3428 ij	13.4 mn	46.6 lm	50.0 l
	SUF13	-	5172 bc	14.7 h-k	54.7 h-k	62.6 fg
S51-H9	WAR13	-	3072 kl	13.4 mn	83.3 ab	55.2 jk
	PTR13	-	3097 kl	13.3 mn	55.5 h-j	58.4 hi
	SUF13	-	4111 ef	14.6 i-k	66.5 c-f	71.1 ab
S56-G6	WAR13	-	2539 o	13.1 no	56.2 hi	42.9 no
	PTR13	-	3554 hi	13.8 lm	44.8 m	47.2 lm
	SUF13	-	5357 b	14.9 f-j	48.7 k-m	64.8 ef
95Y40	WAR13	-	3219 jk	14.3 k	71.0 c	55.7 i-k
	PTR13	-	3428 ij	15.0 e-i	51.0 i-m	54.1 k
	SUF13	-	4513 d	16.9 b	52.1 i-l	70.4 a-c
95Y60	WAR13	-	2922 lm	13.2 no	67.7 c-e	48.4 l
	PTR13	-	3210 jk	13.1 no	48.4 k-m	47.9 lm
	SUF13	-	4480 d	15.3 e-g	60.4 f-h	65.8 de
P5610RY	WAR13	-	2606 no	15.9 c	63.2 ef	42.0 o
	PTR13	-	3435 ij	16.7 b	45.2 m	45.5 mn
	SUF13	-	4959 c	18.4 a	53.7 i-k	64.6 ef
P5655RY	WAR13	-	2872 l-n	14.6 i-k	69.5 c-e	42.6 o
	PTR13	-	3241 jk	15.5 c-e	49.6 j-m	47.1 lm
	SUF13	-	5653 a	16.8 b	79.7 b	62.5 fg
SS5112NR2	WAR13	-	2759 m-o	13.3 mn	88.5 a	57.0 ij
	PTR13	-	3034 k-m	12.7 o	63.5 d-f	61.4 g
	SUF13	-	3941 fg	14.5 jk	70.0 cd	72.6 a

SS5510NR2	WAR13	-	3085 kl	15.8 cd	63.1 e-g	55.3 jk
	PTR13	-	3414 ij	14.9 g-j	50.1 i-m	61.0 gh
	SUF13	-	4307 de	17.1 b	56.6 g-i	67.8 cd

Table 5.11.2			Seed				
			Yield	Yield Resp. ¥	Quality	Protein	AUDPC-CBS
Cultivar	Location	Fungicide	-----------kg ha^{-1}	-----------		---%---	---%-days---
-	WAR13	Untreated	2945 fg	-	1.1 de	40.0 f	81.3 a
-		R3	2908 g	-38 d	1.2 d	39.4 g	64.0 c
-		R5	2923 g	-22 d	1.1 de	39.4 g	72.5 b
-		R3+R5	3049 e-g	104 b-d	1.1 de	39.6 fg	62.9 c
-	PTR13	Untreated	3099 ef	-	1.0 e	41.4 de	61.4 c
-		R3	3187 e	87 cd	1.1 de	41.1 e	47.2 f
-		R5	3374 d	274 b	1.0 e	41.4 de	48.5 f
-		R3+R5	3766 c	666 a	1.0 e	41.5 c-e	44.9 f
-	SUF13	Untreated	4716 ab	-	2.2 a	42.2 ab	68.8 b
-		R3	4694 b	-37 d	1.9 b	42.0 bc	61.3 cd
-		R5	4694 b	-22 d	1.8 bc	42.6 a	57.3 de
-		R3+R5	4878 a	162 bc	1.77 c	41.7 b-d	56.7 e

Table 5.11.3			AUDPC-CBS
Cultivar	Location	Fungicide	---%-days---
AG5332	-	Untreated	72.1 bc
	-	R3	63.7 d-j
	-	R5	60.5 f-n
	-	R3+R5	55.8 k-p
AG5632	-	Untreated	68.2 c-e
	-	R3	54.5 l-q
	-	R5	55.6 k-p
	-	R3+R5	47.5 q-s

S51-H9	-	Untreated	78.6 b
	-	R3	64.2 d-i
	-	R5	69.2 cd
	-	R3+R5	61.8 d-l
S56-G6	-	Untreated	57.6 i-p
	-	R3	50.7 p-s
	-	R5	44.5 s
	-	R3+R5	46.87 rs
95Y40	-	Untreated	66.5 c-g
	-	R3	56.0 k-p
	-	R5	56.2 j-p
	-	R3+R5	53.4 n-r
95Y60	-	Untreated	65.6 c-h
	-	R3	55.8 k-p
	-	R5	61.0 e-m
	-	R3+R5	53.0 n-r
P5610RY	-	Untreated	60.1 g-n
	-	R3	50.5 p-s
	-	R5	54.1 m-r
	-	R3+R5	51.4 o-s
P5655RY	-	Untreated	77.0 b
	-	R3	62.2 d-k
	-	R5	67.0 c-g
	-	R3+R5	58.9 h-o
SS5112NR2	-	Untreated	93.7 a
	-	R3	65.2 c-h
	-	R5	69.1 cd
	-	R3+R5	68.0 c-f
SS5510NR2	-	Untreated	65.9 c-h
	-	R3	52.3 o-r
	-	R5	56.9 i-p
	-	R3+R5	51.3 p-s

Table 5.11.4

Cultivar	Location	Fungicide	Yield Response ---kg ha^{-1}---
AG5332	-	-	167 ab
AG5632	-	-	-23 c
S51-H9	-	-	51 bc
S56-G6	-	-	251 a
95Y40	-	-	116 a-c
95Y60	-	-	191 ab
P5610RY	-	-	159 a-c
P5655RY	-	-	-26 c
SS5112NR2	-	-	200 ab
SS5510NR2	-	-	220 ab

Table 5.11.5

			Seed		
			Weight	Oil	Rel. leaf drop
Cultivar	Location	Fungicide	g 100 seed^{-1}	---%---	---%---
-	-	Untreated	14.5 b	19.6 a	59.9 a
-	-	R3	14.6 b	19.6 a	58.5 b
-	-	R5	14.9 a	19.5 b	57.1 c
-	-	R3+R5	15.0 a	19.4 b	55.7 d

† Means with different letter within interaction, parameter, and column are significantly different based on Fisher's Protected LSD at P (0.05) level.

‡ Area under disease progress curve for cercospora blight on soybean leaves (CBL) and stems (CBS).

¥ Yield response.

Table 5.12 Location, cultivar, and fungicide interaction influenced area under the disease progress curve for cercospora leaf blight ratings for 2013 maturity group V x foliar fungicide experiments.

			AUDPC-CBL ‡
Location	Cultivar	Fungicide	--%-days--
WAR13	AG5332	R3	54.6 b-q
		R5	48.1 b-t
		R3+R5	48.0 b-t
		0	173.5 a
	AG5632	R3	44.7 c-t
		R5	49.2 b-t
		R3+R5	43.7 c-t
		0	68.9 bc
	S51-H9	R3	42.1 c-t
		R5	44.0 c-t
		R3+R5	41.6 c-t
		0	50.0 b-t
	S56-G6	R3	22.6 t
		R5	22.6 t
		R3+R5	23.6 st
		0	28.5 o-t
	95Y40	R3	37.2 g-t
		R5	45.0 c-t
		R3+R5	32.2 l-t
		0	63.5 b-j
	95Y60	R3	31.5 m-t
		R5	39.0 e-t
		R3+R5	35.1 j-t
		0	44.2 c-t
	P5610RY	R3	26.5 q-t
		R5	25.5 r-t
		R3+R5	26.5 q-t
		0	27.5 p-t
	P5655RY	R3	32.5 l-t
		R5	33.0 k-t
		R3+R5	25.5 r-t
		0	36.2 h-t
	SS5112NR2	R3	40.0 d-t
		R5	42.0 c-t
		R3+R5	43.2 c-t
		0	59.9 b-m
	SS5510NR2	R3	31.5 m-t
		R5	29.5 o-t
		R3+R5	31.5 m-t
		0	41.2 c-t

PTR13	AG5332	R3	51.9 b-s
		R5	46.0 b-t
		R3+R5	42.4 c-t
		0	63.9 b-i
	AG5632	R3	50.6 b-t
		R5	49.0 b-t
		R3+R5	37.7 f-t
		0	64.4 b-h
	S51-H9	R3	55.4 b-p
		R5	49.9 b-t
		R3+R5	43.5 c-t
		0	61.4 b-k
	S56-G6	R3	34.7 k-t
		R5	31.2 n-t
		R3+R5	31.0 n-t
		0	36.4 h-t
	95Y40	R3	52.7 b-r
		R5	42.5 c-t
		R3+R5	39.0 e-t
		0	60.4 b-l
	95Y60	R3	51.2 b-s
		R5	54.4 b-q
		R3+R5	50.0 b-t
		0	59.9 b-m
	P5610RY	R3	39.7 d-t
		R5	36.6 h-t
		R3+R5	37.7 f-t
		0	34.0 k-t
	P5655RY	R3	34.7 k-t
		R5	36.5 h-t
		R3+R5	34.0 k-t
		0	43.9 c-t
	SS5112NR2	R3	52.9 b-r
		R5	51.1 b-t
		R3+R5	46.2 b-t
		0	66.9 b-e
	SS5510NR2	R3	49.2 b-t
		R5	46.7 b-t
		R3+R5	38.7 e-t
		0	52.4 b-r
SUF13	AG5332	R3	49.4 b-t
		R5	58.4 b-n
		R3+R5	61.4 b-k
		0	36.6 h-t
	AG5632	R3	65.2 b-g
		R5	55.6 b-p

	R3+R5	61.2 b-k
	0	69.7 bc
S51-H9	R3	51.7 b-s
	R5	58.5 b-n
	R3+R5	54.7 b-q
	0	49.1 b-t
S56-G6	R3	40.1 d-t
	R5	35.1 j-t
	R3+R5	36.2 h-t
	0	48.7 b-t
95Y40	R3	33.2 k-t
	R5	33.4 k-t
	R3+R5	29.7 o-t
	0	31.2 n-t
95Y60	R3	68.1 b-d
	R5	66.4 b-e
	R3+R5	66.1 b-f
	0	73.7 b
P5610RY	R3	38.7 e-t
	R5	31.5 m-t
	R3+R5	35.4 i-t
	0	41.9 c-t
P5655RY	R3	65.7 b-g
	R5	48.6 b-t
	R3+R5	44.9 c-t
	0	58.4 b-n
SS5112NR2	R3	48.7 b-t
	R5	46.0 b-t
	R3+R5	52.1 b-s
	0	43.5 c-t
SS5510NR2	R3	55.0 b-q
	R5	74.5 b
	R3+R5	56.5 b-o
	0	53.2 b-r

† Means with different letter within a column are significantly different based on Fisher's Protected LSD at P(0.05).

‡ Area under disease progress curve for cercospora blight on soybean leaves (CBL).

CHAPTER VI - CONCLUSION

Double-crop soybean is important to Virginia farmers due to the ability to maximize crop and land productivity and profitability. Even so, there is yield risk associated with double-crop soybean. Reduced double-crop yield can primarily be attributed to: delayed planting that results in a shortened growing season, later-maturing cultivars that terminate main stem growth after flowering and therefore have less growth and nodes; less soil moisture and plant-available nutrient levels due to wheat uptake; greater air and soil temperatures during vegetative development stages that reduce early-season growth; and increased disease during pod and seed development. Soybean grown in double-crop can yield similarly to full-season if timely rainfall events are observed during sensitive reproductive developmental stages; however, typical weather trends observed with double-crop involve decreased rainfall events and reduced water to the crop early-season and increased rainfall and cooler temperatures later-season. To increase double-crop soybean yield, farmers can partially limit environmental influence by using agronomic inputs and management practices that increase early-season growth and nutrient uptake, accelerate canopy closure, protect limited leaf area from foliar disease, and improve seed yield formation.

Our research goal was to maximize double-crop soybean productivity and profitability, while obtaining yield similar to full-season. Experimental locations were chosen to represent the major soybean growing regions of eastern Virginia. Our objectives focused on soybean grown in a wheat-soybean double-crop system and included: 1) evaluate cultivar stem growth habit, seeding rate, seed-applied inoculant, starter N applied at planting and foliar fungicide application on soybean vegetative response, total N uptake, seed yield and quality, and yield components; 2) investigate seed-applied inoculant combined with starter N applied at planting on soybean vegetative response, total N uptake, seed yield and quality, and yield components; and 3) evaluate the response and specific interaction between MG IV and V soybean cultivars and foliar fungicide application.

Experiments demonstrated that early-season growth and yield parameters were primarily controlled by rainfall and water availability. The rainfall experienced in 2012 and 2013 growing seasons at most locations was atypical for double-crop and the yields obtained from our experiments showed how soybean can respond to increased water (or reduced water), even when planting is delayed until June or July. When averaged across all experiments, seed yield ranged from a low of approximately 2800 to a high of 5200 kg ha^{-1}. Even with the lowest attained yield, our studies demonstrated how double-crop soybean has the potential to produce yield similar to full-season. Specifically, the agronomic input experiments' yield ranged from 3100 to 5200 kg ha^{-1}, with a mean of 4000 kg ha^{-1}. Nitrogen rate x inoculant experiments yielded a mean of 4100 kg ha^{-1} and ranged from a low of 2800 to a high of 5100 kg ha^{-1}. The MG IV x foliar fungicide experiments yielded 3000 to 5100, with a mean of 4100 kg ha^{-1}. Finally, the MG V x foliar fungicide study yield ranged from 3000 to 4800, with mean 4000 kg ha^{-1}. Furthermore, even at locations characterized as yield-limited attributed to drought stress, soybean in our experiments responded to agronomic inputs but were very site-specific in all studies. There are however general conclusions that we can glean from these data.

The agronomic input study demonstrated that intensive management of seeding rate, inoculant, N, and fungicide typically was not required simultaneously to improve yield dynamics. Early-maturing indeterminate 95Y01 responded to good yield potential in 2012 and 2013 and generally increased yield over the later-maturing 95Y20, partially attributed to greater seed mass and the ability to avoid drought stress that coincided with the later-maturing cultivar's critical pod-fill stages. The earlier maturity, although not our original intention, provided insight into years characterized by above average rainfall, where early-MG V soybean may provide accelerated early-season growth and canopy closure while increasing yield compared to later-maturing cultivars. In contrast, in years where typical double-crop weather is observed which includes extended periods of drought stress, the later-maturing cultivar may exhibit increased leaf area and plant productivity expressed as more stable seed yield across changing soil moisture regimes. Therefore, there are characteristics of both 95Y01 and 95Y20 that make early-maturing and later-maturing cultivars an option for soybean farmers in Virginia. Furthermore, we did not accomplish the partial objective of comparing indeterminate vs. determinate stem termination due to 95Y01 maturing 7 to 10 days earlier than 95Y20, which was a major controlling factor in our results. Both cultivars are rated as only 2 days apart in maturity; however, as previously stated, maturity differed by at least 7 days. If these experiments were repeated, the cultivars would ideally be isolines that have the same relative maturity and differ only in stem growth habit. This would eliminate the bias of relative maturity and allow the data collection and analysis to properly investigate indeterminate vs. determinate growth habit.

Our research demonstrated the need to maintain current seeding rate recommendations and possibly examine reducing seeding rates. Later-maturing 95Y20 consistently responded to the recommended seeding rate (593,000 seed ha^{-1} and low rate in our research) with a stable, yet productive yield. In contrast, the early-maturing 95Y01 generally maximized yield in combination with the high seeding rate. Previous research has shown increased seeding rate response with early-maturing cultivars when good yield potential is promoted. The seeding rate component to our objectives was not accomplished due to the desired low, but especially high plant populations not being obtained at any location. Furthermore, at some locations, plant populations varied between cultivars. However, we did obtain adequate soybean populations that allowed us to compare treatments and conclude that rarely, should seeding rates be increased above 593,000 seed ha^{-1}; however more research is needed in the Mid-Atlantic examining seeding rates specific to double-crop. Soybean' unique ability to compensate with increased branches at reduced plant population should be further examined in combination with double-crop seeding rates and coastal plain soils.

Seed-applied inoculant performance was variable and interacted in an unpredictable manner with the other tested factors. Inoculant has a very site-specific fit in double-crop soybean and our data demonstrated inoculant slightly improved plant productivity where soybean had been grown previously. Furthermore, in some instances inoculant increased seed weight. The current recommendations are to apply inoculant if soybean has not been grown in the previous three years; the double-crop system may put increased stress on *Bradyrhizobium japonicum* populations due to reduced water availability and may require increased or more-timely inoculant application within intensified management.

Starter N applied at planting benefitted the double-crop system and improved the soybean' ability to more efficiently compensate with yield-limiting factors during vegetative growth. Mid-to-late-season measurements demonstrated greater NDVI during early-pod fill stages and were attributed to starter N, which increased photosynthetic material available for the soybean to utilize and promoted increased yield formation, optimized at 16 kg N ha^{-1}. Application of starter N improved yield component ability to produce soybean seed efficiently, but was site-specific and will ultimately be controlled by return on investment. In some instances, N increased relative yield by almost 10%, whereas, decreased values were also observed, compared to the untreated control, but responses interacted with other factors and were very site-specific. We did observe that if a cultivar was less adapted due to latitude and relative maturity, N application generally improved cultivar competiveness and productivity. The N component to the objectives was interesting to study due to the need to modify our planter to adequately meet this objective. Future work is needed examining the same concept, but N applied in 5-cm by 5-cm band to the side and below the seed furrow, which would more accurately represent production settings.

Seed yield results demonstrated foliar fungicide increased yield by 5%, when averaged across locations and other factors. Furthermore, fungicide performed the most consistently out of all agronomic inputs validated. The two growing seasons when our experiments were conducted exhibited increased disease incidence at some locations due to increased rainfall that promoted canopy closure and disease development and fungicide response would be expected in such environments. Even when fungicide increased seed yield through more efficient seed production, the return on investment was not always positive. Furthermore, our data showed that MG IV and V cultivars and fungicide did not interact to affect seed yield. We partially attribute no cultivar x fungicide yield response to susceptibility differences between cultivars and observed that cultivars did respond to fungicide, but did not consistently respond to specific timings across relative maturity or even within the same maturity. More importantly, application timing was linked to yield development and response to fungicide. The optimum timing fluctuated due to differences in fungal disease infection and development; however R3 and R3+R5 were the best fungicide timings for MG IV and V, respectively. We attribute decreased yield response to R5 to delayed fungicide, which at some locations, was not applied until after disease infection. In contrast, at some locations, fungicide at R5 improved soybean parameters when disease entered the canopy late-season and coincided with later-reproductive stages and previous application at R3 did not provide disease control. However, the risk of delaying fungicide application until R5 was great and generally decreased yield. Foliar fungicide can be effective but should be a single tool within a much larger approach to soybean disease management. With increased and improved canopy closure and architecture being a priority in soybean research initiatives, fungal disease populations may shift even more into the double-crop soybean canopy and increase the need to validate fungicide timing with disease modeling and forecasting, designed to optimize disease control and crop profitability. Well-designed disease modeling and forecasting will provide soybean farmers with the necessary tools to combat soybean disease through recommendations based on fungicide product efficacy, timing, and placement paired with real-time and forecasted weather data. This will assist farmers in protecting soybean yield with fungicide if disease incidence levels are high enough, but will also encourage application only when necessary to promote profitability and limit the further spread of fungicide-resistant pathogens.

Our experiments demonstrated the importance of promoting efficient soybean plant and seed productivity through wise agronomic practices and input management. However, the double-crop soybean growing environment varies by year and soybean can suffer from early-season moisture stress. Due to this increased control rainfall places on our system, intensified management must be promoted to increase productivity and profitability. In the past, double-crop soybean has been viewed as a secondary crop due to sequential planting after wheat harvest. However, excellent yield potential exists but in order to be achieved, double-crop soybean should be treated similar to full-season to maximize yield. Double-crop soybean vegetative growth and yield response to intensive management was achieved; however, our experiments demonstrated the greatest growth or yield response often occurred with single inputs or a combination of inputs that fit a site-specific need that did not require all inputs at once. Furthermore, the associated cost of adopting increased seeding rates, inoculant, N, and foliar fungicide in entirety is expensive and is not realistic to expect farmers to do so. It is crucial for researchers to understand how yield is produced or compensated for at the plant and seed level to more efficiently manage yield potential partially determined by the environment and be able to assist farmers with agronomic and plant pathology decision making concerned with site-specific soybean productivity and profitability. Our results will assist research and Extension personnel, crop consultants, industry representatives, and farmers in making such decisions in double-crop soybean production.

