Alternative and Improved Cropping Systems for Virginia

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ABSTRACT

Feed grain consumption in Virginia and the mid-Atlantic region is more than double the total production. Producing more feed grains in this region could generate more profit for grain growers and lower costs for end-users. Increased feed grain production in this region will necessitate improved corn (*Zea mays* L.) management techniques and adoption of alternative feed grains such as grain sorghum (*Sorghum bicolor* L.). In order to achieve our overall objective of increased corn and grain sorghum production in the region, experiments were conducted to assess tools with the ability to increase the efficiency of sidedress nitrogen (N) application for corn and to test the performance of grain sorghum in both full season and double-crop rotations in this region.

For the corn studies, seven field experiments were established in 2012-2014 with four replications in a randomized complete block design. Treatments included a complete factorial of four different preplant N rate (0, 45, 90, 134 kg ha^{-1}) with three different approach simulation model-prescribed rates (Virginia Corn Algorithm, Maize-N, Nutrient Expert-Maize) and the standard Virginia yield-goal based approach. No differences in corn yield were found between the different simulation model and preplant N rate, however the prescribed sidedress N rate varied significantly due to the simulation model, preplant N rate and the interaction between them. The nitrogen use efficiency (NUE) was estimated based on partial factor productivity (PFP) of nitrogen. The greatest PFP resulted from use of the Virginia Corn Algorithm (VCA), which produced 68 kg grain kg N^{-1} compared with 49 kg grain kg N^{-1} for the yield-goal based approach. While the VCA shows promise as a tool for improving NUE of sidedress applications in corn, more research is needed to validate performance.

Soybean (*Glycine max* L.) is often double-cropped after small grain in the mid-Atlantic region. Growing grain sorghum in this niche in the cropping system instead could result in greater overall feed grain production. In order to assess the performance of grain sorghum as an alternative in common cropping systems, four field experiments were established at the Southern Piedmont Agriculture Research and Extension Center (SPAREC) and Tidewater Agriculture Research and Extension Center (TAREC), near Blackstone and Holland, Virginia, respectively. The experiments were conducted using a split plot design with four replications and fourteen treatments. Main plot was winter small grain crop; either barley (*Hordeum vulgare* L.), triticale (*x Triticosecale*.), wheat (*Triticum aetivum* L.) or winter-fallow and the subplot either soybean or sorghum. In three of four instances, full season sorghum yields were greater than double-cropped sorghum after small grain. At two locations, sorghum yields following triticale were lower than when following barley, possibly indicating an antagonistic or allelopathic effect of triticale. The most profitable cropping system was wheat-soybean based on the price assumptions and measure yields in this experiment. Among the sorghum cropping system, the most profitable system was also wheat-sorghum. Sorghum can be successfully grown in both full-season and double-crop systems and offers good potential to increase feed grain production in this region.

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GENERAL AUDIENCE ABSTRACT

Virginia and the mid-Atlantic region of the USA remains a corn deficit area with demand exceeding supply by approximately 150%. Growing more feed grains in the region could offer greater profits to grain farmers and to end-users, but achieving this goal will require the development of more efficient and effective methods to grow corn as well as the expansion of alterative feed grains such grain sorghum (*Sorghum bicolor* L.). To this end, we conducted field experiments that investigated tools to increase the efficiency of sidedress nitrogen (N) application for corn and to assess the feasibility of incorporating grain sorghum in both full-season and double-crop rotations.

Corn studies compared the sidedress N fertilizer rates prescribed by four in-season N rate recommendation approaches: 1) the Virginia Corn Algorithm (VCA); 2) the Maize-N simulation model; 3) the Nutrient Expert for Maize (NE-Maize) model; and 4) the standard yield goal-based approach used in Virginia, for grain yield and fertilizer uptake efficiency. No differences in corn grain yield between the different systems or preplant N rates were found, however the sidedress N rate recommendation varied significantly between the different systems. At four of seven locations the greatest nitrogen use efficiency, calculated based on partial factor productivity (PFP), was measured when VCA was used to determine sidedress rate recommendations. Overall, PFP for the VCA-recommended rates was 68 kg grain per kg N, compared with 49 kg grain per kg N measured for the yield-goad based approach. The Maize-N model also shows promise for improving sidedress N rate recommendations under these environments.

The objective of cropping systems experiment was to evaluate and compare the yield and agronomic characteristics of grain sorghum with soybean, planted full-season and double-cropped after wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) or triticale (*x Triticosecale*). Full-season grain sorghum yields were greater than double-cropped yields, however double-cropped grain sorghums yields averaged approximately 2.9 Mg ha^{-1}. This indicates that double-crop grain sorghum production is feasible in this region and could be profitable. Net return of grain sorghum in all cropping systems was still less than soybean, especially sorghum following barley (\$189.55 ha^{-1}).

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Cropping Systems and Double-cropping

Grain production and demand

Over the period from 1970 to 1997, corn (*Zea mays* L.) demand in Virginia increased by nearly 50% (approximately 635 M kilograms) (Huffman and Kenyon, 1999). This value was estimated using grain consumption based on average feed intake, days fed, and United States Department of Agriculture, National Agricultural Statistics Service inventory statistics for beef cattle, broilers, cattle on feed, dairy, hogs, horses, layers, and turkeys. Feed consumption was estimated monthly from 1965 to 1997 for each livestock group in Virginia by Huffman and Kenyon (1999) while the total number of animals in each sector was provided annually by the National Agriculture Statistic Service (National Agriculture Statistic Service, 2016). The 1999 assessment showed that the corn and soybean (*Glycine max* L.) used to feed livestock increased at a rate of 25 million and 15 million kg annually over the previous three decades. Maximum corn consumption (Figure 1.1) exceeded 2.032 million Mg (80 million bushels) in 1996. Also in 1996, soybean (Figure 1.2) consumption peaked in excess of 816 million kg (30 million bushels).

In 1999, Huffman and Kenyon found that broilers were the largest consumers of corn (37%) and soybean (43%) followed by turkeys consuming 20% of corn and 26% of soybean, respectively, used in the Commonwealth annually. Huffman and Kenyon (1999) reported that in the period from 1981 to 1996, corn and soybean consumption increased over 30% and 60% respectively.

From 2000 to 2014 overall corn consumption remained basically constant (Table 1.1) However the amount of corn used by sector has changed dramatically over the period with declines in use by all the animal sectors, a slight increase in corn used for seed, and a major increase in Industrial (ethanol) consumption (Table 1.1) (Babcock and Fabiosa, 2011). Despite these changes, the poultry sector still consumes the majority of corn in the state and the animal feeding industry as a whole consumes nearly 69% of all corn used (Figure 1.3).

Total production of corn, sorghum (*Sorghum bicolor* L.) and barley (*Hordeum vulgare* L.) in Delaware, Maryland, North Carolina and Virginia from 1983-2015 is presented in Figure 1.4. Despite significant variability in cumulative grain yield among states over this time, there is no obvious trend or any dramatic change over the 30 years except to note that production tends to suffer in all states during drought years. Greatest total production occurred in 1984 (nearly 8 billion kg) and 1985, however 2013 was estimated to have the third-greatest grain output measured over the period.

Average total production of barley, corn, and sorghum in these four states over the 30-year period was about 5 million Mg (Figure 1.4). Barley production area has decreased over time with a sharp decrease in harvested hectares in 1996 (Figure 1.5). The total harvested barley area in 1995 was 84,000 hectares and dropped to 67,000 hectares in 1996. Harvested barley acres continued to decrease in Virginia through 2005 and have been steady or slightly greater since that time (Figure 1.5). The trend indicates an average annual decrease of 2,300 hectares of barley harvested since 1983. A similar situation exists for corn. Since 1983, corn and barley production in Virginia have declined, but production of the four states combined has remained unchanged due to slightly increased production in Maryland and Delaware in the past five years. Corn production in Virginia from 2000 to 2015 ranged 520,000 Mg in 2012 to 1,380,000 in 2014 with mean production of 950,000 Mg (Figure 1.6). Similar to the 1967 to 1999 period, Virginia remains a corn deficit state (Figure 1.7), consuming more corn than is produced in the state.

In contrast to the mid-Atlantic, total US corn production gradually increased from roughly 200,000,000 Mg in 1995 to more than 350,000,000 Mg in 2014 (Figure 1.8). Over the period 1985-2015, the average price received for corn in the US was \$116 Mg^{-1}. The lowest price occurred in 1986, while the highest price during the period, \$270 Mg^{-1}, was in 2012 and reflects smaller worldwide stocks and high demand for grain (Figure 1.6). The portion of US corn used for fuel and food seed and industrial use (FSI), which also includes the fuel sector, increased gradually from 1985 to 2001, but increased exponentially from 2002 to 2010 (Figure 1.9)

Huffman and Kenyon (1999) reported that Virginia produced approximately 50% of the grain consumed by the animal industries in the state. This is also true in many of the Mid-Atlantic States, including North Carolina. While this situation was tenable for the east coast livestock industry when corn demand in the Midwest was less than today and when transportation costs were significantly less, the situation today is threatening the industry. One potential solution to this situation is to increase the production of feed grains in the mid-Atlantic region to meet more of the local demand. This increase is likely to come from increased yields of currently grown crops such as wheat (*Triticum aestivum* L.), barley, and corn, and also from the expanded acreage of grain sorghum which promises greater drought tolerance than corn.

Crop production distribution by county in Virginia

In recent years, most barley in Virginia has been grown in the central and eastern regions (Figure 1.10). Approximately 29% of barley production was from central counties and about 50% of barley from the eastern counties. An average of 15,890 ha of barley was harvested annually from 2010-2015 with mean yield of approximately 4200 kg ha^{-1} (National Agricultural

Statistics Service, 2015). Corn is produced in most counties in the state with the bulk of production located in the same counties as barley but with significant additional production from several counties in southeast Virginia. The greatest harvested area was in the eastern and southeastern regions, with a total of 42% of total area (Figure 1.11). Soybean production is centered in the Coastal Plain of Virginia, especially the southeastern and eastern counties, but with significant production and high yields in the Shenandoah Valley. Approximately 38% (85,298 ha) of the total soybean harvest in Virginia comes from the southeastern counties, such as Southampton, Sussex, Chesapeake City, and others (Figure 1.12) while 34% (77,148 ha) of total soybean production comes from counties in the eastern region including Accomack, Essex, and Northampton (Figure 1.12). Over 88,000 ha of wheat were harvested annually in Virginia in 2010-2015, and about 45% of total statewide wheat production came from eastern Virginia mostly from counties such as Accomack, Essex, and Northampton which coincides with soybean production. (Figure 1.13). There is also significant wheat produced in northern Virginia and in the southwestern Piedmont (National Agricultural Statistics Service, 2015).

Cropping systems

The most common cropping system in the Mid-Atlantic coastal plain region is soybean grown as a double-crop following a winter small grain, either barley or wheat, rotated with corn, resulting in a 3-crop in 2-years system. Other rotations include a system of four crops in three years; full-season soybean, full-season corn, small grain plus double-crop soybean (Jones et al., 2003). Alley and Roygard (2002) reported on a continuous double cropping system which was barley, double-crop corn, wheat, double-crop soybean.

In a two-year study evaluating soybean planting after small grain for forage, LeMahieu and Brinkman (1990) found greater yields for full-season soybean but double-cropped (barley-soybean and wheat-soybean) systems were feasible and were often more profitable than monocrop soybean in the Upper Midwest. Similar advantages for double-crop systems have been noted by Camper et al. (1972) in Virginia and by Herbek and Bitzer (1998) in Kentucky. Both these studies furthermore demonstrated that soybean yields were higher following barley than the following wheat. Recent work over two seasons comparing double-crop soybeans following either wheat or barley in Virginia concluded that soybean grown after barley yielded more than full-season soybean in two of six locations and more than soybean double-cropped after wheat in three of six locations. Net returns for the barley-soybean system were the greatest (Browning, 2011). Higher soybean yields were attributed to the earlier planting following barley. This same potential advantage due to earlier planting exists for grain sorghum; however, it may not be realized due to other constraints. Additional research will be required to identify any such potential limitations.

Sorghum has been successfully double-cropped with wheat and triticale in Oklahoma and Iowa (Crabtree et al., 1990; Goff et al., 2010). Kelley and Sweeney (2010) studied the previous crop and tillage effects of soybean, corn and grain sorghum on wheat yields in Kansas. They reported wheat grain yields were frequently greater when following corn or soybean than when following grain sorghum. These authors note that N immobilization by sorghum residue was likely not the explanation for these yield differences, but do not identify another suspected cause (Kelley and Sweeney, 2010). In north-central Texas, wheat yields and N uptake were 39% and 36% lower when no-till wheat was planted after grain sorghum compared with a continuous wheat system (Knowles et al., 1993). In a no-till system, the N availability from the previous crop influences and complicates N management. Increased residue levels of grain sorghum compared with soybean have the potential to decrease the N availability to wheat through N immobilization. Grain sorghum N recommendations in Virginia were revisited in 2000 (Khosla et al., 2000) and the overall optimum side-dress rate was reported to be 130 kg N ha^{-1}, though this varies with yield level, with an optimum starter rate based on residual soil N level.

If grain sorghum is planted as a full-season crop, it is likely that small grain will be planted as the following crop in fall. Kelley and Sweeney (2010) reported that in no-tillage systems early season wheat stands were not reduced following sorghum, but yields were lower. They speculated that allelopatheic effects of sorghum roots and residue exudates that result from crop decomposition over time are to blame for this effect. The authors are unaware of reports of this impact in eastern US cropping systems.

Given the recent expansion of market opportunities, there is a need to evaluate the potential for expanded grain sorghum production in Virginia under both full-season and double-crop scenarios.

Grain sorghum

Grain sorghum is a C4 plant, which have greater rates of photosynthesis and more efficient water and nitrogen utilization through use of this photosynthetic pathway. Carbon assimilation in C4 plants concentrates CO_2 in bundle sheath cells resulting in greater efficiency of the enzyme rubisco and higher photosynthetic capacity (Wyrich et al., 1998). These special cell types allow C4 plants generally, and sorghum specifically, greater adaptation to hotter, drier or CO_2 deficient environments compared to plant with C3 carbon assimilation. In the first cycle, phosphoenolpyruvate carboxylase (PEPC) with carbonic anhydrase (CA) facilitates rapid equilibrium between CO_2 and HCO_3^- and goes through the process of hydration and fixation of CO_2 to produce C4 acid (oxaloacetate). Then, the release of CO_2 decarboxylates NADP-ME and diffuses into chloroplasts (Hatch, 1987). This combination of morphological and biochemical features that reduce photorespiration is the reason why C4 photosynthesis results in more carbon assimilation at higher temperature than C3 photosynthesis.

Sorghum grain or forage sorghum production can be favorable under dry and hot conditions since sorghum is drought-resistant (Rosenow et al., 1983). Sorghum is also a short-day crop. Caddel and Weibel (1971) stated that depending on cultivar, development of sorghum plants had been delayed by an increase in photoperiod between 10 and 14 hours day^{-1}. The optimum temperature for sorghum growth is 30°C, though some cultivars of sorghum are able to germinate at a lower temperature. Work by Downes (1968) demonstrated a linear relationship with leaf appearance and increasing air temperature in the range of 13-23°C. Temperature above 40-48°C has proven lethal to sorghum (De Wet, et al., 1967). The average water consumption for a high-yielding, full-season sorghum hybrid is between 450-650mm (Stewart et al., 1983).

Research has demonstrated that planting dates from May 1 to July 1 can produce high sorghum yield in Virginia and North Carolina, so the range of appropriate planting dates for sorghum seems to be wide (Heiniger et al., 2009). The Mid-Atlantic Sorghum Production Handbook lists optimum planting dates for sorghum from May 10 to June 15, with double-crop sorghum planted as late as July 10. There is an increasing risk of fall frost damage from plantings that occur after July 10.

Soybean

Temperature and moisture affect soybean growth, phenology, and duration of the life cycle. The optimum temperature for soybean germination is near 30°C, but there is a wide range of temperatures, 5°C to 40°C, under which germination will occur (Delouche, 1953). Once temperatures drop below 24°C, the time to flowering will increase by 2-3 days for each increment of 0.5°C below that critical temperature, and floral initiation begins when the temperature reaches 15°C. Soil temperature has an effect on the activity of *Rhizobium* as the growth of *Rhizobium* decreases with temperatures in excess of 33°C. The optimum temperature for nodule formation, nodule development, and nitrogen fixation is 27°C (Dart et al., 1975). Water is also important during the soybean growing season. In particular, a soybean seed must achieve about 50% of moisture content to germinate (Norman, 2012).

In the mid-AtlanticUSA, full-season soybean planting typically occurs in April and May, while double-crop plantings occur in June and July. In this region, planting of traditionally used cultivars (maturity groups IV through VI) in mid-May and early June can cause the critical pod and seed development periods to coincide with August drought reducing yield potential in many growing regions (Browning, 2011). The optimum planting date for full-season soybean to achieve adequate vegetative growth and maximize yield potential in Virginia is late-April through early-June (Holshouser, personal communication). Heatherly and Elmore (2004) stated that planting after June 1 generally results in lower yield due a reduction in the number of long-day length days available during vegetative growth. Yield decline of as much as 33% has been reported as the date of planting was delayed from early May to early July. However, seed yields of determinate cultivars did not begin to decline until planting dates were delayed past early June (Beaver and Johnson, 1981; Beuerlein, 1988).

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Corn Nitrogen Management

Corn is grown all over the world because of its ability to grow in diverse climates and different soil conditions (Hallauer et al., 1998). Out of the total world maize production, 65% is for animal feed, 15% for food and 20% for industrial uses (Food and Agriculture Organization, 2016). Nitrogen plays an important role in corn production. Most farmers apply nitrogen fertilizer because nitrogen is essential for amino acid production in plant metabolism (Marschner, 2011). Forty to 60 percent of corn grain yield is dependent on fertilizer (Stewart et al., 2005). According to Huang (2009), the price of anhydrous ammonia (\$755 ton^{-1}) was 1.5 times more in 2008 than in 2007 and three times more than in 1998. The industrial method of fixing atmospheric N_2 gas into ammonia is called the Haber-Bosch process and requires a large amount of fuel (Havlin et al., 2013). This scenario links fuel price and usage with the price of N fertilizer. Funderburg (2001) stated that since it takes 9500 m^{-3} of natural gas to produce one ton of anhydrous ammonia fertilizer, the cost of fertilizer increases \$136 ton^{-1} if the price of fuel increases from \$90 to \$250 m^{-3}. Because of the cost associated with N fertilizer materials and manufacturing, more than 50 percent of N fertilizer used in the US in 2011 was imported (United State Department of Agriculture, Economic Research Service, 2013). The major N fertilizers used in the US are urea, urea ammonium nitrate (UAN), ammonium nitrate and anhydrous ammonia, which is account for 75% of total of N fertilizer used (United State Department of Agriculture, Economic Research Service, 2013).

Nitrogen use efficiency in corn

To increase corn production and take advantage of new, high-yielding hybrids and new technologies, appropriate N fertilizer inputs will continue to be important. However, in order to maximize profitability and minimize negative effects on water quality, improving the utilization of inorganic N fertilizer and increasing the nitrogen use efficiency within plants will be essential. Often, NUE is calculated by the difference method as shown below (Moll et al., 1982):

NUE = [(total cereal N removed) - (N coming from the soil + N deposited in the rainfall)] / (fertilizer N applied to cereals)

Worldwide nitrogen use efficiency (NUE) for all cereal crops is estimated to be 33% while that of US corn production is 42% (Raun and Johnson, 1999). There are several factors such as ammonia volatilization, denitrification, N leaching, and plant losses as ammonia as the pathway that cause the low NUE rate (Raun and Johnson, 1999). Malakoff (1998) estimated that more than \$750,000,000 worth of excess N flows into the Mississippi River every year. Raun and Johnson (1991) also calculated that a 1% increase in worldwide cereal NUE would be worth \$234,658,462. Using the 2014 price for N, increasing NUE by 1% of would worth about

$803,000,000. Proper timing of N applications, multiple inputs of N (Sowers et al., 1994), and avoiding excess N application (Kanampiu et al., 1997) have all been demonstrated to improve NUE. Improving NUE and efficiently managing N will benefit both profitability and environmental sustainability of agriculture.

Though an integral part of crop production, applying the right dose of N fertilizer can be challenging because of the many factors affecting N need and the need to maximize economic return while also minimizing environmental risk. In general, the lower the water holding capacity of a soil (i.e. coarser soil) in the mid-Atlantic region, the lower the yield potential, and the lower the N fertilizer recommendation (Khosla and Alley, 1999). The best N fertilizer management is the application of the right amount of N using the right source at the right timing in the right place (Bruulsema et al., 2009).

