ABSTRACT

ATWELL, RACHEL ANNE. Alternative Mechanisms for Weed Control and Fertility Management in Organic Canola and Corn Production. (Under the direction of Dr. S. Chris Reberg-Horton.)

Two studies were conducted to improve weed management and fertility in organic grain production. The first study investigated manipulating row spacing and seeding rate to reduce weed competition in organic canola (*Brassica napus* L.) production. Increasing seeding rate and widening row spacing to allow for between row cultivations may serve as mechanisms to reduce weed competition in organic canola production. Research was conducted to evaluate the effects of row spacing and seeding rate on weed competition and yield in organic canola production. Canola variety 'Hornet' was planted at five seeding rates (3.4, 6.7, 10.1, 13.4, 16.8 kg ha^{-1}) at three row spacing's (17, 34, 68 cm) in Goldsboro, Kinston, and Salisbury, NC in 2011 and 2012. Between row cultivations were performed in the 68 cm row spacing as weather permitted. Yields were similar across row spacing's at the lower seeding rates in five of the six environments. In the environment with the most competitive weed community, weed suppression and yield was highest in the 68 cm row spacing. Results indicate that in environments with a less competitive weed community, producers have flexibility in row spacing selections and seeding rate selections should be based on desired row spacing. In environments with competitive weed species against canola, widening row spacing to allow for between row cultivations may prove critical to maximize weed suppression and yield for organic canola producers.

The second study investigated the effects of starter fertilizer materials and fertilizer application methods on weed competition and grain yield in organic rotational no-till corn (*Zea mays* L.) production when using cover crop mulches for weed suppression. Research

was conducted at Beltsville, MD, Kinston, NC, and Salisbury, NC, from 2012-2014. Fertility treatments included high rate broadcast poultry litter (HBPL), low rate broadcast poultry litter plus subsurface banded poultry litter (LBPL+SBPL), subsurface banded feather meal (SBFM), subsurface banded poultry litter (SBPL), and no starter fertility. Both weedy and weed-free conditions were maintained across all fertility treatments. A cereal rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth) cover crop mixture was established in the fall across all fertility treatments, and was terminated using a roller-crimper prior to corn planting. Cover crop biomass in excess of 9,000 kg ha^{-1} and excellent weed suppression was observed at four of the six environments. Fertility treatment, but not weed competition, affected corn grain yield at four environments. In a combined analysis of four environments, corn grain yield was similar among the HBPL, LBPL+SBPL, and SBFM fertility treatments, and was significantly lower with the SBPL and no starter fertility treatments. Weed competition only affected corn grain yield at the lowest fertility environment. In this environment, the HBPL fertility treatment had the lowest weed coverage, lowest weed biomass, and highest corn grain yield. Within the same environment, large differences between weedy and weed-free corn grain yields were observed in all fertility treatments except the HBPL. In a high fertility environment excluded from the combined grain yield analysis, fertility treatment did not affect corn grain yield indicating that in a high fertility environment where high cover crop biomass levels are achieved, additional N fertility may not be necessary to maximize corn grain yield. Results from this study indicate that starter fertilizer materials are often necessary to maximize corn grain yield in organic rotational no-till corn production and that producers have flexibility in selecting fertilizer materials and

application methods in high fertility environments. At low fertility environments, added N is critical to ensure crop competitiveness with weeds and high corn grain yield.

Alternative Mechanisms for Weed Control and Fertility Management in Organic Canola and Corn Production

by
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DEDICATION

I would like to dedicate this thesis to my parents, whose hard work and love have provided me with abundant opportunities to pursue my professional goals, my fiancé for his endless support, and all the faculty members at the University of Illinois who invigorated my passion for agriculture.

BIOGRAPHY

Rachel Anne Atwell was raised in Geneseo, IL. Upon high school graduation in 2008, she attended the University of Illinois Urbana-Champaign. She graduated from the University of Illinois in May 2012 with a Bachelor's Degree in Natural Resources and Environmental Sciences and a minor in Crop and Soil Science. In July 2012, she moved to Raleigh, NC and began her graduate studies in the Crop Sciences Department at North Carolina State University under the advisement of Dr. S. Chris Reberg-Horton.

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Row spacing and seeding rate effects on weed competition and yield in winter organic canola production

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INTRODUCTION

Organic product sales surpassed $35.1 billion in the United States in 2013, an 11.5% growth rate from 2012 (OTA, 2014). A large proportion of these sales come from organic dairy and livestock products, which has increased the demand for organic grain and oilseed production (USDA ERS, 2000). Canola is an oilseed crop with several desirable end uses, including oil for human consumption and as a feed source for organic livestock production.

Winter canola production fits well into cropping rotations in the Southeastern United States and can provide a profitable alternative to small grain production (Bishoni et al., 2007). Producers can use existing small grain equipment for canola production, thus requiring minimal novel infrastructure investment for the addition of canola into current rotations (Johnson and Hanson, 2003). These reasons, along with the presence of new local oilseed processors, have led to an increase in canola production in the Southeastern USA.

Herbicide resistant canola varieties have been readily adopted in large canola producing regions of North America (Hall et al., 2003), and in the Canadian Prairie over 95% of canola acreage was herbicide resistant by 2007 (Smyth et al., 2011). Opportunities are abundant for contamination of organic canola varieties by transgenic varieties. Gene flow from one canola variety to the next can occur through seed mixing during commercial production, cross-pollination, volunteer canola in subsequent crops, inter-specific hybridization, and pollen transfer (Hall et al., 2003). In the Alberta province of Canada, the introduction of genetically modified canola varieties has driven the decline of organic oilseed production from 9% in 1998 to only 1% in 2002 (Degenhardt et al., 2005). Canola is grown on low acreage in the Southeastern USA when compared to larger canola producing regions

of North America, therefore the likelihood of contamination from transgenic varieties into organic varieties is reduced. This allows producers in the Southeast an advantage to fill market demand for organic and non-GMO canola.

Weed competition is one of the major limiting factors to yield in organic oilseed production (Valantin-Morison & Meynard, 2008). Synthetic herbicide use is restricted in organic production and producers are heavily dependent on cultural and mechanical mechanisms of weed suppression (Reberg-Horton et al., 2013). Manipulations in row spacing and seeding rate are two cultural practices that can suppress weeds. Canola yields are very plastic and can adjust across a broad range of populations (Diepenbrock, 2000), therefore it is plausible that row spacing and seeding rate adjustments can be utilized to minimize weed competition without compromising yield in organic canola production.