APPENDIX A - CULTURAL PRACTICE FIELD MANAGEMENT INFORMATION FOR 2012 AND 2013 SOYBEAN EXPERIMENTS CONDUCTED AT MT. HOLLY, VIRGINIA BEACH, WARSAW, PAINTER, AND SUFFOLK, IN VIRGINIA

Appendix A.1 Cultural practice field management information for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Cultural practice	*2012*			*2013*		
	Mt. Holly	**Painter**	**Suffolk**	**Warsaw**	**Painter**	**Suffolk**
Crop rotation †	C-W/S-C-W/S	P-W/F-P-W/S	W/S-C-W/S-Ct	W/F-C-S-W/F	W/F-SC-P-W/F	C-S-C-S
Land preparation	None	Plow/disk/ FC £	Disk/FC	Plow/disk harrow/FC	Plow/disk/ FC	Disk
Liming rate and application date	2.2 mt ha^{-1} 3/1/12	None	2.2 mt ha^{-1} 10/18/11	None	1.7 mt ha^{-1} 10/18/12	3.4 mt ha^{-1} 11/6/12
Wheat cultivar and planting date	VA 258 ‡ 10/17/11	Dominion § 10/25/11	USG 3555 ¥ 10/22/11	Jamestown ‡ 10/25/12	Jamestown ‡ 10/24/12	USG 3665 ¥ 11/10/12
Wheat fertilizer application date, rate, and source	10/5/11: 67 kg P ha^{-1}, 134 kg K ha^{-1}; 10/17/11: 39 kg N ha^{-1}; 1/26/12: 46 kg N ha^{-1} ; 3/20/12: 82 kg N ha^{-1}	10/21/11: 34 kg N ha^{-1}; 4/4/12: 67 kg N ha^{-1}	10/18/11: 20 kg N ha^{-1}, 54 kg P ha^{-1}, 121 kg K ha^{-1} 2/15/12: 67 kg N ha^{-1} ; 3/14/12: 67 kg N ha^{-1} ; 7/30/12: 4.5% Mn 2.3 L ha^{-1}	10/18/12: 34 kg N ha^{-1}, 67 kg P ha^{-1}, 67 kg K ha^{-1}, 6 kg S ha^{-1}; 3/29/13: 78 kg N ha^{-1}, 11 kg S ha^{-1}	10/22/12: 34 kg N ha^{-1}; 4/13/13: 67 kg N ha^{-1}; 8/12/13: 6% Mn 7.0 L ha^{-1}	11/6/12: 20 kg N ha^{-1}, 59 kg P ha^{-1}, 119 kg K ha^{-1} ; 2/21/13: 67 kg N ha^{-1} + 1.7 L Mn ha^{-1}; 7/20/13: 4.5% Mn 3.5 L ha^{-1}
Wheat harvest	6/12/12	6/26/12	6/8/12	6/24/13	7/8/13	6/15/13

† Previous four years; (C): corn; (S): soybean; (Ct): cotton; (W/S): wheat/soybean; (W/F): wheat/fallow; (SC): sweet corn; (P): potato.

£ Field cultivate.

‡ Virginia Tech and Virginia Crop Improvement Association, Mechanicsville, VA.

§ Crop Production Services, Ridgeland, MS.

¥ UniSouth Genetics, Dickson, TN.

Appendix A.2 Cultural practice field management information for 2012 and 2013 N rate x inoculant soybean experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Cultural practice	*2012*			*2013*			
	Mt. Holly	**Painter**	**Suffolk**	**V. Beach**	**Warsaw**	**Painter**	**Suffolk**
Crop rotation †	C-W/S-C-W/S	P-W/F-P-W/S	W/S-C-W/S-Ct	C-W/S-C-W/S	W/F-C-S-W/F	W/F-SC-P-W/F	C-S-C-S
Land preparation	None	Plow/disk/FC £	Disk/FC	Turbo-till	Plow/disk harrow/FC	Plow/disk/FC	Disk
Liming rate and application date	2.2 mt ha^{-1} 3/1/12	None	2.2 mt ha^{-1} 10/18/11	2.2 mt ha^{-1} 3/1/12	None	1.7 mt ha^{-1} 10/18/12	3.4 mt ha^{-1} 11/6/12
Wheat cultivar and planting date	VA 258 ‡ 10/17/11	Dominion § 10/25/11	USG 3555 ¥ 10/22/11	Shirley § 10/11/12	Jamestown ‡ 10/25/12	Jamestown ‡ 10/24/12	USG 3665 ¥ 11/10/12
Wheat fertilizer application date, rate, and source	10/5/11: 67 kg P ha^{-1}, 134 kg K ha^{-1}; 10/17/11: 39 kg N ha^{-1} 1/26/12: 46 kg N ha^{-1}; 3/20/12: 82 kg N ha^{-1}	10/21/11: 34 kg N ha^{-1}; 4/4/12: 67 kg N ha^{-1}	10/18/11: 20 kg N ha^{-1}, 54 kg P ha^{-1}, 121 kg K ha^{-1} 6-16-36; 2/15/12: 67 kg N ha^{-1}; 3/14/12: 67 kg N ha^{-1}; 7/30/12: 4.5% Mn 2.3 L ha^{-1}	10/15/12: 34 kg N ha^{-1}, 45 kg P ha^{-1} 67 kg K ha^{-1} 17 kg S ha^{-1} 2/15/13: 112 kg N ha^{-1}	10/18/12: 34 kg N ha^{-1}, 67 kg P ha^{-1}, 67 kg K ha^{-1}, 6 kg S ha^{-1} 3/29/13: 78 kg N ha^{-1}, 11 kg S ha^{-1}	10/22/12: 34 kg N ha^{1}; 4/13/13: 67 kg N ha^{-1}; 8/12/13: 6% Mn 7.0 L ha^{-1}	11/6/12: 20 kg N ha^{-1}, 59 kg P ha^{-1} 119 kg K ha^{-1} ; 2/21/13: 67 kg N ha^{-1} + 1.7 L Mn ha^{-1} 7/20/13: 4.5% Mn 3.5 L ha^{-1}
Wheat harvest	6/12/12	6/26/12	6/8/12	6/23/13	6/24/13	7/8/13	6/15/13

† Previous four years; (C): corn; (S): soybean; (Ct): cotton; (W/S): wheat/soybean; (W/F): wheat/fallow; (SC): sweet corn; (P): potato.

£ Field cultivate.

‡ Virginia Tech and Virginia Crop Improvement Association, Mechanicsville, VA.

§ Crop Production Services, Ridgeland, MS.

¥ UniSouth Genetics, , Dickson, TN.

Appendix A.3 Cultural practice field management information for 2012 and 2013 maturity group IV and V soybean x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Cultural practice	*2012*			*2013*		
	Mt. Holly	**Painter**	**Suffolk**	**Warsaw**	**Painter**	**Suffolk**
Crop rotation †	C-W/S-C-W/S	P-W/G-P-W/S	S-Ct-S-S	W/F-C-S-W/F	W/F-SC-P-SC	C-S-C-Ct
Land preparation	None	Plow/disk/ FC £	None	Plow/disk harrow/FC	Plow/disk/ FC	None
Liming rate and application date	2.2 mt ha^{-1} 3/1/12	None	None	None	1.7 mt ha^{-1} 10/18/12	2.2 mt ha^{-1} 11/30/12
Wheat cultivar and planting date	VA 258 ‡ 10/17/11	Dominion § 10/25/11	USG 3555 ¥ 11/15/11	Jamestown ‡ 10/25/12	Jamestown ‡ 10/24/12	Progeny 185 Φ 12/3/12
Wheat fertilizer application date, rate, and source	10/5/11: 67 kg P ha^{-1}, 134 kg K ha^{-1}; 10/17/11: 39 kg N ha^{-1}; 1/26/12: 46 kg N ha^{-1} ; 3/20/12: 82 kg N ha^{-1}	10/21/11: 34 kg N ha^{-1}; 4/4/12: 67 kg N ha^{-1}	2/14/12: 67 kg N ha^{-1}; 3/15/12: 67 kg N ha^{-1}; 4/19/12: 8 kg N ha^{-1}, 25 kg P ha^{-1}, 84 kg K ha^{-1}; 7/23/12: 4.5% Mn 3.7 L ha^{-1}	10/18/12: 34 kg N ha^{-1}, 67 kg P ha^{-1}, 67 kg K ha^{-1}, 6 kg S ha^{-1}; 3/29/13: 78 kg N ha^{-1}, 11 kg S ha^{-1}	10/22/12: 34 kg N ha^{-1}; 4/13/13: 67 kg N ha^{-1}; 8/12/13: 6% Mn 7.0 L ha^{-1}	11/30/12: 20 kg N ha^{-1}, 59 kg P ha^{-1}, 119 kg K ha^{-1}; 2/21/13: 45 kg N ha^{-1} + 1.7 L Mn ha^{-1}; 3/15/13: 67 kg N ha^{-1} + 1.2 L Mn ha^{-1}; 7/20/13: 4.5% Mn 3.5 L ha^{-1}
Wheat harvest	6/12/12	6/26/12	6/11/12	6/24/13	7/8/13	6/15/13

† Previous four years; (C): corn; (S): soybean; (Ct): cotton; (W/S): wheat/soybean; (W/F): wheat/fallow; (W/G): green bean, (SC): sweet corn; (P): potato.
£ Field cultivate.
‡ Virginia Tech and Virginia Crop Improvement Association, Mechanicsville, VA.
§ Crop Production Services, Ridgeland, MS.
¥ UniSouth Genetics, , Dickson, TN.
Φ Progeny Ag Products, Wynne, AR.

APPENDIX B - ADDITIONAL INFORMATION FOR 2012 AND 2013 AGRONOMIC INPUT SOYBEAN EXPERIMENTS

Appendix B.1 Soil chemical characteristics for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

				Soil Extractable Nutrient Levels β											
Site-Year	pH ‡	OM ¥	CEC§	NH_4	NO_3	P	K	Ca	Mg	Zn	Mn	Cu	Fe	B	SS £
2012		--%--	meq $100g^{-1}$	--mg L^{-1}--		-----------------------------mg kg^{-1}-----------------------------									
Mt. Holly	5.89	1.4	3.5	0.46	0.94	31	94	290	78	1.3	14.5	0.3	10.9	0.2	115
Painter	5.98	1.3	4.0	0.38	0.04	80	75	473	68	0.6	12.4	1.0	16.0	0.2	64
Suffolk	6.12	1.6	4.6	0.44	0.16	29	107	563	78	0.7	5.1	0.4	17.3	0.2	77
2013															
Warsaw	6.40	1.1	3.2	0.87	0.51	25	105	354	89	1.1	23.1	0.3	6.0	0.2	58
Painter	6.24	1.0	5.0	0.43	0.08	145	71	624	76	1.0	10.1	1.7	20.8	0.2	51
Suffolk	6.54	1.5	4.3	4.39	0.82	46	123	560	90	0.7	4.9	0.5	28.5	0.2	90

‡ Measured soil to water pH (1:1) (Maguire and Heckendorn, 2011).

¥ % Organic matter by loss on ignition method (Maguire and Heckendorn, 2011).

§ Cation exchange capacity summation method (Maguire and Heckendorn, 2011).

β Soil NH_4-N and NO_3-N by colorimetric method (Mulvaney, 1996); P, K, Ca, Mg, Zn, Mn, Cu, Fe, B, SS by Mehlich-1 soil test (Maguire and Heckendorn, 2011).

£ Soluble salts.

Appendix B.2 Agronomic characteristics for soybean cultivars grown in 2012 and 2013 agronomic input experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Cultivar †	
Characteristic	95Y01 λ	95Y20 λ
Relative maturity	5.0	5.2
Herbicide tolerant trait	Roundup Ready®	Roundup Ready®
Canopy width ‡	7	7
Plant height for maturity γ	6	5
Growth habit	Indeterminate	Determinate
Flower color	Purple	Purple
Pubescence color	Tawny	Tawny
Pod color	Brown	Tan
Hilum color	Black	Black
Field emergence Ω	7	7
Harvest standability §	7	9
Shattering δ	8	7
Seed kg^{-1}	5727	7159
Seed treatment	Treated ¥	Treated ¥
% protein Φ	35.4	36.3
% oil Φ	19.3	18.8
% germ	85	85
Iron chlorosis	- Θ	-
Soybean cyst nematode β	R3,14	R3,14
PRR resistance gene £	-	-
PRR field tolerance £	5	-
Sudden death syndrome §	4	5
Stem canker gene μ	9	-
Stem canker field tolerance §	5	-
Charcoal rot §	6	-
Frogeye leaf spot §	6	6
Southern root-knot nematode §	2	8

† Pioneer Hi-Bred Int., Inc.
λ Anonymous, 2013a; 2013b, respectively.
‡ Canopy width rating scale: 9 = extremely bushy, 1 = very narrow.
γ Plant height scale: 9 = tall, 1 = short.
Ω Field emergence scale: 1-3 = below average, 4-6 = average, 7-9 = excellent.
§ Rating scale: 9 = excellent, 1 = poor.
δ Shattering scale: 9 = excellent tolerance, 1 = poor tolerance.
¥ Seed treatments: Gaucho, Trilex, Pioneer Premium Seed Treatment, Allegiance.
Φ Collected at 13% moisture.
Θ Insufficient data collected.
β Soybean cyst nematode: R, resistance; #, race 1, 3, 5, 9, or 14.
£ Phytophthora root rot.
μ Stem canker gene: 9 = resistant, 5 = moderate resistance, 1 = no resistance.

Appendix B.3 Test of fixed effects and interactions for growth, N uptake, seed yield and quality parameters as affected by input main effects cultivar (C), seeding rate (S), inoculant (I), nitrogen (N), and fungicide (F), and all interactions for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Seed Yield					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.9163 †	0.8165	0.0008	0.6417	0.3921	0.2505
F ‡	0.2276	<.0001	0.0002	<.0001	0.2054	0.0011
C £	0.1231	0.0183	0.8387	<.0001	0.0002	0.0215
S β	0.3063	0.2471	0.0377	0.5670	0.0081	0.9835
I ¥	0.0672	0.3663	0.0479	0.8901	0.6711	0.9613
N*F	0.7434	0.5831	0.7768	0.5496	0.1461	0.9918
N*C	0.0674	0.0058	0.2816	0.7859	0.4112	0.4774
F*C	0.8555	0.0479	0.2221	0.4833	0.4979	0.1204
N*S	0.1180	0.6191	0.9059	0.1159	0.7409	0.6647
F*S	0.4009	0.1260	0.3750	0.5452	0.3463	0.5902
C*S	0.2490	0.1192	0.1561	0.0042	0.0002	0.0021
N*I	0.5395	0.8660	0.4887	0.8511	0.5119	0.2647
F*I	0.1547	0.9811	0.4028	0.9224	0.0288	0.2652
C*I	0.6304	0.7629	0.3792	0.7478	0.0051	0.8235
S*I	0.0269	0.6888	0.0299	0.9471	0.6880	0.2154
N*F*C	0.5302	0.6240	0.3474	0.8071	0.0838	0.2480
N*F*S	0.1251	0.7897	0.5078	0.8895	0.4133	0.1068
N*C*S	0.7332	0.1067	0.6937	0.4242	0.2166	0.5588
F*C*S	0.0615	0.3002	0.4070	0.2596	0.3102	0.6720
N*F*I	0.7425	0.3208	0.2441	0.4350	0.3092	0.9192
N*C*I	0.1875	0.5843	0.5631	0.9317	0.7762	0.7432
F*C*I	0.3443	0.3466	0.0426	0.0083	0.4208	0.7018
N*S*I	0.3666	0.7869	0.3002	0.3425	0.7102	0.9901
F*S*I	0.8437	0.7095	0.5522	0.1188	0.1222	0.7468
C*S*I	0.7037	0.1594	0.1149	0.6489	0.8316	0.4763
N*F*C*S	0.7552	0.7193	0.8522	0.1856	0.8314	0.7539
N*F*C*I	0.3270	0.1490	0.8331	0.4514	0.6083	0.9686
N*F*S*I	0.3466	0.8369	0.0547	0.7951	0.9768	0.6326
N*C*S*I	0.5038	0.9870	0.0550	0.1724	0.3103	0.5415
F*C*S*I	0.1632	0.2861	0.2366	0.3784	0.0785	0.9225
N*F*C*S*I	0.5257	0.7580	0.8670	0.8783	0.5847	0.6150

	Plant Population					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.5268 †	0.0068	0.7360	0.2187	0.7317	0.0047
C £	<.0001	0.0255	0.0055	0.3450	0.0001	0.0703
S β	0.0004	0.0014	<.0001	0.0004	0.0002	<.0001
I ¥	0.9076	0.4859	0.5256	0.6157	0.5647	0.0807
N*C	0.6545	0.7608	0.4090	0.6657	0.7060	0.3636
N*S	0.3696	0.3420	0.5825	0.4766	0.1249	0.0240
C*S	0.0107	0.0478	0.3162	0.6048	<.0001	0.0600
N*I	0.1874	0.1355	0.1670	0.1049	0.7344	0.4527

C*I	0.8139	0.1931	0.6070	0.7232	0.0034	0.6223
S*I	0.9445	0.5392	0.1826	0.1379	0.1408	0.2409
N*C*S	0.4928	0.2648	0.9462	0.5994	0.5647	0.7708
N*C*I	0.5442	0.9867	0.9575	0.2997	0.3954	0.2269
N*S*I	0.1366	0.2333	0.0899	0.2961	0.2085	0.6479
C*S*I	0.3289	0.6944	0.1229	0.2275	0.7894	0.3561
N*C*S*I	0.6981	0.8248	0.2589	0.1810	0.7131	0.4231

	V4 Plant Height					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.9792 †	0.5498	0.4511	0.0002	0.1689	0.3129
C £	0.0713	0.0885	0.0393	0.3345	0.2338	0.3955
S β	0.1438	0.0010	0.0151	0.0615	0.1645	0.2322
I ¥	0.3532	0.6924	0.2372	0.8378	0.7284	0.3906
N*C	0.8552	0.0585	0.0882	0.9381	0.8188	0.9042
N*S	0.7478	0.8551	0.3248	0.8933	0.8639	0.7995
C*S	0.9653	0.0982	0.4315	0.8933	0.0014	0.0285
N*I	0.9238	0.9838	0.4918	0.6065	0.9185	0.3480
C*I	0.3444	0.2658	0.8358	0.8599	0.0304	0.0665
S*I	0.7876	0.2572	0.9405	0.2289	0.6052	0.7926
N*C*S	0.0228	0.0206	0.5564	0.6875	0.2070	0.2427
N*C*I	0.2562	0.8951	0.3330	0.4591	0.0506	0.7249
N*S*I	0.0050	0.4595	0.2308	0.1050	0.2217	0.9538
C*S*I	0.3532	0.4005	0.7717	0.5870	0.2070	0.7585
N*C*S*I	0.8688	0.5035	0.1397	0.5119	0.6751	0.9113

	V4 Total N Uptake					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.7929 †	0.8350	0.3857	0.1177	0.3232	0.4051
C £	0.7388	0.9771	0.6938	0.3201	0.5579	0.0959
I ¥	0.8135	0.9902	0.8829	0.3253	0.9706	0.4471
N*C	0.6669	0.9323	0.0586	0.5536	0.2703	0.7922
N*I	0.5158	0.8329	0.7804	0.5594	0.3732	0.5268
C*I	0.1405	0.8650	0.5036	0.1328	0.7198	0.8632
N*C*I	0.3319	0.7221	0.6477	0.5577	0.5409	0.9235

	V4 NDVI					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	-Φ	-	-	<.0001 †	<.0001	0.3636
C £	-	-	-	0.0124	<.0001	<.0001
S β	-	-	-	0.0379	0.0002	0.1152
I ¥	-	-	-	0.7216	0.6329	0.7690
N*C	-	-	-	0.1873	0.2588	0.9173
N*S	-	-	-	0.8007	0.3596	0.9845
C*S	-	-	-	0.3779	<.0001	0.0024
N*I	-	-	-	0.6875	0.4225	0.5612
C*I	-	-	-	0.4774	0.1813	0.0364
S*I	-	-	-	0.2875	0.8596	0.6481
N*C*S	-	-	-	0.7295	0.5931	0.7120

N*C*I	-	-	-	0.5339	0.8399	0.2283
N*S*I	-	-	-	0.4848	0.1139	0.4252
C*S*I	-	-	-	0.8650	0.5118	0.3858
N*C*S*I	-	-	-	0.8220	0.8842	0.8720