In-season N rate determination

Yield goal

The most common methods of determining the most appropriate N rate for a field is the yield goal method (Khosla and Alley, 1999). The premise of yield goal based N rate recommendations is that each additional unit of N fertilizer input produces a yield increase until the point that nitrogen is no longer the limiting factor and yield will no longer respond to increased fertilizer. Dahnke et al. (2011) stated that yield goal is the yield per acre you hope to realistically produce in a field. Generally, grain yield goals used to determine N application rates are calculated as the average of recent 5-years crop yield history multiplied by an assumed N need per unit of grain yield, usually one kg of N per every 56 kg grain, and then increased by 10-30% to assure adequate N for growing conditions (Dahnke et al., 2011). Similarly, Johnson

(1991), defined the yield goal as the average of the most recent five-year yield history plus 30%. While simple in implementation, the yield goal approach does not consider the effect of current season conditions on corn N need. Also establishing a yield goal in practice is challenging due to all the factors in addition to N that influence crop yield.

Soil testing

Because of the ephemeral nature of N in soil systems, N rate recommendations are not typically made based on soil test sufficiency levels (Havlin et al, 2013), especially in humid areas. However a few soil test-based approaches for N rate recommendations in corn have gained modest adoption.

One of these is pre-side dress nitrate test (PSNT), which measures the soil NO_3-N concentration in the surface 30 cm of soil when the corn is 20-30 cm tall (Magdoff et al., 1984). Basically, it is a point-in-time assessment of the spring accumulation of soil NO_3-N just before corn begins rapid N uptake used to adjust the previous N rate estimate based on soil N availability (Magdoff et al., 1984; Spellman et al., 1996). This method is generally used in humid-temperate climate zones. One potential drawback of this test is that it only estimates N availability in a portion of the rooting zone and allows no estimate for the portion of this N that the plant may actually access or take up. Also, it has some practical sampling challenges such as sampling error due to spatial resolution, or collecting soil sample in a short time window. Collecting a representative soil sample can be challenging especially when the surface soil is dry. Inaccurate sampling can result in erroneous results and inaccurate N management (Eghball et al., 2003). The PSNT is often of greatest value for evaluating N sufficiency levels in soils with high N content, as common in livestock system (Klausner et al., 1993; Evanylo and Alley, 1993).

While this method does allow N rate adjustment based on current season conditions, it is affected by soil moisture and temperature prior to sampling and these factors must be used to interpret the final results (Evanylo and Alley, 1993).

Several methods to estimate N mineralization potential for a field have been proposed. One of the earliest was the potentially mineralizable N test proposed by Stanford and Smith (1972). They developed a method to estimate the potentially mineralizable N in soil based on the mineral N release during a 30 week aerobic incubation under optimum temperature and moisture conditions for microbial growth. While this method accurately estimates N mineralization, the time necessary for the incubation limits its utility for making N rate recommendations. Similar to the PSNT, actual N mineralization in a given year is heavily dependent on moisture and temperature conditions. So determining the appropriate N credit for soil mineralized N in a given year is difficult (Curtin and Campbell, 2007). In an effort to remedy several of the complications and disadvantages of the methods of Stanford and Smith, Marumoto et al. (1982) proposed a method to estimate N mineralization based on C mineralized during a 28 day aerobic incubation. In their methods, samples are incubated for 4 weeks with alkali traps (10 ml of 1M KOH) then back titrated with 1 N HCl at 25 °C to determine respired carbon. This is probably the most cost effective laboratory analysis for accurately measuring soil respiration but it is still time-consuming and requires significant technical expertise to ensure consistency and accuracy (Marumoto et al., 1982).

Plant tissue testing

Destructive plant sampling can determine the actual nutrient content of corn at specific growth stages. These values can be related to sufficiency levels in order to infer nutrient adequacy (Donohue, 2000). Tissue sampling is highly effective and diagnosing nutrient deficiencies, toxicities or imbalances. It can also be used to monitor nutrient status as a basis for managing a crop or evaluating the effectiveness of a fertility program (Donohue, 2000). Because the actual crop is being destructively sampled, tissue sampling and assessment of plant nutrient status facilitates recommendations based on the current season. However there are several concerns with the use of plant nutrient content as a guide for N rate recommendations. Samples must be accurately collected to represent the entire field and collection and analysis of samples can take several days, which may delay needed N rate decisions. The current nutrient status of the crop may be influenced by factors other total nutrient availability, including size of the root system, soil compaction, soil moisture and others. Finally, and perhaps most importantly, current recommendations for N sufficiency or deficiency in corn plants at various stages represent very wide ranges in content. This wide range of acceptable levels makes it extremely difficult to make a precise recommendation for N rate.

Plant-based assessment

An alternative to soil and plant based measurements is non-destructive or remote-seasons estimates of plant N status. These remote sensing tools often utilize measurements made using a chlorophyll meter or light reflectance from plants (Islam et al., 2011). Several researchers have reported strong correlation between chlorophyll content and leaf N concentration allowing the use of indirect chlorophyll content measurement as a tool to estimate of crop N need (Schepers et al., 1992; Varvel et al., 2007).

The leaf color chart (LCC) is a basic tool created in the early 1990’s in Japan that helps the farmer to monitor real-time N status in rice (Furuya, 1987) then further improved by the

International Rice Research Institute (IRRI) and the University of California (Witt et al., 2005). The manager compares the color of specific rice leaves to reference photos on the LCC. Singh et al (2010) stated that additional N application is required once the leaf color, monitored at specific intervals (7-10 days in rice), falls below the critical LCC score. While simple, this approach does not make allowances for color difference among rice cultivars and it is somewhat subjective based on the perceptions of the viewer.

The SPAD chlorophyll meter (SPAD 502 Chlorophyll meter, Minolta Camera Col. Osaka, Japan) can be used to directly monitor leaf chlorophyll status. The instrument functions by measure red and near-infrared (NIR) light transmittance through the leaf. In-season nitrogen rate recommendations for corn, cotton, rice, and wheat have been developed using the SPAD meter (Cabangon et al., 2011; Follett et al., 1992; Schepers et al., 1992; Turner and Jund, 1994; Wood et al., 1992). In order to accurately estimate current season N need most researchers recommend the use of a high N reference plot as a comparison (Fox et al., 1994). This led to the development of the concept of the SPAD N sufficiency index which is calculated using the formula below:

N sufficiency index = [(as-needed treatment/ well-fertilized treatment) x 100]

In-season N rate was then prescribed on a sliding scale when the index value dropped under 95% (Blackmer and Scheper, 1995). The SPAD chlorophyll meter is fairly inexpensive compared to another sensors and provides instant results. However, measurements are generally taken from a single leaf on each plant which can result in significant variability among readings. Similarly, while it is possible to capture spatial variation in N need with the SPAD, a large number of readings must be acquired especially in fields with high variability. Piekkielek and Fox (1992) reported that the SPAD meter was at least as successful as the PSNT at determining the likelihood of N response in a particular field, but did not accurately estimate the optimum N rate to apply.

Multiple crop parameters such as productivity, potential yield, and photosynthetic capacity have been measured via remote sensing using sensors that assess the plant canopy at various resolutions (Ma et al., 2001; Raun et al., 2001; Teal et al., 2006). Several studies had correlated spectral measurements to plant biomass (Kleman and Fagerlund, 1987; Bronson et al., 2003) and plant N content (Bronson et al., 2003) that can use to estimate N requirements. In winter wheat, the plant N spectral index had been correlated with total N uptake to determine N requirements (Stone et al., 1996).

Typically, ratios of visible and NIR light reflectance or indices combining reflectance at multiple wavelengths have proven most effective at detecting differences in plant nutrient status (Pinter et al., 2003). One of the most widely used spectral indices to quantify living biomass and also plant N content is the Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1973). Per Tucker (1979), NDVI is calculated as:

$$\text{NDVI} = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED}$$

where ρNIR and ρRED are the fraction of emitted NIR and RED radiations, respectively returned from the reflectance measurements (Teal et al., 2006). In most applications that incorporate NDVI into N rate recommendations other inputs such as crop developmental stage and previous N applied are included (Raun et al., 2001; Holland and Schepers, 2010). Compared to the SPAD meter, plant canopy remote sensing allows assessment of the entire plant or plant canopy, and depending on the tool used to collect the data, can be more readily applied across the entire field. Similar to the limitations of plant tissue testing and chlorophyll meters, other factors that might influence plant nutrient uptake may not be elucidated.

Simulation models

Mechanistic models that account for the interaction between environmental conditions, field management and N dynamics to estimate N fertilizer requirements have been developed and tested recently. Numerous N computational models have been described in recent years including LEACHMN (Wagenet and Hutson, 1989), SOILN (Johnsson et al., 1987), Adapt-N® (Melkonian et al., 2008), MRTN (Sawyer et al., 2006) and others. LEACHMN, developed by Addiscot and Wagenet (1985), simulates water and solute movement, biological processes including N mineralization and N losses to arrive at an N rate recommendation. It simulates N transformations and the main processes are mineralization, nitrification, denitrification and volatilization (Jemison et al., 1994). The SOILN model is focused on the processes of plant uptake, mineralization, immobilization, leaching and denitrification (Bergstrom et al., 1991). It has a one-dimensional layered structure for dealing with transformations and transport of nitrogen in the soil.

The Adapt-N® model attempts to provide precisely managed N inputs for growers by giving field-specific management information. This model can be run from any device with access to the internet, however, it requires detailed information about the field and management applied: such as latitude and longitude, cultivar, soil texture, rooting depth, slope, prior crop, current season weather and current and previous N application information (Melkonian et al., 2008). The simulation combines two approaches: a corn growth and N uptake prediction tool that estimates N demand and the LEACHN model (Hutson, 2003) that simulates N dynamics and availability in soil. The two components are then reconciled to develop a recommended N rate.

The Maize-N decision tool similarly incorporates estimates for maize yield potential, soil N dynamics, N use efficiency and yield response to develop field-specific N rate recommendations (Setiyono et al., 2011). The Maize-N model also incorporates the price of fertilizer inputs in order to generate an estimate of the economically optimum N rate (EONR). The model first derives an estimate of attainable yield for that site based on output from the Hybrid-Maize model (Yang et al., 2004). Indigenous N supply is calculated mechanistically from the DK C&N model (Yang and Janssen, 2000) while N use efficiency of fertilizer is based on uptake and recover efficiency values determined from previous agronomic studies. The Maize-N model was developed at the University of Nebraska and validated using data from 11 locations in the western US Corn Belt. Setiyono et al (2011) report that that N recommendations based on Maize-N were more accurate than standard empirical recommendation methods in the various states based on lower root mean square error. Importantly, the creators provide users the ability to edit almost all parameters relevant to model output. The model can thus be calibrated for local conditions with local data to improve model accuracy.

Other models depend on deterministic estimates of N need. These systems typically rely on previous research data in a region. The maximum return to N (MRTN) approach is based on multiple years and locations of corn N rate field trials throughout the US Corn Belt and uses these data to generate a quadratic-plateau curve that provides a recommended range of N rates based on agronomic and economic optimum response (Vanotti and Bundy, 1994). The recommendations vary with grain-to-fertilizer price ratio, which should provide the highest average net return over years (Melkonian et al., 2008). This system, which largely abandons the mass-balance method has been adopted by several leading US corn producing states (Nafziger et al., 2006). The Nutrient Expert® for Maize similarly uses an algorithm developed from regional nutrient response studies conducted using site-specific nutrient management practices (Pampolino et al., 2012). Requirements for N, phosphorus and potassium are based on the expected yield response to addition of each nutrient, according to the difference between environmentally attainable yield and nutrient-limited yield. The nutrient limited yield represents yield level supported by indigenous soil fertility (Dobermann et al., 2003). The software is used to estimate nutrient response, but also environmental yield potential and optimal planting density for a site (Pampolino et al., 2011). Users input information about previous crop yields, nutrient additions, previous crop residue removal rates and soil texture and organic matter content for the field in question. While other models that use similar regional databases exist, the NE for Hybrid Maize database for Southeast Asia includes data from humid subtropical and temperate continental zones and sandy to loamy soils making it particularly suited for testing in Virginia and the mid-Atlantic region.

In-season algorithms for estimating appropriate N rates for corn based on plant spectral reflectance have been developed in several regions in the US including Nebraska (Holland and Schepers, 2010), Missouri (Scharf et al., 2011) North Dakota (Franzen et al., 2014), and Oklahoma (Raun et al., 2002). The Virginia Corn Algorithm similarly utilizes a deterministic approach to estimate N need, based on corn development and reflectance. Specifically, the normalized difference vegetation index is measured at typical sidedressing time from both high-N (reference) areas and low-N areas established at planting. The difference between these values and the days from seeding are then used to estimate current plant N uptake and the potential for response to added N (Thomason, 2011). While this approach does require installation of reference areas at planting it requires much less field-specific grower input compared to the previously discussed approaches. Overall, improved understanding of the various approaches to improving N management in the region, and finding the most effective strategies can provide both economic and environmental benefits.

Overall objectives

While there are many management questions to be answered in relation to corn, improving the efficiency of nitrogen use is likely the most important current avenue for corn research in the region. Corn alone is not enough to erase the grain deficit in Virginia. Introducing sorghum to mid-Atlantic cropping systems could fill the deficit as long as it proves economically and practically viable.

The overall objectives of this project are to highlight ways to increase total feed grain production and improve the efficiency of that grain production in the region. This will require the integration of improved management strategies, better overall crop management, and expanded production of non-traditional grain crops such as grain sorghum.

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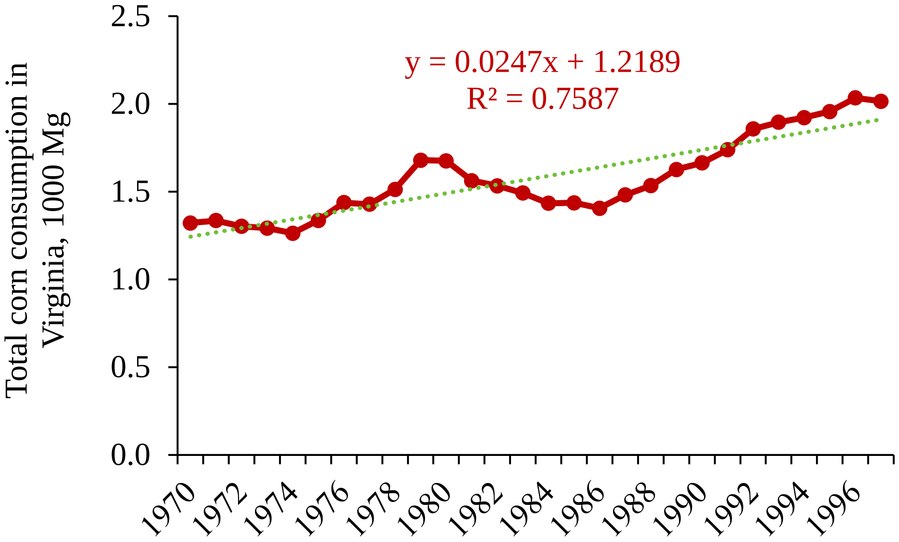
Table 1.1 Corn consumption by sector in Virginia, 2000-2014

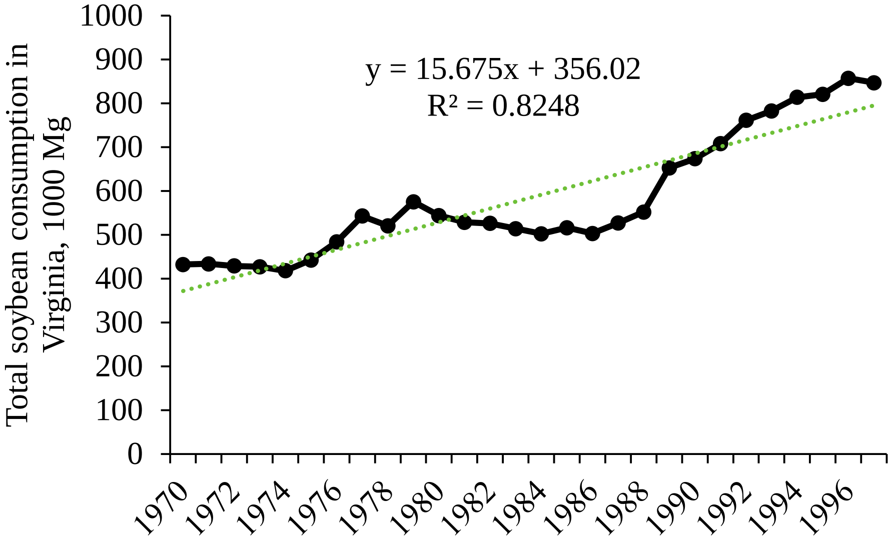
	Dairy	Cattle on Feed	Other Cattle	Hogs and Pigs	Poultry	Other Livestock	Food and industrial use	Seed use
	---1000 Mg---							
2000	222.55	65.95	121.80	264.30	1535.13	17.53	365.43	2.80
2001	292.20	98.13	167.63	339.30	1550.55	15.73	365.43	3.10
2002	230.05	67.48	128.83	254.48	1540.48	14.95	367.75	3.18
2003	200.70	70.13	123.53	228.70	1641.98	5.23	368.90	3.00
2004	178.43	72.28	120.73	232.63	1552.38	14.60	217.40	3.18
2005	179.77	71.81	120.93	236.89	1489.82	15.03	219.25	3.13
2006	182.30	71.68	136.19	318.78	1555.03	15.95	220.65	3.05
2007	160.47	68.64	118.31	213.63	1334.53	13.17	220.90	3.43
2008	168.63	70.80	117.53	219.70	1350.08	12.85	235.65	2.98
2009	152.28	62.07	99.24	194.82	1199.04	11.68	235.29	3.05
2010	153.73	42.89	105.91	201.52	1229.79	11.85	790.43	3.10
2011	154.52	44.58	112.50	153.13	1224.25	11.07	795.65	3.13
2012	156.67	50.95	110.67	140.24	1225.84	10.56	795.90	3.05
2013	151.46	50.17	114.33	158.54	1259.94	10.80	810.65	3.20
2014	150.84	43.84	106.17	171.88	1310.37	10.45	810.29	3.10

Figure 1.1 Estimated corn consumption by livestock in Virginia, 1970-1997.†



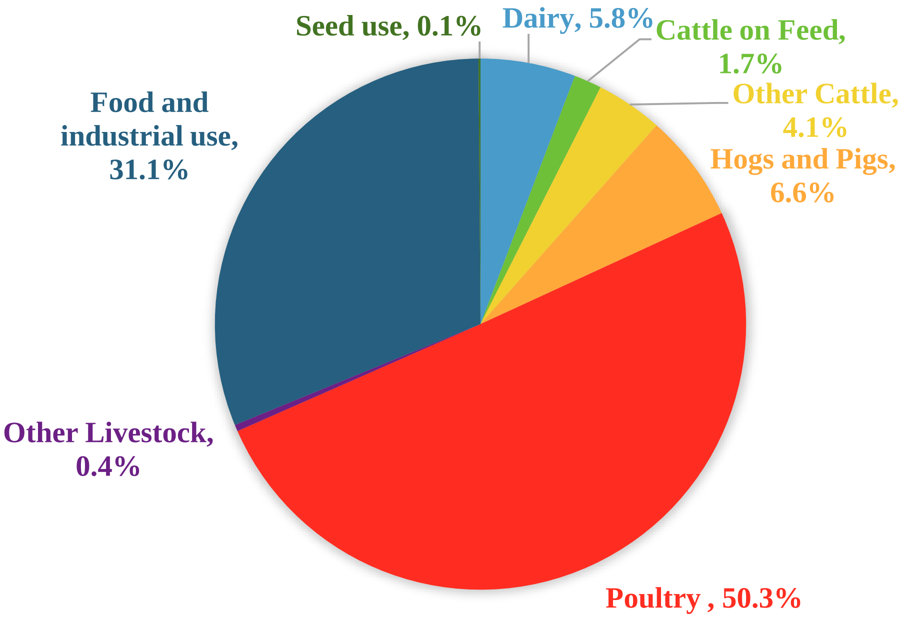
† Source: Huffman and Kenyon, 1999

Figure 1.2 Estimated soybean consumption by livestock in Virginia: 1970-1997.†



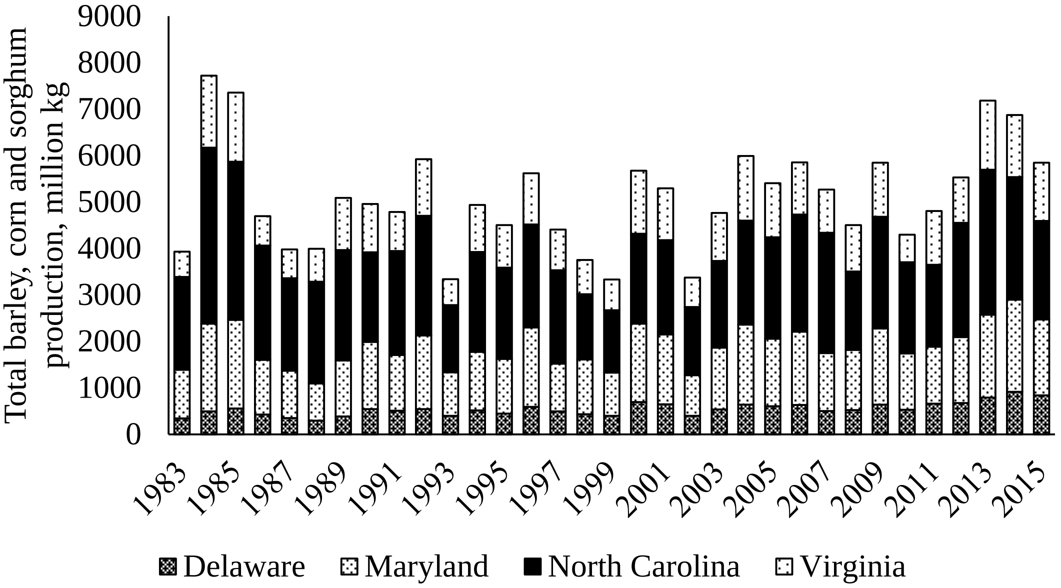
† Source: Huffman and Kenyon, 1999

Figure 1.3 Corn use in Virginia by sector, 2014.