The majority of studies conducted on the effects of row spacing and seeding rate in canola production have been performed in environments with low weed competition due to herbicide use (O'Donovan, 1994). Many studies evaluating different row spacing's in canola production have evaluated row spacing's ranging from 7-30 cm (Christensen & Drabble, 1984; Lewis & Knight, 1987; Morrison et al., 1990), and row spacing recommendations between 15 and 38 cm are common for conventional canola production (Buntin et al., 2013; Boyles et al., 2009). Research performed in New South Wales showed that 75 cm row spacing led to yield declines compared with narrow row spacing's in canola production, however herbicides were used for weed control (Martin et al., 2011). The restriction of synthetic herbicide use in organic production limits the applicability of the row spacing and seeding rate results from these studies.

Cultivation is widely used in organic grain production for weed suppression throughout the growing season. Many organic grain producers employ between row cultivations to eliminate weeds which were not terminated through earlier weed suppressive mechanisms (Reberg-Horton et al., 2013). Conventional canola row spacing recommendations are too narrow for common cultivation equipment to pass through, and rarely have studies been conducted on canola row spacing's that would be wide enough to perform between row cultivations with existing cultivation equipment. Widening row spacing to allow for between row cultivation could be a critical component of an effective weed management program for organic canola producers, however while wide row spacing can facilitate between row cultivations, if weather conditions prohibit cultivation, narrower row spacing may prove better adept to reduce weed pressure in organic canola production. Narrow row spacing can lead to quicker canola crop canopy closure, and therefore reduce weed competition compared with wider row spacing's (Boyles et al., 2004).

Increasing crop seeding rate is another cultural control tactic that can be employed to suppress weeds (O'Donovan, 1994). Canola is very competitive against weeds in years where adequate heat and soil moisture lead to quick canopy closure (Smyth et al., 2011). High plant densities can reduce weed pressure through minimizing light available low in the crop canopy (Tetio-Kagho & Gardner, 1988). Several studies have shown improved competitiveness with weeds when higher than recommended seeding rates were employed in canola production (Harker et al., 2003; O'Donovan, 1994). In addition to improving weed suppression, high seeding rates may also improve canola yield. Canola plant density was shown to increase linearly with increases in seeding rate from 1-9 kg ha^{-1} in Ontario, which

generally led to higher yields (May et al., 1993). In another study, increasing canola seeding rate from 2.5 to 20 kg ha^{-1} led to increases in yields (Clarke et al., 1978). Other studies have shown no increase in yield accompanied with high seeding rates in *Brassica* species, however herbicide use was employed in these studies (Bilgili et al., 2003; Lewis & Knight, 1987). Weed suppression and yield responses to higher than recommended seeding rates are typically greater in studies where herbicide use is absent (Harker et al., 2003), therefore in an organic context where herbicide use is restricted, high seeding rates could have a larger impact on yield and weed suppression than previous seeding rate research in conventional canola production settings would indicate.

While it is possible that higher seeding rates could lead to greater weed suppression and higher yields, high seeding rates have also been shown to cause lodging in oilseed crops (Kondra, 1975). Lodging at high seeding rates in oilseed production can result in yield declines (Hanson et al., 2008; Morrison et al., 1990), which negates the positive effects on weed suppression potentially obtained at high seeding rates

In conventional crop production, high seed costs associated with genetically modified seed can be prohibitive in motivating producers to employ high seeding rates for weed control. Utilizing high seeding rates for weed control in canola production were found to be "financially costly and risky practice" in a study conducted in Canada, however the economic analysis in this study used seed prices that included technology fees and seed treatment costs (Upadhyay et al., 2006). Organic seed costs are typically lower than conventional seed costs containing technology fees, and with higher weed pressure in organic systems it may prove economically viable to utilize high seeding rates for weed control. Increasing seeding rate

beyond the recommended rate for conventional production provided enhanced weed control and led to higher yield and economic returns in organic soybean production (Place et al., 2009).

The objective of this research was to evaluate the effects of widening row spacing to allow for between row cultivation and increasing seeding rate above recommended rates on weed competition and yield in organic canola production.

MATERIALS AND METHODS

Experiments were conducted over two winter canola growing seasons (2011-2013) at three research sites throughout North Carolina. These research sites included the Caswell Research Station in Kinston, NC, the Center for Environmental Farming Systems in Goldsboro, NC, and the Piedmont Research Station in Salisbury, NC. Each growing season will be referred to as the year in which the canola was harvested. The combination of year and location will be referred to as an environment. The Kinston trials were conducted on a Pocalla Loamy Sand (loamy, siliceous, subactive, thermic Arenic Plinthic Paleudults), the Goldsboro trials were conducted on a Wickham Loamy Sand (fine-loamy, mixed, semiactive, thermic Typic Hapludults) and the Salisbury trials were conducted on a Mecklenburg Clay Loam (fine, mixed, active, thermic Ultic Hapludalfs). These locations were selected to represent a range of growing conditions which could be experienced by current and potential canola producers in North Carolina.

Treatments were arranged in a split-plot design with six replications per environment. Main plot factor was row spacing and subplot factor was seeding rate. Row spacing was evaluated at: 17, 34, and 68 cm. The seeding rates included: 3.4, 6.7, 10.1, 13.4, and 16.8 kg ha^{-1} (~75,000 seeds lb^{-1}). All canola planted was of the variety 'Hornet'. Varietal selection was based on canola variety trials conducted in North Carolina which indicated that 'Hornet' performed well in North Carolina. Canola was seeded into a clean-tilled seedbed using a Hege 1000 Series cone planter modified to facilitate individual row spacing treatments. Planting date ranged from mid-September through mid-October across environments (Table

1). Between row cultivations occurred as weather permitted in the 68 cm row spacing (Table 1).

Fall and final stand counts were taken from each plot by counting the number of plants in one linear meter. Fall stand counts were captured from the end of October throughout November depending on environment (Table 1). Final stand counts were taken following canola harvest to reduce crop canopy damage prior to harvest (Table 1). Visual weed ratings were obtained on a 0-100% weed coverage scale, with 0% corresponding to no weed coverage and 100% corresponding to total weed coverage. Weed coverage data was not obtained in the Kinston 2012 and Salisbury 2012 environments due to low weed pressure. Lodging ratings were taken at harvest. Lodging was assessed visually from the combine cab on a 0-100% scale, where 0% represented no lodging, and 100% represented total lodging. Lodging was only experienced in the Goldsboro 2013 and Salisbury 2013 environments, and therefore ratings were only obtained in these two environments. Plots were harvested using a Wintersteiger model Delta combine. Canola yield data was adjusted to 8.5% moisture content. Plots sizes were 1.5 m by 6.7 m.