	R3 NDVI					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	------------------------------------	------------------------------------	------------------------------------Pr > F	------------------------------------	------------------------------------	------------------------------------
N §	-Φ	-	-	0.1729 †	0.2244	0.6402
C £	-	-	-	<.0001	0.0173	0.5473
S β	-	-	-	0.8655	0.0017	0.1827
I ¥	-	-	-	0.2264	0.3218	0.8353
N*C	-	-	-	0.0272	0.1969	0.6392
N*S	-	-	-	0.4348	0.0740	0.7063
C*S	-	-	-	0.4933	0.2807	0.7467
N*I	-	-	-	0.1184	0.5925	0.3626
C*I	-	-	-	0.2202	0.0111	0.1913
S*I	-	-	-	0.7247	0.7069	0.2443
N*C*S	-	-	-	0.4210	0.0434	0.1091
N*C*I	-	-	-	0.0846	0.4330	0.9416
N*S*I	-	-	-	0.0510	0.2167	0.4887
C*S*I	-	-	-	0.1730	0.5395	0.6520
N*C*S*I	-	-	-	0.7006	0.1599	0.7368

	R5 Total N Uptake					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	------------------------------------	------------------------------------	------------------------------------Pr > F	------------------------------------	------------------------------------	------------------------------------
N §	0.8477 †	0.9381	0.6200	0.2561	0.4464	0.5171
C £	0.4074	0.9083	0.2064	0.5524	0.5371	0.7071
I ¥	0.9891	0.7623	0.8046	0.7240	0.2836	0.3611
N*C	0.4839	0.9984	0.5249	0.4829	0.2870	0.6510
N*I	0.7533	0.7409	0.3537	0.5491	0.9455	0.9449
C*I	0.1547	0.8766	0.6894	0.4182	0.7033	0.3534
N*C*I	0.5213	0.7519	0.6818	0.4002	0.4423	0.4780

	R5 NDVI					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	------------------------------------	------------------------------------	------------------------------------Pr > F	------------------------------------	------------------------------------	------------------------------------
N §	0.6543 †	0.9882	0.1589	0.1578	0.0587	0.0420
F ‡	0.6728	0.1153	0.0915	0.0020	0.7741	0.0006
C £	0.6358	0.1011	0.2086	0.2035	0.6279	<.0001
S β	0.9142	0.7229	0.1649	0.2024	0.2323	0.1069
I ¥	0.5497	0.8213	0.2141	0.9225	0.1551	0.6846
N*F	0.7641	0.3668	0.8328	0.5089	0.7099	0.1118
N*C	0.2109	0.1142	0.2662	0.1399	0.4957	0.5051
F*C	0.3847	0.4613	0.4752	0.3527	0.5877	0.0013
N*S	0.9903	0.1269	0.7366	0.2404	0.0232	0.9599
F*S	0.0176	0.8653	0.6318	0.6773	0.8512	0.2090
C*S	0.6839	0.6359	0.7312	0.7185	0.0034	0.2626
N*I	0.6825	0.0499	0.9989	0.3919	0.8332	0.9408
F*I	0.2604	0.6114	0.7491	0.3174	0.2097	0.1185
C*I	0.0100	0.6682	0.2492	0.1709	0.0084	0.9980

S*I	0.9221	0.7638	0.0401	0.1109	0.9716	0.7513
N*F*C	0.4409	0.2674	0.9327	0.8229	0.4584	0.9679
N*F*S	0.5392	0.4862	0.6571	0.2326	0.9937	0.3318
N*C*S	0.5983	0.7395	0.2082	0.6107	0.2339	0.6558
F*C*S	0.6332	0.6420	0.9508	0.4713	0.5734	0.0729
N*F*I	0.8334	0.5423	0.7067	0.6088	0.8932	0.6750
N*C*I	0.6074	0.1431	0.1119	0.6464	0.6595	0.3660
F*C*I	0.4428	0.6917	0.6939	0.6474	0.9317	0.5863
N*S*I	0.3286	0.7594	0.2047	0.3723	0.4957	0.3455
F*S*I	0.1874	0.4284	0.2176	0.4658	0.2286	0.4733
C*S*I	0.1553	0.8107	0.6067	0.7772	0.9838	0.7228
N*F*C*S	0.2351	0.2265	0.8182	0.6846	0.8241	0.8054
N*F*C*I	0.7112	0.2513	0.9965	0.7960	0.4077	0.3515
N*F*S*I	0.9880	0.2113	0.9442	0.8544	0.6648	0.2861
N*C*S*I	0.3376	0.4911	0.5662	0.3526	0.1559	0.7215
F*C*S*I	0.4710	0.8685	0.6908	0.7932	0.3551	0.5044
N*F*C*S*I	0.4989	0.6847	0.9241	0.9751	0.8895	0.7367

	R8 Plant Height					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--Pr > F--					
N §	- Φ	-	-	0.0066 †	0.1531	0.0531
F ‡	-	-	-	0.2717	0.1478	0.8282
C £	-	-	-	<.0001	0.0387	0.7802
S β	-	-	-	0.1309	0.1531	0.6420
I ¥	-	-	-	0.2983	0.5188	0.9753
N*F	-	-	-	0.4569	0.0680	0.4389
N*C	-	-	-	0.3883	0.1531	0.8768
F*C	-	-	-	0.4218	0.8697	0.1651
N*S	-	-	-	0.8347	0.3607	0.8768
F*S	-	-	-	0.7885	0.4941	0.2055
C*S	-	-	-	0.2468	0.0002	0.0796
N*I	-	-	-	0.5318	0.5569	0.4763
F*I	-	-	-	0.6126	0.8244	0.6870
C*I	-	-	-	0.3566	0.1531	0.1310
S*I	-	-	-	0.6550	0.1325	0.7331
N*F*C	-	-	-	0.7885	0.0680	0.0297
N*F*S	-	-	-	0.5715	0.4470	0.1651
N*C*S	-	-	-	0.1166	0.0680	0.5983
F*C*S	-	-	-	0.2717	0.8096	0.5154
N*F*I	-	-	-	0.7885	0.2299	0.3695
N*C*I	-	-	-	0.7885	0.9003	0.2793
F*C*I	-	-	-	0.5318	0.8244	0.7802
N*S*I	-	-	-	0.3566	0.9615	0.6420
F*S*I	-	-	-	0.8815	0.6787	0.5983
C*S*I	-	-	-	0.4569	0.4134	0.8768
N*F*C*S	-	-	-	0.7885	0.6927	0.1027
N*F*C*I	-	-	-	0.2983	0.6787	0.4033
N*F*S*I	-	-	-	0.8815	0.2529	0.6870
N*C*S*I	-	-	-	0.7885	0.9615	0.8768
F*C*S*I	-	-	-	0.3883	0.5188	0.9259
N*F*C*S*I	-	-	-	0.6985	0.1098	0.1027

	Lodging					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	-	0.0925 †	0.1480	1.0000	0.0009	0.7750
F ‡	-	0.1600	0.1480	0.0136	0.0047	0.0003
C £	-	0.0010	0.0024	<.0001	0.8838	<.0001
S β	-	0.0925	0.0006	0.0816	0.8838	0.0726
I ¥	-	0.2601	0.8354	0.8020	0.6878	0.6339
N*F	-	0.2601	0.8354	0.1346	0.4995	0.5051
N*C	-	0.3976	0.5333	0.3170	0.2228	0.6339
F*C	-	1.0000	0.5333	0.6161	0.0108	0.2172
N*S	-	0.1600	0.5333	0.8020	0.2228	0.1550
F*S	-	0.5724	0.5333	0.8020	0.6878	0.3919
C*S	-	0.3976	0.1480	0.4524	0.0001	0.3919
N*I	-	0.7776	0.5333	0.8020	0.6745	0.7750
F*I	-	0.5724	0.1480	0.4524	0.4881	0.6339
C*I	-	0.1600	0.0241	0.8020	0.1364	0.5051
S*I	-	0.0503	0.0638	0.6161	0.4881	0.1076
N*F*C	-	0.7776	0.5333	0.6161	0.2228	0.3919
N*F*S	-	0.7776	0.3001	0.8020	0.8982	0.2172
N*C*S	-	1.0000	0.5333	0.4524	0.0222	0.9241
F*C*S	-	0.7776	0.3001	0.8020	0.6878	0.6339
N*F*I	-	0.7776	0.1480	0.4524	0.8982	0.7750
N*C*I	-	1.0000	0.0638	0.8020	0.8982	0.6339
F*C*I	-	0.7776	0.3001	0.0068	0.3432	0.9241
N*S*I	-	0.5724	0.3001	0.3170	0.8982	0.7750
F*S*I	-	0.3976	0.1480	0.6161	0.8838	0.3919
C*S*I	-	0.5724	0.8354	1.0000	0.6878	0.0726
N*F*C*S	-	0.5724	0.5333	0.2117	0.6745	0.7750
N*F*C*I	-	1.0000	0.3001	0.0068	0.8982	0.7750
N*F*S*I	-	0.5724	0.1480	0.6161	0.8982	0.7750
N*C*S*I	-	0.7776	0.5333	0.6161	0.4995	0.6339
F*C*S*I	-	0.2601	0.1480	0.3170	0.1364	0.6339
N*F*C*S*I	-	0.7776	0.8354	1.0000	0.8982	0.2958

	100 Seed Weight					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.9475 †	0.1381	0.0383	0.958	0.1111	0.2165
F ‡	0.0401	0.0325	<.0001	<.0001	0.0063	<.0001
C £	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S β	0.0006	0.4909	0.4554	0.0497	0.1036	0.0070
I ¥	0.9475	0.5969	0.6081	0.6865	0.8659	0.6793
N*F	0.5983	0.4909	0.8489	0.9580	0.5351	0.6793
N*C	0.1019	0.5969	0.6288	0.0847	0.8309	0.7010
F*C	0.3746	0.3291	0.4209	0.1206	0.6231	0.0651
N*S	0.8951	0.3787	0.4554	0.3907	0.0778	0.7904
F*S	0.7668	0.0676	0.7141	0.8745	0.2274	0.5354
C*S	0.4492	0.0378	0.6081	0.6110	0.0106	0.0016
N*I	0.7668	0.8852	0.7141	0.9860	0.7506	0.9529
F*I	0.2642	0.4327	0.5289	0.7125	0.9209	0.1583

C*I	0.4691	0.0630	0.8719	0.6865	0.8039	0.2276
S*I	0.9475	0.7606	0.8032	0.1573	0.4480	0.1671
N*F*C	0.2642	0.4142	0.2146	0.6609	0.0093	0.0739
N*F*S	0.8951	0.0509	0.6081	0.4723	0.4276	0.9294
N*C*S	0.1161	0.0378	0.9649	0.2277	0.0589	0.2632
F*C*S	0.7668	0.6193	0.1659	0.6865	0.5515	0.4789
N*F*I	0.3746	0.7606	0.5100	0.2858	0.8039	0.7230
N*C*I	0.7668	0.7851	0.9883	0.3355	0.4629	0.1342
F*C*I	1.0000	0.5969	0.4554	0.0911	0.5582	0.8826
N*S*I	0.1788	0.1557	0.6924	0.5628	0.9485	0.7453
F*S*I	0.2373	0.5113	0.5289	0.2858	0.8387	0.9294
C*S*I	0.7418	0.5113	0.6288	0.9580	0.4021	0.9059
N*F*C*S	0.3241	0.4142	0.5289	0.7654	0.1548	0.1956
N*F*C*I	0.4492	0.6885	0.7583	0.5866	0.3515	0.3925
N*F*S*I	0.3084	0.4516	0.3273	0.7388	0.9485	0.4258
N*C*S*I	0.9213	0.8852	0.6709	0.8469	0.7771	0.4090
F*C*S*I	0.7418	0.6193	0.9416	0.2413	0.3644	0.1004
N*F*C*S*I	0.1088	0.9361	0.8719	0.1126	0.1868	0.8132

	Seed Quality					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.4963 †	0.8027	0.2746	0.8563	0.0881	0.7749
F ‡	0.3648	0.1362	0.2746	0.2068	0.5701	0.0039
C £	0.0009	0.0265	0.8265	0.0203	0.0881	<.0001
S β	1.0000	0.6175	0.2746	0.8563	0.5701	0.6337
I ¥	0.3648	1.0000	0.0509	0.5872	0.5701	0.7749
N*F	0.4963	0.8027	0.0509	0.8563	0.5655	0.2170
N*C	1.0000	0.6175	0.8265	0.8563	0.0894	0.2170
F*C	0.4963	0.8027	0.8265	0.5872	0.5655	0.6337
N*S	0.8204	0.2135	0.8265	0.2068	0.5655	0.6337
F*S	0.1752	0.6175	0.8265	0.8563	0.0894	0.2170
C*S	0.8204	0.8027	0.8265	0.8563	0.5655	0.1075
N*I	0.4963	0.0828	0.8265	0.8563	0.5655	0.7749
F*I	0.3648	0.6175	0.0509	0.5872	0.5655	0.3917
C*I	0.0433	0.4542	0.5113	0.0486	0.5655	0.2170
S*I	0.6499	0.6175	0.8265	0.1055	0.5655	0.9240
N*F*C	0.3648	1.0000	0.8265	0.3662	0.5701	0.1549
N*F*S	0.4963	0.8027	0.2746	0.3662	0.0881	0.6337
N*C*S	0.6499	0.1362	0.1273	0.8563	0.5701	0.9240
F*C*S	0.2579	0.0828	0.8265	0.0203	0.0881	0.6337
N*F*I	0.8204	0.8027	0.8265	0.5872	0.5701	0.3917
N*C*I	0.6499	0.6175	0.1273	0.8563	0.5701	0.6337
F*C*I	0.8204	0.2135	0.8265	0.8563	0.5701	0.0725
N*S*I	0.8204	0.4542	0.8265	0.8563	0.5701	0.7749
F*S*I	0.3648	0.6175	0.1273	0.0486	0.5701	0.2170
C*S*I	0.0433	0.4542	0.8265	0.8563	0.5701	0.7749
N*F*C*S	0.3648	0.1362	0.8265	0.8563	0.0894	0.6337
N*F*C*I	0.6499	0.3189	0.5113	0.8563	0.5655	0.7749
N*F*S*I	0.2579	0.4542	0.8265	0.2068	0.5655	0.1549
N*C*S*I	0.6499	0.6175	0.2746	0.8563	0.5655	0.3917
F*C*S*I	0.1144	0.8027	0.2746	0.2068	0.5655	0.7749

N*F*C*S*I	0.3648	0.6175	0.8265	0.5872	0.5701	0.3917
	Percent PSS					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.1003 †	0.7351	0.4226	0.3074	0.5030	0.0209
F ‡	0.4087	0.5731	0.4226	0.0135	0.5030	0.9575
C £	0.4087	0.0342	0.2856	<.0001	0.1819	<.0001
S β	0.4087	0.5731	0.0343	0.7802	0.0465	0.2431
I ¥	0.4087	0.7351	0.7889	0.4033	0.1819	0.5947
N*F	1.0000	0.0342	0.2856	0.6420	0.1819	0.4566
N*C	1.0000	0.9102	0.0633	0.1650	0.5030	0.7494
F*C	0.4087	0.9102	0.7889	0.0345	0.5030	0.0814
N*S	1.0000	0.5731	0.4226	0.9259	1.0000	0.7901
F*S	0.4087	0.0576	0.0633	0.3074	1.0000	0.3951
C*S	0.4087	0.9102	0.1106	0.5153	0.0465	0.0353
N*I	1.0000	0.9102	0.2856	0.7802	0.5030	0.4252
F*I	0.4087	0.4305	0.2856	0.0796	0.0465	1.0000
C*I	0.4087	0.5731	0.4226	0.4033	1.0000	0.7494
S*I	0.0146	0.7351	0.7889	0.4033	0.5030	0.3130
N*F*C	1.0000	0.0108	0.2856	0.4033	1.0000	0.0120
N*F*S	1.0000	0.5731	0.5925	0.5153	0.5030	0.7901
N*C*S	1.0000	0.9102	0.4226	0.7802	0.1819	0.2651
F*C*S	0.4087	0.7351	0.7889	0.5153	0.1819	0.7494
N*F*I	1.0000	0.3113	0.1827	0.9259	0.1819	0.8731
N*C*I	1.0000	0.4305	0.2856	0.7802	0.5030	0.5584
F*C*I	0.4087	0.0931	0.2856	0.0796	0.0465	0.2883
N*S*I	0.1003	0.1448	0.5925	0.9259	1.0000	0.0909
F*S*I	0.4087	0.9102	0.0343	0.7802	0.1819	0.7901
C*S*I	0.4087	0.5731	0.1827	0.4033	0.5030	0.2651
N*F*C*S	0.1003	0.3113	0.0343	0.7802	0.5030	0.0814
N*F*C*I	0.1003	0.4305	0.0633	0.9259	1.0000	0.0648
N*F*S*I	1.0000	0.2165	0.4226	0.642	0.5030	0.5947
N*C*S*I	1.0000	0.1448	1.0000	0.9259	0.1819	0.8313
F*C*S*I	0.4087	0.0108	0.1106	0.7802	0.0085	0.9575
N*F*C*S*I	1.0000	0.7351	0.0633	0.642	0.5030	0.9152
	Seed Oil Concentration					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.233 †	0.2941	0.0570	0.7192	0.4124	0.6993
F ‡	0.3864	0.0611	0.3380	0.0654	0.0114	0.0111
C £	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S β	0.6856	0.4192	0.8100	0.5540	0.7893	0.8738
I ¥	0.0908	0.6164	0.8487	0.1314	0.5457	0.6269
N*F	0.1799	0.3417	0.6351	0.7606	0.2739	0.0936
N*C	0.6628	0.9974	0.3692	0.9302	0.6128	0.7210
F*C	0.3197	0.4844	0.1731	0.0235	0.0232	0.8883
N*S	0.0224	0.6753	0.3905	0.5770	0.1834	0.1229
F*S	0.3039	0.2987	0.7744	0.4361	0.0758	0.9760
C*S	0.4193	0.3487	0.0904	0.8458	0.2311	0.8945
N*I	0.0159	0.9643	0.0009	0.7035	0.0980	0.8414

F*I	0.7616	0.9259	0.6814	0.6149	0.1114	0.3764
C*I	0.0954	0.5317	0.4902	0.6975	0.7909	0.4392
S*I	0.0929	0.7117	0.4638	0.5646	0.9560	0.9464
N*F*C	0.3989	0.2579	0.7612	0.2489	0.3002	0.4297
N*F*S	0.0713	0.0248	0.5814	0.4935	0.5407	0.1875
N*C*S	0.9497	0.7488	0.2300	0.6004	0.9919	0.5670
F*C*S	0.2829	0.7562	0.6813	0.2553	0.0036	0.3016
N*F*I	0.4244	0.1118	0.2647	0.6362	0.8087	0.0228
N*C*I	0.4639	0.7382	0.1649	0.7003	0.4134	0.9006
F*C*I	0.4209	0.6573	0.9705	0.8375	0.6207	0.7514
N*S*I	0.8457	0.9177	0.8653	0.2835	0.7258	0.9646
F*S*I	0.4605	0.3908	0.2872	0.1484	0.1072	0.9860
C*S*I	0.6946	0.7291	0.6207	0.6119	0.5556	0.2776
N*F*C*S	0.8662	0.6117	0.3415	0.9586	0.2985	0.4332
N*F*C*I	0.9795	0.4114	0.0089	0.0135	0.7493	0.3460
N*F*S*I	0.7714	0.0389	0.7193	0.5429	0.3554	0.5195
N*C*S*I	0.0081	0.3869	0.0330	0.4777	0.7156	0.3685
F*C*S*I	0.6394	0.1641	0.6937	0.9002	0.5263	0.7006
N*F*C*S*I	0.7353	0.2765	0.9636	0.0505	0.1809	0.6628

	Seed Protein Concentration					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.1552 †	0.4153	0.3897	0.3774	0.2264	0.6971
F ‡	0.9388	0.4158	0.3221	0.0378	0.0686	0.1152
C £	0.1256	0.0229	0.0438	<.0001	0.5732	0.6249
S β	0.0316	0.5819	0.8657	0.3019	0.8806	0.7883
I ¥	0.6150	0.5797	0.5737	0.1189	0.1720	0.1112
N*F	0.7200	0.0338	0.9653	0.4732	0.8956	0.5971
N*C	0.1585	0.5030	0.9012	0.5942	0.6403	0.5121
F*C	0.3454	0.9485	0.4729	0.3119	0.8717	0.8321
N*S	0.1751	0.0770	0.0463	0.8560	0.9778	0.3133
F*S	0.9392	0.0166	0.6030	0.1965	0.8020	0.7190
C*S	0.2506	0.0418	0.3243	0.0560	0.8296	0.3601
N*I	0.9705	0.2683	0.0037	0.9175	0.1274	0.3052
F*I	0.8456	0.3537	0.4617	0.2502	0.7995	0.1763
C*I	0.4862	0.2872	0.0620	0.2275	0.0009	0.5998
S*I	0.1598	0.7929	0.7533	0.3999	0.9715	0.7975
N*F*C	0.0316	0.5819	0.8657	0.7741	0.5826	0.8361
N*F*S	0.5516	0.8558	0.2724	0.1766	0.0242	0.5194
N*C*S	0.3944	0.4903	0.0522	0.1253	0.3794	0.9914
F*C*S	0.5030	0.3295	0.2545	0.9693	0.6957	0.7875
N*F*I	0.5519	0.9320	0.4091	0.8451	0.0323	0.5225
N*C*I	0.3304	0.6711	0.9353	0.0419	0.4433	0.8751
F*C*I	0.8066	0.8546	0.7760	0.1575	0.8039	0.8832
N*S*I	0.0893	0.1002	0.0225	0.6267	0.5425	0.1366
F*S*I	0.4017	0.2569	0.4215	0.5956	0.8369	0.1487
C*S*I	0.1069	0.3452	0.1974	0.8290	0.4304	0.2944
N*F*C*S	0.2812	0.8693	0.3129	0.3962	0.4711	0.9063
N*F*C*I	0.8602	0.6627	0.9605	0.0969	0.8943	0.7592
N*F*S*I	0.4559	0.1720	0.4866	0.8757	0.9344	0.8478
N*C*S*I	0.9292	0.9049	0.0165	0.4950	0.6019	0.6821

F*C*S*I	0.9534	0.1501	0.5186	0.4908	0.2008	0.9889
N*F*C*S*I	0.0253	0.5786	0.6659	0.4669	0.1125	0.9659

§ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

‡ Foliar application pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 460 mL ha^{-1} (0.25% v/v) applied by 3-pt. sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) (Fehr and Caviness, 1977).