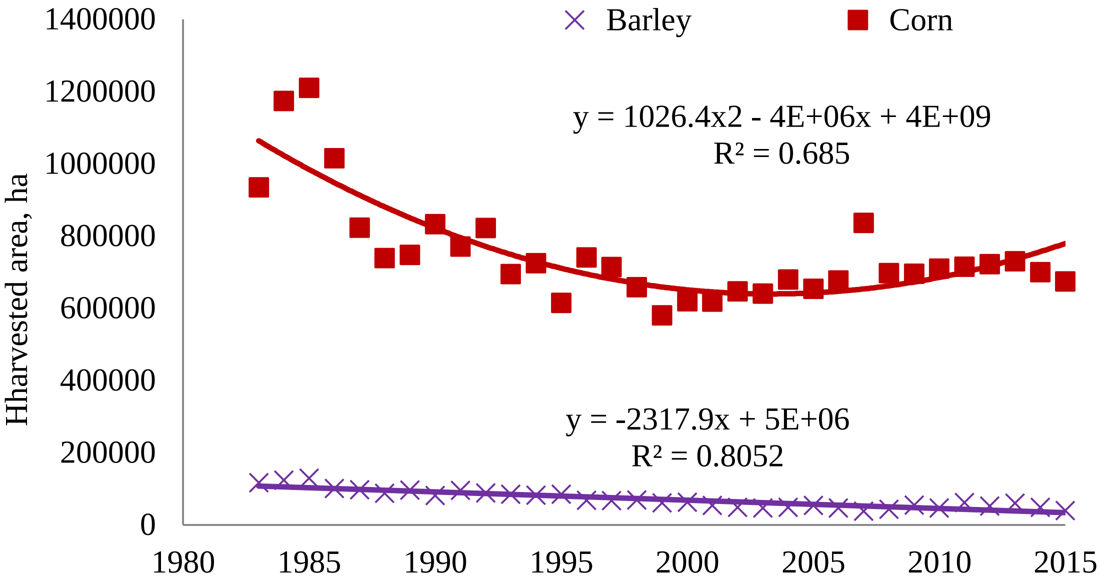
†

Figure 1.4 Total production of barley, corn, and sorghum in Delaware, Maryland, North Carolina, and Virginia, 1983-2015.†‡



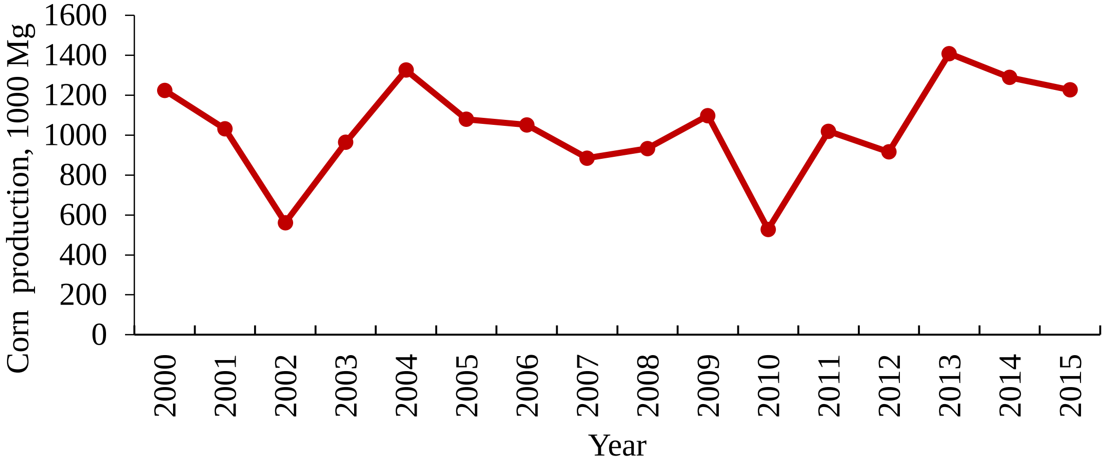
† Source: National Agricultural Statistic Service, 2015
‡Mid-Atlantic states include: Delaware, Maryland, North Carolina and Virginia.

Figure 1.5 Total hectares of corn and barley harvested in Delaware, Maryland, North Carolina, and Virginia, 1983-2015.†



† Source: National Agricultural Statistic Service, 2015

Figure 1.6 Corn production in Virginia, 2000-2015.†



† Source: National Agricultural Statistic Service, 2015

Figure 1.7 Total Virginia corn deficit, 2000-2014.

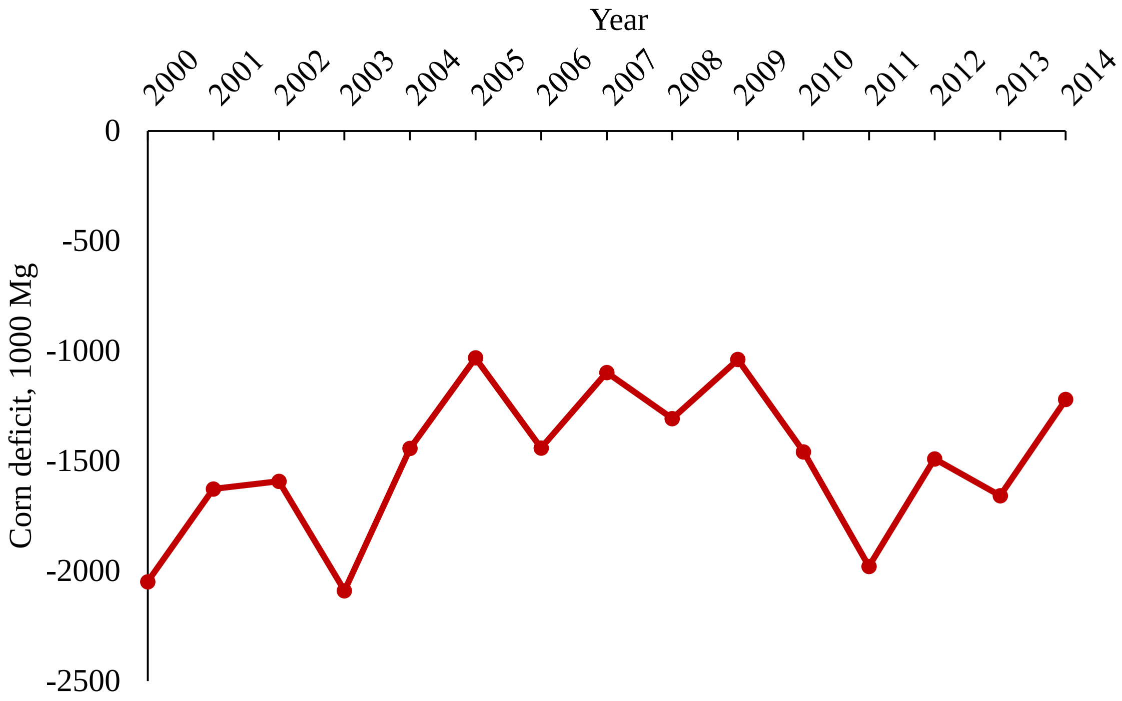
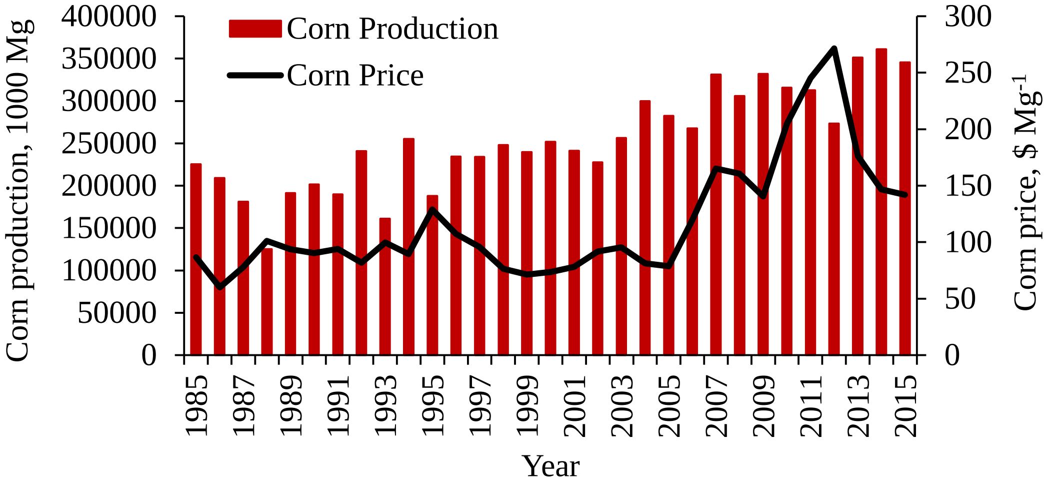
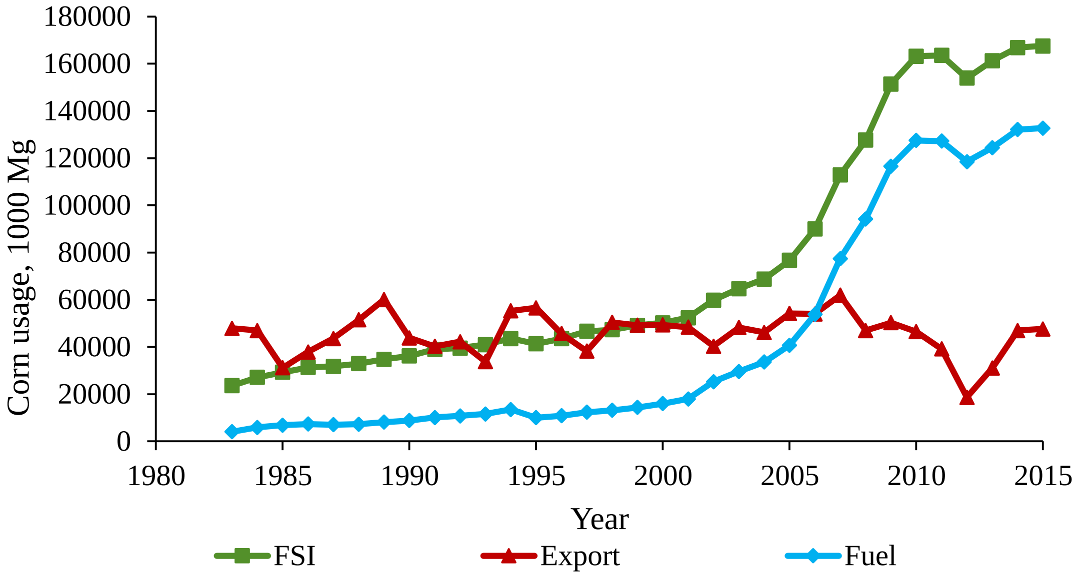


Figure 1.8 Total United States corn production and price received by farmers, 1985-2015.†



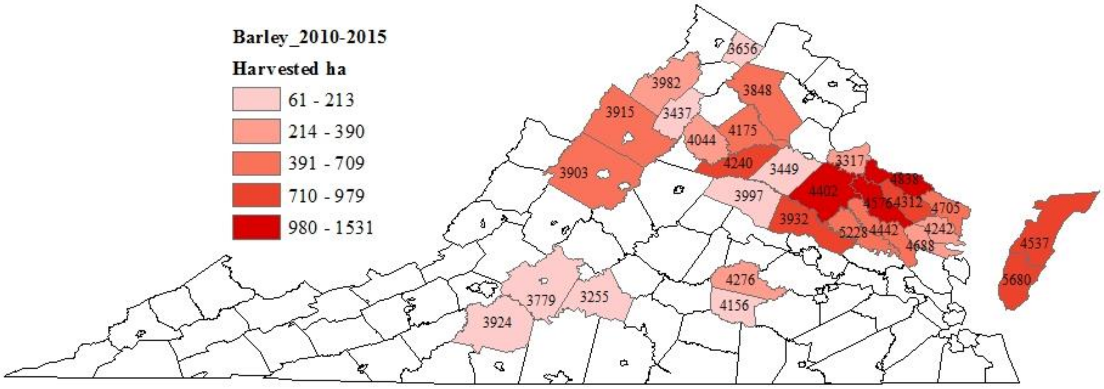
† Source: National Agricultural Statistic Service, 2015

Figure 1.9 United States corn processed by end-use segment, 1983-2015.†



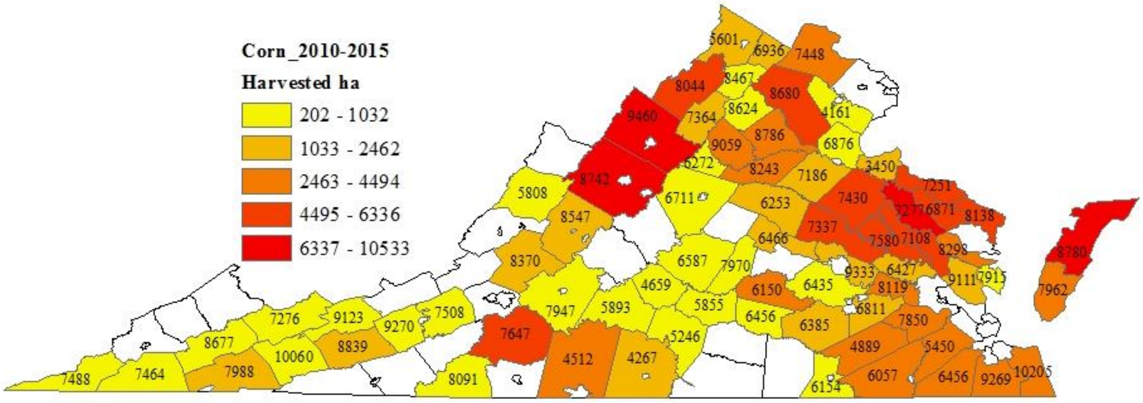
† Source: USDA, ERS, 2015
FSI: Food, Seed, and Industrial use

Figure 1.10 Barley average yield (kg ha^{-1}), as labeled in each county, and harvested area by the county in Virginia, 2010-2015.†



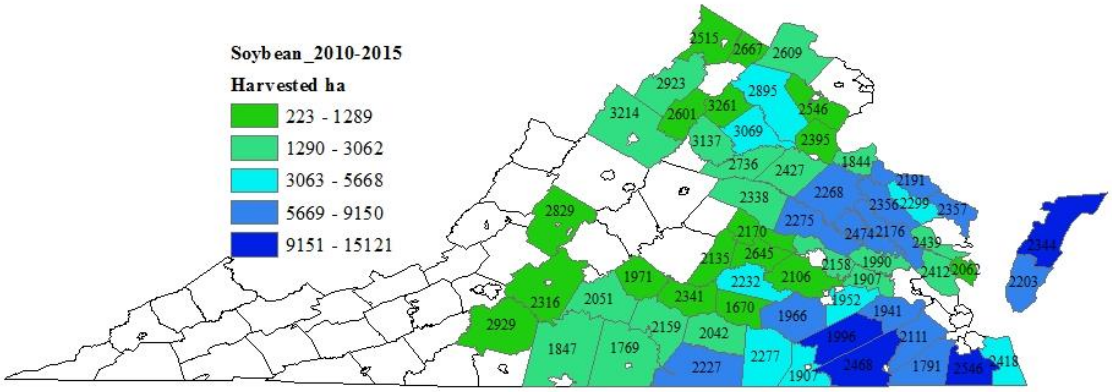
† Source: National Agricultural Statistic Service, 2010-2015

Figure 1.11 Corn average yield (kg ha^{-1}), as labeled in each county, and harvested area by the county in Virginia, 2010-2015.†



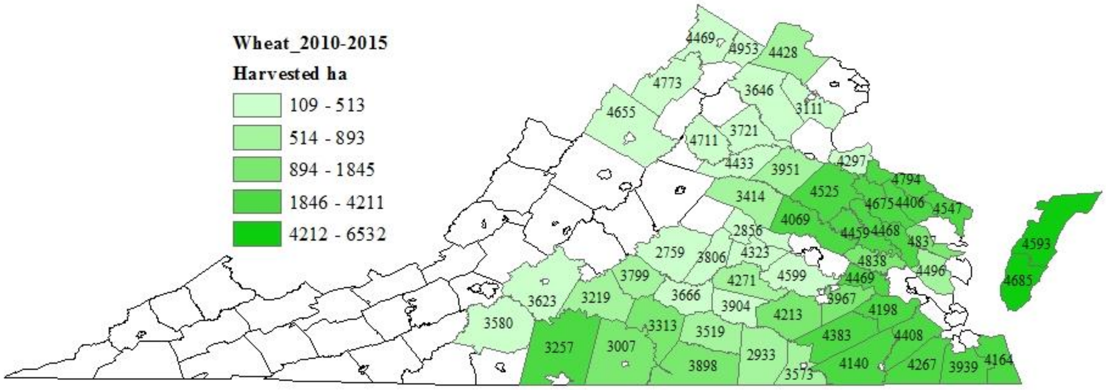
† Source: National Agricultural Statistic Service, 2010-2015

Figure 1.12 Soybean average yield (kg ha^{-1}), as labeled in each county, and harvested area by the county in Virginia, 2010-2015.†



† Source: National Agricultural Statistic Service, 2010-2015

Figure 1.13 Wheat average yield (kg ha^{-1}), as labeled in each county, and harvested area by the county in Virginia, 2010-2015.†



† Source: National Agricultural Statistic Service, 2010-2015

Chapter 2

Improving nitrogen use efficiency of corn sidedress applications with in-season decision support tools

ABSTRACT

In corn (*Zea mays* L.) production, determining appropriate nitrogen (N) rates is a critical part of achieving profitable yields while minimizing negative environmental effects. Many tools to assist in the determination of optimum corn sidedress N rates exist, however those that are low cost, that can be used in real time and that do not require extensive scouting or sampling may be preferred. This study compared the rates prescribed by four in-season N rate recommendation approaches: 1) the Virginia Corn Algorithm (VCA); 2) the Maize-N simulation model; 3) the Nutrient Expert for Maize (NE-Maize) model; and 4) the standard yield goal-based approach used in Virginia for N rate prescription, nitrogen use efficiency (NUE), and corn performance. The VCA uses canopy reflectance from preexisting high and low N areas to determine potential response to additional N fertilizer. Maize-N generates recommendations based on crop and soil-specific input parameters as well as long-term and current season weather data. The NE-Maize model requires input of site and crop specific data, as well as the history of inputs and crop rotation and generates recommendations based on previous result from studies conducted in similar environments. The purpose of this study was to compare N rate recommendations from these various systems for performance and utility in the mid-Atlantic region. A total of seven field trials were conducted from 2012 to 2014 in Virginia each with four replications in a randomized complete block design. Treatments evaluated included a complete factorial of four different pre-plant rates (0, 45, 90 and 134

kg ha^{-1}) with the three different simulation model-prescribed rates and the yield-goal approach applied at sidedress. There were no differences in corn grain yield between the different systems or preplant N rate application at any location. Corn grain and stover N uptake were infrequently affected by treatment, but generally increased with increasing N rate applied, when a difference existed. Partial factor productivity (PFP) of nitrogen generally declined with increasing preplant N rate for all in-season N recommendation systems. The PFP for the in-season N rate recommendations generated from the VCA approach was greatest in four of seven instances with a mean of 68 kg grain kg N^{-1}. Additionally, based on our results the Maize-N model, 56 kg grain kg N^{-1}, also shows promise in this environment. While additional research is needed to validate these findings, producers should consider the use of sidedress N rate decision support tools to increase efficiency of N fertilizer.

INTRODUCTION

Nitrogen (N) is frequently the most limiting factor in cereal crop production and 115 million metric tons of nitrogenous fertilizers are applied annually to support crop production (FAO, 2015). Fertilizer nitrogen use efficiency (NUE), the portion of N fertilizer taken up by the subsequent crop in that year, is estimated to be 33% and 42% for global cereal and US corn production, respectively (Raun and Johnson, 1999). Though global NUE is low, consumption and cost of N fertilizers are generally increasing year to year (Mosier et al., 2004). Therefore, improving NUE and efficiently managing N will benefit both profitability and environmental sustainability of agriculture.