Statistical analyses were performed using the PROC Mixed and PROC Reg procedures in SAS 9.3 (SAS Institute, Cary, NC). Row spacing and seeding rate were considered fixed factors and replication and environment were considered random factors. Linear, quadratic, cubic, and lack of fit contrasts were performed to evaluate the effect of row spacing and seeding rate on non-transformed fall populations, final populations, weed coverage, and yield. Linear regression of row spacing and seeding rate on fall populations, final populations, weed coverage, and yield was conducted. Treatment means were reported

using least square means. Treatments effects were considered significant at $P<0.05$. Fall and final population data were combined across all six environments due to non-significant three-way interactions between row spacing, seeding rate, and environment (Table 2). Due to very different weed communities and weed pressure at each environment, the weed coverage data violated homogeneity of variance for a combined analysis and environments were analyzed individually. When all six environments were combined for yield analysis, a three-way interaction between row spacing, seeding rate, and environment with a P-value<0.15 raised concerns about combining across all six environments. A combined yield analysis occurred over four environments (Goldsboro 2012, Kinston 2012, Kinston 2013, and Salisbury 2012) and two environments were analyzed individually. The three-way interaction between row spacing, seeding rate, and environment was not significant when combining across the four environments ($P=0.42$).

RESULTS AND DISCUSSION

Population. Row spacing and seeding rate interacted to have a significant effect on fall and final populations in the combined analyses (Table 2). The highest fall canola populations were achieved in the 17 cm row spacing as seeding rate increased (Figure 1). Fall populations were similar at the 34 and 68 cm row spacing's at the lowest seeding rate, however as seeding rate increased higher populations were achieved in the 34 cm row spacing (Figure 1). Results indicate that thinning occurred rapidly in the wider row spacing's. Previous research illustrated that high auto-regulation of plant density occurs subsequently after rapeseed planting (Sierts et al., 1987). It has also been shown that higher mortality is experienced when canola is planted in rows compared with broadcast seeding, and that reductions in plant densities at wider row spacing's are often observed (CCC, 2014). Similar trends were observed in winter wheat production, where intraspecific competition was intensified at wider row spacing's (Drews et al., 2009). Morrison et al. (1990) observed greater rapeseed survival with more even distribution of plants in narrow row spacing's.

Final populations followed similar trends to fall populations (Figure 1). Final populations were highest in the 17 cm row spacing, followed by the 34 then 68 cm row spacing's (Figure 1). Sierts et al. (1987) found similar results where a reduction in plant stand occurred in the wider row spacing's when the same targeted plant density was planted across row spacing's, which the author attributed to intraspecific competition.

Thinning of the canola stand intensified from fall into spring (Figure 1), with reductions in populations occurring across all row spacing's and seeding rates. These results are aligned with previous research showing plant densities are reduced during the canola

growing season by intraspecific competition, and that only a portion of plants present at emergence will remain into the pod-bearing stage (Diepenbrock, 2000). Beyond intraspecific competition, winter kill is another possible factor that could lead to reductions in plant populations over the winter. During the rosette stage, canola is more susceptible to winter kill when temperature fluctuates without gradual decreases in temperatures before a freeze occurs (Buntin et al., 2013). North Carolina experiences large fluctuations in temperature during an average winter, and winter kill could have contributed to some reduction in plant population from fall to spring across all row spacing and seeding rate combinations.

Weed Competition. Both row spacing and seeding rate had an effect on weed coverage in Goldsboro 2012 (Table 2). Weed coverage was highest in the 68 cm row spacing (Figure 2). Weather conditions prohibited between row cultivations in the 68 cm row spacing at this environment (Table 1), which is likely one reason higher weed pressure was observed in the 68 cm row spacing. One disadvantage producers may experience when depending on cultivation for weed control is that wet winters, often experienced in the Southeastern USA, can limit cultivation opportunities. Canola is most sensitive to weed pressure early in the growing season (O'Donovan, 1992), and the wider row spacing's would not reach canopy closure to outcompete weeds early in the season. This coupled with the absence of cultivation limited weed control in the 68 cm row spacing at this environment. Similar results were observed in organic wheat production, where in the absence of cultivation weed coverage was greater in the wider row spacing's compared with the narrow row spacing's (Drews et al., 2009). At this environment, weed coverage declined as seeding rate increased across all row spacing's. These results are similar to previous studies in canola production which have

documented declines in weed biomass with increasing crop seeding rate (Blackshaw et al., 2005; O'Donovan, 1994).

The Goldsboro 2013 environment had the most competitive weed community with canola across all environments. Row spacing and seeding rate interacted to have a significant effect on weed coverage at this environment (Table 2). Weed coverage declined with increasing seeding rate in the 17 cm row spacing and weed coverage remained similar as seeding rate increased in the 34 and 68 cm row spacing's (Figure 2). It is possible that intraspecific competition leading to population declines at the higher seeding rates in the wider row spacing's led to a less competitive canola stand with weeds. There was much lower weed coverage in the 68 cm row spacing at this environment, which received between row cultivation, compared to the narrow row spacing's (Figure 2). Similar results were observed in organic wheat production, where reductions in weed biomass were experienced with wider row spacing that allowed for more intensive mechanical weed control compared to narrower row spacing's in an environment with heavy weed pressure (Rasmussen, 2003). Hairy vetch (*Vicia villosa*), white clover (*Trifolium repens*), and buttercup (*Ranunculus sardous*) were present at this environment. Winter clover and hairy vetch were particularly competitive with canola, and their vining growth habit caused problems for harvest. Between row cultivation is typically more effective on large weeds, and due to the vining growth habit of these weed species, cultivation may have played a more effective role in the termination of these weed species than that which could be achieved by interspecific plant competition in the narrow row spacing's. These weed species are not commonly reported as problems in canola production, and therefore information is lacking in regards to their affect on

production. While these weeds may not be common competitors in conventional canola production, these species can be problematic in organic systems where they were used as cover crops in previous years, set seed, and have become weeds in subsequent cash crops (SARE, 2007).

The Kinston 2013 environment had similar trends to the Goldsboro 2013 environment, with both seeding rate and row spacing having a significant effect on weed coverage (Table 2), and the lowest weed coverage being observed with the 68 cm row spacing (Figure 2). The differences in weed coverage between the 68 cm row spacing and 17 and 34 cm row spacing's were less pronounced in this environment compared to the Goldsboro 2013 environment (Figure 2). Weed coverage declined with increasing seeding rate in the 17 cm row spacing, but not in the other row spacing's (Figure 2). While this environment had high overall weed coverage, the weed community consisted primarily of common chickweed (*Stellaria media*), which did not appear to be a strong competitor with canola. O'Donovan (1992) found that weeds at high densities may have a minimal impact on canola yield if they emerge after the crop. Canola was planted into a clean-tilled seedbed which could have minimized the impact of high weed coverage on yield at this environment.

At the Salisbury 2013 environment, there was very low weed pressure and only seeding rate had an effect on weed coverage (Figure 2, Table 2). Weed coverage declined as seeding rate increased (Figure 2). O'Donovan (1994) found that increasing plant density and seeding rates had a greater effect on weed suppression than manipulations in row spacing, which are aligned with the results from this environment, but contrast weed coverage results

from Goldsboro 2012, Goldsboro 2013, and Kinston 2013 where both row spacing and seeding rate affected weed coverage.