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

β 593,000 and 725,000 seed ha^{-1}.

¥ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

† P (0.05) level significance.

Φ Data not collected.

Appendix B.4 Main effects cultivar (C), seeding rate (S), inoculant (I), nitrogen (N), and fungicide (F) influenced plant population, growth, and seed quality parameters for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Site-Year					
	MTH12	**PTR12**	**SUF12**	**WAR13**	**PTR13**	**SUF13**
C £	-------------------------Plant population (plants per ha)-------------------------					
95Y01	343,925 b†	407,210 b	364,061 b	428,318 a	242,085 a	434,370 a
95Y20	389,390 a	437,695 a	393,836 a	437,396 a	210,941 b	453,311 a
S β						
593,000	346,166 b	400,374 b	355,805 b	415,205 b	211,278 b	420,921 b
725,000	387,149 a	444,532 a	402,092 a	450,509 a	241,748 a	466,760 a
N ‡						
With	363,090 a	403,885 b	377,174 a	426,936 a	225,161 a	428,878 b
Without	370,225 a	441,020 a	380,723 a	438,779 a	227,865 a	458,803 a
I §						
With	367,311 a	427,160 a	375,605 a	430,448 a	228,785 a	434,706 a
Without	366,004 a	417,746 a	382,292 a	435,267 a	224,241 a	452,975 a
C £	-------------------------------R8 Plant Height (cm)-------------------------------					
95Y01	- ¥	-	-	98.1 b	67.1 b	94.0 a
95Y20	-	-	-	106.4 a	70.0 a	93.6 a
S β						
593,000	-	-	-	103.3 a	67.6 a	93.5 a
725,000	-	-	-	101.2 a	69.6 a	94.1 a
N ‡						
With	-	-	-	104.1 a	69.6 a	95.0 a
Without	-	-	-	100.4 b	67.6 a	92.5 a
I §						
With	-	-	-	101.6 a	68.1 a	93.8 a
Without	-	-	-	102.9 a	69.0 a	93.8 a
F Φ						
With	-	-	-	103.0 a	67.6 a	93.9 a
Without	-	-	-	101.5 a	69.6 a	93.7 a
C £	--------------------------------------Lodging--------------------------------------					
95Y01	1 †	3.4 b	1.8 a	1.8 b	1.4 a	1.8 b
95Y20	1	3.8 a	1.5 b	2.7 a	1.4 a	2.3 a
S β						
593,000	1	3.5 a	1.5 b	2.2 a	1.4 a	2.0 a
725,000	1	3.7 a	1.8 a	2.3 a	1.4 a	2.1 a
N ‡						
With	1	3.5 a	1.6 a	2.2 a	1.5 a	2.0 a
Without	1	3.7 a	1.7 a	2.2 a	1.3 b	2.0 a
I §						

With	1	3.7 a	1.6 a	2.2 a	1.4 a	2.1 a
Without	1	3.6 a	1.7 a	2.2 a	1.4 a	2.0 a
F Φ						
With	1	3.7 a	1.6 a	2.3 a	1.3 b	2.2 a
Without	1	3.6 a	1.7 a	2.2 b	1.5 a	1.9 b
C £	-----------------------------------Seed Quality-----------------------------------					
95Y01	2.0 a †	1.5 a	1.8 a	1.1 b	1.0 a	3.3 a
95Y20	1.7 b	1.3 b	1.8 a	1.2 a	1.0 a	2.6 b
S β						
593,000	1.8 a	1.4 a	1.8 a	1.1 a	1.0 a	3.0 a
725,000	1.8 a	1.4 a	1.8 a	1.1 a	1.0 a	2.9 a
N ‡						
With	1.8 a	1.4 a	1.8 a	1.1 a	1.0 a	2.9 a
Without	1.9 a	1.4 a	1.8 a	1.1 a	1.0 a	2.9 a
I §						
With	1.8 a	1.4 a	1.84 a	1.2 a	1.0 a	2.9 a
Without	1.9 a	1.4 a	1.77 a	1.1 a	1.0 a	2.9 a
F Φ						
With	1.8 a	1.4 a	1.8 a	1.1 a	1.0 a	2.8 b
Without	1.9 a	1.4 a	1.8 a	1.2 a	1.0 a	3.1 a
C £	-------------------------------Purple Seed Stain (%)------------------------------					
95Y01	0.06 a †	0.77 a	0.50 a	0.80 a	0.03 a	6.03 b
95Y20	0.03 a	0.47 b	0.37 a	0.03 b	0.09 a	11.69 a
S β						
593,000	0.03 a	0.58 a	0.31 b	0.39 a	0.02 b	9.20 a
725,000	0.06 a	0.66 a	0.56 a	0.44 a	0.11 a	8.52 a
N ‡						
With	0.02 a	0.64 a	0.48 a	0.50 a	0.05 a	8.17 b
Without	0.08 a	0.59 a	0.39 a	0.33 a	0.08 a	9.55 a
I §						
With	0.03 a	0.64 a	0.42 a	0.48 a	0.03 a	9.02 a
Without	0.06 a	0.59 a	0.45 a	0.34 a	0.09 a	8.70 a
F Φ						
With	0.06 a	0.58 a	0.39 a	0.20 b	0.05 a	8.87 a
Without	0.03 a	0.66 a	0.48 a	0.62 a	0.08 a	8.84 a
C £	---------------------------Seed Oil Concentration (%)---------------------------					
95Y01	19.7 a †	19.8 a	20.7 a	19.7 a	19.6 a	21.5 a
95Y20	19.1 b	19.2 b	20.4 b	18.8 b	19.1 b	21.2 b
S β						
593,000	19.4 a	19.5 a	20.6 a	19.3 a	19.4 a	21.4 a
725,000	19.4 a	19.4 a	20.5 a	19.2 a	19.4 a	21.4 a
N ‡						
With	19.3 a	19.4 a	20.6 a	19.3 a	19.3 a	21.4 a
Without	19.4 a	19.5 a	20.5 a	19.2 a	19.4 a	21.4 a
I §						

With	19.5 a	19.5 a	20.5 a	19.2 a	19.4 a	21.4 a
Without	19.3 a	19.5 a	20.6 a	19.3 a	19.4 a	21.3 a
F Φ						
With	19.4 a	19.4 a	20.5 a	19.2 a	19.3 b	21.3 b
Without	19.4 a	19.6 a	20.6 a	19.4 a	19.5 a	21.5 a
C £	-------------------------Seed Protein Concentration (%)-------------------------					
95Y01	40.6 a †	43.6 a	43.0 a	41.7 a	41.0 a	42.1 a
95Y20	40.9 a	43.2 b	42.6 b	40.4 b	41.2 a	42.0 a
S β						
593,000	40.7 a	43.4 a	42.8 a	41.0 a	41.1 a	42.0 a
725,000	40.9 a	43.5 a	42.8 a	41.1 a	41.1 a	42.1 a
N ‡						
With	40.7 a	43.3 a	42.9 a	41.0 a	41.2 a	42.0 a
Without	40.9 a	43.5 a	42.7 a	41.1 a	41.0 a	42.1 a
I §						
With	40.7 a	43.5 a	42.7 a	40.9 a	41.0 a	42.2 a
Without	40.8 a	43.4 a	42.8 a	41.2 a	41.2 a	41.9 a
F Φ						
With	40.8 a	43.3 a	42.7 a	40.9 b	40.9 a	41.9 a
Without	40.8 a	43.5 a	42.9 a	41.2 a	41.3 a	42.2 a

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

¥ Data not collected.

β Seed ha^{-1}.

‡ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

Φ Foliar application pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 460 mL ha^{-1} (0.25% v/v) applied by 3-pt. sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) (Fehr and Caviness, 1977).

† Means with different letter within parameter, main effect, and column significantly different P (0.05).

Appendix B.5 Test of fixed effects and interactions for soybean yield component parameters as affected by main effects cultivar (C), seeding rate (S), inoculant (I), nitrogen (N), and fungicide (F), and all interactions for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Soybean per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.9358 †	0.5212	0.1324	0.3305	0.3573	0.2054
F ‡	0.0473	0.0259	0.3427	0.0436	0.2985	0.7988
C £	0.0083	0.5212	0.0012	0.0002	0.0051	0.3693
S β	0.0096	0.0020	0.0884	0.0193	0.0004	0.0176
I ¥	0.4371	0.4302	0.0359	0.6256	0.6302	0.6224
N*F	0.7677	0.2382	0.7772	1.0000	0.9680	0.6466
N*C	0.7677	0.0575	0.4880	0.2848	0.1881	0.8517
F*C	0.8090	0.8433	0.7772	0.1747	0.3369	0.3020
N*S	0.0600	0.0462	0.5207	0.0911	0.6302	0.8517
F*S	0.3221	0.1416	0.0455	0.8071	0.9041	0.9864
C*S	0.3768	0.9606	0.5893	0.1107	0.6020	0.9053
N*I	0.5732	0.2018	0.4262	0.8451	0.6020	0.5525
F*I	0.8509	0.6567	0.0023	0.4949	0.1117	0.4659
C*I	0.9786	0.1416	0.6252	0.9222	0.6302	0.6224
S*I	0.9786	0.6215	0.9795	0.5915	0.5475	0.8517
N*F*C	0.0053	0.0789	0.4565	0.3808	0.7787	0.7727
N*F*S	0.2294	0.7669	0.5893	0.1107	0.0953	0.0466
N*C*S	0.8509	0.7295	0.2292	0.5915	0.7481	0.9323
F*C*S	0.6482	0.1696	0.3971	0.8835	0.2159	0.8517
N*F*I	0.9358	0.2194	0.1603	0.3305	0.1631	0.4063
N*C*I	0.5732	0.7669	0.5207	0.3305	0.4004	0.1520
F*C*I	0.4371	0.5212	0.5893	0.6256	0.0683	0.6961
N*S*I	0.6872	0.3752	0.5544	0.1600	0.2309	0.7988
F*S*I	0.8509	0.3494	0.0318	0.8835	0.0626	0.0584
C*S*I	0.7271	0.8433	0.8570	0.6605	0.4465	0.9323
N*F*C*S	0.2294	0.2792	0.2494	0.1903	0.8724	0.7469
N*F*C*I	0.0674	0.4595	0.3175	0.0079	0.2804	0.2054
N*F*S*I	0.4371	0.1066	0.3693	0.1335	0.2309	0.5987
N*C*S*I	0.6482	0.3752	0.8169	0.1600	0.5744	0.6711
F*C*S*I	0.9358	0.4021	0.5893	0.7325	0.2467	0.9593
N*F*C*S*I	0.9358	0.1066	0.0884	0.8835	0.3369	0.9593

	Branches per plant					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.1696 †	0.1225	0.0269	0.6472	0.0826	0.2835
F ‡	0.1570	0.0543	0.1625	0.8154	0.4735	0.8684
C £	<.0001	<.0001	0.0320	<.0001	<.0001	<.0001
S β	0.0050	0.0087	0.7159	0.0041	0.0035	0.0045
I ¥	0.4986	0.2354	0.2564	0.0463	0.8970	0.3046
N*F	0.0643	0.6704	0.0930	0.1501	0.3740	0.7737
N*C	0.0387	0.7972	0.7709	0.6246	0.1100	0.4058
F*C	0.7275	0.4134	0.2770	0.9548	0.1847	0.2149

N*S	0.2712	0.1208	0.6801	0.0890	0.6100	0.7257
F*S	0.1722	0.3044	0.8461	0.8383	0.6896	0.1167
C*S	0.0399	0.9691	0.3100	0.9530	0.4648	0.4004
N*I	0.6894	0.4845	0.0166	0.2969	0.1894	0.0723
F*I	0.8861	0.2067	0.0156	0.7804	0.9512	0.6735
C*I	0.5040	0.2067	0.5286	0.2857	0.8145	0.8397
S*I	0.7436	0.8964	0.5446	0.4053	0.6421	0.5285
N*F*C	0.0102	0.3077	0.2013	0.3225	0.5274	0.2426
N*F*S	0.9778	0.6551	0.8083	0.4957	0.0423	0.1912
N*C*S	0.9437	0.4671	0.0254	0.7220	0.6750	0.7999
F*C*S	0.6800	0.5572	0.6801	0.4365	0.9558	0.9417
N*F*I	0.4213	0.7066	0.0138	0.4774	0.7533	0.7385
N*C*I	0.6644	0.2043	0.3100	0.7135	0.7043	0.3648
F*C*I	0.1722	0.7918	0.3707	0.5101	0.3459	0.4182
N*S*I	0.7696	0.9747	0.1422	0.5188	0.9241	0.7905
F*S*I	0.7926	0.1635	0.7709	0.1797	0.0261	0.1264
C*S*I	0.1900	0.3143	0.8842	1.0000	0.8701	0.8857
N*F*C*S	0.4462	0.0725	0.9420	0.3720	0.0816	1.0000
N*F*C*I	0.6277	0.5339	0.4528	0.4718	0.0516	0.6314
N*F*S*I	0.5599	0.1144	0.9227	0.5883	0.1922	0.5973
N*C*S*I	0.6490	0.2551	0.5607	0.1483	0.5903	0.0709
F*C*S*I	0.9199	0.7702	0.7159	0.2631	0.8255	0.3001
N*F*C*S*I	0.6429	0.6150	0.4243	0.8900	0.1094	0.6664

	Nodes per plant					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.1243 †	0.3005	0.0466	0.3745	0.0084	0.9338
F ‡	0.0545	0.0005	0.5818	0.2137	0.5829	0.3830
C £	0.0994	<.0001	0.7188	<.0001	<.0001	0.0805
S β	<.0001	0.0024	0.5423	0.0030	0.0284	0.0022
I ¥	0.7680	0.1444	0.4074	0.6604	0.6817	0.7064
N*F	0.2519	0.4402	0.9005	0.8183	0.6984	0.5530
N*C	0.2443	0.3082	0.2756	0.4287	0.3497	0.1242
F*C	0.3575	0.5225	0.9239	0.5050	0.2841	0.5789
N*S	0.6010	0.0888	0.6541	0.0766	0.4970	0.8132
F*S	0.0047	0.3005	0.3911	0.5757	0.3577	0.3693
C*S	0.9620	0.2781	0.9005	0.5836	0.7035	0.7447
N*I	0.3288	0.9271	0.2012	0.0105	0.6389	0.1729
F*I	0.2084	0.9403	0.6754	0.9815	0.7691	0.3560
C*I	0.5244	0.7965	0.6970	0.5601	0.1115	0.8132
S*I	0.1952	0.6716	0.6862	0.9447	0.0274	0.1435
N*F*C	0.0501	0.3749	0.1315	0.1403	0.6690	0.6782
N*F*S	0.8416	0.6122	0.1863	0.3036	0.9423	0.6504
N*C*S	0.1650	0.3161	0.4074	0.1302	0.6564	0.5616
F*C*S	0.4646	0.7583	0.6435	0.2863	0.3391	0.4951
N*F*I	0.8120	0.0112	0.0567	0.3649	0.5985	0.8132
N*C*I	0.3674	0.4804	0.4677	0.1365	0.5616	0.1977
F*C*I	0.8715	0.5012	0.3373	0.8596	0.6792	0.9847
N*S*I	0.6277	0.7965	0.1679	0.8247	0.5477	0.5530
F*S*I	0.3382	0.6006	0.0077	0.8713	0.0091	0.6782
C*S*I	0.3288	0.9668	0.8198	0.8570	0.8871	0.4185

N*F*C*S	0.6549	0.4907	0.7744	0.1663	0.2795	0.2940
N*F*C*I	0.4089	0.5443	0.0987	0.2185	0.3228	0.9847
N*F*S*I	0.4197	0.1489	0.2012	0.2733	0.7878	0.2999
N*C*S*I	0.2223	0.9007	0.9824	0.6857	0.9174	0.7544
F*C*S*I	0.7392	0.2638	0.6123	0.3145	0.8269	0.5278
N*F*C*S*I	0.2598	0.3241	0.0800	0.6145	0.7061	0.0744

	Reproductive Nodes per plant					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.5585 †	0.7592	0.3201	0.2543	0.0283	0.2599
F ‡	0.1052	0.0105	0.7704	0.1267	0.2213	0.8575
C £	<.0001	0.0305	<.0001	0.6986	0.2665	0.0005
S β	0.0011	0.0003	0.4360	0.0024	0.0033	0.0006
I ¥	0.9177	0.2283	0.3267	0.4250	0.5841	0.8359
N*F	0.5936	0.9651	0.5373	0.6154	0.3483	0.5259
N*C	0.5023	0.5026	0.7395	0.4946	0.4907	0.2657
F*C	0.6544	0.3904	0.5108	0.1619	0.1887	0.2270
N*S	0.1052	0.1253	0.6889	0.0419	0.8074	0.9559
F*S	0.0081	0.1288	0.7808	0.4843	0.6893	0.2657
C*S	0.4701	0.4148	0.8652	0.1769	0.7621	0.6194
N*I	0.6794	0.3669	0.3136	0.1668	0.6426	0.1880
F*I	0.4597	0.9418	0.4602	0.8367	0.7831	0.4652
C*I	0.3449	0.9302	0.1591	0.9803	0.3407	0.7613
S*I	0.5936	0.6829	0.7808	0.2476	0.2445	0.3709
N*F*C	0.0490	0.5795	0.9837	0.9277	0.4368	0.4486
N*F*S	0.7048	0.6199	0.6889	0.5262	0.4612	0.3494
N*C*S	0.9725	0.4232	0.0822	0.6986	0.7862	0.4164
F*C*S	0.6668	0.9070	0.2373	0.1875	0.9869	0.1543
N*F*I	0.9040	0.0192	0.0204	0.4843	0.8415	0.9559
N*C*I	0.5701	0.8040	0.8759	0.5699	0.4695	0.1835
F*C*I	0.3717	0.6829	0.7912	0.6624	0.6743	0.8467
N*S*I	0.6176	0.7152	0.1754	0.2221	0.5851	0.8684
F*S*I	0.7828	0.4663	0.0403	0.7604	0.0160	0.2542
C*S*I	0.1164	0.8724	0.7600	0.2221	0.4907	0.8252
N*F*C*S	0.9588	0.4401	0.6989	0.2611	0.9683	0.5349
N*F*C*I	0.3194	0.5895	0.0565	0.0243	0.3970	0.7300
N*F*S*I	1.0000	0.8267	0.2373	0.0233	0.1896	0.2960
N*C*S*I	0.1328	0.8609	0.8227	0.1619	0.5499	0.5532
F*C*S*I	0.5936	0.2069	0.8017	0.5811	0.6964	0.4086
N*F*C*S*I	0.2953	0.7481	0.1111	0.5050	0.9280	0.0699

	Percent reproductive node					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.3116 †	0.5128	0.5245	0.4487	0.3192	0.0368
F ‡	<.0001	0.6809	0.2868	0.2835	0.1686	0.2021
C £	<.0001	<.0001	<.0001	<.0001	0.0008	<.0001
S β	0.2915	0.0040	0.5380	0.0849	0.0060	0.0511
I ¥	0.7619	0.6069	0.4520	0.4488	0.5930	0.9204
N*F	0.4630	0.3969	0.4127	0.4186	0.3142	0.7100
N*C	0.7553	0.9576	0.5955	0.7997	0.7071	0.6980