Optimum N rates for corn have traditionally been based on expected yield, adjusted to account for N mineralized from organic sources such as manures, biosolids and legumes (Alley et al., 2009). The rationale for using yield goal to determine N fertilization rate is that each additional unit of N fertilizer produces a yield increase until some other crop production factor becomes most limiting. However, in practice, establishing a yield goal is challenging due to many factors, such as temporal variation in crop N demand, yield potential and soil mineralization that in addition to N rate influence crop yield. Other methods to determine appropriate N rates based on soil testing include the pre-sidedress nitrate test (PSNT) (Binford et al., 1992), relative N mineralization (Stanford and Smith, 1972) and aerobic and anaerobic mineralization analysis (Curtin and Campbell, 2007). While these tests have proven useful, they are generally time and labor intensive and may lack temporal sensitivity.

As scientists have developed a greater understanding of plant N uptake patterns, many have documented increased NUE by matching N supply with crop demand during the season (Aldrich, 1984; Fox et al., 1986; Olson and Kurtz, 1982). This approach often results in less leaching or denitrification losses (Russelle et al., 1981). Therefore, tools that enable refinements to in-season rate recommendations are desirable.

Refining methods to derive the optimum side-dress rate for corn has recently received significant attention and one area that has seen major advances is the use of remote sensing for detecting plant N status, particularly using active sensors (Baloch et al., 2010; Dellinger et al., 2009; Holland and Schepers, 2010; Scharf et al, 2011; Raun et al., 2008). Previous work has reported the successful use of active remote sensing as a tool to determine the optimum sidedress N fertilizer rate and to predict crop yield potential (Teal et al., 2006; Kitchen et al., 2010). They reported the ability to accurately predict the optimum rate in 50% of cases producing an average profit increase of \$25-\$50 ha^{-1}. Relative to the producer's N rate, sensor-based rate recommendations increased partial profit by \$42 ha^{-1}, increased yield by 110 kg ha^{-1}, and reduced average N applied by 16 kg N ha^{-1}. A similar strategy, the VCA, that employs in-season remote sensing as the basis for N rate determination has been developed and validated in Virginia (Thomason, 2011). Because of the inclusion of local and regional data in this algorithm, it was included in our studies.

Boote et al. (1996) stated that the major reasons for operationalizing crop model are research knowledge synthesis, crop system decision management and policy analysis. Our goal was to test potentially useful mechanistic and deterministic models for in-season N rate decision support.

Mechanistic, model-based approaches rely on the input of multiple factors such as previous year and/or current season weather, soil chemical and physical attributes, and crop-specific inputs to estimate in-season corn N need. The Maize-N$^{®}$ simulation model, developed by the University of Nebraska, is designed to estimate the N requirement for corn grown under intensive management and is a subunit of the Hybrid-Maize simulation model (Yang et al., 2006). It also relies on an extensive database of rate-to-response studies paired with historic climate data to develop these estimates. The program predicts corn yield potential, estimates recovery efficiency of applied N fertilizers, and estimates the economically optimal N rate (EONR) of fertilizer for the current corn crop (Yang et al., 2006). While there are many other mechanistic models for N management, the Hybrid-Maize model was included in our studies for several important reasons. The user may edit almost all parameters relevant to model output allowing for local calibration, it is relatively simple to use, and it has been validated in multiple environments.

The Nutrient Expert$^{®}$ (NE) model is a nutrient decision support software that uses the principles of site-specific nutrient management (SSNM) and allows development of field-specific fertilizer recommendations (International Plant Nutrition Institute, 2016). Nutrient Expert$^{®}$ incorporates the most important factors affecting nutrient management recommendations and uses a systematic approach. The algorithm for calculating fertilizer requirements in NE is determined from on-farm trial data using SSNM guidelines (International Plant Nutrition Institute, 2016). The goal of SSNM is to tailor the supply of crop nutrients and management to a specific growing environment (Pampolino et al., 2012). In previous work, the NE recommendation system delivered increased corn yield and profit of farmers in both Indonesia (0.9 Mg ha^{-1}) and the Philippines (1.6 Mg ha^{-1}) (Pampolino et al., 2012). While other models that use similar regional databases exist, the NE for Hybrid Maize database for Southeast Asia includes data from humid subtropical and temperate continental zones and sandy to loamy soils making it particularly suited for testing in Virginia and the mid-Atlantic region.

Nitrogen fertilizer represents one of the most costly crop inputs for corn growers and, because of the detrimental effects of excess N on the environment, one of the most scrutinized. Improving the accuracy of sidedress N rate recommendations for corn can improve profitability and reduce potential negative environmental impacts of over-fertilization.

The objective of this experiment was to compare yield and NUE of side-dress N rates prescribed by: 1) the Virginia Corn Algorithm; 2) the Maize-N® computer simulation model; 3) the Nutrient Expert® for Maize computer simulation model and 4) the standard yield-goal based rate. Our hypotheses were that: 1) grain yield would be similar among models due to adequate N supply; 2) that NUE would be lower for the yield-goal based approach compared to the other systems because it does not include site- or time-specific refinements to the overall recommendation; and 3) that NUE for the VCA would be greatest among the in-season decision support tools because the system was developed specifically for corn production in the mid-Atlantic region.

MATERIALS AND METHODS

Experiments were conducted in throughout Virginia in New Kent County (2012), Virginia Beach, New Kent, and near Blacksburg (Kentland Farm) in 2013. Additional trials were conducted in 2014 at Lottsburg, New Kent and Kentland. All sites were planted into previous crop residue with no-tillage methods. Previous crop was corn at Kentland in both years and soybean at all other locations. Treatments were four different pre-plant N rates (0, 45, 90 and 134 kg N ha^{-1}) applied as urea (46% N) in a factorial with the three different model-prescribed rates and the yield-goal approach. Fertilizer source for all sidedress applications was liquid UAN (30%N). Experimental design was a randomized complete block design (RCBD) with sixteen treatments and four replications with a plot size of 3.1 m x 9.1 m and 0.61 m alley and corn planted in 76 cm rows. Composite surface soil samples (0-15cm) were collected from the experimental area prior to study initiation and resulting standard soil test parameters are shown in Table 2.1. Crop cultivars, seeding rate and field activities are presented in Table 2.2. Other management practices and inputs followed Virginia Cooperative Extension recommendations for corn production (Brann et al., 2000)

The standard side-dress rate was determined based on guidelines in the Virginia Nutrient Management Standards and Criteria (Virginia Department of Conservation and Recreation, 2014). Yield estimates were based on the soil productivity assigned to the dominate soil series for each site. Nitrogen rate recommendations were based on prescribing 1 kg N ha^{-1} for every 56 kg of estimated grain yield ha^{-1} and then subtracting the appropriate amount of pre-plant fertilizer applied, if any.

The Virginia Corn algorithm (VCA) rate was determined from the difference in normalized difference vegetative index (NDVI) from high (134 kg N ha^{-1}) and low (0 N) preplant N reference plots established at planting at each research site to calculate the potential N response index. These readings were collected from the center two rows of the four row plot at approximately the V6 growth stage using a GreenSeeker® 505 handheld sensor unit (Trimble Navigation, Sunnyvale, CA). An average NDVI measurement from each plot that was to receive the VCA-prescribed rate was then used in conjunction with the N response index and the days from planting to derive a different side-dress rate prediction for each pre-plant rate (Jones et al, 2012).

The N fertilizer recommendation developed by Maize-N® is based on user supplied information on the current corn crop, last season's crop, tillage and crop residue management, basic soil properties, fertilizer management and manure application, and long-term weather data from the site (Yang et al., 2006).

The rate recommendations derived from the Nutrient Expert® model are based on input of growing environment characteristics (irrigated, fully rainfed, or rainfed with supplemental irrigation), soil fertility indicators (soil texture, organic matter content, soil test results, etc), crop sequence in the cropping pattern, current yields, crop residue management, and fertilizer inputs (International Plant Nutrition Institute, 2016).

At grain maturity, a 3.1 m section from each of the two center rows was hand harvested and all ears counted and weighed. After removal of the ear in 2013 and 2014, all plants in the harvested area were cut at ground level and weighed. After ear harvest, a five-plant subsample was collected and dried to a constant weight to determine corn stover mass. A six-ear subsample was selected from the total ears collected from each plot and shelled by hand to determine grain weight and moisture. Grain moisture was measured with a dickey-John GAC 2500 (dickey-John, Auburn, IL). Grain yield was adjusted to 155 g kg^{-1} moisture content. From the subsample, the weight of 1000 kernels was determined. The number of kernels per ear was calculated from the product of individual kernel mass and total grain weight divided by number of ears. Grain N was estimated on whole grain subsamples of approximately 50 g using a Foss XDS near infrared analyzer (Foss North America, Eden Prairie, MN). Grain N uptake was calculated as the product of grain N concentration and grain mass. Corn stover N was also estimated with NIR analysis but prior to scanning, Corn stover was dried to a constant weight and then samples were ground to <0.36 mm using a Wylie Mill (Arthur H Thomason Co., Philadelphia, PA). Harvest index (HI) was calculated as the quotient of grain mass divided by the mass of stover plus grain.

Partial factor productivity (PFP) of nitrogen was calculated by dividing the grain mass (kg ha^{-1}) by the total N rate applied (kg ha^{-1}).

Corn grain yield, yield components, grain N uptake, stover mass, stover N uptake, HI and PFP were compared among the standard N, Virginia Corn Algorithm (VCA), Maize-N® and NE-Maize® systems. Analysis of variance using PROC GLM of SAS (SAS Institute, 2011) was conducted to evaluate treatment effects with all factors except replication considered fixed effects. Treatment means were separated using a protected LSD test when F-tests indicated that significant differences existed ($P<0.05$).

RESULTS AND DISCUSSION

Grain yield

Grain yield ranged from 5.8 to 11.5 Mg ha^{-1} among experimental sites (Table 2.3). This range reflects variation in weather, primarily rainfall, among the sites and years. Neither preplant N rate nor in-season N recommendation system affected corn grain yield. This is not unexpected as all approaches seem to have provided N at agronomically appropriate or higher rates. Efficacy of the various in-season recommendation systems of supplying sufficient N has previously been noted for sensor-based systems (Raun et al., 2002), NE-Maize (Pampolino et al., 2012) and Maize-N (Setiyono et al., 2011).

The overall average of 8.7 Mg ha^{-1} is slightly greater than the statewide average yield of 8.4 Mg ha^{-1} over this same period (National Agricultural Statistics Service, 2016) and likely reflects selection of favorable sites within fields and good overall management. Compared with the realistic yield estimates provided in the Virginia DCR nutrient management standards and criteria (Virginia Department of Conservation and Recreation, 2014), measured yields were slightly (0.45 Mg ha^{-1}) greater than would have been forecast for nutrient management inputs.

Side-dress N rate

Sidedress N rate recommendations differed by systems, pre-plant N rates, and the interaction between simulation models and pre-plant N rate at all locations (Table 2.4). All systems recommended decreasing sidedress rates with increasing preplant N application rates, however it is obvious that not all systems accounted for the preplant application in the same manner as the decrease was not uniform across systems. At the zero preplant N rate over locations, the sidedress rates prescribed averaged 122, 170, 185, and 181 kg N ha^{-1}, for the VCA, Maize-N, NE Maize, and standard systems, respectively (Table 2.4). At the greatest preplant rate of 134 kg N ha^{-1}, the sidedress rates prescribed averaged 14, 34, 60 and 46 kg N ha^{-1}, for the VCA, Maize-N, NE Maize, and standard systems, respectively. The lowest recommended rates were generally associated with the VCA and the highest with NE-Maize (Table 2.4). Models developed in other ecoregions may not adequately assess the severity of acute moisture stress that often occurs in these sandy soils with low water holding capacity, resulting in an overestimate of N need. In contrast with the other systems, utilization of in-season canopy sensors with the VCA allowed a more accurate (lower) estimate of temporal N need based on lower estimate of yield potential and current plant N status. Similar results of improved accuracy of in-season N rate needs assessment with in-season remote sensing have been reported for corn (Kitchen et al., 2010; Solari et al., 2008) and wheat (Pavuluri et al., 2015).

Partial factor productivity of nitrogen

Partial factor productivity of preplant N rate did not interact with N sidedress recommendation system at New Kent in 2012 or 2013. At New Kent in 2012,, the highest PFP (averaged over N rates) occurred with the NE-Maize model that produced 55 kg grain kg N^{-1} applied and the lowest PFP occurred with the Maize-N model (32 kg grain kg N^{-1}) (Figure 2.1). In 2013 at New Kent the VCA had the greatest PFP (64 kg grain kgN^{-1}), while the lowest PFP occurred by following the recommendations of the NE-Maize model (44 kg grain kg N^{-1}) (Figure 2.1). In 2013 at Kentland, PFP differed among systems when 0, 45 and 90 kg N ha^{-1} were applied, but not with the highest preplant N rate. The greatest NUE resulted from use of the Maize-N program, followed by the VCA (Figure 2.2a). The Virginia Beach location was the highest yielding trial in the study and the highest PFP was associated with the rates prescribed by the VCA, followed by Maize-N (Figure 2.2b). Setiyono et al. (2011) reported similar increases in NUE when using the Maize-N model for N rate recommendations in the US corn belt while greater NUE for sensor-based N rate recommendation systems has been reported by other researchers (Kitchen et al., 2010; Solari et al., 2008), southern plains (Raun et al., 2002) and coastal plain (Jones et al., 2012) regions.

In 2014 at New Kent, the highest PFP was observed with use of the VCA at 0, 45, and 90 kg ha^{-1} preplant N rates and was equal to Maize-N at the 134 kg ha^{-1} preplant rate (Figure 2.3a). When 134 kg N ha^{-1} was applied preplant, the PFP using the VCA was 87 kg grain kg N^{-1} which was least of any of the other rates, but still greater than the standard assumed efficiency of 56 kg grain kg N^{-1} (Alley et al., 2009). At Kentland, the greatest NUE was similarly associated with use of the VCA, but overall, PFP for the VCA at this site was less (64 kg grain kg N^{-1}) than at New Kent (Figure 2.3b). There was no approach that consistently produced the highest PFP at Lottsburg in 2014 (Figure 2.3c) but PFP for the VCA at this site was still 59 kg grain kg N^{-1}.

Grain N uptake

Preplant N rate did not interact with N recommendation system for grain N uptake, calculated as the product on grain yield and N concentration, at New Kent 2012, Virginia Beach 2013, or Lottsburg 2014. The main effect of preplant N application rate was significant at two locations, New Kent, 2012 and Virginia Beach, 2013 (Figure 2.4). At New Kent, greater N uptake was measured for the 134 and 0 kg N ha^{-1} application rates than the 45 kg N ha^{-1} rate (Figure 2.4). However the absolute difference between these treatments is less than 15 kg N ha^{-1} and the differences detected probably reflect variation at the site and not true differences since lower N uptake is typically associated with lower N application rates. Lowest N uptake at Virginia Beach, 2013 was observed for the 0 preplant rate with no differences between the other preplant rates (Figure 2.4).

This relationship of greater efficiency of N use with lower overall rates is common in all cereals (Ladha et al., 2005) and reflects diminishing returns to higher rates, even if those higher rates result in greater yields or profits.

Significance of the main effect of in-season N rate recommendation system was found at two locations, New Kent, 2012 and Lottsburg, 2014 (Figure 2.5). At Lottsburg, grain N uptake was the least for the VCA, compared to the other systems. A similar trend was observed at New Kent, but uptake in the VCA treatment was similar to the standard and Maize-N systems while lower than the NE-Maize system (Figure 2.5). These results were generally as expected and reflect the overall application rates in most cases. Raun et al. (2002) have also reported greater NUE for sensor-based N rate recommendations (~15% increase) while Ma et al. (2014) in on-farm studies in Canada found no increase in NUE for sensor-based variable rate recommendations compared to fixed rates. They did, however, report greater NUE with split application. Since grain uptake continued to increase after grain yield reached a maximum at New Kent and Lottsburg (Figure 2.5), it is likely that luxury uptake occurred in some instances. An interaction between sidedress recommendation system and preplant N rate for grain N uptake was observed at New Kent, 2013 (Figure 2.6). In general, N uptake was greater when using the NE-Maize system at 0, 90, and 134 kg ha^{-1} preplant rates, but was greatest with the VCA or the standard approach at the 45 kg ha^{-1} preplant rate (Figure 2.6).

Stover biomass and N uptake

Only at Lottsburg in 2014 was corn stover biomass and N uptake affected by N sidedress recommendation. At that site, averaged over preplant N rate, the greatest stover biomass and N uptake were measured for the Maize-N system (Table 2.5). Again this trend likely reflects the mean sidedress N rates prescribed; 80, 129, 123, and 110 kg N ha^{-1} for the VCA, Maize-N, NE-Maize, and standard approaches, respectively.

The least mass and N uptake in stover were associated with 0 preplant N. There were no differences for either mass or uptake between other preplant N rates (Table 2.6).

Harvest index

Harvest index was unaffected by treatment at New Kent 2013, Virginia Beach 2013, or Kentland 2014, where the average harvest indices were 0.59, 0.72, and 0.71, respectively. At Lottsburg, 2014, only the main effect of in-season N recommendation system was significant. Averaged over preplant N rate, the greatest HI (0.64) was observed with the standard sidedress approach and the lowest following the recommendations of the Maize-N system (Figure 2.7). As grain yields among systems were not different, this finding reflects the differences in stover biomass measured at this site (Table 2.5). Harvest index was affected by the main effect of preplant N rate at the New Kent location in 2014 where the greatest HI of 0.68 was measured with 0 kg N ha^{-1} preplant and the lowest HI (0.63) observed when 90 kg N ha^{-1} was applied preplant (Figure 2.8). Similar to what was observed at Lottsburg, this high HI reflects lower biomass; in this case due to zero preplant N.

CONCLUSIONS

There were no differences in grain yield between the different in-season rate determination systems at any location. This indicates that all approaches supplied adequate N to reach environmentally achievable maximum yield. Corn stover N uptake was only affected by these treatments at one location and generally increased with increasing N rate applied. Grain N uptake effects were more common but generally followed the trend of increasing uptake with increasing N rates. At four of seven locations, sidedress rates prescribed by the VCA were significantly less than the other systems, especially at lower preplant N rates. In two of these cases, New Kent, 2012 and Lottsburg, 2014 N uptake in the VCA treatment was less than with the other systems.

There were differences in NUE among the in-season rate recommendation systems as measured by the PFP of nitrogen fertilizer applied. The NE- simulation had the greatest PFP in 2012, but there was only a single environment in this year of testing. In 2013, the Maize-N simulation had greatest PFP at one location while PFP was greatest for the VCA at two sites. In 2014, PFP was greatest for the VCA at two locations while results were mixed at the third. Overall, NUE declined with increasing preplant N rate, generally regardless of in-season N recommendation system. This is not surprising since in-season applications better match N supply with crop demand, resulting in increased NUE. The greatest PFP usually resulted from implementing the in-season N rate recommendations generated from the VCA approach (four of seven locations), though the Maize-N model also shows promise in these environment. Growers should consider new techniques that utilize current season data, such as the VCA, to refine sidedress N rates.

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Table 2.1 Initial surface (0-15 cm) soil chemical characteristics and classification for Kentland, New Kent, Lottsburg and Virginia Beach, 2012-2014.

Location	pH[†]	P[‡]	K[‡]
		---------------mg kg^{-1}-----------------	
Kentland, 2013	6.6	27	119
Classification:	Unison and Braddock soils (fine, mixed, semiactive, mesic Typic Hapludults)		
Kentland, 2014	6.6	36	133
Classification:	Unison and Braddock soils (fine, mixed, semiactive, mesic Typic Hapludults)		
New Kent, 2012	7.0	11	127
Classification:	Tetotum loam (fine-loamy, mixed, semiactive, thermic Aquic Hapludults)		
New Kent, 2013	6.9	58	115
Classification:	Altavista-Dogue complex (fine –loamy, mixed, semiactive, thermic Aquic Hapludults)		
New Kent, 2014	6.5	13	108
Classification:	Tetotum loam (fine-loamy, mixed, semiactive, thermic Aquic Hapludults)		
Lottsburg, 2014	6.5	70	120
Classification:	Woodstown fine sandy loam (fine-loamy, mixed, active, mesic Aquic Hapludults)		
Virginia Beach, 2013	5.8	45	108
Classification:	Nimmo loam (coarse-loamy, mixed, semiactive, thermic Typic Endoaquults)		

[†] pH: 1:1 Soil: Water

[‡] P and K: Mehlich III extraction

Table 2.2 Field activities and hybrid listing for experiments at New Kent, Virginia Beach, Kentland, Lottsburg, VA, 2012-2014.