Yield. For the combined yield analysis of four environments, row spacing and seeding rate interacted to affect canola grain yield (Table 2). Yields were similar across all row spacing's at the 3.4 and the 6.7 kg ha^{-1} seeding rate, however as seeding rate increased, yield continued to increase in the 17 cm row spacing, while yield declined in the 34 and 68 cm row spacing's (Figure 3). Canola yield is positively correlated with uniform plant distribution (Angadi et al., 2003), and high seeding rates in wider row spacing's increased plant non-uniformity from intraspecific competition, which could lead to yield declines compared to narrow row spacing's where a more uniform distribution could be achieved with high seeding rates.

The two environments excluded from the combined yield analysis include Goldsboro 2013 and Salisbury 2013. In the Goldsboro 2013 environment, row spacing had a significant effect on yield and seeding rate did not (Table 2). Yields were highest in the 68 cm row spacing at the lower seeding rates (Figure 3). As seeding rate increased, yield declined in the 68 cm row spacing, a trend that existed at all environments and is likely attributed to intraspecific competition (Figure 3). While seeding rate did not have a significant effect on yield, yield did increase with increasing seeding rate at the 17 cm row spacing, a trend that existed in five of the six environments (Figure 3). This environment had a highly competitive weed community, and weed coverage was significantly less in the 68 cm row spacing (Figure 2). This may help explain the higher yields obtained in the 68 cm row spacing at this environment, while yields in the 68 cm row spacing tended to be lower at the other environments. Similar results were observed by Kolb et al. (2012) who found that wide row

spacing's receiving between row cultivations increased wheat yield and weed suppression compared with narrow row spacing's which did not receive between row cultivations. Lodging was experienced in the Goldsboro 2013 environment. Row spacing had an effect on lodging at alpha 0.1 (P=0.10), with the 17 cm row spacing experiencing the most lodging among row spacing's. Seeding rate did not affect lodging (P=0.87). In addition to less weed coverage in the 68 cm row spacing at this environment, lodging in the narrow row spacing may have led to lower yields compared with the 68 cm row spacing.

In the Salisbury 2013 environment, row spacing and seeding rate did not significantly affect yield (Table 2). These results are aligned with a range of studies showing no impact of row spacing or seeding rate on yield in rapeseed production (Johnson & Hanson, 2003; Lewis & Knight, 1987; Christensen & Drabble, 1984; Degenhardt & Kondra, 1981; Kondra, 1977). Results from this environment are more likely to resemble previous row spacing and seeding rate results from studies conducted in environments with herbicide use, due to low weed coverage at this environment. While seeding rate did not have a significant effect on yield, this was the only environment where yield declined with increasing seed rate in the 17 cm row spacing (Figure 3). Lodging was experienced in the Salisbury 2013 environment. Spacing had no effect on lodging (P=0.82), but seeding rate significantly affected lodging (P=0.002). Lodging began at seeding rates of 10.1 kg ha^{-1} and increased with increasing seeding rate across all row spacing's. These results are similar to those found by Bilgili et al. (2003), who showed that canola stands with narrow row spacing and high seeding rates were more prone to lodging. Lodging at higher seeding rates has been shown to cause yield declines in rapeseed production (Hanson et al., 2008; Kondra, 1975; Morrison et al., 1990).

Lodging may explain the yield declines in the 17 cm row spacing at high seeding rates observed in this environment.

CONCLUSIONS

Results from this study indicate that in fields with weed pressure from species competitive with canola, widening row spacing to allow for between row cultivations may serve as a critical component of suppressing weeds and maximizing yield for organic canola producers. In environments with less competitive weed species, producers have flexibility when selecting row spacing's at low seeding rates. Seeding rate had a significant effect on weed coverage in four of the six environments. Results indicate that the most economically viable option for organic canola producers would be to employ low seeding rates. It should be noted that disease pressure was very low or absent across all environments. If diseases were present, row spacing and seeding rate recommendations for organic canola producers may change. Another caveat is the lack of weed pressure from Italian ryegrass (*Lolium multiflorum*) across all six environments. Italian ryegrass is a current problem for organic wheat producers in North Carolina and can reduce canola yields if not controlled (Bushong et al., 2011). Additional studies that investigate the effects of row spacing and seeding rate at environments with disease pressure and Italian ryegrass are necessary in organic canola production.

LITERATURE CITED

Angadi, S.V., H.W. Cutforth, B.G. McConkey, and Y. Gan. 2003. Yield adjustment by canola grown at different plant populations under semi-arid conditions. Crop Sci. 43:1358-1366.

Bilgili, U., M. Sincik, A. Uzun, and E. Acikgoz. 2003. The influence of row spacing and seeding rate on seed yield and yield components of forage turnip (*Brassica rapa* L.). J. Agronomy & Crop Sci. 189:250-254.

Bishnoi, U.R., S. Kumar, E. Cebert, and R.S. Mentreddy. 2007. Agronomic and economic performance of winter canola in Southeastern US. World J. of Agricultural Sci. 3: 263-268.

Blackshaw, R.E., H.J. Beckie, L.J. Molnar, T. Entz, and J.R. Molnar. 2005. Combining agronomic practices and herbicides improves weed management in wheat-canola rotations within zero-tillage production systems. Weed Sci. 53:528-535.

Boyles, M., T. Pepper, and M. Stamm. 2009. Great plains canola production handbook. Oklahoma State University, Kansas State University, University of Nebraska. http://canola.okstate.edu/productionguides/canolaproductionhandbook2009.pdf (accessed 29 Nov. 2014).

Boyle, M.C., T.F. Peeper, and C.R. Martin. 2004. Producing winter hardy canola in Oklahoma. Winter canola planting guide for the Southern Great Plains. Oklahoma Cooperative Extension Service, Oklahoma State University.http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2594/PSS-2131web.pdf (accessed 9 Dec. 2014).

Buntin, D., T. Gray, G.H. Harris, D. Phillips, J. Buck, E. Prostko, P. Raymer, N. Smith, P. Sumner, and J. Woodruff. 2013. Canola production in Georgia. University of Georgia Extension. http://extension.uga.edu/publications/files/pdf/B%201331_4.PDF (accessed 29 Nov. 2014).

Bushong, J., T. Peeper, M. Boyles, and A. Stone. 2011. Italian ryegrass (*Lolium perenne*), feral cereal rye (*Secale cereale*), and volunteer wheat (*Triticum aestivum*) control in winter canola. Weed Tech. 25:344-349.

Canola Council of Canada. 2014. Canola Grower's Manual. http://www.canolacouncil.org/crop-production/canola-grower's-manual-contents/ (accessed 9 Dec. 2014).