F*C	0.0517	0.3520	0.2570	0.1014	0.2728	0.1663
N*S	0.0321	0.4695	0.9463	0.1757	0.2682	0.6039
F*S	0.2048	0.1448	0.5659	0.0467	0.1817	0.3314
C*S	0.0943	0.9425	0.8402	0.2234	0.4705	0.8348
N*I	0.7491	0.2057	0.9255	0.4949	0.8678	0.6587
F*I	0.9870	0.9641	0.4265	0.8475	0.8488	0.8082
C*I	0.4927	0.8419	0.0365	0.3821	0.8604	0.8756
S*I	0.7677	0.2870	0.9199	0.0713	0.8558	0.5651
N*F*C	0.2765	0.9554	0.1076	0.0705	0.1077	0.3186
N*F*S	0.6384	0.1840	0.3709	0.9864	0.3927	0.3056
N*C*S	0.1302	0.7835	0.0376	0.2618	0.9272	0.4686
F*C*S	0.7210	0.8860	0.1020	0.4449	0.4901	0.0818
N*F*I	0.6656	0.2290	0.0847	0.8497	0.9496	0.7083
N*C*I	0.8978	0.2827	0.2518	0.6510	0.1005	0.4013
F*C*I	0.3186	0.9804	0.4817	0.6593	0.8449	0.5248
N*S*I	0.5946	0.8316	0.5079	0.0906	0.2608	0.2095
F*S*I	0.1545	0.4495	0.5466	0.6842	0.1560	0.0688
C*S*I	0.0979	0.8652	0.6929	0.0393	0.2414	0.4206
N*F*C*S	0.8413	0.7580	0.6196	0.7023	0.4617	0.5677
N*F*C*I	0.4205	0.7707	0.1697	0.0387	0.6186	0.5710
N*F*S*I	0.4842	0.3739	0.4076	0.0149	0.0871	0.5810
N*C*S*I	0.2335	0.6285	0.8415	0.0587	0.5343	0.3543
F*C*S*I	0.2760	0.3224	0.2316	0.9771	0.5401	0.4852
N*F*C*S*I	0.5809	0.1843	0.4614	0.5718	0.7115	0.3767

	Total pod per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.5597 †	0.5973	0.4792	0.4224	0.2159	0.9104
F ‡	0.3095	0.9610	0.8332	0.4945	0.1010	0.6874
C £	0.0114	0.0016	<.0001	0.6969	<.0001	0.0518
S β	0.1966	0.2063	0.3310	0.9802	0.1625	0.6895
I ¥	0.9724	0.8459	0.4670	0.4299	0.6227	0.9701
N*F	0.4808	0.7869	0.1157	0.3143	0.0603	0.7729
N*C	0.7417	0.5091	0.4252	0.8891	0.0743	0.4920
F*C	0.6114	0.5415	0.7753	0.6234	0.6967	0.7466
N*S	0.4014	0.1371	0.0930	0.9761	0.8887	0.5131
F*S	0.1637	0.9023	0.1677	0.3860	0.3061	0.1026
C*S	0.2491	0.5105	0.1907	0.6438	0.3003	0.3709
N*I	0.9175	0.7521	0.4102	0.9221	0.5228	0.5614
F*I	0.8506	0.5720	0.0449	0.5228	0.3375	0.8018
C*I	0.5104	0.4110	0.1469	0.9553	0.3097	0.5672
S*I	0.9275	0.5913	0.4368	0.3597	0.1923	0.3911
N*F*C	0.5939	0.1720	0.3991	0.0309	0.7623	0.3361
N*F*S	0.3624	0.7226	0.3810	0.0574	0.7566	0.2826
N*C*S	0.4925	0.5401	0.2097	0.4561	0.3252	0.8796
F*C*S	0.1627	0.2869	0.1172	0.2490	0.3073	0.9287
N*F*I	0.9349	0.2908	0.1439	0.0044	0.1025	0.7829
N*C*I	0.3808	0.3426	0.4847	0.3009	0.3604	0.4984
F*C*I	0.6092	0.8137	0.9394	0.1431	0.2308	0.8118
N*S*I	0.5534	0.2698	0.9201	0.0793	0.8966	0.5066
F*S*I	0.2581	0.9662	0.0985	0.6739	0.2495	0.8489

C*S*I	0.2379	0.7852	0.9956	0.7913	0.5490	0.5653
N*F*C*S	0.3447	0.8595	0.4806	0.5450	0.5441	0.9001
N*F*C*I	0.1459	0.0762	0.5426	0.0665	0.8552	0.4715
N*F*S*I	0.5024	0.0392	0.1233	0.7954	0.7795	0.2432
N*C*S*I	0.3641	0.1740	0.5027	0.2565	0.3762	0.9885
F*C*S*I	0.4540	0.3201	0.1683	0.7182	0.0603	0.7109
N*F*C*S*I	0.1831	0.3077	0.8799	0.5144	0.3375	0.5374

	Main stem pod per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.1883 †	0.8245	0.1829	0.9340	0.4738	0.9575
F ‡	0.0980	0.2469	0.6861	0.5244	0.3688	0.7727
C £	<.0001	<.0001	0.3230	<.0001	0.0066	0.0444
S β	0.3782	0.6914	0.1500	0.3790	0.4566	0.7513
I ¥	0.7394	0.6813	0.1017	0.7843	0.1822	0.5976
N*F	0.8618	0.3719	0.5267	0.4272	0.1355	0.8428
N*C	0.8376	0.3132	0.9251	0.8826	0.0192	0.3919
F*C	0.5050	0.5536	0.9465	0.4569	0.7746	0.5976
N*S	0.0775	0.2308	0.0981	0.6632	0.7079	0.4976
F*S	0.6516	0.9548	0.5542	0.3273	0.8100	0.1873
C*S	0.3416	0.4018	0.4225	0.4833	0.0927	0.5352
N*I	0.3854	0.0914	0.7417	0.7081	0.8903	0.9078
F*I	0.4172	0.4617	0.0008	0.7296	0.2444	0.5865
C*I	0.5775	0.3214	0.2429	0.5268	0.2692	0.7589
S*I	0.6804	0.8005	0.3482	0.8854	0.1722	0.3252
N*F*C	0.0238	0.4372	0.6883	0.0319	0.7773	0.3952
N*F*S	0.4693	0.7688	0.5423	0.0844	0.3088	0.0965
N*C*S	0.8102	0.5791	0.9917	0.6271	0.4053	0.5851
F*C*S	0.0905	0.2281	0.6386	0.4027	0.2515	0.6186
N*F*I	0.6265	0.5400	0.9679	0.0464	0.0881	0.6300
N*C*I	0.6740	0.3067	0.7349	0.4991	0.2501	0.4121
F*C*I	0.5479	0.8138	0.9204	0.4128	0.0814	0.3618
N*S*I	0.4639	0.5131	0.8357	0.1320	0.2632	0.4963
F*S*I	0.7796	0.7401	0.3573	0.7135	0.7027	0.4008
C*S*I	0.5421	0.8218	0.7507	0.7733	0.4315	0.2640
N*F*C*S	0.0775	0.8325	0.3589	0.6632	0.7211	0.9126
N*F*C*I	0.0472	0.1377	0.6709	0.1027	0.2347	0.6867
N*F*S*I	0.2002	0.1168	0.0331	0.7568	0.4524	0.3282
N*C*S*I	0.2426	0.2832	0.6408	0.4169	0.9662	0.5768
F*C*S*I	0.4147	0.3522	0.4831	0.6502	0.1184	0.8919
N*F*C*S*I	0.1391	0.3181	0.3102	0.2983	0.1879	0.4664

	Total pods per plant					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.4575 †	0.6911	0.1681	0.1065	0.0534	0.2885
F ‡	0.0872	0.0907	0.8259	0.2234	0.1785	0.7248
C £	0.6580	0.1625	0.5857	<.0001	<.0001	0.4342
S β	0.0003	<.0001	0.1599	0.0319	0.0003	0.0162
I ¥	0.5053	0.9803	0.1890	0.2279	0.474	0.9099
N*F	0.8643	0.9882	0.0590	0.3746	0.0902	0.6886

N*C	0.6793	0.6269	0.3709	0.2236	0.5286	0.9719
F*C	0.7898	0.2513	0.8536	0.3063	0.6536	0.1861
N*S	0.1512	0.2179	0.5896	0.0816	0.7875	0.3888
F*S	0.0198	0.2308	0.5959	0.5870	0.5754	0.3551
C*S	0.1808	0.6874	0.2965	0.2926	0.4257	0.4163
N*I	0.8671	0.0695	0.1136	0.4221	0.7274	0.1433
F*I	0.7645	0.7689	0.0531	0.4621	0.4780	0.5096
C*I	0.3326	0.9527	0.2393	0.7048	0.3994	0.6476
S*I	0.8383	0.4523	0.5694	0.5648	0.4903	0.9103
N*F*C	0.0223	0.7371	0.2045	0.6030	0.9860	0.3457
N*F*S	0.5147	0.8569	0.8055	0.9431	0.0196	0.0813
N*C*S	0.9868	0.3063	0.0273	0.6439	0.8427	0.7398
F*C*S	0.9692	0.1269	0.6263	0.2748	0.7471	0.7895
N*F*I	0.9165	0.2443	0.0074	0.3666	0.7309	0.1846
N*C*I	0.5729	0.9037	0.3819	0.7719	0.7122	0.2306
F*C*I	0.1073	0.1465	0.5655	0.7065	0.2034	0.7568
N*S*I	0.8874	0.4627	0.2882	0.8365	0.6242	0.9560
F*S*I	0.4187	0.3650	0.9877	0.8833	0.1175	0.0706
C*S*I	0.1554	0.7689	0.7220	0.4276	0.3641	0.9129
N*F*C*S	0.5053	0.6622	0.6458	0.4748	0.2407	0.9742
N*F*C*I	0.4314	0.2072	0.1027	0.1214	0.2606	0.5988
N*F*S*I	0.3473	0.6766	0.8384	0.1661	0.2765	0.8015
N*C*S*I	0.8097	0.8241	0.7220	0.0382	0.6669	0.6765
F*C*S*I	0.3567	0.5839	0.6287	0.4723	0.8214	0.7703
N*F*C*S*I	0.2068	0.1632	0.0909	0.9858	0.9321	0.5217

	Total pods per reproductive node per plant					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.5669 †	0.4869	0.2539	0.0751	0.3745	0.351
F ‡	0.2605	0.7282	0.4446	0.5674	0.3050	0.5527
C £	0.0040	0.0067	<.0001	<.0001	<.0001	0.0005
S β	0.0011	0.0019	0.2462	0.2975	0.0006	0.2069
I ¥	0.1942	0.4726	0.1817	0.1732	0.8184	0.8210
N*F	0.6814	0.9674	0.0121	0.2220	0.0753	0.6419
N*C	0.9936	0.9336	0.1112	0.1302	0.9067	0.3894
F*C	0.9266	0.3301	0.34900	0.5340	0.8166	0.2850
N*S	0.3251	0.4502	0.6309	0.3142	0.9906	0.3333
F*S	0.1339	0.7178	0.1898	0.7913	0.9557	0.4272
C*S	0.0766	0.7047	0.1201	0.4793	0.2112	0.3667
N*I	0.9261	0.0688	0.1038	0.6813	0.9389	0.2566
F*I	0.3173	0.5189	0.0257	0.2477	0.2322	0.6195
C*I	0.5161	0.8429	0.3748	0.6210	0.6821	0.7595
S*I	0.4115	0.2058	0.3006	0.8927	0.8129	0.5109
N*F*C	0.0209	0.4035	0.0210	0.3985	0.5566	0.3213
N*F*S	0.4323	0.9126	0.9501	0.5953	0.0100	0.0747
N*C*S	0.8179	0.2546	0.0477	0.8203	0.7671	0.4387
F*C*S	0.9540	0.0779	0.6938	0.6193	0.3888	0.6758
N*F*I	0.8943	0.9544	0.0232	0.2341	0.6453	0.0664
N*C*I	0.4639	0.6444	0.2197	0.7998	0.2514	0.3903
F*C*I	0.1037	0.1013	0.4240	0.6548	0.1022	0.7118
N*S*I	0.8274	0.4034	0.5542	0.4572	0.1433	0.8734

F*S*I	0.2733	0.3100	0.1560	0.4655	0.6456	0.0380
C*S*I	0.3716	0.6923	0.3721	0.7785	0.2683	0.6085
N*F*C*S	0.3424	0.8736	0.6565	0.8271	0.1059	0.6730
N*F*C*I	0.6785	0.2080	0.2691	0.5910	0.2455	0.2227
N*F*S*I	0.0728	0.4573	0.1984	0.8445	0.6934	0.7265
N*C*S*I	0.3407	0.7269	0.7710	0.0152	0.2255	0.8240
F*C*S*I	0.3645	0.9730	0.9589	0.3333	0.3778	0.2726
N*F*C*S*I	0.1810	0.1335	0.3261	0.5611	0.5740	0.7527

	Main stem pods per plant					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.1373 †	0.3181	0.2493	0.1976	0.0231	0.1915
F ‡	0.1317	0.0596	0.7214	0.2293	0.1263	0.9225
C £	<.0001	<.0001	0.0006	0.6795	0.1292	0.0024
S β	0.0055	<.0001	0.3143	0.1102	0.0004	0.0145
I ¥	0.7005	0.5799	0.3627	0.4439	0.9233	0.8763
N*F	0.1263	0.5157	0.1552	0.3664	0.0526	0.6215
N*C	0.9737	0.2366	0.5650	0.3503	0.7335	0.9256
F*C	0.3517	0.8204	0.9586	0.1919	0.4001	0.2230
N*S	0.3085	0.1868	0.4491	0.1577	0.7731	0.4606
F*S	0.0178	0.0588	0.1715	0.6426	0.6604	0.3267
C*S	0.5078	0.6391	0.4533	0.1967	0.2983	0.3723
N*I	0.2115	0.7598	0.1673	0.6919	0.5070	0.3560
F*I	0.4848	0.7278	0.5090	0.6325	0.4331	0.5016
C*I	0.5125	0.6696	0.0815	0.9910	0.3198	0.4606
S*I	0.5078	0.8204	0.2754	0.9548	0.1418	0.8336
N*F*C	0.1373	0.1660	0.7059	0.5545	0.9614	0.2799
N*F*S	0.2063	0.8916	0.8853	0.9842	0.1106	0.1297
N*C*S	0.5125	0.1696	0.0979	0.9684	0.8688	0.9442
F*C*S	0.8403	0.6434	0.8689	0.4540	0.7113	0.4773
N*F*I	0.8061	0.0386	0.0324	0.7214	0.8641	0.2410
N*C*I	0.8806	0.7876	0.5526	0.4608	0.8785	0.2364
F*C*I	0.4318	0.4555	0.7862	0.6146	0.4767	0.7764
N*S*I	0.9328	0.9686	0.2401	0.9436	0.8250	0.9442
F*S*I	0.9212	0.4555	0.2250	0.8606	0.1339	0.1241
C*S*I	0.1937	0.6740	0.5838	0.3923	0.1556	0.4893
N*F*C*S	0.8517	0.1405	0.6602	0.4290	0.8582	0.7527
N*F*C*I	0.4985	0.5717	0.0419	0.0446	0.8875	0.3912
N*F*S*I	0.0744	0.8820	0.7025	0.1071	0.5725	0.8610
N*C*S*I	0.8460	0.7278	0.7474	0.0449	0.6851	0.8886
F*C*S*I	0.3051	0.1089	0.6770	0.4241	0.7238	0.7586
N*F*C*S*I	0.1354	0.4664	0.2918	0.6067	0.8909	0.4262

	Branch pods per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.5135 †	0.4614	0.5875	0.1048	0.2761	0.7412
F ‡	0.7555	0.1955	0.8652	0.6238	0.1337	0.6685
C £	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S β	0.0008	0.0561	0.8519	0.1795	0.0054	0.1727
I ¥	0.7125	0.3901	0.3436	0.1945	0.498	0.3632

N*F	0.1339	0.5754	0.0343	0.3408	0.2155	0.7484
N*C	0.3878	0.9671	0.0983	0.5878	0.8645	0.8731
F*C	0.9521	0.6533	0.5197	0.9154	0.7809	0.9031
N*S	0.4330	0.1641	0.3744	0.4478	0.5485	0.7127
F*S	0.0523	0.7635	0.0705	0.7284	0.2062	0.1299
C*S	0.0013	0.8078	0.1673	0.9200	0.8095	0.3235
N*I	0.1906	0.1511	0.2650	0.7027	0.4220	0.1488
F*I	0.4775	0.8496	0.2987	0.3920	0.8413	0.7603
C*I	0.6334	0.7107	0.2545	0.3765	0.7274	0.4406
S*I	0.7125	0.4739	0.8719	0.0764	0.6143	0.7388
N*F*C	0.0466	0.0969	0.0310	0.1776	0.4569	0.4387
N*F*S	0.4705	0.3065	0.4117	0.1473	0.1291	0.7845
N*C*S	0.3487	0.6181	0.0170	0.3858	0.5559	0.5990
F*C*S	0.7339	0.5642	0.0201	0.2273	0.7554	0.5580
N*F*I	0.4363	0.2040	0.0051	0.0018	0.5241	0.8781
N*C*I	0.0349	0.5642	0.3881	0.2295	0.8820	0.8458
F*C*I	0.0905	0.4664	0.7730	0.0555	0.9497	0.3616
N*S*I	0.8977	0.1899	0.9189	0.1397	0.1731	0.6987
F*S*I	0.0915	0.7509	0.0609	0.7327	0.0374	0.3666
C*S*I	0.1741	0.4320	0.6593	0.9017	0.9497	0.6166
N*F*C*S	0.5546	0.9343	0.9594	0.5227	0.2049	0.6548
N*F*C*I	0.9567	0.1104	0.5701	0.1458	0.1309	0.3454
N*F*S*I	0.6539	0.0405	0.9256	0.9382	0.2307	0.3054
N*C*S*I	0.8931	0.1941	0.5307	0.2273	0.1766	0.3990
F*C*S*I	0.7598	0.4392	0.0983	0.9428	0.2437	0.3069
N*F*C*S*I	0.6133	0.4589	0.0856	0.8206	0.9704	0.8359

	Branch pods per plant					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	-------------------------------------Pr > F-------------------------------------					
N §	0.9909 †	0.3131	0.1768	0.1195	0.1540	0.5323
F ‡	0.1364	0.2441	0.9423	0.3937	0.3053	0.5597
C £	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001
S β	0.0004	0.0029	0.1299	0.0256	0.0015	0.0451
I ¥	0.4622	0.8004	0.1498	0.1530	0.3298	0.6917
N*F	0.3505	0.7249	0.0476	0.5593	0.1992	0.8138
N*C	0.5379	0.9988	0.3090	0.2217	0.2666	0.9719
F*C	0.7535	0.1858	0.7260	0.7621	0.8877	0.2151
N*S	0.1501	0.3822	0.7838	0.0990	0.5739	0.3842
F*S	0.0738	0.5951	0.8014	0.6317	0.5859	0.4703
C*S	0.0110	0.7909	0.2616	0.7009	0.5999	0.5481
N*I	0.4726	0.0344	0.1328	0.2684	0.9171	0.0654
F*I	0.3139	0.5844	0.0080	0.3920	0.5799	0.5854
C*I	0.3194	0.7694	0.6046	0.4446	0.5359	0.9424
S*I	0.8416	0.4079	0.9635	0.2691	0.9146	0.6480
N*F*C	0.0164	0.2580	0.0727	0.7981	0.9565	0.5188
N*F*S	0.9818	0.7671	0.5966	0.9047	0.0156	0.0821
N*C*S	0.5917	0.5613	0.0202	0.3701	0.6997	0.4650
F*C*S	0.9226	0.0931	0.3443	0.2228	0.8079	0.7859
N*F*I	0.7234	0.6949	0.0066	0.1723	0.6937	0.1935
N*C*I	0.3222	0.7718	0.3329	0.6722	0.6593	0.3008
F*C*I	0.0592	0.1486	0.4629	0.14400	0.1589	0.3554

N*S*I	0.7753	0.3465	0.4224	0.7431	0.4015	0.8518
F*S*I	0.2396	0.4491	0.3037	0.9519	0.1727	0.0656
C*S*I	0.2308	0.5592	0.8879	0.6496	0.6499	0.5759
N*F*C*S	0.3744	0.8317	0.6864	0.7032	0.1140	0.7725
N*F*C*I	0.4867	0.1951	0.2984	0.6859	0.1252	0.9413
N*F*S*I	0.9545	0.5488	0.5128	0.5303	0.2180	0.7652
N*C*S*I	0.5996	0.6475	0.7432	0.1288	0.3878	0.3298
F*C*S*I	0.5267	0.8877	0.2522	0.7056	0.9097	0.3600
N*F*C*S*I	0.4251	0.1673	0.0514	0.5002	0.8371	0.7117