Field Activity	New Kent			Virginia Beach	Kentland farm		Lottsburg
Planting date	4/25/2012	4/24/2013	4/28/2014	4/15/2013	5/3/2013	5/19/2014	4/24/2014
Hybrid	Pioneer Brand P1184AM1	Dekalb DKC 65-19	Dekalb DKC 65-19	Pioneer Brand P1319 HR	Mid Atlantic 5120GT3VIP	Mid Atlantic 5091GT3VIP	Pioneer Brand P0604AM1
Seeding rate, seeds ha^{-1}	66,700	66,700	66,700	88,900	69,200	69,200	70,000
Preplant N fertilization date	4/30/2012	5/4/2013	4/28/2014	5/4/2013	5/13/2013	5/19/2014	4/24/2014
Side dress N fertilization date	6/4/2012	6/5/2013	6/10/2014	6/6/2013	6/20/2013	6/25/2014	5/27/2014
Harvest date	8/29/2012	9/10/2013	9/19/2014	8/29/2013	10/8/2013	10/26/2014	9/4/2014

Table 2.3 Corn grain yield by experimental location, 2012-2014.

Year	Site	Grain Yield, Mg ha^{-1}	Estimated yield potential, Mg ha^{-1}†
2012	New Kent	7.7	9.4
2013	New Kent	9.2	11.3
	Virginia Beach	11.5	10.7
	Kentland	5.8	9.4
2014	New Kent	10.3	11.3
	Lottsburg	10.2	9.4
	Kentland	6.5	9.4

† Virginia Department of Conservation and Recreation, 2014

Table 2.4. Analysis of variance and sidedress N rate applied by system and preplant N rate, Kentland, Virginia Beach, and New Kent, VA. 2013; and Kentland, Lottsburg, and New Kent, VA. 2014.

Year	Location	Preplant N rate	VCA	Maize-N	NE-Maize	Standard
2012	New Kent	0	137	222	130	168
		45	78	174	92	123
		90	62	134	54	78
		134	45	92	18	34
2013	New Kent	0	146	168	224	202
		45	112	123	190	157
		90	78	78	146	112
		134	34	34	112	67
2013	Virginia Beach	0	112	168	202	190
		45	67	112	168	146
		90	34	78	134	101
		134	0	34	90	56
2013	Kentland	0	112	78	190	168
		45	78	34	145	123
		90	34	0	100	78
		134	0	0	55	34
2014	New Kent	0	101	190	168	202
		45	56	112	101	157
		90	0	45	78	112
		134	0	0	34	67
2014	Lottsburg	0	134	235	190	168
		45	112	168	146	123
		90	56	90	101	78
		134	17	22	56	34
2014	Kentland	0	112	134	190	168
		45	67	101	146	123
		90	22	78	101	78
		134	0	56	56	34
Sources				Pr>f		
System		***	***	***	***	***
Preplant N		***	***	***	***	***
System*PreN		***	***	***	***	***

***,**, * significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant; Pre N- Preplant N rate; VCA- Virginia Corn Algorithm; NE-Maize- Nutrient Expert-Maize simulation model; Standard- Virginia Standard.

Table 2.4 Corn stover mass and N uptake by in-season N rate recommendations system, averaged over preplant N rates, Lottsburg, 2014.

System	Stover mass		Stover N uptake	
	-----------kg ha^{-1}-----------			
VCA	5393	B	34	B
Maize-N	6374	A	43	A
NE-Maize	5785	AB	37	B
Standard	5195	B	33	B

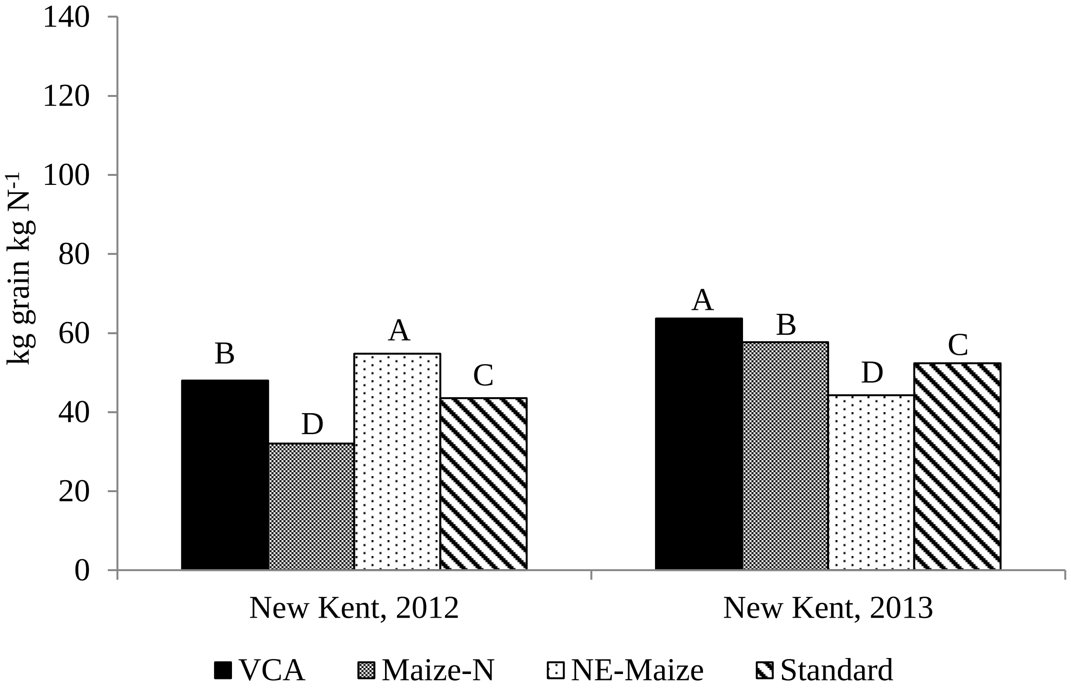
Means within a column followed the same letter are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.
VCA- Virginia Corn Algorithm.

Table 2.5 Corn stover mass and N uptake by preplant N rate, averaged over in-season N rate recommendation system, Lottsburg, 2014.

Preplant N rate	Stover mass		Stover N uptake	
--------------------------kg ha^{-1}------------------------------				
0	5112	B	32	B
45	6180	A	41	A
90	5804	AB	37	AB
134	5652	AB	37	AB

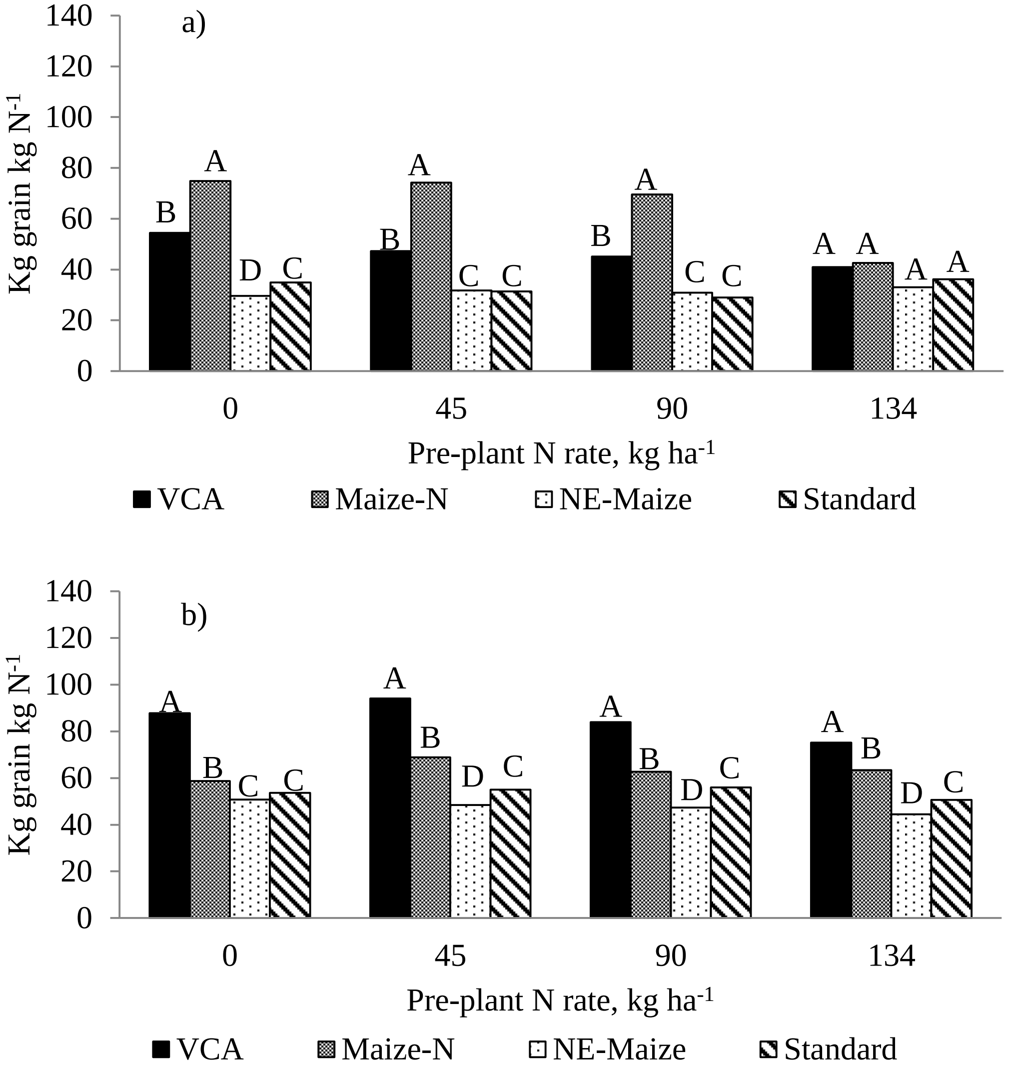
Means within a column followed the same letter are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.
VCA- Virginia Corn Algorithm.

Figure 2.1 Partial factor productivity of nitrogen of four in-season N sidedress recommendations systems at New Kent, 2012 and 2013.



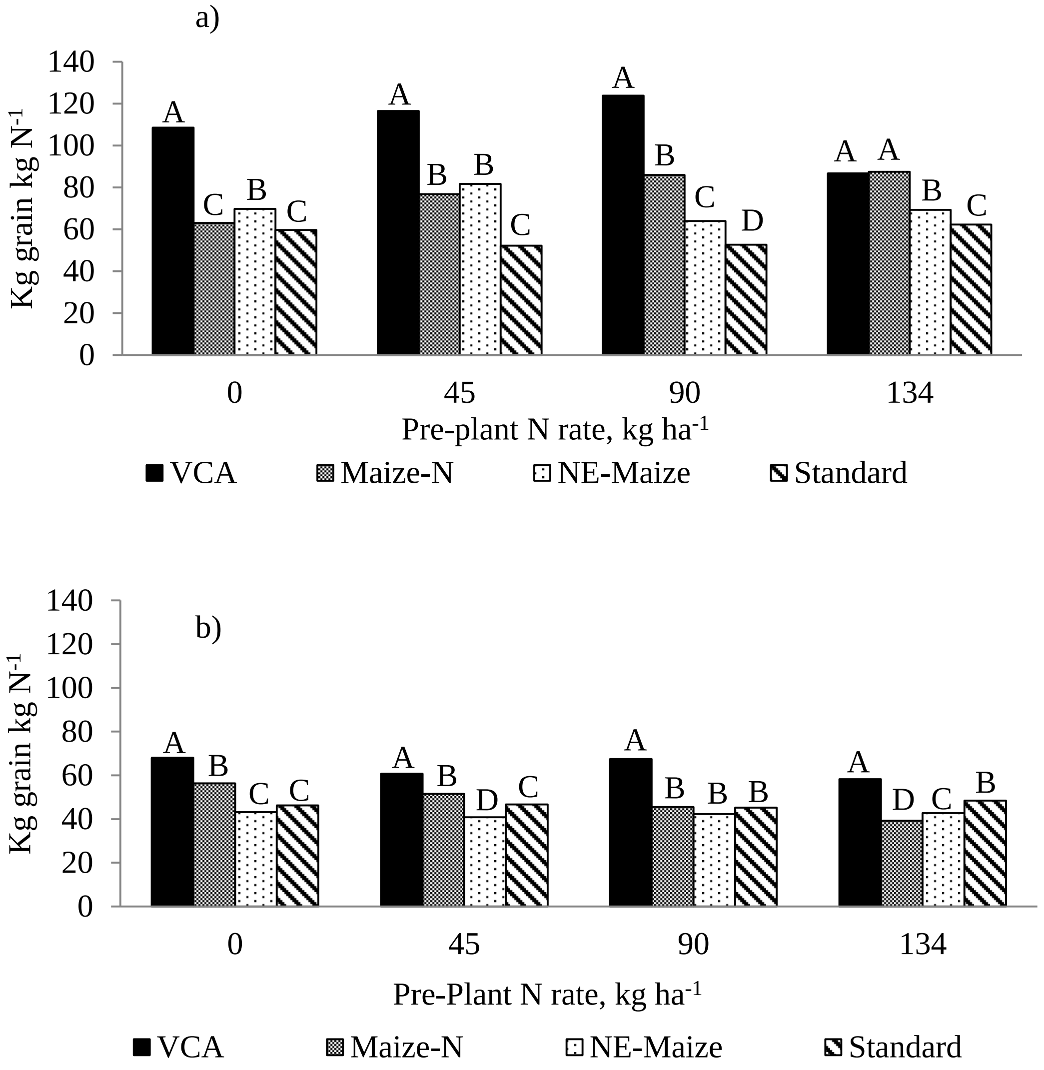
§ Means within a column for a given location followed by the same letter are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.
VCA- Virginia Corn Algorithm; NE-Maize- Nutrient Expert-Maize simulation model; Standard-Virginia Standard;

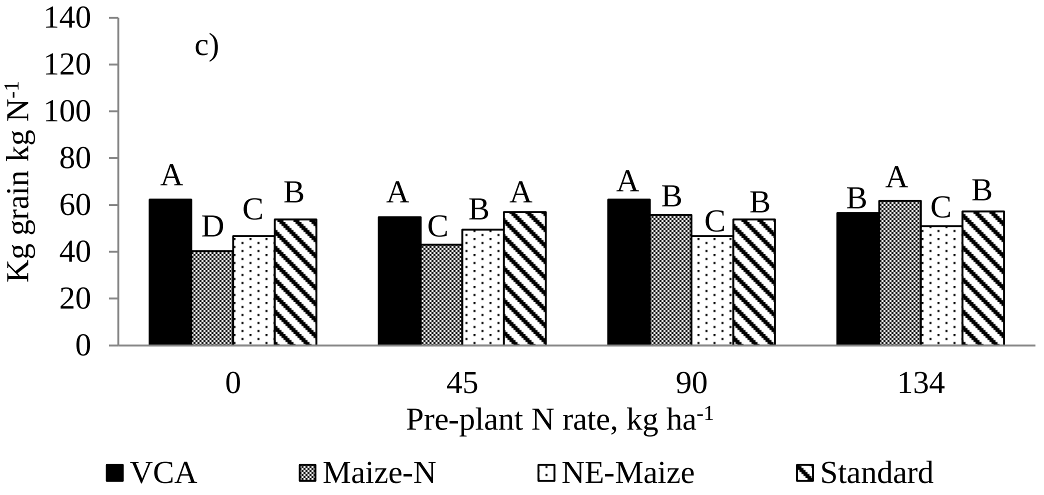
Figure 2.2 Partial factor productivity of nitrogen of four in-season N sidedress recommendations systems at four preplant N rates, Kentland (a) and Virginia Beach (b), 2013.



Columns labeled with the same letter within a preplant rate are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.
VCA- Virginia Corn Algorithm.

Figure 2.3 Partial factor productivity of nitrogen of four in-season N sidedress recommendations systems at four preplant N rates, New Kent, (a), Kentland (b) and Lottsburg (c), 2014.

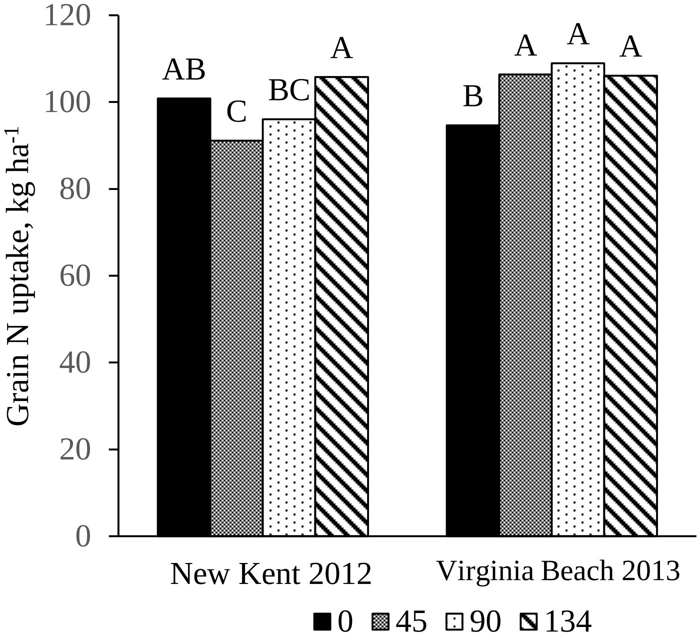




Columns labeled with the same letter within a preplant rate are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.

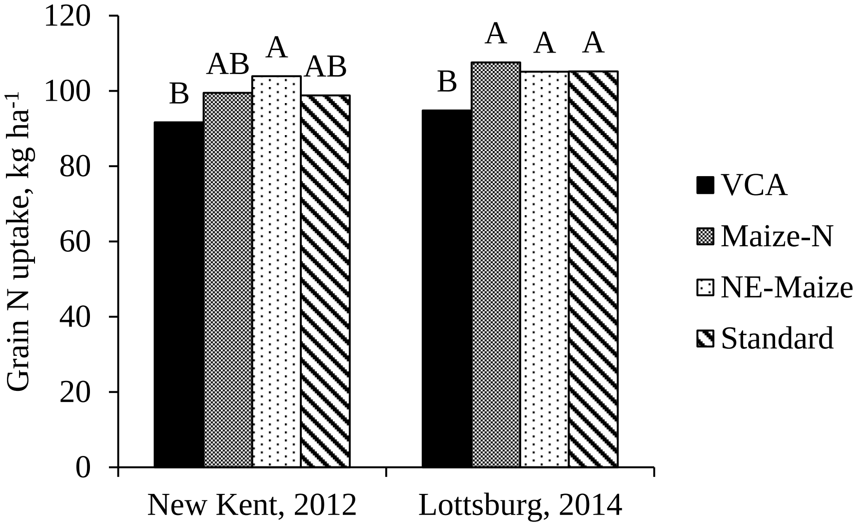
VCA- Virginia Corn Algorithm.

Figure 2.4 Grain N uptake by preplant N rate (kg ha^{-1}), over system at New Kent, 2012 and Virginia Beach, 2013.



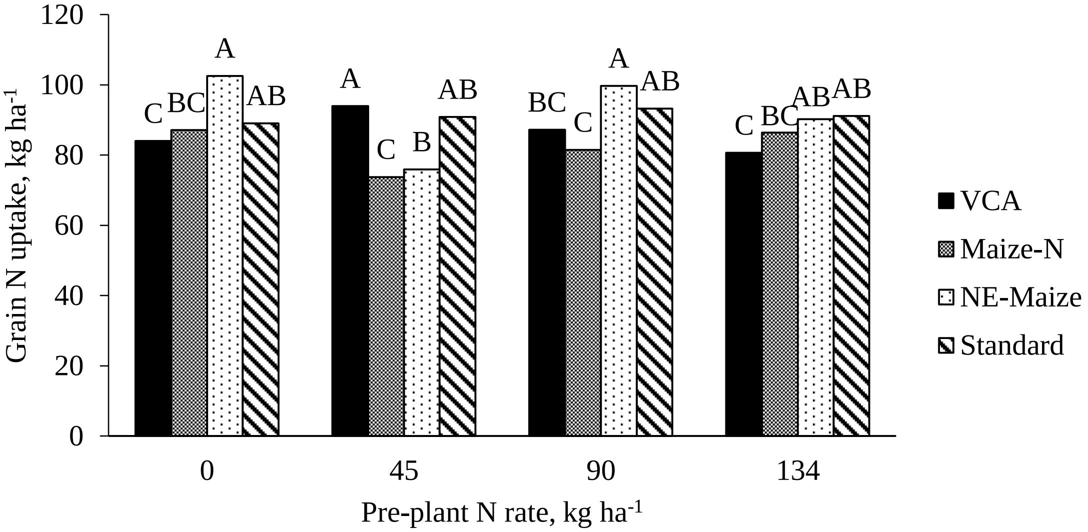
Columns labeled with the same letter within a location are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.

Figure 2.5 Grain N uptake of four in-season N sidedress recommendations systems, averaged over preplant N rate at New Kent, 2012 and Lottsburg, 2014.