Christensen, J.V., and J.C. Drabble. 1984. Effect of row spacing and seeding rate on rapeseed yield in Northwest Alberta. Can. J. Plant Sci. 64:1011-1013.

Clarke, J.M., F.R. Clarke, and G.M. Simpson. 1978. Effect of method and rate of seeding on yield of *Brassica napus*. Can. J. Plant Sci. 58:549-550.

Degenhardt, R., R. Martin, and D. Spaner. 2005. Organic farming in central Alberta: Current trends, production constraints and research needs. J. Sustain. Agric. 27(2):153-173.

Degenhardt, D.F., and Kondra, Z.P. 1981. The influence of seeding date and seeding rate on seed yield and growth characteristics of five genotypes of *Brassica napus*. Can. J. Plant Sci. 61:185-190.

Diepenbrock, W. 2000. Yield analysis of winter oilseed rape (*Brassica napus* L.): a review. Field Crops Research. 67:35-49.

Drews, S., D. Neuhoff, and U. Kopke. 2009. Weed suppression ability of three winter wheat varieties at different row spacing under organic farming conditions. Weed Research 49:526-533.

Hall, L., A. Good, H.J. Beckie, and S.I. Warwick. 2003. Gene flow in herbicide-resistant canola (Brassica napus): The Canadian experience. In T. Lelley, E. Balazs, and M. Tepfer (Eds), Ecological Impact of GMO Dissemination in Agro-Ecosystems (pp 57-66). Austria: Facultas Verlagsund Buchhandels AG.

Hanson, B.K., B.L. Johnson, R.A. Henson, and N.R. Riveland. 2008. Seeding rate, seeding depth, and cultivar influence on spring canola performance in the Northern Great Plains. Agron. J. 100:1339-1346.

Harker, K.N., G.W. Clayton, R.E. Blackshaw, J.T. O'Donovan, and F.C. Stevenson. 2003. Seeding rate, herbicide timing, and competitive hybrids contribute to integrated weed management in canola (*Brassica napus*). Can. J. Plant Sci. 83:433-440.

Kolb, L.N., E.R. Gallandt, and E. B. Mallory. 2012. Impact of spring wheat planting density, row spacing, and mechanical weed control on yield, grain protein, and economic return in Maine. Weed Sci. 60:244-253.

Kondra, Z.P. 1977. Effect of planted seed size and seeing rate on rapeseed. Can. J. Plant Sci. 57:277-280.

Kondra, Z.P. 1975. Effects of row spacing and seeding rate on rapeseed. Can. J. Plant Sci. 55: 339-341.

Johnson, B.L. and B.K. Hanson. 2003. Row-spacing interactions on spring canola performance in the Northern Great Plains. Agron. J. 95:703-708.

Lewis, C.E. and C.W. Knight. 1987. Yield response of rapeseed to row spacing and rates of seeding and fertilization in interior Alaska. Can. J. Plant Sci. 67:53-57.

Martin, P., J. Edwards, B. Haskins, J. Walker, N. Fettell, K. Moore, and G. McMullen. 2011. Response of canola to wider row spacing in southern New South Wales. In 17th Australian Research Assembly on Brassicas (ARAB), Wagga, Wagga.

May, W.E., D.J. Hume, and B.A. Hale. 1993. Effects of agronomic practices on free fatty acid levels in the oil of Ontario-grown spring canola. Can. J. Plant Sci. 74267-274.

Morrison, M.J., P.B.E. McVetty, and R. Scarth. 1990. Effect of row spacing and seed rate on summer rape in Southern Manitoba. Can. J. Plant Sci. 70:127-137.

Place, G.T., S.C. Reberg-Horton, J.E. Dunphy, and A.N. Smith. 2009. Seeding rate effects on weed control and yield for organic soybean producers. Weed Tech. 23:497-502.

O'Donovan, J.T. 1994. Canola (*Brassica rapa*) plant density influences Tartary Buckwheat (*Fagopyrum tataricum*) interference, biomass, and seed yield. Weed Sci. 42:385-389.

O'Donovan, J.T. 1992. Seed yields of volunteer barley as influenced by their relative times of emergence. Can. J. Plant. Sci. 72:263-267.

Organic Trade Association. 2014. American appetite for organic products breaks through $35 billion mark. https://ota.com/news/press-releases/17165 (accessed 29 Nov. 2014).

Rasmussen, I.A. 2003. The effect of sowing date, stale seedbed, row width and mechanical weed control on weeds and yields of organic winter wheat. Weed Res. 44: 12-20.

Reberg-Horton, S.C., R. Weisz, A. York, G. Place, and M. Hamilton. 2013. Weed Management in North Carolina Organic Grain Production Guide. North Carolina State University. http://www.cefs.ncsu.edu/resources/organicgrainfinal.pdf (accessed 29 Nov. 2014).

SARE. 2007. Chart 4B Potential Disadvantages. In A. Clark editor, Managing cover crops profitably, third edition. United Book Press, Inc. Gwynn Oak, MD. p. 72.

Sierts, H-P., G. Geisler, J. Leon, and W. Diepenbrock. 1987. Stability of yield components from winter oil-seed rape (*Brassica napus* L.). J. Agronomy & Crop Sci. 158:107-113.

Smyth, S.J., M. Gusta, K. Belcher, P.W.B. Phillips, and D. Castle. 2011. Environmental impacts from herbicide tolerant canola production in Western Canada. Agricultural Systems 104:403-410.

Tetio-Kagho, F., and F.P. Gardner. 1988. Responses of maize plant population density. I. Canopy development, light relationships, and vegetative growth. Agron. J. 6:930-935.

United States Department of Agriculture, Economic Research Service. 2000. Recent growth patterns in the US organic foods market. http://www.ers.usda.gov/media/255736/aib777c_1_.pdf (accessed 30 Nov. 2014).

Upadhyay, B.M., E.G. Smith, G.W. Clayton, and R.E. Blackshaw. 2006. Economics of integrated weed management in herbicide-resistant canola. Weed Sci. 54:138-147.

Valantin-Morison, M. and J.M. Meynard. 2008. Diagnosis of limiting factors of organic oilseed rape yield. A survey of farmers' fields. Agron. Sustain. Dev. 28:527-539.

Table 1. Dates for canola planting, canola harvest and other management events.

	Management Event					
Environment	Planting	Fall SC†	Cultivations‡	Weed Ratings	Harvest	Final SC†
Goldsboro 2012	September 30	November 18	–§	March 29	May 22	June 6
Kinston 2012	October 5	November 16	Jan 26 & Feb 7	–¶	May 24	June 11
Salisbury 2012	October 6	November 21	–§	–¶	June 4	June 4
Goldsboro 2013	September 25	November 11	November 14	March 20	June 5	June 10
Kinston 2013	October 11	November 5	Nov 28 & Feb 6	March 20	June 14	June 19
Salisbury 2013	September 27	October 31	November 20	March 27	June 26/27	June 27

† Abbreviation: SC, stand counts.