	Total seed number per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.7848 †	0.54400	0.8311	0.0849	0.2237	0.9732
F ‡	0.2606	0.7908	0.7680	0.5185	0.1957	0.8499
C £	0.4337	0.0363	0.0006	0.6217	<.0001	0.5715
S β	0.0669	0.1305	0.6156	0.7953	0.2455	0.4760
I ¥	0.4320	0.6602	0.4676	0.9508	0.3463	0.9981
N*F	0.3734	0.4836	0.1461	0.2445	0.1760	0.7353
N*C	0.5799	0.5130	0.4045	0.9933	0.1965	0.5933
F*C	0.5489	0.5371	0.7801	0.7600	0.4694	0.9997
N*S	0.4524	0.6024	0.2819	0.5696	0.4599	0.4840
F*S	0.2192	0.5197	0.1712	0.5853	0.1875	0.0636
C*S	0.3285	0.6253	0.3454	0.6246	0.5908	0.4497
N*I	0.6393	0.7631	0.6491	0.2551	0.6622	0.6108
F*I	0.8928	0.5160	0.0908	0.9875	0.7403	0.8307
C*I	0.5750	0.4345	0.2274	0.8025	0.7437	0.5532
S*I	0.8667	0.5864	0.6887	0.5535	0.1521	0.4908
N*F*C	0.9672	0.1349	0.5081	0.2513	0.9991	0.2818
N*F*S	0.1752	0.3949	0.2399	0.8901	0.6173	0.2275
N*C*S	0.4957	0.4427	0.1034	0.6231	0.2934	0.6709
F*C*S	0.3673	0.1910	0.1307	0.1035	0.2764	0.6645
N*F*I	0.9248	0.0626	0.1314	0.0578	0.1817	0.5281
N*C*I	0.2150	0.3001	0.7688	0.2700	0.5188	0.6203
F*C*I	0.6778	0.7499	0.9228	0.4654	0.3901	0.7297
N*S*I	0.6352	0.5572	0.6105	0.1732	0.6348	0.6184
F*S*I	0.3635	0.9861	0.0943	0.5875	0.1205	0.6719
C*S*I	0.1571	0.3710	0.8887	0.3916	0.6380	0.6055
N*F*C*S	0.9741	0.9166	0.6461	0.9266	0.4411	0.6189
N*F*C*I	0.2284	0.0612	0.6378	0.0829	0.8213	0.4661
N*F*S*I	0.4813	0.0655	0.2306	0.4090	0.9615	0.1576
N*C*S*I	0.3613	0.1685	0.6718	0.1726	0.5203	0.8814
F*C*S*I	0.4822	0.4573	0.4968	0.2466	0.0775	0.6150
N*F*C*S*I	0.2600	0.6594	0.8270	0.4912	0.3913	0.4289

	Total seed per pod					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.4770 †	0.9759	0.1109	0.0718	0.7710	0.8754
F ‡	0.4100	0.2800	0.7802	0.9866	0.3108	0.4037
C £	<.0001	0.0005	<.0001	0.8735	0.0354	<.0001
S β	0.0670	0.3243	0.1906	0.6638	0.4206	0.2528

I ¥	0.0275	0.4419	0.6945	0.4056	0.1773	0.9241
N*F	0.5173	0.0080	0.8829	0.5381	0.1059	0.5950
N*C	0.6964	0.9504	0.6046	0.9964	0.1077	0.7493
F*C	0.4801	0.8857	0.7142	0.2437	0.1600	0.3491
N*S	0.6935	0.0029	0.0085	0.3467	0.1033	0.7997
F*S	0.7637	0.1099	0.9545	0.8632	0.3829	0.3770
C*S	0.6958	0.5419	0.1501	0.6251	0.3014	0.6675
N*I	0.1696	0.0440	0.1756	0.0910	0.7511	0.6658
F*I	0.9776	0.8241	0.0990	0.4071	0.0591	0.8639
C*I	0.5872	0.9477	0.4494	0.8805	0.0219	0.9713
S*I	0.5561	0.8977	0.1532	0.906	0.6960	0.9165
N*F*C	0.0654	0.9069	0.5361	0.3693	0.0628	0.4562
N*F*S	0.3657	0.1181	0.3648	0.0270	0.3796	0.5656
N*C*S	0.8594	0.6534	0.2214	0.1399	0.4339	0.3430
F*C*S	0.1665	0.4561	0.8756	0.3138	0.7598	0.2529
N*F*I	0.9451	0.0079	0.9845	0.3139	0.4107	0.1671
N*C*I	0.2553	0.9852	0.1648	0.9092	0.3541	0.3773
F*C*I	0.4790	0.6641	0.3080	0.3984	0.3573	0.6881
N*S*I	0.8373	0.1384	0.0176	0.9344	0.1084	0.6250
F*S*I	0.5912	0.7283	0.6511	0.2721	0.0971	0.0150
C*S*I	0.7850	0.1007	0.9442	0.1904	0.4649	0.9779
N*F*C*S	0.0074	0.4503	0.3057	0.4080	0.4825	0.2031
N*F*C*I	0.4705	0.8706	0.5539	0.7473	0.6957	0.9373
N*F*S*I	0.6785	0.7240	0.1274	0.1131	0.6488	0.2304
N*C*S*I	0.7809	0.5013	0.3644	0.6092	0.1863	0.5889
F*C*S*I	0.9120	0.5267	0.0003	0.2407	0.3338	0.7820
N*F*C*S*I	0.7003	0.2065	0.7967	0.8595	0.9903	0.3378

	Main stem seed number per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	----------------------------------Pr > F----------------------------------					
N §	0.4075 †	0.9087	0.4376	0.2179	0.4047	0.8394
F ‡	0.1013	0.5399	0.4421	0.6957	0.4204	0.8998
C £	<.0001	<.0001	0.1876	0.0001	0.0014	0.0005
S β	0.8827	0.4424	0.2799	0.5391	0.5404	0.7592
I ¥	0.1614	0.9758	0.1032	0.8045	0.1310	0.6988
N*F	0.9592	0.9291	0.6393	0.2290	0.3004	0.7557
N*C	0.8705	0.1778	0.9399	0.5096	0.1087	0.4954
F*C	0.5182	0.3764	0.7655	0.6177	0.7537	0.9325
N*S	0.0905	0.7378	0.3078	0.9163	0.8050	0.5624
F*S	0.9362	0.9934	0.5626	0.9770	0.5523	0.1040
C*S	0.2843	0.3421	0.6570	0.4987	0.1211	0.6303
N*I	0.8267	0.2240	0.8045	0.7341	0.9817	0.9109
F*I	0.5484	0.5160	0.0010	0.6108	0.4365	0.6905
C*I	0.7555	0.3467	0.3121	0.3913	0.5034	0.6789
S*I	0.6035	0.7199	0.5814	0.6430	0.0996	0.4254
N*F*C	0.1122	0.4600	0.4522	0.2043	0.5075	0.3299
N*F*S	0.1778	0.9846	0.3158	0.6660	0.4242	0.0809
N*C*S	0.8147	0.2696	0.8476	0.3235	0.3572	0.4423
F*C*S	0.2137	0.4024	0.5616	0.1610	0.1668	0.3558
N*F*I	0.3893	0.1915	0.9755	0.2193	0.0911	0.3285
N*C*I	0.9577	0.2751	0.9534	0.4910	0.4569	0.5156

F*C*I	0.6905	0.8236	0.6974	0.6785	0.0846	0.3208
N*S*I	0.3820	0.8971	0.4549	0.4036	0.6103	0.6066
F*S*I	0.9546	0.5423	0.2992	0.8900	0.7748	0.9914
C*S*I	0.4557	0.5606	0.9951	0.4940	0.5243	0.3294
N*F*C*S	0.4442	0.9451	0.5210	0.8649	0.9817	0.7514
N*F*C*I	0.1431	0.2132	0.9473	0.3560	0.2126	0.6632
N*F*S*I	0.2531	0.1422	0.0382	0.3741	0.2892	0.1592
N*C*S*I	0.2061	0.1121	0.7191	0.4933	0.8753	0.8350
F*C*S*I	0.5034	0.6486	0.8093	0.2963	0.3778	0.9355
N*F*C*S*I	0.3228	0.7185	0.3683	0.5819	0.1825	0.4125

	Branch seed number per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.5344 †	0.3289	0.5730	0.0867	0.3507	0.6780
F ‡	0.8485	0.2329	0.6824	0.4310	0.2835	0.8221
C £	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S β	0.0008	0.0608	0.6728	0.0520	0.0248	0.2612
I ¥	0.6332	0.4418	0.4833	0.4931	0.8828	0.5226
N*F	0.0990	0.1679	0.0448	0.7251	0.3515	0.7967
N*C	0.4397	0.7067	0.1179	0.1660	0.7880	0.9291
F*C	0.8344	0.9193	0.3917	0.7629	0.4639	0.8870
N*S	0.3477	0.5717	0.4961	0.2295	0.4117	0.5206
F*S	0.0383	0.2362	0.0837	0.1919	0.1887	0.1176
C*S	0.0021	0.8320	0.2541	0.8258	0.4397	0.3504
N*I	0.2595	0.0518	0.2690	0.0345	0.5145	0.1778
F*I	0.5740	0.6630	0.2674	0.2600	0.7682	0.8624
C*I	0.5567	0.7354	0.3540	0.2275	0.8471	0.5016
S*I	0.6930	0.5616	0.9650	0.6178	0.6655	0.8003
N*F*C	0.0414	0.0605	0.0396	0.8692	0.5103	0.3951
N*F*S	0.5294	0.1268	0.3795	0.2054	0.1333	0.8747
N*C*S	0.3650	0.9041	0.0087	0.3766	0.5451	0.7584
F*C*S	0.9568	0.1542	0.0479	0.2678	0.8446	0.5840
N*F*I	0.3259	0.0569	0.0093	0.0310	0.8055	0.8538
N*C*I	0.0336	0.5278	0.5529	0.1928	0.8471	0.9576
F*C*I	0.2041	0.4003	0.7647	0.3424	0.6272	0.3866
N*S*I	0.7470	0.3557	0.9993	0.1007	0.2364	0.7751
F*S*I	0.0910	0.4991	0.0843	0.2862	0.0131	0.3232
C*S*I	0.1236	0.3352	0.7976	0.4882	0.9625	0.6564
N*F*C*S	0.3348	0.9109	0.9695	0.8941	0.2585	0.5389
N*F*C*I	0.8465	0.0464	0.4493	0.0173	0.1204	0.3432
N*F*S*I	0.7844	0.0926	0.6796	0.8630	0.2632	0.3665
N*C*S*I	0.9506	0.4991	0.7505	0.0502	0.2806	0.4908
F*C*S*I	0.7160	0.4050	0.1359	0.4948	0.0926	0.3090
N*F*C*S*I	0.4850	0.6973	0.1413	0.5795	0.9277	0.6519

	Total seed weight per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.7212 †	0.5280	0.4992	0.1284	0.1488	0.6749
F ‡	0.5716	0.6728	0.3810	0.1675	0.2859	0.5392
C £	0.0018	0.0615	0.9637	0.0063	0.5170	0.0905

S β	0.0811	0.1430	0.3372	0.8377	0.3806	0.5050
I ¥	0.4909	0.8781	0.7108	0.4793	0.2333	0.8358
N*F	0.4558	0.7337	0.0584	0.1432	0.2555	0.8635
N*C	0.6651	0.3611	0.6166	0.9348	0.0347	0.8467
F*C	0.9279	0.5040	0.6212	0.7733	0.2491	0.7322
N*S	0.5587	0.4852	0.2005	0.4968	0.5631	0.3224
F*S	0.2312	0.7225	0.1982	0.4407	0.2786	0.0367
C*S	0.5845	0.4805	0.5284	0.4389	0.5364	0.6064
N*I	0.5976	0.9731	0.8810	0.3463	0.5024	0.5097
F*I	0.9886	0.4014	0.0349	0.7229	0.8439	0.5766
C*I	0.4968	0.2853	0.2708	0.8898	0.3798	0.3991
S*I	0.9962	0.6837	0.4397	0.5358	0.2657	0.4768
N*F*C	0.7499	0.1491	0.8148	0.1195	0.9859	0.5042
N*F*S	0.2239	0.6351	0.0906	0.3997	0.8735	0.2042
N*C*S	0.3404	0.2820	0.1810	0.9401	0.3917	0.9278
F*C*S	0.9204	0.3308	0.1749	0.0655	0.2775	0.7527
N*F*I	0.9355	0.1042	0.1669	0.0448	0.3473	0.4696
N*C*I	0.2348	0.2534	0.9481	0.2772	0.6133	0.6152
F*C*I	0.6310	0.7114	0.8401	0.3534	0.4497	0.8635
N*S*I	0.8453	0.4355	0.7597	0.1588	0.9621	0.8320
F*S*I	0.5150	0.8488	0.1281	0.9495	0.4258	0.5280
C*S*I	0.2067	0.2787	0.9896	0.4254	0.2202	0.4341
N*F*C*S	0.8602	0.9077	0.3638	0.6494	0.5636	0.5689
N*F*C*I	0.2169	0.0910	0.7697	0.0668	0.5721	0.4530
N*F*S*I	0.3749	0.1027	0.1188	0.4572	0.8735	0.2853
N*C*S*I	0.2906	0.1138	0.6963	0.1594	0.5262	0.5193
F*C*S*I	0.5780	0.5087	0.4870	0.1665	0.1469	0.5086
N*F*C*S*I	0.4849	0.7003	0.8198	0.0858	0.5958	0.6626

	Main stem seed weight per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.9582 †	0.6729	0.2066	0.2488	0.2719	0.4528
F ‡	0.3603	0.6566	0.2099	0.5084	0.6488	0.5955
C £	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S β	0.9373	0.6405	0.1168	0.3172	0.3562	0.7961
I ¥	0.2565	0.7740	0.2597	0.8111	0.0989	0.9315
N*F	0.9582	0.8703	0.2338	0.1442	0.4618	0.7842
N*C	1.0000	0.1778	0.5936	0.4913	0.0284	0.7807
F*C	0.8957	0.4548	0.9780	0.7653	0.5306	0.7061
N*S	0.0970	0.7913	0.3000	0.6853	0.9612	0.3464
F*S	0.7531	0.8969	0.5561	0.9670	0.8221	0.0625
C*S	0.2206	0.3486	0.8974	0.3506	0.0880	0.9724
N*I	0.8236	0.1607	0.6720	0.8284	0.8498	0.8669
F*I	0.6466	0.3602	0.0006	0.9750	0.6178	0.3746
C*I	0.5734	0.1850	0.4566	0.6612	0.3012	0.4662
S*I	0.9061	0.9865	0.3492	0.7147	0.1769	0.4641
N*F*C	0.0498	0.5179	0.2635	0.0900	0.4766	0.6038
N*F*S	0.2731	0.9327	0.0992	0.8408	0.3510	0.0791
N*C*S	0.5298	0.1962	0.8901	0.5727	0.6271	0.7864
F*C*S	0.4962	0.4154	0.5936	0.1063	0.1766	0.5310
N*F*I	0.4403	0.2243	0.8828	0.1902	0.304	0.2616

N*C*I	0.9269	0.2243	0.8828	0.5941	0.5194	0.6230
F*C*I	0.7831	0.7826	0.8466	0.5486	0.1675	0.4813
N*S*I	0.9895	0.6894	0.5021	0.3583	0.4001	0.8660
F*S*I	0.7831	0.5473	0.4622	0.8185	0.4600	0.7689
C*S*I	0.3954	0.4753	0.8974	0.5726	0.2374	0.2164
N*F*C*S	0.5298	0.9416	0.2374	0.5062	0.8649	0.6763
N*F*C*I	0.1105	0.2995	0.8394	0.3415	0.3802	0.5947
N*F*S*I	0.1800	0.2893	0.0135	0.5129	0.4612	0.3776
N*C*S*I	0.1885	0.1196	0.6520	0.5610	0.9911	0.7485
F*C*S*I	0.4879	0.7061	0.7127	0.2934	0.3890	0.7304
N*F*C*S*I	0.5213	0.6812	0.1848	0.1362	0.3301	0.7317
	Branch seed weight per m^2					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.5595 †	0.4861	0.6775	0.3018	0.3359	0.7015
F ‡	0.8547	0.1573	0.9805	0.0898	0.2491	0.6087
C £	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
S β	0.0013	0.0232	0.7690	0.0165	0.0120	0.2502
I ¥	0.8004	0.4954	0.4204	0.2862	0.8765	0.5027
N*F	0.1534	0.3745	0.0469	0.7766	0.3591	0.9264
N*C	0.4285	0.9763	0.1022	0.1231	0.5042	0.9614
F*C	0.7339	0.7329	0.3732	0.9735	0.2813	0.8949
N*S	0.2486	0.3007	0.3003	0.4988	0.3840	0.5068
F*S	0.0774	0.3825	0.1022	0.1118	0.1438	0.0977
C*S	0.0101	0.8703	0.3117	0.8600	0.2476	0.2316
N*I	0.2088	0.0571	0.3998	0.1062	0.3985	0.1937
F*I	0.5595	0.6456	0.4418	0.4034	0.7585	0.7636
C*I	0.6194	0.7107	0.2783	0.2408	0.9036	0.4812
S*I	0.8821	0.4325	0.8352	0.5329	0.9197	0.7094
N*F*C	0.0420	0.0453	0.0567	0.9931	0.3888	0.5047
N*F*S	0.4387	0.2939	0.3175	0.1520	0.1564	0.8400
N*C*S	0.3614	0.6670	0.0083	0.1990	0.4383	0.7743
F*C*S	0.4701	0.3906	0.0665	0.4133	0.9560	0.6856
N*F*I	0.2416	0.1029	0.0063	0.0721	0.8189	0.7335
N*C*I	0.0235	0.5048	0.7504	0.1899	0.9934	0.7555
F*C*I	0.2151	0.2742	0.9026	0.40500	0.6039	0.3673
N*S*I	0.7339	0.3076	0.7504	0.2096	0.2595	0.8383
F*S*I	0.1220	0.6778	0.0598	0.7488	0.0298	0.3186
C*S*I	0.2348	0.2261	0.8448	0.5375	0.6163	0.6809
N*F*C*S	0.2486	0.7441	0.8929	0.7366	0.2543	0.5381
N*F*C*I	0.8959	0.0468	0.4135	0.0344	0.0474	0.3980
N*F*S*I	0.8684	0.0649	0.6865	0.7501	0.2400	0.3317
N*C*S*I	0.8547	0.2742	0.8929	0.0564	0.3013	0.3269
F*C*S*I	0.9236	0.4154	0.0757	0.3498	0.2042	0.3290
N*F*C*S*I	0.6694	0.8238	0.1814	0.4272	0.7136	0.6684
	Seed size (seed per kg)					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.0808 †	0.9644	0.1401	0.1883	0.9873	0.2234
F ‡	0.0945	0.3910	0.0623	0.0898	0.2461	0.9161

C £	<.0001	<.0001	<.0001	<.0001	<.0001	0.0005
S β	0.7564	0.7687	0.1229	0.4298	0.7202	0.5556
I ¥	0.5166	0.4127	0.2286	0.0740	0.6294	0.3021
N*F	0.4678	0.4049	0.0594	0.8232	0.2479	0.1987
N*C	0.9628	0.5168	0.2820	0.5658	0.0031	0.2612
F*C	0.1040	0.8513	0.4758	0.1728	0.1480	0.3102
N*S	0.5387	0.3874	0.8694	0.8996	0.6634	0.2663
F*S	0.9410	0.4708	0.6746	0.2831	0.9438	0.2548
C*S	0.3501	0.3182	0.2722	0.6752	0.6035	0.3168
N*I	0.9324	0.4317	0.7990	0.4516	0.3463	0.4251
F*I	0.6817	0.4368	0.1738	0.8468	0.6766	0.2427
C*I	0.5997	0.3202	0.7693	0.9015	0.1636	0.2774
S*I	0.4610	0.7641	0.1997	0.6129	0.1167	0.4735
N*F*C	0.3720	0.8618	0.2808	0.6560	0.9385	0.2163
N*F*S	0.7516	0.0988	0.0839	0.0390	0.2868	0.4192
N*C*S	0.6948	0.1459	0.1775	0.1011	0.5016	0.2328
F*C*S	0.1299	0.2291	0.8404	0.7882	0.3910	0.2823
N*F*I	0.3802	0.5780	0.3769	0.4390	0.0619	0.3697
N*C*I	0.7743	0.8358	0.3727	0.3440	0.9484	0.5266
F*C*I	0.9486	0.5131	0.5134	0.3682	0.8732	0.3455
N*S*I	0.1217	0.2144	0.3570	0.6849	0.0817	0.2598
F*S*I	0.6102	0.3995	0.3449	0.0794	0.0425	0.3563
C*S*I	0.8892	0.4797	0.9857	0.3847	0.0079	0.3060
N*F*C*S	0.5633	0.9423	0.1774	0.6764	0.4516	0.3872
N*F*C*I	0.7455	0.4277	0.2588	0.4948	0.2808	0.3602
N*F*S*I	0.6830	0.3018	0.1607	0.3003	0.4787	0.2901
N*C*S*I	0.8542	0.3080	0.6987	0.3853	0.6466	0.1874
F*C*S*I	0.6389	0.8068	0.5914	0.9141	0.8696	0.3456
N*F*C*S*I	0.4409	0.7524	0.2479	0.2554	0.2546	0.3170