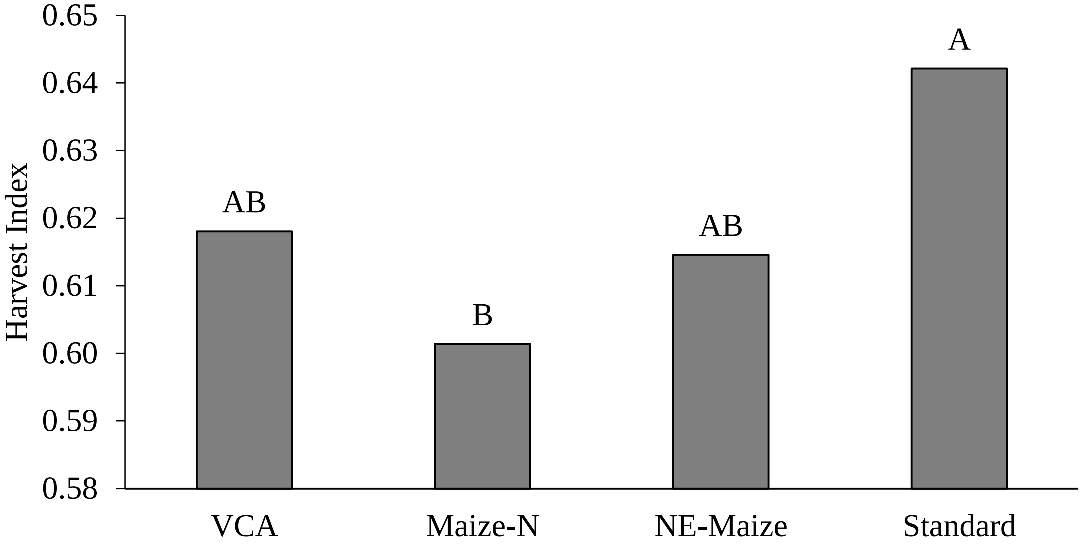
Columns labeled with the same letter within a location are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.
VCA- Virginia Corn Algorithm.

Figure 2.6 Grain N uptake of four in-season N sidedress recommendations systems at four preplant N rates, New Kent, 2013.



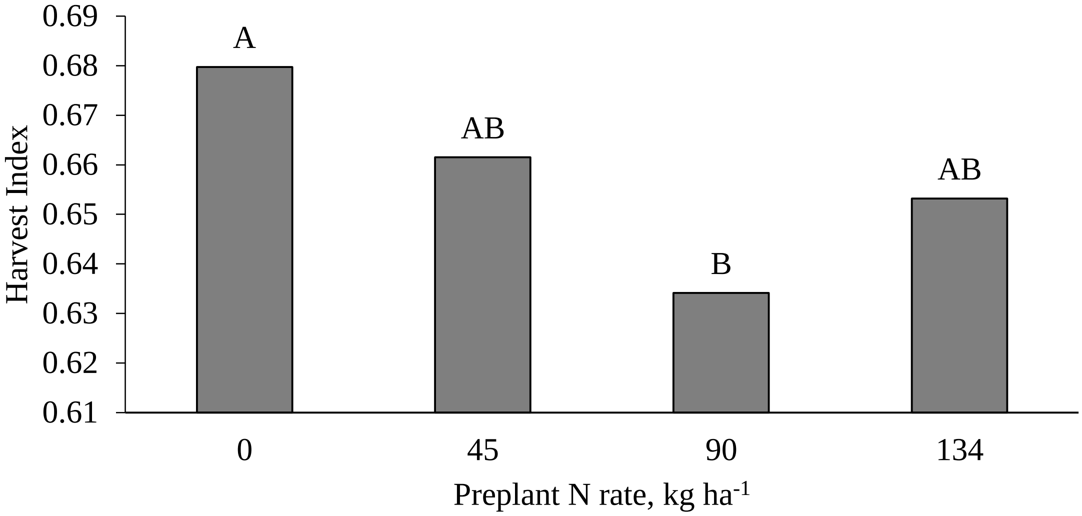
Columns labeled with the same letter within a preplant rate are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.
VCA- Virginia Corn Algorithm.

Figure 2.7 Harvest index by in-season N rate recommendation system, averaged over preplant N rate, Lottsburg, 2014.



Columns labeled with the same letter within a recommendations system are not significantly different at the 0.05 probability level using Fisher's protected least significant difference. VCA- Virginia Corn Algorithm.

Figure 2.8 Harvest index by preplant N rate, averaged over in-season recommendation, New Kent, 2014.



Columns labeled with the same letter within a preplant N rate are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.

Chapter 3

Comparison of full-season and double-crop soybean and grain sorghum systems in central and southeast Virginia

ABSTRACT

Full-season and double-crop soybean (*Glycine max* L.), usually grown after a small-grain crop, is a common practice in the Mid-Atlantic region. Grain sorghum (*Sorghum bicolor* L. Moench) is an alternative to soybean and its production in the region is increasing due to greater local demand for feed grains. The objective of this experiment was to evaluate and compare the yield and agronomic characteristics of grain sorghum planted full-season or double-cropped after wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) or triticale (*x Triticosecale*) with soybean in the same rotations. A total of four field experiments were conducted in Virginia in 2012-2014. At three of four site-years, full-season grain sorghum yields were greater than double-crop sorghum, while this was true in half of trials for soybean. Double-crop grain sorghum averaged over 2.9 Mg ha^{-1} indicating has a strong potential for this use in the region. Estimated net return to land and management was generally greater for soybean than sorghum except sorghum double-crop following triticale. The greatest net return was estimated for soybean double-cropped following wheat (\$745.64 ha^{-1}), and the lowest net return was sorghum following barley (\$189.55 ha^{-1}), due to the lower sorghum grain yield and the lower value of barley.

INTRODUCTION

In the Mid-Atlantic Coastal Plain region of the United States of America, the most prevalent cropping systems are a three crop in two year rotation of corn (*Zea mays* L.), barley or wheat, double-cropped with soybean or a four crops in three years rotation of full-season soybean, corn, wheat or barley and double-crop soybean (Jones et al., 2003). An advantage of the latter system includes decreased risk of soybean crop failure due to multiple planting dates (Camper et al, 1972) and both systems benefit from intensification of production per unit of land (Caviglia et al., 2011).

Compared to corn, grain sorghum has greater water use efficiency, greater drought tolerance and requires less N fertilization to reach maximum yield (Geng et al., 1989; Bennett et al., 1990). Brann et al. (2000) stated that on soils in the Coastal Plain with low holding capacity, sorghum could be a viable alternative for corn. Despite some potential advantages, sorghum production and land area have decreased over time in Virginia and the Mid-Atlantic region.

Grain sorghum has the potential to fit in several niches within our current row crop rotation, including planted in May (full-season) or planted following small grains in June (double-cropped). Recent research in Iowa compared yields of 12 different sorghum genotypes grown either full-season or double-cropped following triticale (Triticosecale *hx*) (Goff et al., 2009). These authors reported similar grain sorghum yields between the full-season and double-crop systems with significant variation among sites. The authors also note hybrid characteristics that favor the double-crop system; specifically early maturity (Goff et al., 2009).

Yields from grain sorghum trials conducted in Virginia in the early 1990’s typically ranged from 2,000 to 3,000 kg ha^{-1} (Ball et al., 1990; 1991). Yields of over 6,000 kg ha^{-1} have been reported in more recent work in Virginia (Balota et al., 2015), however average yields in studies conducted in Virginia and North Carolina in 2009-2010 were slightly greater than 3,100 kg ha^{-1} (Balota et al., 2011) and over 4,000 kg ha^{-1} over five locations in 2012 (Balota et al., 2012). Balota et al. (2014) also stated that even in a favorable temperature and rainfall, double-crop sorghum produced no more than 4,700 kg ha^{-1}. Grain sorghum planting dates from May 1 to July 1 have all proven successful in achieving acceptable yields in Virginia and North Carolina, so there is a wide range of appropriate planting dates for sorghum (Heiniger et al., 2009). The Mid-Atlantic sorghum production handbook lists optimum planting dates for sorghum from May 10 to June 15, with double-crop sorghum planted as late as July 10. There is an increasing risk of fall frost damage from plantings that occur after July 10.

Previous work with double-crop soybean in Virginia (Camper et al., 1972) and Kentucky (Herbek and Bitzer, 1998) have noted several advantages over full-season soybean alone. Both studies demonstrated that soybean yields were greater following barley than following wheat. Recent work over two seasons comparing double-crop soybeans following either wheat or barley in Virginia concluded that soybean grown after barley yielded more than full-season soybean in two of six locations and more than soybean double-cropped after wheat in three of six locations (Browning, 2011). Net returns for the barley-soybean system were greatest and greater soybean yields were attributed to the earlier planting following barley. Grain sorghum may benefit from the same potential advantages if planted earlier, but more research is needed to quantify any impact.

The objective of this experiment was to evaluate and compare yield and agronomic characteristics of grain sorghum planted either full-season or double-cropped after wheat, barley or triticale with soybean in these same rotations. Based on these results, the relative profitability of sorghum grown full-season and double-cropped with various small grains compared with soybean are reported. Our hypotheses were that: 1) double-crop soybean and grain sorghum would produce lower yields than full-season plantings; 2) earlier harvest of barley and earlier planting would result in greater double-crop yields than those measured after wheat or triticale; and 3) double-crop systems would be more profitable than single crop systems, due to the additional small grain value.

MATERIALS AND METHODS

Two experiments were conducted in each year from 2012 to 2014, one at the Tidewater Agriculture Research and Extension Center (TAREC) near Suffolk, VA on a Eunola loamy fine sand (fine-loamy, silicious, thermic Aquic Hapludults) and the other at the Southern Piedmont Agriculture Research and Extension Center (SPAREC) near Blackstone, VA on an Appling sandy loam (Fine, kaolinitic, thermic Typic Kanhapludults). Treatments were either soybean or grain sorghum grown full-season, or double-cropped after triticale, barley, or wheat. Treatments were arranged in a split-plot design, with winter small grain crop (barley, triticale or wheat) as the main plot and sorghum or soybean as the subplot. There were a total of fourteen treatments with four replications with final sub-plot size of 3.66 m x 6.10 m and 6.10 m of alley. Monthly average temperature and precipitation for both years are shown in Figures 3.1 and 3.2.

Winter small grains were planted at a rate of 325 seeds m^{-2} in 0.19 m rows using a no-till grain drill. Small grain cultivars were: ‘Thoroughbred’ barley, ‘Merl’ soft red winter wheat, and ‘Trical 336’ triticale. Soybean and grain sorghum were planted in 0.38 m rows using this same drill at Blackstone and using a Hege cone planter (Wintersteiger Inc., Salt Lake City, UT) at Suffolk. The sorghum seeding rate was 35 seeds m^{-2} both full-season and double-crop, while soybean seeding rates were 40 and 59 seeds m^{-2} for the full-season and double-crop soybean, respectively. The soybean cultivar was 'Mid-Atlantic 4666NRR' while the sorghum cultivar was DEKALB 'Pulsar'. Other agronomic practices followed Virginia Cooperative Extension recommendations (Brann et al., 2000). Composite soil samples (0-0.15 m) were collected from the experimental area prior to initiation of the studies and standard soil test parameters at each site are shown in Table 3.1. Planting and harvest dates at both locations from 2012-2014 are listed in Table 3.2. Small grain received a total of 134 kg ha^{-1} of N and 36 kg ha^{-1} K_2O. Total grain sorghum N rates were based on the guidelines outlined in the Virginia Nutrient Management Standards and Criteria (Virginia Department of Conservation and Recreation, 2014). Sorghum received 112 kg N ha^{-1} as urea, 27 kg P_2O ha^{-1} as diammonium phosphate (DAP) and 34 kg K_2O ha^{-1}, respectively at planting. Soybean received 27 kg P_2O ha^{-1} as DAP and 34 kg K_2O ha^{-1} prior to planting at all locations and years. Other agronomic practices followed Virginia Cooperative Extension recommendations for pest and weed control (Herbert and Hagood, 2016). No insecticide applications were made during the course of this study. Before grain sorghum harvest, plant height to the top of the spike and the top of the stem were measured from 5 plants in each plot. At grain maturity, all plants from 0.91 m of the two center rows were hand-cut at ground level from each plot and from these samples, total dry weight, stalk weight, plant population density, and grain weight was determined. For soybean, lodging was determined using a scale of 1-10 (1=no lodging; 10=completely lodged) and also plant height were recorded in each plot just prior to harvest. At harvest, all plants from 0.91 m from the two center rows were hand-cut at ground level from each plot and from these samples, total wet weight and plant population density were measured and subsamples of soybean samples were measured after drying the samples and yield component such as pod per meter square, seed per pod and 250 seed weight was measured to calculate grain yield.

Profitability estimates of full-season and double-cropped sorghum and soybean were determined using the Virginia Crop Decision Aid Generator (Groover et al., 2013). The prices for barley, triticale, wheat, soybean and sorghum were determined by the average of the previous five years (2010-2014) commodity price in Virginia (National Agricultural Statistics Service, 2016). The price of triticale was determined using 85% of the average price of barley and the price for sorghum was determined by using 95% of the average price of corn in Virginia over the five year period. These ratios were used because no local price data exist for these crops in Virginia and that they reflect the current strategies of grain buyers in southern and southeastern Virginia. Since no generic triticale budget exists within the Virginia Crop Decision Aid Generator the Intensive wheat management budget was used, with fungicide application omitted. Gross receipts, return over variable costs, and net return to land and management by cropping system were calculated. Analysis of variance was performed using PROC GLIMMIX of SAS (SAS Institute, 2011) was used to evaluate treatment effects with all factors except replication considered fixed effects. Treatment means were separated using the PDIFF option (t-test) of the LSMEANS statement when F-tests indicate that significant differences existed ($P<0.05$). Single-degree of freedom contrasts were used to determine significant differences between full-season and double-cropped systems.

RESULTS AND DISCUSSION

Small grain yield

Mean yields of barley, triticale and wheat were 3,804, 3,068 and 3,573 kg ha^{-1}, respectively (Table 3.3). In general, these yields were less than the five-year Virginia average of 4,449 and 4,462 kg ha^{-1} reported for barley and wheat, respectively (National Agricultural

Statistics Service, 2016), but typical of small grain production with yield of barley>wheat>triticale (Thomason et al., 2015). In addition to the price that was estimated for the various small grain crops, these yields have a major influence on our estimates of profitability of the overall system and reflect appropriate, intensive management for each crop.

Soybean yield and yield components

Full-season soybean yield averaged 1,480 and 1,386 kg ha^{-1} and double-crop soybean yields averaged 1,201 and 2,127 kg ha^{-1} at SPAREC and TAREC, respectively, over the two years of the experiment. Similar to small grain yields, these yields were lower than the five-year Virginia average of 2,614 kg ha^{-1} (includes both full-season and double-crop yields), but lower yields for most crops were expected because of the lower yield potential of the soils used in these experiments. Full-season soybean yield was 1,897 and 1,837 kg ha^{-1} at SPAREC and TAREC, respectively, in 2013. Double-crop soybean planting at SPAREC in 2013 failed due to acute drought stress after planting and weed competition. At TAREC in 2013, double-cropped soybean yields were similar when following wheat or triticale, but significantly lower when following barley (Table 3.4). Ignoring soybean following barley, there was no difference between full-season and double-crop soybean yields (Table 3.4). Full-season soybean yield at SPAREC in 2014 was 1,062 kg ha^{-1}, while double-crop soybean yields varied from 1363 kg ha^{-1} following barley to 1,062 kg ha^{-1} after wheat (Table 3.5). Soybean following barley was planted approximately two weeks earlier than following wheat or triticale (Table 3.2). Earlier planting opportunity often results in greater yields (Herbek and Bitzer, 1998; Browning, 2011) due to a longer period for soybean vegetative growth and greater rainfall during the grain fill period that is often encountered with this planting system. No differences in full-season and double-crop soybean yields were detected (Table 3.5). This is in contrast to the general finding that full-season soybean yields are usually greater (LeMaheiu and Brinkman, 1990; Sanford et al., 1986; Wesley, 1999). Due to unfavorable weather conditions in mid-late summer, soybean yields were limited and these environmental limitations likely explain the lack of differences between full-season and double-crop soybean.

Full-season and double-soybean yield differed at TAREC in 2014 but yields were similar for all double-crop soybean treatments, regardless of prior small grain crop (Table 3.5). The lower yield for full-season soybean at this site is likely due to the distribution of rainfall in 2014 (Figure 3.2). Rainfall in July was 150 mm which was favorable for both full-season and double-crop plantings, but the site received less than 50mm rainfall in August. Full-season soybean were setting pods and filling seed during this period of water stress, which resulted in abortion of some pods and seeds and loss of yield potential. Double-crop plantings matured later and more rainfall in September provided for more favorable conditions.

Browning (2011) reported that lesser soybean yields associated with delayed plantings were often associated with reduced number of pods m^{-2}. There were significant differences in pod number m^{-2} between soybean double-cropped after barley (602 pod m^{-2}) and wheat (833 pod m^{-2}) at TAREC in 2013 (Table 3.4). This is likely due to severe early-season Texas panicum (*Panicum texanum* L.) infestation. Pods m^{-2} were greater for double-crop soybean than full season at this site as well, also matching observed differences in grain yield. In 2014, there were no significant differences in pod number for double-cropped soybean regardless of previous small grain crop at either site, nor did the number of pods differ between full-season and double-crop soybean at SPAREC (Table 3.5). There were significantly more pods m^{-2} with double-crop compared to full-season soybean at TAREC, 2014 (Table 3.5), which relates well to yield.

Browning (2011) reported a strong relationship between final soybean grain yield and the number of pods m^{-2}. This author also emphasized the importance of adequate and timely rainfall for maintaining pod numbers.

The number of seeds pod^{-1} were similar in double-crop plantings within a year, regardless of the preceding small grain type (Tables 3.4 and 3.5). However, the number of seeds pod^{-1} was less for full-season plantings at all site-years where comparison was possible (Table 3.4 and 3.5). Full-season soybean yields were either lower (TAREC) or similar (SPAREC) to double-crop yields as well. In previous work in the region, Browning (2011) reported a range in number of seeds pod^{-1} of 1.4 to 3.3 with an average of 2.01 for full-season soybean. In an extensive study of double-crop soybean management practices, Dillon et al (2014) reported an average of 2.1 seeds pod^{-1} with yield levels of 2.4 to 5.1 Mg ha^{-1}.

Soybean plant height was affected by previous small grain in two instances (Figure 3.3), but there was no consistent trend. Full-season soybean was taller than double-crop soybean at TAREC, 2014 and those after barley were taller than after wheat or triticale. This is a common occurrence in these cropping systems as earlier planted soybean often accumulates more growth due to the longer vegetative growth period (Herbek and Bitzer, 1998). The relationship between taller soybean plants and final grain yield was not consistent. In some cases, taller plants produced greater yields (e.g. TAREC, 2013) but in others (TAREC, 2014) they did not.

Grain sorghum plant measures and grain yield

Plant population

The number of plants ha^{-1} at SPAREC in 2013 were greater for full-season sorghum compared to the mean of the double-crop systems, however no difference were noted among the preceding small grain crop type (Table 3.6). The same seeding rate (35 seeds m^{-2}) was used for both plantings but lower germination and greater seedling death resulted in reduced double-crop stands. The reduced stand may reflect interplant competition from the high seeding rate, but environmental conditions were likely much more impactful. Rainfall occurred at this location just prior to the double-crop planting date but conditions afterward were quite dry, impacting early season development (Figure 3.1). At TAREC in 2013, grain sorghum plant population was similar among small grain crop types but was greater for double-crop compared to full-season (Table 3.6). In 2014, plant population at SPAREC was similar across treatments (Table 3.7). At TAREC fewer plants were found in the full-season planting compared to double-crop. Within the double-crop plantings, more plants were observed after triticale (34 plants m^{-2}) than for barley (24 plants m^{-2}) (Table 3.7). Overall, few consistent effects of cropping system treatment were observed for grain sorghum plant population. The differences observed in the current study were much more likely attributable to acute drought stress that affected either full-season or double-crop plantings.

Stalk mass

There were no significant differences in double-cropped grain sorghum stalk biomass among previous small grain crops (Tables 3.6 and 3.7). Full-season sorghum stalk biomass was greater than the mean of the double-cropped systems in all four studies. Almodares and Darany (2006) report a similar trend of greater sweet sorghum stem biomass and stem diameter associated with earlier planting dates.

Harvest Index

Harvest index (HI) at SPAREC in 2013 was low for all cropping systems (mean of 0.23) but was greater for full-season sorghum than double-crop sorghum (Table 3.6). Greater HI for full-season sorghum was observed in three of the four experiments (Tables 3.6 and 3.7). Similar to the trends observed for grain yield, HI was greatest after barley at TAREC in 2013 and least after triticale at TAREC in 2014. Prihar and Stewart (1991) reported that in studies conducted in Texas, HI was independent from plant mass indicating that large plant size is not essential to producing high grain yields. Harvest index in these studies was typically lower than the values reported by Prihar and Stewart (1991) but would support the independence of plant mass and HI.

Plant height

In 2013, full-season grain sorghum was taller than the mean of the plant height measured in the double-crop systems (Figure 3.4). In 2014, full-season sorghum was taller than double-crop at TAREC but smaller at SPAREC. In general, the systems that had the tallest plants also had the greatest sorghum grain yield (Tables 3.6 and 3.7). This is inconsistent with the lack of a relationship observed between HI and grain yield in sorghum in this study and by Prihar and Stewart (1991). It is likely that taller plants reflect the presence of a vigorous, main stem tiller which could contribute significantly to increased grain yield. So while the total plant mass may include a number of tillers that contribute little to final grain yield, plant height may be a strong indicator of grain yield potential in this environment.