‡ Cultivations occurred in the 68 cm row spacing only.

§ Weather prohibited the occurrence of cultivation.

¶ Weed ratings were not obtained due to very low weed pressure.

Table 2. ANOVA results for the effects of row spacing (S), seeding rate (R), environment (E), and the relevant interactions on fall populations, final populations, weed coverage, and yield for combined analyses and by individual environment.

				Environment					
	Source	Combined 6 environments	Combined 4 environments‡	Goldsboro 2012	Kinston 2012	Salisbury 2012	Goldsboro 2013	Kinston 2013	Salisbury 2013
				P>F					
Fall Population	S	<0.001	–	–	–	–	–	–	–
	R	<0.001	–	–	–	–	–	–	–
	E	0.001	–	–	–	–	–	–	–
	S*R	0.001	–	–	–	–	–	–	–
	S*E	0.05	–	–	–	–	–	–	–
	R*E	0.03	–	–	–	–	–	–	–
	S*R*E	NS	–	–	–	–	–	–	–
Final Population	S	<0.001	–	–	–	–	–	–	–
	R	<0.001	–	–	–	–	–	–	–
	E	0.001	–	–	–	–	–	–	–
	S*R	0.006	–	–	–	–	–	–	–
	S*E	0.01	–	–	–	–	–	–	–
	R*E	0.004	–	–	–	–	–	–	–
	S*R*E	NS	–	–	–	–	–	–	–
Weed Coverage	S	NS	–	<0.001	–	–	<0.001	0.01	NS
	R	0.01	–	0.01	–	–	0.02	0.05	<0.001
	E	0.01	–	–	–	–	–	–	–
	S*R	0.01	–	NS	–	–	0.001	NS	NS
	S*E	<0.001	–	–	–	–	–	–	–
	R*E	NS	–	–	–	–	–	–	–
	S*R*E	NS	–	–	–	–	–	–	–
Yield	S	NS	NS	–	–	–	0.002	–	NS
	R	NS	NS	–	–	–	NS	–	NS
	E	<0.001	0.001	–	–	–	–	–	–
	S*R	NS	0.01	–	–	–	NS	–	NS
	S*E	0.001	NS	–	–	–	–	–	–
	R*E	NS	NS	–	–	–	–	–	–
	S*R*E	NS	NS	–	–	–	–	–	–

† Abbreviations: S, Row Spacing; R, Seeding Rate; E, Environment; NS, nonsignificant at the 0.05 level.

‡ The four environments in the combined analysis include: Goldsboro 2012, Kinston 2012, Salisbury 2012, and Kinston 2013.

§ Data not presented (–) because environments were included in a combined analysis or source pertains only to a combined analysis.

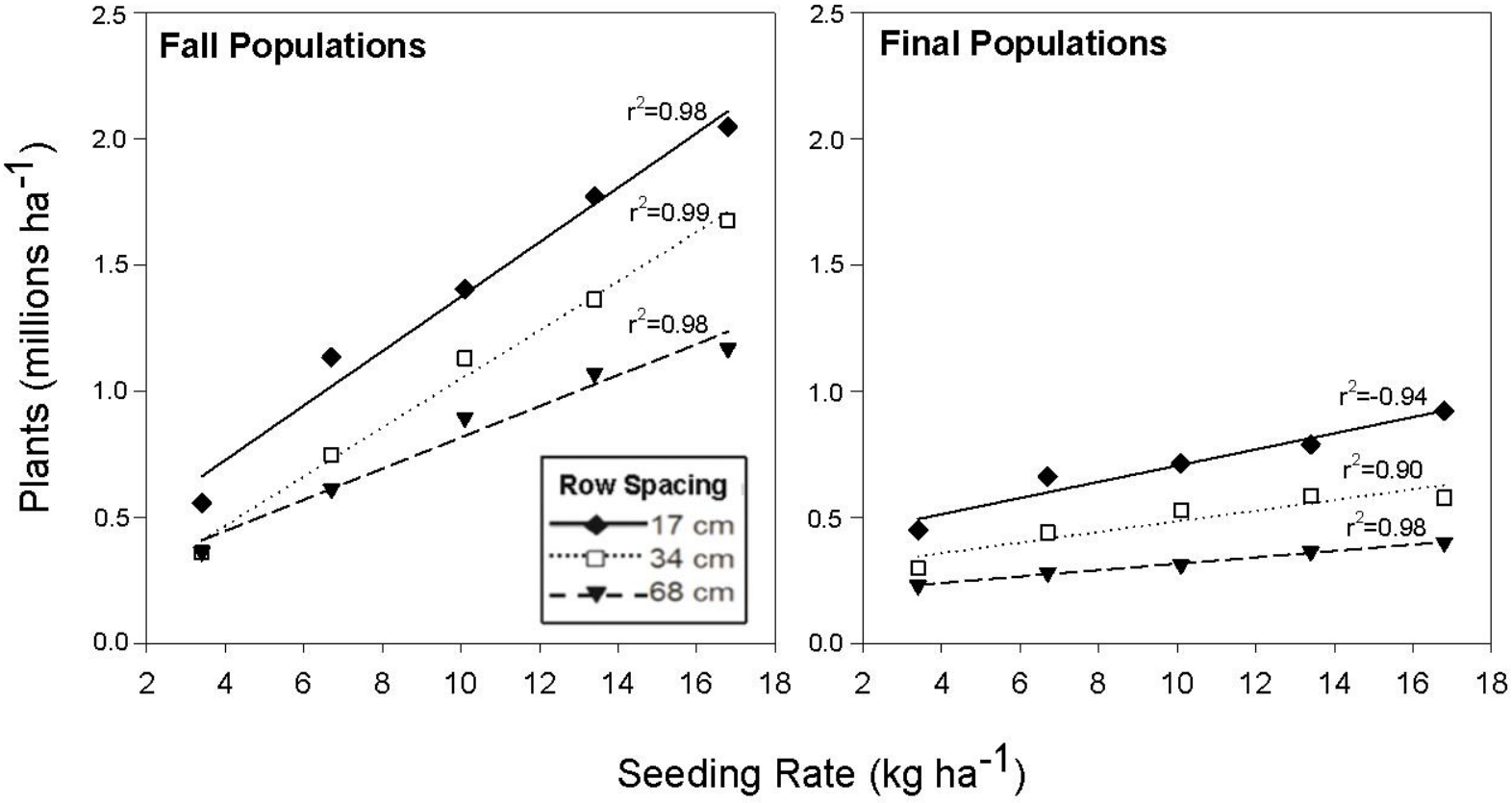

Figure 1. Effect of row spacing and seeding rate on fall and final canola populations. Mean plant population values combined across six environments.