	Total dry matter					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	--------------------------------------Pr > F--------------------------------------					
N §	0.8101 †	0.4605	0.8205	0.1075	0.0259	0.7372
F ‡	0.1146	0.5557	0.5011	0.0246	0.0539	0.2397
C £	0.1630	0.6166	0.2158	0.5831	0.9694	0.5630
S β	0.0628	0.2792	0.2806	0.5831	0.5627	0.6282
I ¥	0.5028	0.8430	0.3827	0.2399	0.3394	0.7177
N*F	0.5791	0.7866	0.2220	0.3893	0.4491	0.6775
N*C	0.5943	0.2827	0.4969	0.6133	0.4961	0.9491
F*C	0.7718	0.9871	0.9826	0.8376	0.6889	0.7894
N*S	0.5642	0.1604	0.0250	0.8821	0.9558	0.4518
F*S	0.1458	0.6598	0.1449	0.4889	0.9490	0.0187
C*S	0.5240	0.6893	0.3390	0.8787	0.4025	0.3831
N*I	0.6848	0.8147	0.7919	0.9756	0.3288	0.8519
F*I	0.9230	0.4508	0.0053	0.8139	0.7917	0.9228
C*I	0.6409	0.5858	0.5603	0.5307	0.3907	0.7515
S*I	0.9890	0.7897	0.3128	0.6885	0.3104	0.5741
N*F*C	0.7424	0.1435	0.8864	0.3869	0.2794	0.7283
N*F*S	0.2057	0.5290	0.1260	0.3775	0.3247	0.1684
N*C*S	0.2872	0.3143	0.2633	0.4569	0.1731	0.8797
F*C*S	0.6768	0.4178	0.5716	0.0447	0.9456	0.4200

N*F*I	0.9669	0.4341	0.0833	0.0170	0.1591	0.9642
N*C*I	0.2038	0.5775	0.5762	0.4648	0.3436	0.3508
F*C*I	0.5348	0.9067	0.7458	0.3199	0.3436	0.7019
N*S*I	0.8662	0.3359	0.9584	0.2416	0.9864	0.5239
F*S*I	0.6252	0.8907	0.1688	0.6473	0.1507	0.6034
C*S*I	0.2386	0.4155	0.7765	0.7306	0.9864	0.6793
N*F*C*S	0.9098	0.9678	0.2972	0.7339	0.8479	0.7479
N*F*C*I	0.2077	0.0600	0.8520	0.0369	0.0919	0.3806
N*F*S*I	0.5421	0.0515	0.2747	0.8856	0.6124	0.2324
N*C*S*I	0.4354	0.0925	0.6275	0.3157	0.3309	0.7641
F*C*S*I	0.7718	0.6745	0.4760	0.6012	0.1174	0.8630
N*F*C*S*I	0.5133	0.2863	0.7559	0.3055	0.8313	0.4405

	Harvest index					
	MTH12	PTR12	SUF12	WAR13	PTR13	SUF13
Source	------------------------------------Pr > F------------------------------------					
N §	0.0076 †	0.5090	0.1699	0.8531	0.3335	0.6684
F ‡	0.0019	0.5170	0.5315	0.3068	0.2988	0.1876
C £	<.0001	<.0001	0.0116	<.0001	0.4679	<.0001
S β	0.8480	0.2811	0.7484	0.6345	0.7188	0.5890
I ¥	0.7536	0.7809	0.2373	0.4534	0.9449	0.6012
N*F	0.2464	0.0716	0.0989	0.1239	0.6452	0.0930
N*C	0.9560	0.5590	0.6849	0.6940	0.0934	0.5818
F*C	0.5779	0.0707	0.2119	0.8573	0.0261	0.6457
N*S	0.8668	0.0703	0.0155	0.1990	0.5954	0.2484
F*S	0.6420	0.7959	0.6704	0.4069	0.1389	0.4439
C*S	0.9389	0.2580	0.3926	0.1752	0.5249	0.2541
N*I	0.3460	0.5515	0.9013	0.0755	0.9406	0.1774
F*I	0.7902	0.9529	0.1263	0.2998	0.9759	0.2722
C*I	0.4073	0.0557	0.0993	0.1332	0.8894	0.0517
S*I	0.9205	0.4724	0.6313	0.4931	0.7296	0.4390
N*F*C	0.9915	0.9708	0.6301	0.1388	0.1124	0.3229
N*F*S	0.8069	0.6175	0.6683	0.7708	0.1384	0.9577
N*C*S	0.9342	0.4572	0.7079	0.2675	0.3554	0.9576
F*C*S	0.3510	0.3725	0.0457	0.7650	0.1048	0.1128
N*F*I	0.5099	0.0062	0.3009	0.6356	0.4285	0.0474
N*C*I	0.8379	0.0990	0.1183	0.3109	0.5663	0.2354
F*C*I	0.4856	0.1448	0.2778	0.7804	0.9267	0.3840
N*S*I	0.9207	0.9090	0.6135	0.5022	0.9602	0.1393
F*S*I	0.3164	0.8930	0.5679	0.4554	0.2830	0.7038
C*S*I	0.3414	0.6591	0.3424	0.3102	0.0499	0.1377
N*F*C*S	0.6703	0.9704	0.6642	0.7204	0.5307	0.6215
N*F*C*I	0.6050	0.8926	0.9365	0.8178	0.1035	0.6687
N*F*S*I	0.1785	0.9487	0.1213	0.2211	0.5054	0.7148
N*C*S*I	0.1298	0.9396	0.8374	0.4446	0.8375	0.5739
F*C*S*I	0.2779	0.2988	0.9672	0.0354	0.8753	0.0981
N*F*C*S*I	0.4988	0.2080	0.8619	0.0742	0.2744	0.6571

§ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

‡ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.
β 593,000 and 725,000 seed ha^{-1}.
¥ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.
† P (0.05) level significance.

Appendix B.6 Main effect cultivar (C), seeding rate (S), nitrogen (N), inoculant (I), and fungicide (F) influenced soybean yield components for 2012 and 2013 agronomic input soybean experiments conducted at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Site-Year					
	MTH12	**PTR12**	**SUF12**	**WAR13**	**PTR13**	**SUR13**
C £	------------------------------Soybean per m^2------------------------------					
95Y01	43.6 b †	44.5 a	38.3 b	51.7 a	51.6 a	52.4 a
95Y20	49.1 a	45.9 a	45.5 a	43.0 b	43.7 b	55.3 a
S β						
593,000	43.6 b	41.7 b	40.1 a	44.7 b	42.6 b	50.0 b
725,000	49.0 a	48.8 a	43.7 a	50.0 a	52.8 a	57.8 a
N ‡						
With	46.4 a	44.5 a	40.3 a	46.3 a	46.4 a	55.9 a
Without	46.2 a	45.9 a	43.5 a	48.4 a	48.9 a	51.8 a
I §						
With	45.5 a	46.1 a	39.6 b	46.8 a	47.0 a	54.7 a
Without	47.1 a	44.3 a	44.1 a	47.9 a	48.3 a	53.1 a
F Φ						
With	48.4 a	42.7 b	42.3 a	49.6 a	49.1 a	54.3 a
Without	44.3 b	47.7 a	40.9 a	45.0 b	46.2 a	53.5 a
C £	--------------------------Branches per plant--------------------------					
95Y01	1.8 b †	2.5 b	2.9 b	1.9 b	1.7 b	1.9 b
95Y20	3.3 a	4.3 a	3.3 a	2.8 a	3.2 a	2.6 a
S β						
593,000	2.8 a	3.8 a	3.1 a	2.6 a	2.7 a	2.5 a
725,000	2.3 b	3.0 b	3.1 a	2.1 b	2.2 b	2.0 b
N ‡						
With	2.4 a	3.2 a	3.3 a	2.4 a	2.6 a	2.1 a
Without	2.7 a	3.6 a	2.9 b	2.3 a	2.3 a	2.3 a
I §						
With	2.6 a	3.2 a	3.2 a	2.6 a	2.5 a	2.1 a
Without	2.5 a	3.6 a	3.0 a	2.2 b	2.5 a	2.3 a
F Φ						
With	2.4 a	3.7 a	3.0 a	2.3 a	2.4 a	2.2 a
Without	2.7 a	3.1 a	3.2 a	2.4 a	2.5 a	2.3 a
C £	------------------------------Nodes per plant------------------------------					
95Y01	13.6 a †	14.0 b	16.0 a	12.9 b	11.6 b	14.1 a
95Y20	14.0 a	15.6 a	15.9 a	14.6 a	12.9 a	14.6 a
S β						
593,000	14.3 a	15.2 a	16.1 a	14.1 a	12.5 a	14.9 a
725,000	13.3 b	14.4 b	15.9 a	13.3 b	12.0 b	13.8 b
N ‡						
With	14.0 a	14.9 a	16.3 a	13.8 a	12.6 a	14.3 a
Without	13.6 a	14.7 a	15.7 b	13.6 a	11.9 b	14.4 a

I §						
With	13.8 a	14.6 a	16.1 a	13.8 a	12.3 a	14.3 a
Without	13.8 a	15.0 a	15.9 a	13.7 a	12.2 a	14.4 a
F Φ						
With	14.0 a	15.3 a	15.9 a	13.5 a	12.2 a	14.5 a
Without	13.6 a	14.3 b	16.1 a	13.9 a	12.3 a	14.2 a
C £	--------------------------Main stem pod per m^2--------------------------					
95Y01	774.6 a †	832.4 a	907.3 a	798.8 a	784.7 a	1242.2 a
95Y20	635.2 b	612.7 b	943.7 a	641.0 b	698.0 b	1131.2 b
S β						
593,000	693.9 a	728.9 a	898.9 a	706.5 a	729.8 a	1178.1 a
725,000	715.9 a	716.3 a	952.1 a	733.3 a	752.9 a	1195.3 a
N ‡						
With	721.3 a	719.0 a	900.9 a	721.1 a	752.5 a	1188.2 a
Without	688.5 a	726.1 a	950.1 a	718.6 a	730.3 a	1185.3 a
I §						
With	700.8 a	729.1 a	895.2 a	724.0 a	720.6 a	1201.1 a
Without	709.0 a	716.0 a	955.8 a	715.7 a	762.1 a	1172.3 a
F Φ						
With	725.7 a	704.1 a	932.9 a	729.5 a	727.4 a	1194.5 a
Without	684.2 a	741.1 a	918.1 a	710.2 a	755.3 a	1178.9 a
C £	---------------------------Total pods per plant---------------------------					
95Y01	22.6 a †	26.4 a	33.1 a	19.4 b	21.7 b	30.1 a
95Y20	22.1 a	28.8 a	34.0 a	24.3 a	32.5 a	31.6 a
S β						
593,000	24.5 a	31.1 a	34.8 a	23.0 a	30.7 a	33.2 a
725,000	20.2 b	24.0 b	32.3 a	20.6 b	23.5 b	28.5 b
N ‡						
With	22.8 a	27.2 a	34.8 a	22.7 a	28.9 a	29.9 a
Without	21.9 a	27.9 a	32.3 a	20.9 a	25.3 a	31.9 a
I §						
With	22.7 a	27.5 a	34.8 a	22.5 a	27.8 a	30.7 a
Without	22.0 a	27.6 a	32.3 a	21.1 a	26.4 a	31.0 a
F Φ						
With	21.4 a	29.0 a	33.3 a	21.1 a	25.8 a	30.5 a
Without	23.3 a	26.1 a	33.7 a	22.5 a	28.3 a	31.2 a
C £	------------------------Main stem pods per plant------------------------					
95Y01	18.4 a †	19.5 a	24.7 a	16.0 a	15.7 a	24.9 a
95Y20	13.1 b	14.0 b	21.5 b	16.2 a	16.9 a	21.5 b
S β						
593,000	16.6 a	18.2 a	23.5 a	16.6 a	17.8 a	24.5 a
725,000	14.9 b	15.2 b	22.6 a	15.5 a	14.9 b	21.9 b
N ‡						
With	16.2 a	17.1 a	23.6 a	16.5 a	17.2 a	22.5 a
Without	15.3 a	16.4 a	22.6 a	15.6 a	15.4 b	23.9 a

I §						
With	15.9 a	16.6 a	23.5 a	16.3 a	16.4 a	23.3 a
Without	15.6 a	16.9 a	22.7 a	15.8 a	16.3 a	23.1 a
F Φ						
With	15.3 a	17.4 a	22.9 a	15.6 a	15.7 a	23.2 a
Without	16.2 a	16.1 a	23.2 a	16.5 a	16.9 a	23.3 a
C £	---------------------------Branch pods per m^2---------------------------					
95Y01	172.0 b †	243.8 b	279.7 b	175.8 b	262.4 b	240.4 b
95Y20	401.8 a	629.2 a	526.9 a	317.3 a	599.0 a	500.9 a
S β						
593,000	320.5 a	462.2 a	405.7 a	259.4 a	473.0 a	394.4 a
725,000	253.3 b	410.8 a	400.9 a	233.6 a	388.4 b	346.9 a
N ‡						
With	280.6 a	426.7 a	410.3 a	262.1 a	446.8 a	364.9 a
Without	293.1 a	446.3 a	396.3 a	230.9 a	414.6 a	376.4 a
I §						
With	290.4 a	425.1 a	415.6 a	259.0 a	440.7 a	354.9 a
Without	283.4 a	447.9 a	391.1 a	234.1 a	420.7 a	386.4 a
F Φ						
With	283.9 a	453.8 a	401.1 a	251.2 a	408.4 a	378.1 a
Without	289.9 a	419.2 a	405.5 a	241.8 a	453.0 a	363.2 a
C £	--------------------------Branch pods per plant--------------------------					
95Y01	4.3 b †	6.8 b	8.4 b	3.5 b	5.9 b	5.2 b
95Y20	9.0 a	14.8 a	12.6 a	8.0 a	15.6 a	10.1 a
S β						
593,000	8.0 a	12.9 a	11.3 a	6.4 a	12.9 a	8.6 a
725,000	5.3 b	8.7 b	9.6 a	5.1 b	8.6 b	6.7 b
N ‡						
With	6.6 a	10.1 a	11.2 a	6.2 a	11.7 a	7.3 a
Without	6.6 a	11.5 a	9.7 a	5.3 a	9.8 a	7.9 a
I §						
With	6.9 a	11.0 a	11.3 a	6.1 a	11.4 a	7.5 a
Without	6.4 a	10.6 a	9.7 a	5.4 a	10.1 a	7.8 a
F Φ						
With	6.1 a	11.6 a	10.4 a	5.5 a	10.1 a	7.4 a
Without	7.2 a	10.0 a	10.5 a	6.0 a	11.4 a	7.9 a
C £	-------------------Main stem seed number per m^2-------------------					
95Y01	1791.8 a †	1561.9 a	1986.7 a	1684.3 a	1746.8 a	2716.0 a
95Y20	1378.3 b	1121.4 b	1892.3 a	1324.1 b	1524.1 b	2290.7 b
S β						
593,000	1580.9 a	1364.6 a	1900.2 a	1476.8 a	1614.9 a	2521.3 a
725,000	1589.2 a	1318.7 a	1978.1 a	1531.5 a	1655.9 a	2485.4 a
N ‡						
With	1545.1 a	1338.2 a	1911.8 a	1559.3 a	1663.4 a	2515.2 a
Without	1625.0 a	1345.1 a	1967.2 a	1449.0 a	1607.5 a	2491.5 a

I §						
With	1608.6 a	1340.8 a	1881.0 a	1493.2 a	1584.5 a	2526.0 a
Without	1561.5 a	1342.6 a	1998.1 a	1515.2 a	1686.4 a	2480.7 a
F Φ						
With	1632.0 a	1323.4 a	1966.9 a	1521.6 a	1608.4 a	2510.7 a
Without	1538.1 a	1360.0 a	1912.1 a	1486.8 a	1662.5 a	2496.0 a
C £	-----------------------Branch seed number per m^2-----------------------					
95Y01	363.6 b †	469.1 b	567.1 b	359.9 b	554.3 b	456.7 b
95Y20	836.7 a	1109.7 a	1035.0 a	668.5 a	1264.3 a	973.1 a
S β						
593,000	674.8 a	838.1 a	813.4 a	555.1 a	986.7 a	754.5 a
725,000	525.5 b	740.6 a	788.7 a	473.3 a	832.0 b	675.4 a
N ‡						
With	586.9 a	764.3 a	817.6 a	550.1 a	940.9 a	700.4 a
Without	613.3 a	814.5 a	784.5 a	478.2 a	877.7 a	729.5 a
I §						
With	610.2 a	769.6 a	821.6 a	528.4 a	914.3 a	692.5 a
Without	590.0 a	809.2 a	780.5 a	499.9 a	904.4 a	737.4 a
F Φ						
With	596.1 a	820.2 a	789.0 a	530.6 a	873.0 a	722.8 a
Without	604.2 a	758.6 a	813.0 a	497.8 a	945.7 a	707.1 a
C £	-------------------Main stem seed weight (g) per m^2-------------------					
95Y01	276.0 a †	277.6 a	337.7 a	232.9 a	277.3 a	430.3 a
95Y20	187.2 b	168.0 b	284.0 b	164.0 b	196.2 b	321.0 b
S β						
593,000	231.3 a	225.1 a	301.4 a	192.6 a	231.7 a	378.2 a
725,000	232.0 a	220.5 a	320.3 a	204.3 a	241.7 a	373.2 a
N ‡						
With	231.4 a	220.7 a	303.3 a	205.2 a	242.7 a	382.9 a
Without	231.8 a	224.8 a	318.4 a	191.7 a	230.8 a	368.5 a
I §						
With	226.9 a	224.2 a	304.1 a	199.9 a	227.7 a	376.5 a
Without	236.4 a	221.4 a	317.6 a	197.1 a	245.7 a	374.9 a
F Φ						
With	235.4 a	220.6 a	318.3 a	202.3 a	234.3 a	380.8 a
Without	227.8 a	225.0 a	303.4 a	194.6 a	239.2 a	370.6 a
C £	----------------------Branch seed weight (g) per m^2----------------------					
95Y01	58.9 b †	84.4 b	100.0 b	45.9 b	80.4 b	70.7 b
95Y20	110.5 a	166.2 a	154.5 a	78.9 a	152.4 a	137.2 a
S β						
593,000	95.2 a	133.8 a	128.5 a	69.5 a	127.5 a	109.8 a
725,000	74.3 b	116.7 b	125.9 a	55.3 b	105.2 b	98.1 a
N ‡						
With	82.9 a	122.7 a	129.1 a	65.4 a	120.5 a	102.0 a
Without	86.6 a	127.8 a	125.4 a	59.4 a	112.2 a	105.9 a

I §						
With	85.5 a	122.8 a	130.8 a	65.5 a	117.0 a	100.5 a
Without	83.9 a	127.8 a	123.6 a	59.3 a	115.7 a	107.4 a
F Φ						
With	84.1 a	130.5 a	127.1 a	67.4 a	111.4 a	106.6 a
Without	85.3 a	120.0 a	127.3 a	57.4 a	121.4 a	101.4 a
C £	----------------------Total dry matter (g per m^2)----------------------					
95Y01	637.6 a †	692.5 a	828.5 a	621.4 a	665.8 a	913.0 a
95Y20	609.7 a	706.0 a	869.0 a	635.2 a	666.8 a	939.8 a
S β						
593,000	642.3 a	714.0 a	831.1 a	635.2 a	673.8 a	937.6 a
725,000	605.0 a	684.5 a	866.4 a	621.4 a	658.9 a	915.2 a
N ‡						
With	626.0 a	689.2 a	845.0 a	648.7 a	695.5 a	934.2 a
Without	621.3 a	709.3 a	852.4 a	607.9 a	637.2 b	918.6 a
I §						
With	617.0 a	696.6 a	834.5 a	643.1 a	654.0 a	918.0 a
Without	630.3 a	701.9 a	863.0 a	613.5 a	678.6 a	934.8 a
F Φ						
With	639.4 a	707.2 a	859.7 a	657.1 a	641.2 a	953.7 a
Without	607.9 a	691.3 a	837.8 a	599.6 b	691.4 a	899.1 a

£ Pioneer Hi-bred Int., Inc. 95Y01 or 95Y20 soybean cultivars.

β Seed ha^{-1}.

‡ 32% urea ammonium nitrate solution applied at 31.4 kg N ha^{-1} at planting, 5.1 cm deep, between rows.