Spike length

The spike length of double-cropped sorghum was less than full-season at SPAREC in 2013 and TAREC in both years (Figure 3.5). At SPAREC 2013, sorghum spike length was greater when planted after barley (20.4 cm) than after triticale (18.9 cm) (Figure 3.5). Heinrich et al. (1983) evaluated grain sorghum yield components under 14 environments and reported a strong relationship between seeds m^{-2} and grain yield, but weak correlation with final yield and seeds $head^{-1}$. Therefore, it is unlikely that the size of the main spike alone will be useful for estimating grain yield potential.

Net returns

When viewed over all trial results, gross receipts for double-cropped soybean following barley were greater (\$1,789 ha^{-1}) than sorghum (\$1,436 ha^{-1}), but the highest gross receipts were associated with double-cropped soybean following wheat, which was \$2,147 per hectare (Table 3.8). Browning (2011) reported greater returns to soybean produced after barley than after wheat, but those authors used different price assumptions. Lowest gross values were associated with single crop (full-season) for both crops, due to the lack of additional sales from double-cropping. Return over variable input costs for soybean ranged from \$1,054 double-cropped after wheat to \$560 ha^{-1} when double-cropped after triticale. Grain sorghum also had the greatest return above variable costs when grown after wheat, but the lowest return when grown as the sole crop (Table 3.8). The highest net return to land and management was double-cropped soybean following wheat (\$746 ha^{-1}). The lowest net return was to double-cropped sorghum following barley, which was \$190 ha^{-1} and the lowest return over variable costs was full-season sorghum (\$469 ha^{-1}). In general, the net return to soybean in different cropping systems was higher than sorghum, except double-cropped sorghum following triticale. Camper et al. (1972) working in Virginia also found double-crop soybean to be more profitable than double-crop sorghum, when planting after June 25.

CONCLUSIONS

Grain sorghum was successfully produced in both full-season and double-crop settings at all trial locations. This indicates a wide range of adaptation to planting dates and preceding crops. In three of four instances, full-season sorghum yields were higher than yields when double-cropped after small grain. Double-crop sorghum yields were similar when grown after either wheat or barley, even when planting after barley occurred earlier. This likely indicates that grain sorghum is less sensitive to planting date in a double-crop system than soybean. Final yields and overall success depends heavily on local weather, especially rainfall patterns.

In the mid-Atlantic region, full-season soybean typically yields more than double-crop plantings, but in our studies there was no difference in yields between planting system in two experiments. Double-crop soybean yields were higher in one instance. Again, this reflects the weather and rainfall patterns experienced in these studies and highlights the over-riding influence of rainfall over other management practices.

Based on our price assumptions and measured yields, the most profitable cropping system choice was wheat-soybean. Similarly, the most profitable system including grain sorghum was wheat-sorghum double-crop. Price estimates for the various commodities strongly influence these outcomes, however and individual decisions about cropping system choices should use local prices, when possible.

Overall, it appears that soybean and grain sorghum can be successfully grown both full-season and double-cropped after small grain in this region. Commodity prices and other management consideration will likely determine the mix and extent of both crops.

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Table 3.1 Initial surface (0-0.15m) soil chemical characteristics and classification at Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, prior to study initiation.

Location	pH[†]	Total N[§]	Organic C[§]
SPAREC	6.1	1.2	20.6
Classification	Appling fine sandy loam (fine, kaolinitic, thermic Typic Kanhapludults)		
TAREC	5.5	0.6	6.0
Classification	Eunola loamy fine sand (fine-loamy, silicious, thermic Aquic Hapludults)		

[†] pH: 1:1 Soil: Water

[§] Total N and Organic C: Elementar CN dry combustion analyzer

Table 3.2 Planting and harvest dates for experiments at Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, in year 2012-2013 and 2013-14.

Crops	**Year 2012-2013**				**Year 2013-2014**			
	Planting Date		**Harvest Date**		**Planting Date**		**Harvest Date**	
	TAREC	**SPAREC**	**TAREC**	**SPAREC**	**TAREC**	**SPAREC**	**TAREC**	**SPAREC**
Triticale	22-Oct	7-Nov	10-Jul	26-Jun	21-Nov	19-Dec	12-Jun	23-Jun
Wheat	22-Oct	7-Nov	10-Jul	26-Jun	21-Nov	19-Dec	12-Jun	23-Jun
Barley	22-Oct	7-Nov	6-Jun	26-Jun	21-Nov	19-Dec	5-Jun	18-Jun
FS† Soybean	15-May	14-May	8-Oct	8-Oct	22-May	23-May	16-Oct	16-Oct
FS Sorghum	16-May	14-May	19-Sep	19-Sep	22-May	23-May	16-Oct	16-Oct
DC Soybean after Barley	20-Jun	16-Jul	8-Oct	na	23-Jun	2-Jul	14-Nov	14-Nov
DC Sorghum after Barley	20-Jun	16-Jul	8-Oct	7-Nov	23-Jun	2-Jul	14-Nov	14-Nov
DC Soybean after Wheat and Triticale	16-Jul	16-Jul	7-Nov	na	8-Jul	2-Jul	14-Nov	14-Nov
DC Sorghum after Wheat and Triticale	16-Jul	16-Jul	7-Nov	7-Nov	8-Jul	2-Jul	14-Nov	14-Nov

†FS – Full Season; DC – Double-cropped; na – not available.

Table 3.3 Average winter barley, triticale, and wheat grain yield (kg ha^{-1}) at Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2012-13 and 2013-14.

Location	Small grain	Grain yield, kg ha^{-1}	
		2012-2013	2013-2014
SPAREC	Barley	3537	3542
	Triticale	3178	2327
	Wheat	4202	3351
TAREC	Barley	3902	4232
	Triticale	2767	3997
	Wheat	2884	3854

Table 3.4 Analysis of variance and treatment means for soybean pod m^{-2}, seed per pod, weight per seed, and grain yield at Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2013.

Location		SPAREC				TAREC			
Cropping	Sources	Pod m^{-2}	Seed pod^{-1}	Weight seed^{-1}, mg	Grain yield, kg ha^{-1}	Pod m^{-2}	Seed pod^{-1}	Weight seed^{-1}, mg	Grain yield, kg ha^{-1}
		Means square							
	Rep	1946^{ns}	0.1^{ns}	53^{ns}	111599^{ns}	31080^{ns}	0.2^{ns}	97^{**}	507333^{*}
	Crop	na	na	na	na	73248^{**}	0.06^{ns}	1728^{***}	616068^{**}
	Plant ha^{-1}	44888^{ns}	0.2^{ns}	648^{**}	721036^{*}	3059^{ns}	0.0003^{ns}	22^{ns}	28384^{ns}

Cropping system	Following crop	Treatment means											
Double Cropped	Barley	na	na	na	na	602	b	2	a	113	b	1460	b
Double Cropped	Triticale	na	na	na	na	739	ab	2	a	123	a	2158	a
Double Cropped	Wheat	na	na	na	na	833	a	2	a	123	a	2419	a
Full Season	Soybean	643	2	130	1896	557		2		150		1837	

Contrast	Pr>f							
Full-season vs double-cropped	na	na	na	na	**	ns	***	ns

***, **, * significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant; na- not available

§ Means within a column for a given location followed by the same letter are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.

Table 3.5 Analysis of variance and treatment means for pod m^{-2}, seed per pod, weight per seed, and grain yield at Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2014.

Location		SPAREC				TAREC			
Cropping	Sources	Pod m^{-2}	Seed pod^{-1}	Weight seed^{-1}, mg	Grain yield, kg ha^{-1}	Pod m^{-2}	Seed pod^{-1}	Weight seed^{-1}, mg	Grain yield, kg ha^{-1}
		Means square							
	Rep	4786**	0.04^{ns}	359**	80496**	5351^{ns}	1.7*	671*	1052023**
	Crop	5656**	0.3**	70^{ns}	75242**	30993**	3.2**	41^{ns}	3098952***
	Plant ha^{-1}	1.9^{ns}	0.06^{ns}	89^{ns}	1.3^{ns}	38.5^{ns}	0.28^{ns}	6.1^{ns}	462974^{ns}
Cropping system	Following crop	Treatment means							
Double Cropped	Barley	350 a	2 a	169 a	1363 a	486 a	4 a	167 a	2627 a
Double Cropped	Triticale	302 a	2 a	170 a	1177 ab	396 a	3 a	172 a	1698 a
Double Cropped	Wheat	257 a	2 a	161 a	1062 b	433 a	4 a	167 a	2399 a
Full Season	Soybean	306	2	169	1062	304	2	165	934
Contrast		Pr>f							
Full-season vs double-cropped		ns	**	ns	ns	**	**	ns	**

***, **, * significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant; na- not available

§ Means within a column for a given location followed by the same letter are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.

Table 3.6 Analysis of variance and treatment means for plants ha^{-1}, stalk mass, grain yield and harvest index (HI) at Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2013.

Location		SPAREC				TAREC			
Cropping	Source	Plant, ha	Stalk, kg ha^{-1}	Grain yield, kg ha^{-1}	Harvest index	Plant, ha	Stalk, kg ha^{-1}	Grain yield, kg ha^{-1}	Harvest index
		Means square							
	Rep	351579813^{ns}	1301122^{ns}	199332^{ns}	0.005^{ns}	753528854^{ns}	5992821*	2654498^{ns}	0.010^{ns}
	Crop	7554577302***	4937228^{ns}	30624698***	0.11***	25911591287**	9502127**	7733225***	0.86***
Cropping system	Following crop	Treatment means							
Double Cropped	Barley	211600 a	6841 a	1291 a	0.15 a	387336 a	5848 a	4357 a	0.42 a
Double Cropped	Triticale	191875 a	7026 a	1727 a	0.2 a	414234 a	6757 a	2772 b	0.3 b
Double Cropped	Wheat	188288 a	6442 a	1491 a	0.18 a	421407 a	7020 a	3391 ab	0.33 b
Full Season	Sorghum	247464	8093	5076	0.39	312020	4863	4935	0.51
Contrast		Pr>f							
Full-season vs double-cropped		**	**	***	***	***	**	**	***

***, **, * significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant; na- not available

§ Means within a column for a given location followed by the same letter are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.

Table 3.7 Analysis of variance and treatment means for plants ha^{-1}, stalk mass, grain yield and harvest index (HI) at Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2014.

Location		SPAREC				TAREC			
Cropping	Sources	Plants, ha	Stalk, kg ha^{-1}	Grain yield, kg ha^{-1}	Harvest index	Plants, ha	Stalk, kg ha^{-1}	Grain yield, kg ha^{-1}	Harvest index
		Means square							
	Rep	1618534849^{ns}	5885750^{ns}	2020229^{ns}	0.009*	844270493^{ns}	606627^{ns}	1986585**	0.014**
	Crop	398017417^{ns}	10643150**	1820826^{ns}	0.012**	19943358204**	49483671***	6813553***	0.021***

Cropping system	Following crop	Treatment means							
Double Cropped	Barley	265397 a	5565 a	4328 a	0.44 a	240292 b	4253 a	2057 a	0.33 ab
Double Cropped	Triticale	249258 a	5744 a	5465 a	0.49 a	349678 a	3595 a	1087 b	0.24 b
Double Cropped	Wheat	249259 a	5634 a	4437 a	0.44 a	310227 ab	4476 a	2598 a	0.35 a
Full Season	Sorghum	259419	7724	4896	0.4	251051	8479	3105	0.27

Contrast	Pr>f							
Full-season vs double-cropped	ns	**	ns	**	**	***	***	ns

***, **, * significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant; na- not available

§ Means within a column for a given location followed by the same letter are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.

Table 3.8 Gross receipts (\$ ha^{-1}), return over variable cost (\$ ha^{-1}), and return to land and managements (\$ ha^{-1}) for full season and double-crop grain sorghum and soybean.

Cropping System	Following crops	Soybean	Sorghum	Soybean	Sorghum	Soybean	Sorghum
		Gross receipts, \$ ha^{-1}		Return over variable costs, \$ ha^{-1}		Net Return to land and management, \$ ha^{-1}	
Double-Crop	Barley	\$1,789.37	\$1,435.96	\$756.14	\$483.92	\$331.60	\$189.55
Double-Crop	Triticale	\$1,541.80	\$1,645.64	\$560.32	\$680.66	\$260.07	\$385.27
Double-Crop	Wheat	\$2,146.75	\$1,699.43	\$1,054.74	\$709.93	\$745.64	\$412.56
Full-Season		\$1,104.39	\$1,117.90	\$652.13	\$468.83	\$512.92	\$321.57

Figure 3.1 Maximum and minimum temperature and precipitation at SPAREC, 2012-2014.

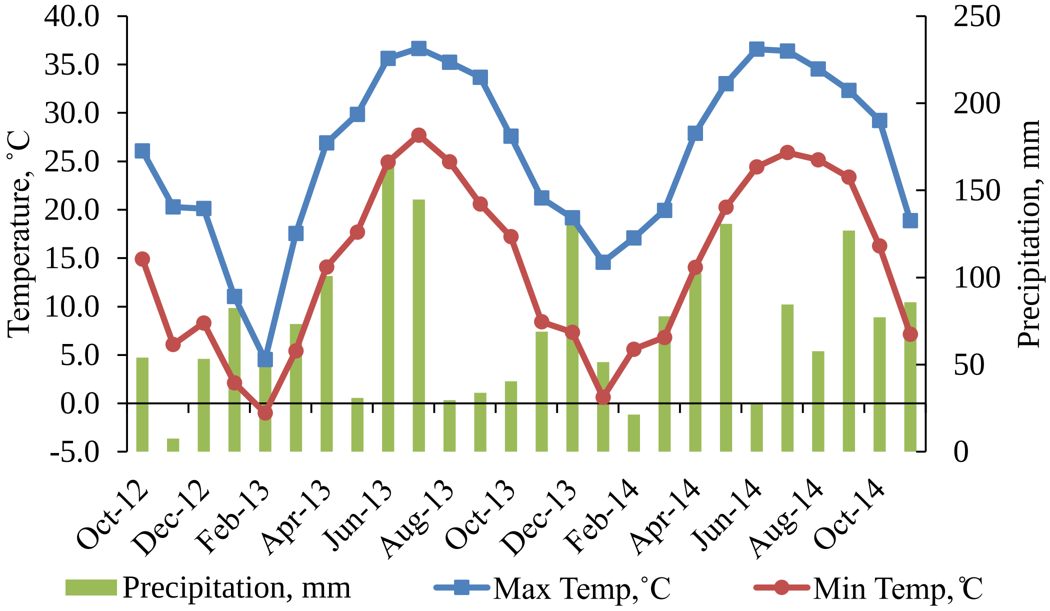


Figure 3.2 Maximum and minimum temperature and precipitation at TAREC, 2012-2014.

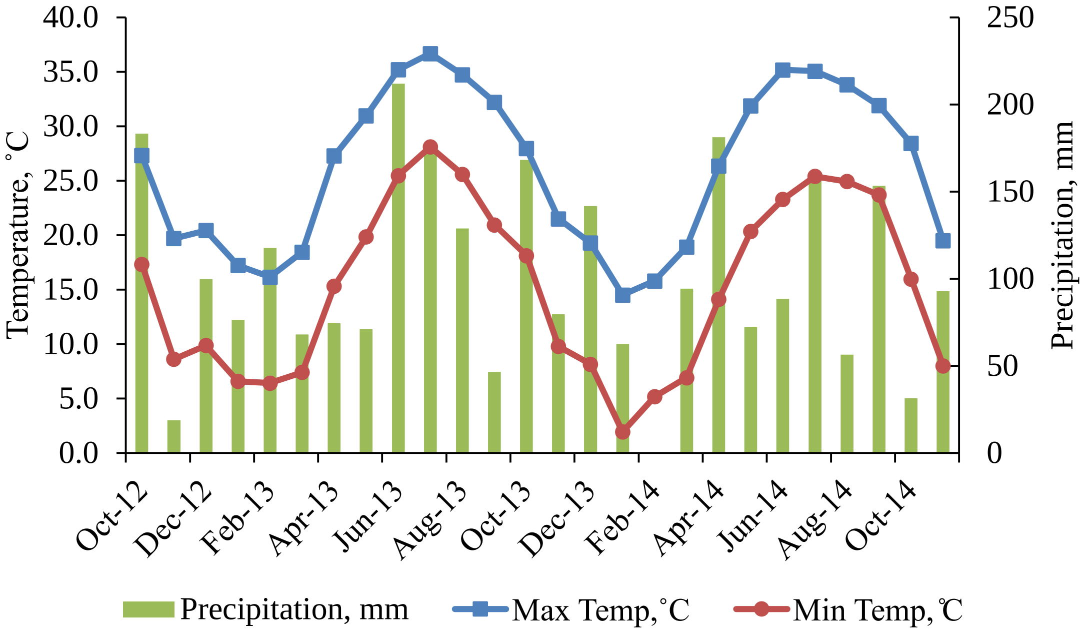
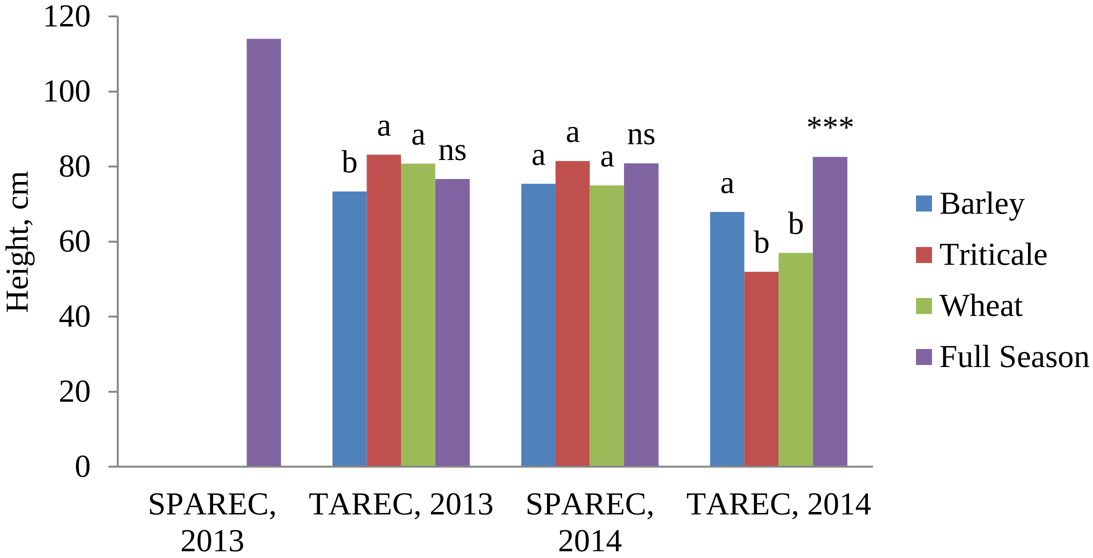
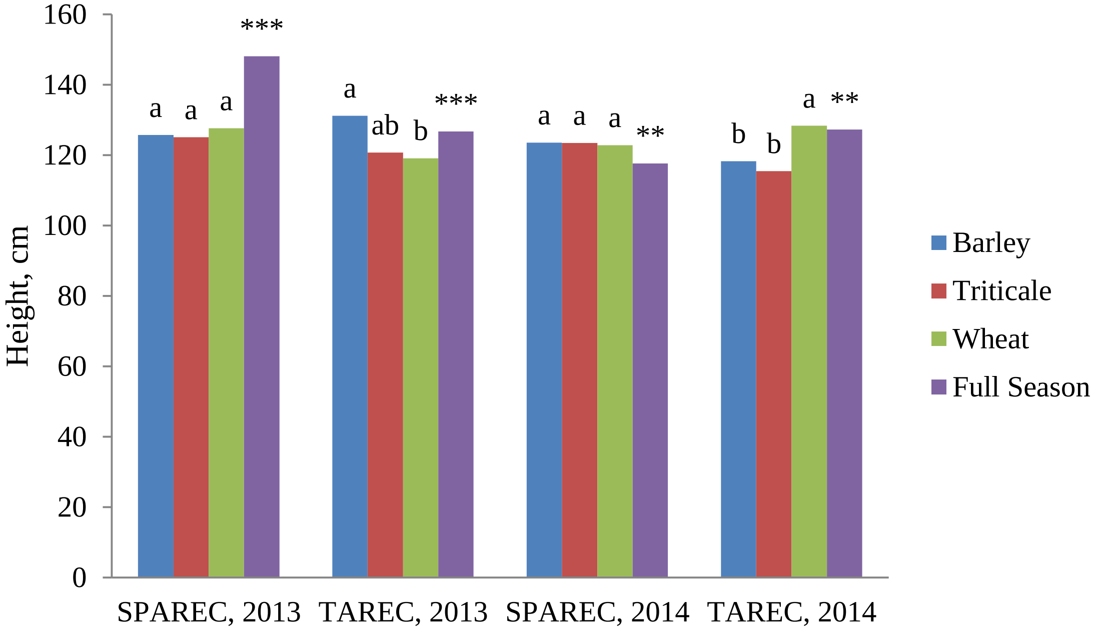


Figure 3.3 Soybean height at the Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2013-2014.