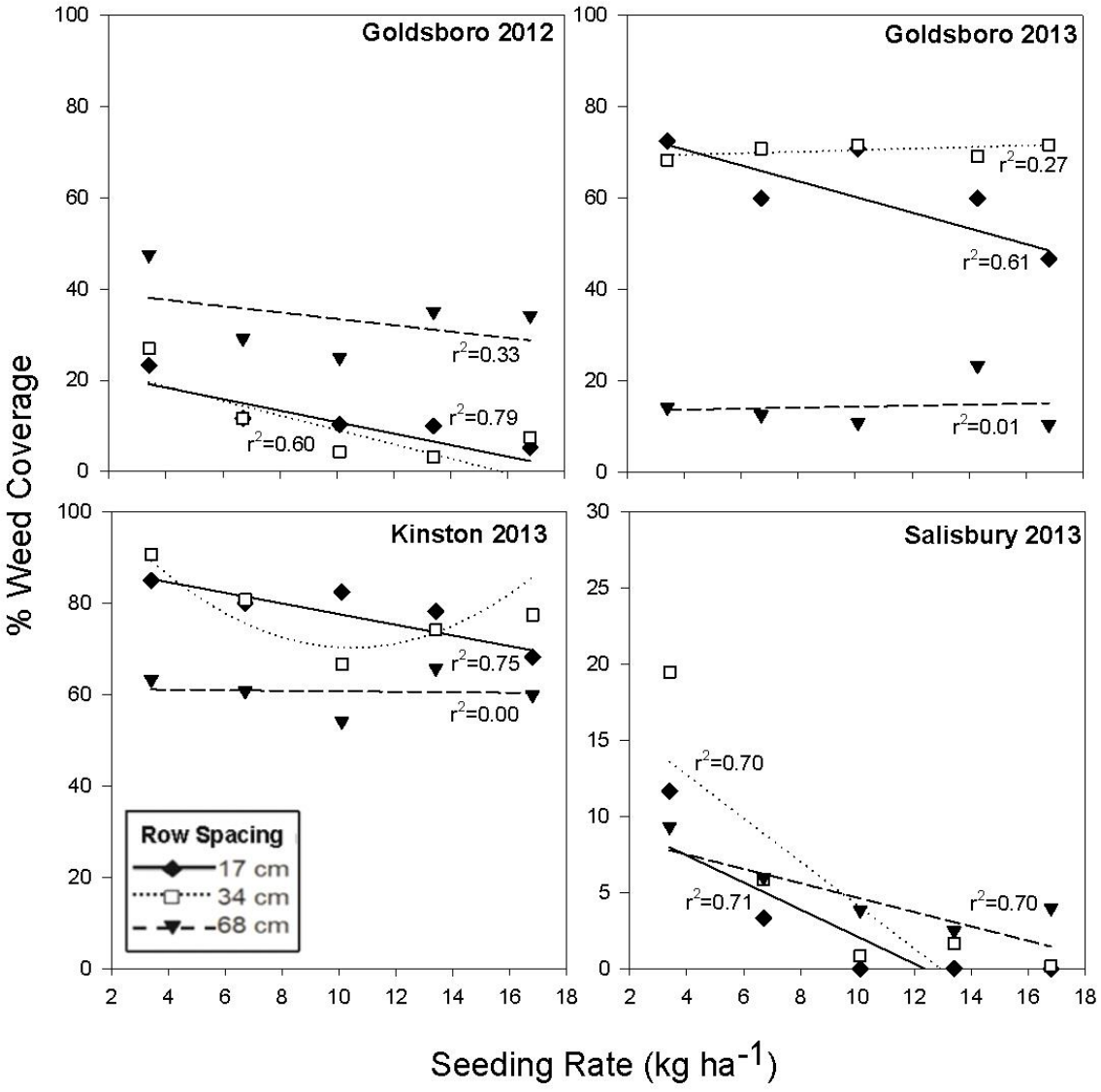

Figure 2. Effect of row spacing and seeding rate on weed coverage at Goldsboro 2012, Goldsboro 2013, Kinston 2013, and Salisbury 2013.

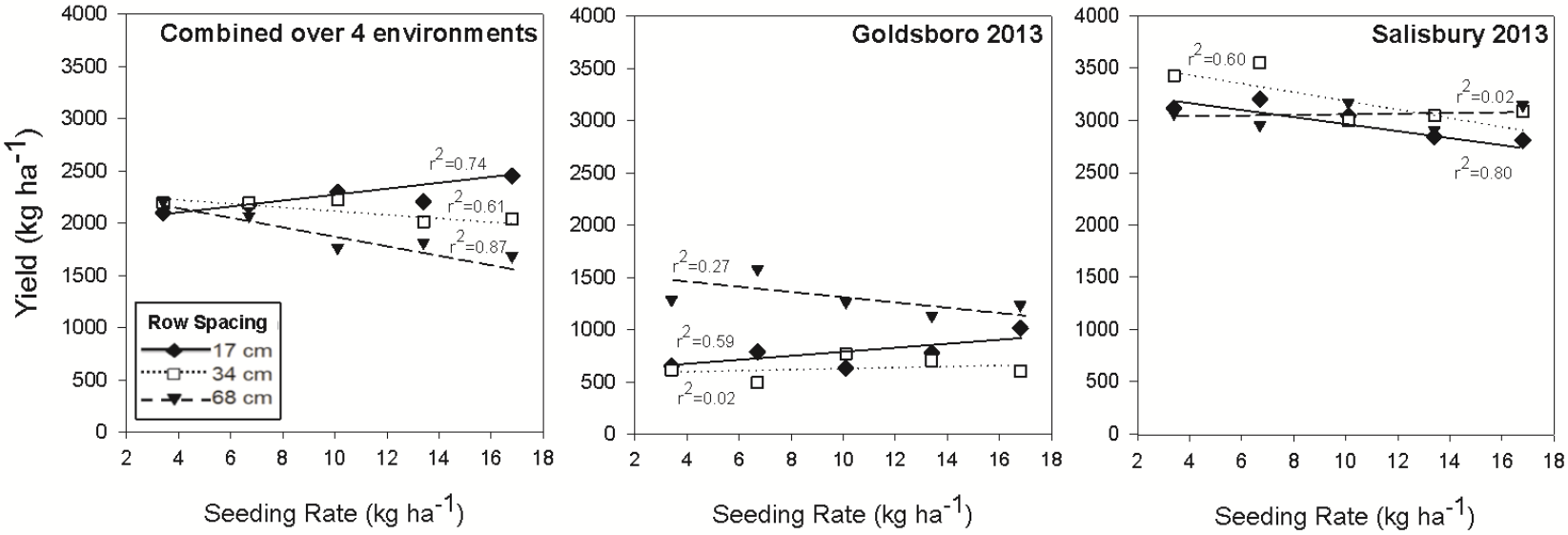

Figure 3. Effect of row spacing and seeding rate on canola yield for a combined analysis of four environments, Goldsboro 2013, and Salisbury 2013. Mean yield values averaged across Goldsboro 2012, Kinston 2012, Salisbury 2012, and Kinston 2013 for the combined yield analysis.