† Means with different letter within parameter, main effect, and column are significantly different at P (0.05).

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

Φ Foliar application of pyraclostrobin + fluxapyroxad at a.i. 333 g L^{-1} + 167 g L^{-1}, respectively + non-ionic surfactant at 0.25% v/v by three point sprayer in 187 L ha^{-1} water when 50% soybean reached R3 (beginning pod) and R5 (beginning seed) stages (Fehr and Caviness, 1977).

APPENDIX C - ADDITIONAL INFORMATION FOR 2012 AND 2013 N RATE X INOCULANT SOYBEAN EXPERIMENTS

Appendix C.1 Soil chemical characteristics for 2012 and 2013 N rate x inoculant soybean experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

				Soil Extractable Nutrient Levels β											
Site-Year	pH ‡	OM ¥	CEC §	NH_4	NO_3	P	K	Ca	Mg	Zn	Mn	Cu	Fe	B	SS £
2012		--%--	meq $100g^{-1}$	--mg L^{-1}--		------------------------------mg kg^{-1}------------------------------									
Mt. Holly	5.89	1.4	3.5	0.46	0.94	31	94	290	78	1.3	14.5	0.3	10.9	0.2	115
Painter	5.98	1.3	4.0	0.38	0.04	80	75	473	68	0.6	12.4	1.0	16.0	0.2	64
Suffolk	6.12	1.6	4.6	0.44	0.16	29	107	563	78	0.7	5.1	0.4	17.3	0.2	77
2013															
V. Beach	6.12	5.1	9.5	1.02	0.79	93	73	1244	185	5.3	5.2	0.6	12.7	0.6	102
Warsaw	6.41	1.8	4.4	0.56	0.34	24	137	482	113	1.5	35.9	0.4	5.5	0.3	67
Painter	6.25	0.8	4.8	0.41	0.07	140	78	629	74	0.8	10.6	1.3	18.9	0.2	45
Suffolk	6.53	1.4	4.3	1.57	0.23	49	122	590	95	0.7	5.1	0.5	29.0	0.2	64

‡ Measured soil to water pH (1:1) (Maguire and Heckendorn, 2011).

¥ % Organic matter by loss on ignition method (Maguire and Heckendorn, 2011).

§ Cation exchange capacity summation method (Maguire and Heckendorn, 2011).

β Soil NH_4-N and NO_3-N by colorimetric method (Mulvaney, 1996); P, K, Ca, Mg, Zn, Mn, Cu, Fe, B, SS by Mehlich-1 soil test (Maguire and Heckendorn, 2011).

£ Soluble salts.

Appendix C.2 Agronomic characteristics for soybean cultivars grown in 2012 and 2013 N rate x inoculant experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

	Cultivar †
Characteristic	95Y01 λ
Relative maturity	5.0
Herbicide tolerant trait	Roundup Ready®
Canopy width ‡	7
Plant height for maturity γ	6
Growth habit	Indeterminate
Flower color	Purple
Pubescence color	Tawny
Pod color	Brown
Hilum color	Black
Field emergence Ω	7
Harvest standability §	7
Shattering δ	8
Seed kg^{-1}	5727
Seed treatment	Treated ¥
% protein Φ	35.4
% oil Φ	19.3
% germ	85
Iron chlorosis	- Θ
Soybean cyst nematode β	R3,14
PRR resistance gene £	-
PRR field tolerance £	5
Sudden death syndrome §	4
Stem canker gene μ	9
Stem canker field tolerance §	5
Charcoal rot §	6
Frogeye leaf spot §	6
Southern root-knot nematode §	2

† Pioneer Hi-Bred Int., Inc.

λ Anonymous, 2013a.

‡ Canopy width rating scale: 9 = extremely bushy, 1 = very narrow.

γ Plant height scale: 9 = tall, 1 = short.

Ω Field emergence scale: 1-3 = below average, 4-6 = average, 7-9 = excellent.

§ Rating scale: 9 = excellent, 1 = poor.

δ Shattering scale: 9 = excellent tolerance, 1 = poor tolerance.

¥ Seed treatments: Gaucho, Trilex, Pioneer Premium Seed Treatment, Allegiance.

Φ Collected at 13% moisture.

Θ Insufficient data collected.

β Soybean cyst nematode: R, resistance; #, race 1, 3, 5, 9, or 14.

£ Phytophthora root rot.

μ Stem canker gene: 9 = resistant, 5 = moderate resistance, 1 = no resistance.

Appendix C.3 Main effect location influenced soybean node and pod yield components for 2012 and 2013 N rate x inoculant experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Site-Year	Nodes per plant	Reproductive nodes		Pods		
	----------no. per plant----------		--%--	no. per m^2	no. per plant	no. per RN
12MTH	14.1 c †	10.6 bc	75.0 c	936.0 d	24.9 bc	2.31 cd
12PTR	14.5 bc	11.1 ab	76.7 c	1145.6 c	27.8 b	2.46 c
12SUF	15.4 a	11.7 a	76.3 c	1306.6 b	35.6 a	3.02 a
13EXP	14.6 bc	10.3 c	70.5 d	1174.9 c	22.9 c	2.20 d
13WAR	13.2 d	10.0 c	75.0 c	1114.6 c	22.6 c	2.23 d
13PTR	11.7 e	10.0 c	86.0 a	1101.2 c	22.9 c	2.27 cd
13SUF	14.8 ab	11.9 a	80.2 b	1437.4 a	33.2 a	2.75 b

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

Appendix C.4 Main effect location influenced soybean seed and biomass yield components for 2012 and 2013 N rate x inoculant experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Site-Year	Seed			TDM ‡	Seed size	HI ¥
	--no. per m^2--	-no. per pod-	----------g per m^2----------		-seed per kg-	---%---
12MTH	2071.5 c †	2.22 c	336.0 c	640.5 e	6204.1 cd	52.3 bc
12PTR	2225.5 c	1.94 d	414.0 b	808.9 bc	5372.3 f	51.5 c
12SUF	2899.4 b	2.21 c	487.4 a	911.9 a	5947.3 de	53.6 ab
13EXP	2346.7 c	1.99 d	410.6 b	848.9 ab	5765.9 e	47.9 d
13WAR	2255.8 c	2.02 d	350.1 c	746.1 cd	6443.7 c	46.8 d
13PTR	2775.3 b	2.54 b	377.1 bc	702.8 de	7417.0 b	53.6 ab
13SUF	4657.7 a	3.25 a	502.5 a	922.5 a	9325.6 a	54.5 a

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.
‡ Total dry matter.
¥ Harvest index.

Appendix C.5 Main effect inoculant influenced soybean population, growth, and N uptake parameters for 2012 and 2013 N rate x inoculant experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Inoculant §	Population	V4 Plant Height	V4 TNU ¥	R5 TNU	V4 NDVI §	R3 NDVI	R5 NDVI
	-plants per ha-	------cm------	------kg N per ha------				
With	348,778 a †	40.7 a	50.1 a	209.2 a	0.7180 a ‡	0.9121 a ‡	0.8940 a
Without	349,826 a	40.0 a	48.1 a	221.6 a	0.7127 a	0.9096 a	0.8923 a

§ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

¥ Total N uptake.

§ Normalized difference vegetative index.

‡ Data collected only at 2013 site-years.

Appendix C.6 Interaction between N rate and inoculant influenced soybean population, growth, and N uptake parameters for 2012 and 2013 N rate x inoculant experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

N rate §	Inoculant Φ	Population	V4 Plant Height	V4 TNU ¥	R5 TNU	V4 NDVI β	R3 NDVI	R5 NDVI
		-plants per ha-	------cm------	--------kg N per ha--------				
0	With	350,788 a †	41.2 a	48.8 ab	207.9 bc	0.7085 a ‡	0.9075 b ‡	0.8887 bc
	Without	348,739 a	39.1 a	42.4 b	229.9 ab	0.7075 a	0.9059 b	0.8874 c
16	With	346,604 a	40.6 a	47.8 ab	218.4 abc	0.7263 a	0.9068 b	0.8940 abc
	Without	357,449 a	41.0 a	43.7 b	212.2 abc	0.7284 a	0.9109 b	0.8934 abc
31	With	350,304 a	40.8 a	51.6 ab	197.5 bc	0.7179 a	0.9229 a	0.8962 a
	Without	341,452 a	39.5 a	43.6 b	225.5 abc	0.7087 a	0.9065 b	0.8945 abc
47	With	347,202 a	41.2 a	52.2 ab	224.9 abc	0.7131 a	0.9126 b	0.8966 a
	Without	359,925 a	41.1 a	55.9 a	248.5 a	0.7098 a	0.9105 b	0.8912 abc
63	With	348,995 a	39.6 a	49.9 ab	197.2 bc	0.7244 a	0.9106 b	0.8946 abc
	Without	341,566 a	39.1 a	55.1 a	191.8 c	0.7093 a	0.9144 ab	0.8949 ab

§ kg N ha^{-1} of 32% urea ammonium nitrate solution at planting, 5.1 cm deep, between rows.

Φ *Bradyrhizobia japonicum* applied at recommended rate to seed prior to planting.

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

¥ Total N uptake.

β Normalized difference vegetative index.

‡ Data collected only at 2013 site-years.

Appendix C.7 Interaction between location and N rate influenced V4 soybean height for 2012 and 2013 N rate x inoculant experiments at Virginia Beach, Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Site-year	N rate §	V4 Plant Height
		------cm------
12MTH	0	30.1 mn †
	16	30.9 mn
	31	29.4 n
	47	31.6 lmn
	63	32.6 k-n
12PTR	0	61.8 a
	16	58.2 a
	31	59.5 a
	47	60.0 a
	63	59.9 a
12SUF	0	35.7 g-l
	16	36.2 g-k
	31	34.8 h-m
	47	35.9 g-l
	63	31.7 lmn
13EXP	0	39.0 d-h
	16	36.2 g-k
	31	38.8 e-i
	47	38.8 e-i
	63	37.9 f-i
13WAR	0	42.9 de
	16	49.1 b
	31	48.4 b
	47	47.5 bc
	63	42.6 de
13PTR	0	30.2 mn
	16	31.9 k-n
	31	31.3 mn
	47	34.5 i-m
	63	33.2 j-n
13SUF	0	41.3 def
	16	43.4 cd
	31	38.8 e-i
	47	39.7 d-g
	63	37.5 f-j

§ kg N ha^{-1} of 32% urea ammonium nitrate solution at planting, 5.1 cm deep, between rows.

† Means with different letter within column are significantly different based on Fisher's Protected LSD at P (0.05) level.

APPENDIX D - ADDITIONAL INFORMATION FOR 2012 AND 2013 SOYBEAN CULTIVAR X FOLIAR FUNGICIDE EXPERIMENTS

Appendix D.1 Soil chemical characteristics for 2012 and 2013 maturity group (MG) IV and V soybean x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

MG IV Experiments				Extractable Nutrient Levels β									
Site-Year	pH ‡	OM ¥	CEC §	P	K	Ca	Mg	Zn	Mn	Cu	Fe	B	SS £
		--%--	meq 100g^{-1}	--------------------------------mg kg^{-1}--------------------------------									
MTH12	5.89	1.4	3.5	31	94	290	78	1.3	14.5	0.3	10.9	0.2	115
PTR12	5.98	1.3	4.0	80	75	473	68	0.6	12.4	1.0	16.0	0.2	64
SUF12	5.81	2.0	6.2	57	135	618	107	0.9	3.5	0.4	33.5	0.2	115
WAR13	6.59	1.3	3.7	19	102	434	110	1.2	25.3	0.3	5.7	0.3	58
PTR13	6.33	0.8	4.9	156	72	632	68	1.0	11.3	1.2	16.5	0.2	48
SUF13	6.41	2.8	9.6	42	168	1300	190	1.1	7.6	0.3	20.2	0.4	77
MG V Experiments													
MTH12	5.89	1.4	3.5	31	94	290	78	1.3	14.5	0.3	10.9	0.2	115
PTR12	5.98	1.3	4.0	80	75	473	68	0.6	12.4	1.0	16.0	0.2	64
SUF12	5.81	2.0	6.2	57	135	618	107	0.9	3.5	0.4	33.5	0.2	115
WAR13	6.60	1.4	3.8	20	113	446	113	1.3	26.5	0.3	5.4	0.3	74
PTR13	6.32	0.9	5.3	150	63	674	61	1.5	14.2	1.3	15.6	0.2	45
SUF13	6.36	2.9	8.7	38	195	1091	163	1.1	7.0	0.3	16.6	0.3	83

‡ Measured soil to water pH (1:1) (Maguire and Heckendorn, 2011).

¥ % organic matter by loss on ignition method (Maguire and Heckendorn, 2011).

§ Cation exchange capacity summation method (Maguire and Heckendorn, 2011).

β Mehlich-1 soil test (Maguire and Heckendorn, 2011).

£ Soluble salts.

Appendix D.2 Plant characteristics for maturity group IV and V soybean grown in 2012 and 2013 cultivar x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Brand	Cultivar	RM §	HTT †	PT ‡	GH ¥	Flower color	Pubescence color	Hilum color
Progeny	5655RY	5.6	GenRR2Y	- Θ	D	White	Gray	Buff
	5610RY	5.6	GenRR2Y	-	D	Purple	Gray	Imp. black
	4850RY	4.8	GenRR2Y	-	I	Purple	Gray	Imp. black
	4811RY	4.8	GenRR2Y	-	I	Purple	Light tawny	Black
Southern States	4711NR2	4.7	GenRR2Y	TH	I	Purple	Tawny	Black
	4700R2	4.7	RR2Y/STS	TH	I	Purple	Tawny	Black
	5112NR2	5.1	GenRR2Y	M	D	White	Gray	Buff
	5510NR2	5.5	GenRR2Y	M	I	Purple	Tawny	Brown
Asgrow	4632	4.6	RR2Y/STS	MB	I	Purple	Light tawny	Black
	4732	4.7	GenRR2Y	MB	I	Purple	Light tawny	Black
	5332	5.3	GenRR2Y	MB	I	Purple	Tawny	Black
	5632	5.6	RR2Y/STS	B	D	White	Gray	Buff
Pioneer Hi-Bred	94Y22	4.2	RR	6	I	White	Light tawny	Brown
	94Y23	4.2	RR	6	I	White	Light tawny	Brown
	94Y70	4.7	RR	7	I	Purple	Tawny	Black
	95Y40	5.4	RR	7	D	White	Tawny	Black
	95Y60	5.6	RR	7	D	Purple	Gray	Varies
NK	S51-J3	5.1	GenRR2Y	M	D	Purple	Gray	Imp. black
	S51-H9	5.1	GenRR2Y	M	D	White	Gray	Buff
	S56-G6	5.6	RR	MB	D	Purple	Tawny	Black
USG	74A79R	4.7	RR2Y/STS	MB	I	Purple	Light tawny	Black
	74B81R	4.8	RR2Y/STS	TH	I	Purple	Light tawny	Black
Public VA	V04-1022	4.9	RR	-	D	White	Gray	Buff

§ Relative maturity.

† Herbicide tolerant trait: RR2Y/STS, Roundup Ready 2 Yield$^{®}$ and STS; GenRR2Y, Genuity$^{®}$ Roundup Ready 2 Yield$^{®}$; RR, Roundup Ready$^{®}$

‡ Plant type: MB, medium bushy, TH, thin (narrow); M, medium; B, bushy. Number scale: 9 = extremely bushy, 1 = very narrow.

¥ Growth habit: I, indeterminate; D, determinate.

Θ Insufficient data collected.

Appendix D.3 Management and production characteristics for maturity group IV and V soybean grown in 2012 and 2013 cultivar x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Brand	Cultivar	Seed kg^{-1}	Seed treatment †	% germ	Emerg.	Standabil.	No-till adapt.	Iron chlorosis
Progeny	5655RY	6388	None	80	- Θ	Excellent	-	-
	5610RY	5947	None	80	-	Excellent	-	-
	4850RY	6063	None	80	-	Excellent	-	-
	4811RY	6691	None	80	-	Good	-	4 γ
Southern States	4711NR2	5359	#1	80	-	Good	-	-
	4700R2	5672	None	85	-	Good	-	-
	5112NR2	6658	None	90	-	Good	-	-
	5510NR2	6097	None	90	-	Excellent	-	-
Asgrow ‡	4632	6982	#2	90	2	3	2	5
	4732	6211	#2	90	2	3	1	5
	5332	6740	None	85	2	4	3	6
	5632	6828	None	85	2	2	3	5
Pioneer Hi-Bred β	94Y22	6278	#3	85	7	8	-	2
	94Y23	5077	#3	90	8	8	Suitable	4
	94Y70	6278	#3	85	8	8	-	-
	95Y40	6498	#3	85	7	9	-	-
	95Y60	6167	#3	80	8	7	-	-
NK γ	S51-J3	5727	None	85	4	1	-	5
	S51-H9	6283	#4	85	3	3	-	3
	S56-G6	7048	#4	80	4	2	-	4
USG ¥	74A79R	4317	#5	85	1.5	2	-	-
	74B81R	5595	#5	85	1.9	2.3	-	-
Public VA	V04-1022	6355	None	99	-	1.4 Ω	-	-

† Seed treatments: #1 42-S Thiram and TBZ Fungicides; LSP. #2 ABCGP code. #3 Gaucho, Trilex, Pioneer Premium Seed Treatment, Allegiance. #4 CMX + Vibrance. #5 RenPro Plus Seed Treatment Package: thiamethoxam, mefenoxam, fludioxnil, azoxystrobin, molybdenum.

Θ Insufficient data collected.

‡ Rating scale: 1-2 = excellent; 3-4 = very good; 5-6 = good; 7-8 = fair; 9 = poor.

β Rating scale: 9 = excellent, 1 = poor.

γ Rating scale: 1 = best, 9 = worst.

¥ Rating scale: 1 = excellent to 5 = poor.

Ω Standability scale: 1 = erect, 5 = 100% flat.

Appendix D.4 Pest sensitivity characteristics for maturity group IV and V soybean grown in 2012 and 2013 cultivar x foliar fungicide experiments at Mt. Holly, Warsaw, Painter, and Suffolk in Virginia.

Brand	Cultivar	SCN †	PR ‡	PFT β	SDS ¥	SSC ¥	FLS ¥	SRK †
Progeny	5655RY	R3	- Θ	-	MS †	MS †	MS †	S †
	5610RY	R3, MR14	Rps1c	-	-	-	R †	R †
	4850RY	R3, MR14	Rps1c	-	MR	R	MR	S
	4811RY	-	Rps1c	-	MS	R	MR	-
Southern States	4711NR2	R3,14	Rps1c	T	-	MR	-	-
	4700R2	-	Rps1c	T	MS	-	-	-
	5112NR2	R3	Rps1c	T	MR	MS	R	-
	5510NR2	R3,14	-	-	-	-	-	-
Asgrow £	4632	MR3	Rps1a	4	5	3	3	S †
	4732	R3	Rps1c	5	6	4	3	S †
	5332	R3	Suscept.	5	6	3	4	S †
	5632	R3	Suscept.	5	5	3	6	S †
Pioneer Hi-Bred ϕ	94Y22	R3,14	Rps1c	4	6	-	6	-
	94Y23	R3	-	3	6	-	4	-
	94Y70	R3,14	-	-	6	-	-	2
	95Y40	R3	-	-	6	-	5	4
	95Y60	R1,3,5	-	-	-	-	5	8
NK γ	S51-J3	MR3,14	-	6	6	-	3	9
	S51-H9	R3,MR14	Rps1c	3	5	2	4	6
	S56-G6	R3	Rps1c	4	5	1	6	2
USG §	74A79R	-	Rps1c	6	6	9	7.5	-
	74B81R	R3,MR14	-	7.5	5	7.5	6	-
Public VA	V04-1022	-	-	-	-	-	-	-

† Soybean cyst nematode and southern root knot; R, res.; MR, mod. res.; MR/MS, mod. res. to mod. susc.; S, susc.; #, race 1, 3, 5, 9, or 14 (SCN).

‡ Phytophthora gene specific res.: Rps1a resistance races (1, 2, 10-11, 13-18, 24, 26, 27, 31, 32, 36); Rps1c (1-3, 6-11, 13, 15, 17, 21, 23-24, 26, 28-30, 32, 34, 36).

Θ Insufficient data collected.

β Phytophthora field tolerance scores: T, tolerant. <4 = very good; 4 = good; 5 = above average; 6 = average; 7 = below average; >7 = poor.

¥ SDS, sudden death syndrome; SSC, southern stem canker; FLS, frogeye leaf spot.

£ Rating scale: 1-2 = excellent; 3-4 = very good; 5-6 = good; 7-8 = fair; 9 = poor.

ϕ Rating scale: 9 = excellent, 1 = poor; γ Rating scale: 1 = best, 9 = worst; § Rating scale: 10 = excellent, 0 = poor.