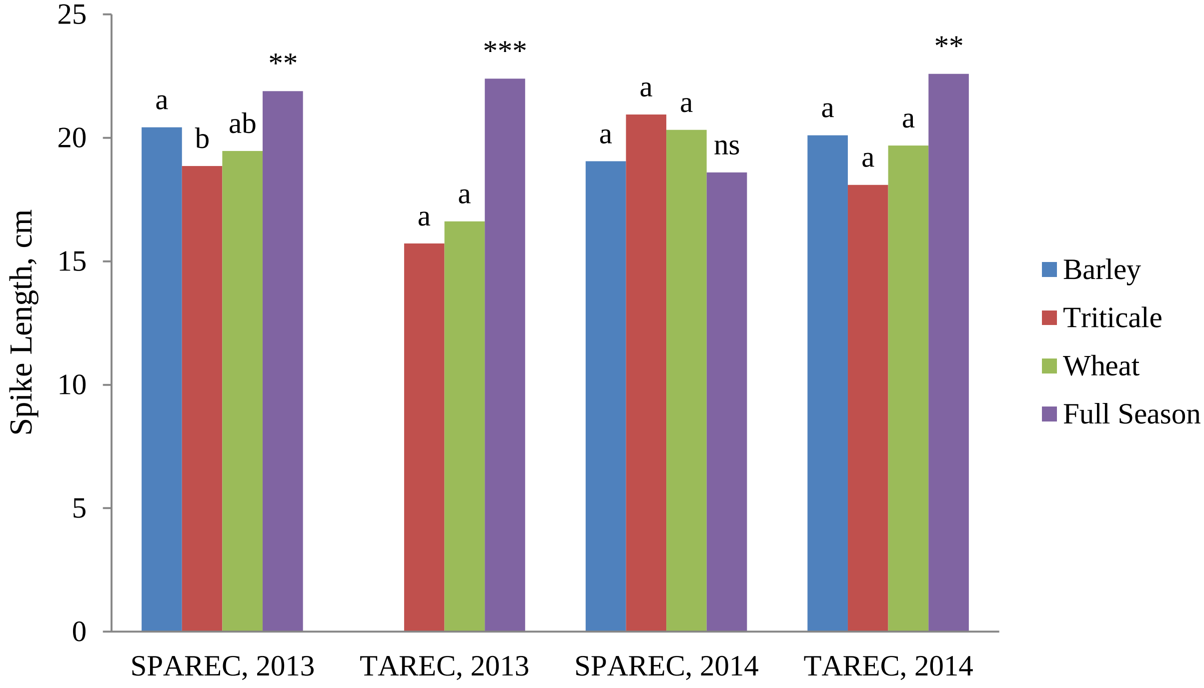
Columns within a location labeled by the same letter are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.
***,**, * single df contrast between full-season and double-cropped significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant.

Figure 3.4 Grain sorghum plant height (cm) at the Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2013-2014.



Columns within a location labeled by the same letter are not significantly different at the 0.05 probability level using Fisher's protected least significant difference.
***,**, * single df contrast between full-season and double-cropped significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant.

Figure 3.5 Grain sorghum spike length (cm) at the Southern Piedmont (SPAREC) and Tidewater Agricultural Research and Extension Center (TAREC), VA, 2013-2014.



Columns within a location labeled by the same letter are not significantly different at the 0.05 probability level using Fisher’s protected least significant difference.
***,**, * single df contrast between full-season and double-cropped significant at 0.01, 0.05, and 0.1 level of probability respectively; ns- not significant.

Chapter 4

CONCLUSIONS

At four of seven locations, sidedress rates prescribed by the VCA were significantly lower than the other systems, especially at lower preplant N rates. Compared to the standard, yield goal-based approach, PFP of sidedress N for the VCA was 39% greater. The reason for greater NUE with the VCA approach is likely a better estimate of temporal yield potential and N need based on directs measures from the current crop compared to historical averages. This level of improvement in sidedress N use efficiency can favorably impact farm profitability as well as reduce potential negative impacts from over application of N fertilizer. All sidedress N rate recommendation systems and preplant N rate combination supplied adequate N to achieve maximum environmentally sustainable yields, as evidenced by the similar yields among systems at a location. Grain N uptake did generally increase with increasing N rate, regardless of system, likely indicating luxury uptake when N was supplied in excess of that necessary to support grain yield. Overall, NUE declined with increasing preplant N rate since in-season applications better match N supply with crop demand, emphasizing the need for continued focus on in-season N management programs for corn in the region. While the VCA shows promise as a tool for improving NUE of sidedress applications in corn, more research is needed to validate performance.

Grain sorghum has a wide range of adaptation to planting date in the mid-Atlantic region and appears to be less sensitive to planting date than soybean. In three of four locations, full season grain sorghum yielded more than when double-cropped after small grain. No consistent differences in double-crop sorghum grain yields due to prior small grain species were found. This was the consistently the case even though planting after barley occurred earlier than after wheat or triticale. Over locations and years, double-cropped sorghum averaged over 2.9 Mg ha^{-1}. Combined with wheat, double-crop grain sorghum provided a net return to land and management of more than \$400 ha^{-1} which indicates this could be a viable system for producers. Final yields and overall success of double-cropping either soybean or grain sorghum depends heavily on the local weather, especially rainfall patterns. The most profitable cropping system was wheat-soybean, and the most profitable sorghum cropping systems was still wheat-sorghum. These results depend heavily on the price estimate for the various commodities but represent an accurate depiction, based on recent reported commodity prices.

Overall, our work demonstrates that grain sorghum can be reliably grown in Virginia in both full season and double-crop systems and can increase the volume of regionally produced feed grains. In corn, refinements to sidedress N rate recommendations using remote sensing and the VCA can improve NUE by nearly 40%. Together these projects can provide support for expanded feed grain production in the mid-Atlantic.

Appendix: Grain test weight, ears ha^{-1}, and kernel composition; DSS studies.

A: New Kent, 2012

System	Preplant N rate	Test Weight	Ears	Moisture	Fiber	Fat	Starch
	kg ha^{-1}	kg m^{-3}	ha^{-1}	-------------------g kg^{-1}----------------			
VCA		810.25	65094	8.8	3.425	3.354	59.400
Maize-N		810.81	63480	9.5	3.223	3.441	59.053
NE-Maize		808.72	65363	9.3	2.982	3.077	59.324
Standard		810.41	64018	9.0	3.262	3.150	58.949
	0	812.42	65228	9.4	3.072	3.324	59.223
	45	808.56	63345	9.1	3.321	3.260	59.043
	90	810.97	64825	8.8	3.245	3.181	59.228
	134	808.24	64556	9.3	3.253	3.256	59.233
VCA	0	813.06	65632	9.5	3.275	3.445	59.413
VCA	45	804.05	66170	8.6	3.506	3.258	59.535
VCA	90	809.52	65094	8.2	3.675	3.489	59.225
VCA	134	814.35	63480	9.1	3.246	3.222	59.428
Maize-N	0	808.88	64018	9.3	2.812	3.372	59.095
Maize-N	45	812.10	59714	9.5	3.294	3.502	58.495
Maize-N	90	818.85	66708	9.8	2.887	3.352	59.290
Maize-N	134	803.41	63480	9.3	3.901	3.537	59.333
NE-Maize	0	812.42	66170	9.4	2.995	3.223	59.100
NE-Maize	45	804.38	65094	8.9	3.211	3.168	59.480
NE-Maize	90	809.84	66708	9.0	2.956	2.777	59.503
NE-Maize	134	808.24	63480	9.8	2.766	3.139	59.213
Standard	0	815.31	65094	9.3	3.208	3.255	59.283
Standard	45	813.71	62404	9.4	3.275	3.112	58.660
Standard	90	805.66	60790	8.2	3.464	3.107	58.893
Standard	134	806.95	67784	9.1	3.101	3.127	58.960

Source			Pr>f			
System	ns	ns	*	ns	**	ns
PreN	ns	ns	ns	ns	ns	ns
System*PreN	ns	ns	ns	ns	ns	ns
SED	0.48	3426.41	0.51	0.38	0.27	0.52
CV	1.1	7.5	7.9	16.7	11.7	1.3

B: New Kent, 2013

System	Preplant N rate	Test Weight	Ears	Moisture	Fiber	Fat	Starch
	kg ha^{-1}	kg m^{-3}	ha^{-1}	-------------------g kg^{-1}----------------			
VCA		787	60656	15.3	3.380	3.810	57.454
Maize-N		780	58773	16.2	3.297	3.829	57.095
NE-Maize		786	59983	15.4	2.835	3.582	57.966
Standard		783	61732	15.3	3.011	3.711	57.468
	0	786	58100	15.4	2.932	3.678	57.295
	45	784	58638	15.5	3.294	3.783	57.462
	90	781	63077	16.0	3.190	3.871	57.740
	134	786	61328	15.2	3.107	3.600	57.487
VCA	0	788	54873	15.7	3.030	3.685	57.175
VCA	45	789	62942	15.4	3.372	3.870	57.032
VCA	90	785	65632	15.2	3.414	3.961	57.553
VCA	134	787	59176	14.8	3.702	3.723	58.058
Maize-N	0	783	57563	15.5	3.025	3.692	57.106
Maize-N	45	774	54335	17.0	3.494	4.071	57.022
Maize-N	90	781	60252	16.0	3.522	3.923	57.686
Maize-N	134	782	62942	16.4	3.146	3.630	56.566
NE-Maize	0	786	60790	15.4	2.697	3.561	57.961
NE-Maize	45	789	57024	14.9	3.176	3.451	57.762
NE-Maize	90	783	65632	16.1	2.754	3.647	58.457
NE-Maize	134	787	56486	15.1	2.715	3.671	57.686
Standard	0	786	59176	15.2	2.977	3.776	56.936
Standard	45	783	60252	14.8	3.133	3.742	58.030
Standard	90	776	60790	16.8	3.070	3.953	57.265
Standard	134	786	66708	14.6	2.865	3.376	57.639
Source				Pr>f			
System		ns	ns	**	ns	**	**
PreN		ns	ns	ns	ns	ns	ns
System*PreN		ns	ns	ns	ns	ns	**
SED		0.86	4776.68	0.40	0.38	0.27	0.54
CV		7.9	11.2	0.9	16.7	11.7	7.8

C: New Kent, 2014

System	Preplant N rate	Test Weight	Ears	Moisture	Fiber	Fat	Starch
	kg ha^{-1}	kg m^{-3}	ha^{-1}	-------------------g kg^{-1}----------------			
VCA		791	67784	12.8	3.034	3.648	56.424
Maize-N		792	68053	12.9	3.056	3.761	57.148
NE-Maize		792	64018	12.9	3.168	3.706	56.787
Standard		793	64825	12.9	3.060	3.807	56.937
	0	797	66842	13.0	3.015	3.857	56.615
	45	794	67111	12.9	3.065	3.631	56.901
	90	789	63749	13.0	3.207	3.768	56.927
	134	789	66977	12.8	3.031	3.666	56.853
VCA	0	797	70474	12.5	3.080	3.967	56.497
VCA	45	796	71550	13.1	3.242	3.541	56.526
VCA	90	788	65094	13.1	2.843	3.420	56.397
VCA	134	785	64018	12.7	2.974	3.665	56.278
Maize-N	0	795	65094	13.2	2.948	3.915	56.594
Maize-N	45	794	72088	13.0	3.045	3.392	57.317
Maize-N	90	786	68322	12.8	3.169	3.864	57.254
Maize-N	134	794	66708	12.8	3.062	3.875	57.425
NE-Maize	0	796	66708	13.3	3.093	3.900	55.948
NE-Maize	45	791	69398	12.7	2.929	3.518	56.979
NE-Maize	90	795	56487	13.0	3.657	4.033	57.415
NE-Maize	134	788	63480	12.7	2.995	3.373	56.808
Standard	0	800	65094	13.0	2.942	3.647	57.421
Standard	45	794	55411	12.7	3.045	4.074	56.782
Standard	90	788	65094	13.0	3.159	3.757	56.642
Standard	134	790	73702	13.0	3.093	3.751	56.901
Source		Pr>f					
System		ns	ns	ns	ns	ns	ns
PreN		**	ns	ns	ns	ns	ns
System*PreN		ns	**	**	ns	ns	ns
SED		0.47	5350.86	0.24	0.37	0.29	0.77
CV		1.1	11.4	2.6	16.8	11.0	1.9

D: Virginia Beach, 2013

System	Preplant N rate	Test Weight	Ears	Moisture	Fiber	Fat	Starch
	kg ha^{-1}	kg m^{-3}	ha^{-1}	-------------------g kg^{-1}----------------			
VCA		772	83788	16.4	2.411	3.533	58.147
Maize-N		776	86747	16.6	2.524	3.620	58.342
NE-Maize		771	85940	16.3	2.811	3.666	58.381
Standard		773	85683	17.2	2.502	3.733	58.519
	0	766	86221	17.4	2.438	3.522	58.202
	45	778	85537	16.2	2.533	3.634	58.084
	90	773	86075	16.0	2.663	3.773	58.667
	134	776	84326	17.0	2.614	3.623	58.435
VCA	0	767	85537	16.9	2.449	3.569	57.575
VCA	45	776	84461	16.2	2.346	3.491	57.712
VCA	90	773	81233	15.2	2.325	3.553	58.564
VCA	134	772	83923	17.4	2.526	3.520	58.737
Maize-N	0	771	87688	17.1	2.448	3.447	58.276
Maize-N	45	782	89302	16.4	2.515	3.616	58.061
Maize-N	90	777	85537	15.8	2.596	3.716	58.261
Maize-N	134	775	8447	17.3	2.537	3.701	58.770
NE-Maize	0	761	83923	16.9	2.549	3.447	58.458
NE-Maize	45	782	82847	15.6	2.775	3.662	58.420
NE-Maize	90	766	89302	16.0	3.031	3.897	58.790
NE-Maize	134	776	87689	16.7	2.890	3.660	57.855
Standard	0	764	87736	18.6	2.308	3.626	58.500
Standard	45	771	85537	16.6	2.497	3.768	58.144
Standard	90	776	88226	16.9	2.701	3.928	59.052
Standard	134	782	81233	16.7	2.504	3.612	58.378
Source				Pr>f			
System		ns	ns	ns	**	ns	ns
PreN		**	ns	***	ns	ns	ns
System*PreN		ns	ns	ns	ns	ns	ns
SED		0.61	3273.23	0.82	0.28	0.20	0.52
CV		1.4	5.4	7.0	15.7	7.7	1.3

E: Kentland, 2013

System	Preplant N rate	Test Weight	Ears	Moisture	Fiber	Fat	Starch
	kg ha^{-1}	kg m^{-3}	ha^{-1}	-------------------g kg^{-1}----------------			
VCA		689	1591	15.8	3.580	3.287	59.847
Maize-N		686	1541	15.9	3.551	3.412	59.619
NE-Maize		685	1573	15.9	3.285	3.251	59.832
Standard		685	1619	15.9	3.523	3.369	59.523
	0	690	1524	16.1	3.605	3.368	59.177
	45	687	1538	15.8	3.438	3.303	59.928
	90	684	1654	15.9	3.539	3.283	60.005
	134	685	1608	15.7	3.357	3.366	59.711
VCA	0	694	1439	15.9	3.907	3.413	59.492
VCA	45	682	1651	15.8	3.758	3.153	60.264
VCA	90	686	1721	15.8	3.688	3.210	60.415
VCA	134	693	1552	15.9	2.967	3.373	59.217
Maize-N	0	684	1510	16.7	3.577	3.569	58.980
Maize-N	45	688	1425	15.5	3.465	3.337	60.261
Maize-N	90	686	1580	15.9	3.684	3.229	59.864
Maize-N	134	687	1651	15.6	3.480	3.515	59.371
NE-Maize	0	689	1595	15.8	3.312	3.131	59.375
NE-Maize	45	690	1495	16.1	3.111	3.227	59.779
NE-Maize	90	680	1721	16.1	3.363	3.299	60.173
NE-Maize	134	683	1482	15.6	3.355	3.348	59.999
Standard	0	693	1552	15.9	3.625	3.359	58.862
Standard	45	688	1580	16.1	3.418	3.495	59.407
Standard	90	685	1594	15.8	3.424	3.395	59.569
Standard	134	676	1750	15.8	3.625	3.229	60.257
Source		Pr>f					
System		ns	ns	ns	ns	ns	ns
PreN		ns	ns	ns	ns	ns	ns
System*PreN		ns	ns	ns	ns	ns	ns
SED		0.70	125.21	0.37	0.35	0.14	0.75
CV		1.8	11.2	3.3	14.3	5.8	1.8

F: Lottsburg, 2014

System	Preplant N rate	Test Weight	Ears	Moisture	Fiber	Fat	Starch
	kg ha^{-1}	kg m^{-3}	ha^{-1}	-------------------g kg^{-1}----------------			
VCA		751	72356	14.3	3.272	3.309	58.135
Maize-N		748	73029	14.2	3.201	3.358	57.829
NE-Maize		751	73970	14.2	2.955	3.288	57.929
Standard		744	72491	14.2	3.129	3.443	57.911
	0	748	70339	14.2	3.071	3.264	58.100
	45	753	73298	14.2	3.067	3.359	57.858
	90	746	71818	14.3	3.111	3.329	57.874
	134	749	76391	14.3	3.307	3.446	57.973
VCA	0	752	67784	14.2	3.434	3.183	58.633
VCA	45	756	73702	14.3	3.060	3.326	57.838
VCA	90	746	72088	14.3	3.363	3.440	57.861
VCA	134	750	75853	14.3	3.230	3.288	58.208
Maize-N	0	748	71550	14.0	3.118	3.362	57.737
Maize-N	45	750	71550	14.3	3.084	3.215	57.573
Maize-N	90	750	72087	14.3	3.217	3.371	57.899
Maize-N	134	746	76929	14.3	3.384	3.485	58.109
NE-Maize	0	755	72625	14.0	2.643	3.077	57.896
NE-Maize	45	752	72625	14.2	2.924	3.391	57.848
NE-Maize	90	747	72626	14.2	2.954	3.179	58.183
NE-Maize	134	751	78005	14.3	3.300	3.504	57.788
Standard	0	736	69398	14.5	3.090	3.434	58.134
Standard	45	753	75316	14.1	3.201	3.503	58.171
Standard	90	740	70474	14.3	2.912	3.328	57.551
Standard	134	747	74777	14.1	3.315	3.508	57.788
Source				Pr>f			
System		*	ns	ns	ns	ns	ns
PreN		ns	*	ns	ns	ns	ns
System*PreN		ns	ns	ns	ns	ns	ns
SED		0.44	4384.76	0.25	0.32	0.18	0.45
CV		1.1	8.5	2.5	14.4	7.8	1.1

G: Kentland, 2014

System	Preplant N rate	Test Weight	Ears	Moisture	Fiber	Fat	Starch
	kg ha^{-1}	kg m^{-3}	ha^{-1}	-------------------g kg^{-1}----------------			
VCA		770	57562	11.6	4.415	3.375	59.200
Maize-N		771	53710	11.4	3.522	3.090	59.437
NE-Maize		773	58421	11.6	3.578	3.184	59.043
Standard		773	57562	11.4	3.243	3.080	59.498
	0	768	55638	11.7	3.707	3.319	59.096
	45	770	57973	11.2	4.089	3.064	59.245
	90	772	56755	11.5	3.466	3.340	59.387
	134	775	56890	11.4	3.497	3.006	59.450
VCA	0	767	60252	12.2	4.772	3.608	59.079
VCA	45	767	55948	11.2	4.787	3.380	59.311
VCA	90	771	55948	11.5	3.954	3.447	58.950
VCA	134	776	58100	11.3	4.149	3.065	59.461
Maize-N	0	768	50031	11.3	2.407	2.731	58.968
Maize-N	45	768	56141	11.0	4.912	3.210	59.412
Maize-N	90	773	55411	11.9	3.375	3.185	60.052
Maize-N	134	774	53259	11.3	3.395	3.233	59.318
NE-Maize	0	771	59011	11.4	4.154	3.494	58.750
NE-Maize	45	773	61163	11.4	2.972	2.833	58.313
NE-Maize	90	771	55949	11.7	3.746	3.284	59.199
NE-Maize	134	775	57562	11.7	3.443	3.123	59.909
Standard	0	768	53259	11.9	3.496	3.442	59.586
Standard	45	774	58638	11.3	3.685	2.832	59.944
Standard	90	774	59714	11.2	2.790	3.444	59.348
Standard	134	776	58638	11.5	3.002	2.603	59.114
Source				Pr>f			
System		ns	ns	ns	**	ns	ns
PreN		ns	ns	ns	ns	ns	ns
System*PreN		ns	ns	ns	ns	ns	ns
SED		0.51	3248.64	0.50	0.81	0.43	0.83
CV		1.2	8.1	6.1	31.3	19.0	2.0