Chapter II

The influence of starter fertilizer materials and application methods on weed competition and grain yield in organic rotational no-till corn production

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INTRODUCTION

Reduced tillage production practices are increasingly implemented in conventional systems and desired in organic cropping systems. Reducing tillage offers a wide range of benefits, including reduced soil erosion (Pimentel et al., 1995), increased soil organic matter (Grandy et al., 2006), soil moisture preservation (Mitchell et al., 2012), improved water infiltration (Holland, 2004), and decreased labor and energy inputs (Triplett & Dick, 2008). Employing conservation tillage can also reduce weed management risks for producers when unfavorable weather prevents timely mechanical cultivation (Mirsky et al., 2012). Synthetic herbicide use has facilitated the increased adoption of conservation tillage in conventional production systems (Young, 2006); however synthetic herbicide use is restricted in organic production. As a result, organic systems remain heavily dependent upon tillage as a primary weed control mechanism, despite increased interest among producers in adopting reduced tillage production practices (Smith et al., 2011). Alternative mechanisms for weed control have been evaluated to provide organic producers with viable options for reduced tillage production.

One alternative is the use of a roller-crimper to create a weed suppressive mulch. The roller-crimper is an implement utilized to terminate cover crops by rolling them down at an appropriate growth stage and crimping their stems to promote cover crop desiccation, thereby creating a mulch into which the cash crop is directly planted (Ashford & Reeves, 2003; Davis, 2010). Cover crop mulches can intensify the benefits of reduced tillage production practices through reduced soil erosion (Hartwig & Ammon, 2002), preservation of soil moisture and improvement of water infiltration (Clark et al., 1995; McVay et al., 1989),

enhanced soil C (Teasdale et al., 2007), and can suppress weeds (Mischler et al., 2010). A cover crop mulch suppresses weed growth through several mechanisms, which include reducing light availability (Teasdale & Mohler, 1993), physical impedance (Teasdale et al., 1991), allelopathy (Reberg-Horton et al., 2005), and reducing soil inorganic N availability for weed growth (Wells et al., 2013). Using the roller-crimper to create a weed suppressive mulch has been successful across a range of organic crops (Delate et al., 2011; Mischler et al., 2010; Smith et al., 2011). This approach is often considered "rotational no-till' because tillage does not occur during the cash crop growing season, however tillage is considered necessary prior to cover crop establishment (Mirsky et al., 2012). The organic rotational no-till system has been particularly successful in organic soybean production, where soybeans are planted into a roller-crimped monoculture of cereal rye (Davis, 2010; Mirsky et al., 2013). Cereal rye can provide for excellent weed suppression in the subsequent crop when adequate biomass levels are obtained (Smith et al., 2011), however due to a high C:N ratio cereal rye typically provides inadequate N release to crops with high N demand (Ranells & Wagger, 1996).

Consistent weed control and restricted N availability have been identified as limiting factors to yield in reduced tillage organic corn production (Mirsky et al., 2012; Peigné et al., 2007). Cover crop species selected for use in organic rotational no-till corn production must maximize the benefits of both N provision and weed suppression. While hairy vetch has been widely recognized for its ability to provide substantial N in this system (Decker et al., 1994; Ebelhar et al., 1984; Wagger, 1989), season long weed control is typically not achieved with a vetch monoculture (Koger & Reddy, 2005; Mischler et al., 2010; Teasdale et al., 2012).

Weed suppression is improved when hairy vetch is planted in mixture with a cereal cover crop (Teasdale & Abdul-Baki, 1998). A rye/vetch mixture can increase cover crop biomass beyond that which can be achieved by monoculture vetch stands, thus increasing the opportunity for season long weed control (Reberg-Horton et al., 2012). In a Michigan study, a rye/vetch cover crop mixture resulted in a 94-95% reduction in weed biomass compared to treatments with no cover crop (Hayden et al., 2012). The same study demonstrated that weed suppression from a rye/vetch cover crop mixture could match that of a rye monoculture (Hayden et al., 2012). In North Carolina, a rye/vetch cover crop mixture was shown to have similar N content as monoculture vetch stands, despite lower % N, due to increased cover crop biomass of the mixture (Parr et al., 2011). A rye/vetch cover crop mixture is one of the most suitable mixtures for fertility provision and weed suppression in organic corn production, however cover crop N release is variable and often not in synchrony with corn N demand (Vaughan & Evanylo, 1998).

Climatic factors, residue placement, and termination date contribute to inconsistency in N release from cover crops, and it is this variability that is recognized as a restricting factor to using N release from decomposing cover crops as the sole nitrogen source for a corn crop (Reberg-Horton et al., 2012). In a North Carolina study where a rye/vetch cover crop mixture produced enough N for high corn grain yield, N release occurred prior to peak corn N demand (Ranells & Wagger, 1996). Additional studies have found that N release from a rye/vetch cover crop mixture was inadequate to provide for maximum corn yields (Clark et al., 1997; Clark et al., 1994; Sullivan et al., 1991). Previous research efforts have focused on aligning corn planting date to optimal N release from the cover crop; however this often

requires a delayed corn planting date which can lead to reductions in corn yield (Cook et al., 2010). These results indicate that additional N fertility beyond that provided through baseline fertility and cover crop mineralization may be necessary to maximize corn grain yield in organic rotational no-till production.

Broiler litter production is highly concentrated in the mid-Atlantic and Southeastern USA states (MacDonald, 2008), and therefore is commonly used as an inexpensive organic fertilizer material in these regions. While poultry litter applications are convenient and relatively inexpensive, excessive use of poultry litter can result in high levels of soil P and Zn, increased P runoff, and the introduction of undesirable bacteria into surface water (Endale et al., 2010). The environmental concerns associated with poultry litter use have led to monitored and restricted litter use in areas of the USA.

Broadcast application is the most common method of applying poultry litter and, unfortunately, this application technique can lead to high levels of N volatilization (Tewolde et al., 2009). Volatilization losses can be reduced through rapid incorporation of broadcast poultry litter (Webb et al., 2005); however incorporation is not possible in the rotational no-till system. An additional approach to poultry litter application is through subsurface banding, which can also reduce N volatilization compared to broadcast applications which are not soil incorporated (Tewolde et al., 2009).

Subsurface banding is a viable option for delivering organic fertilizer materials in organic rotational no-till production. Planters commonly used by organic producers to direct seed into high cover crop biomass stands are typically equipped with dry fertilizer boxes, which can apply subsurface bands of fertilizer materials (Reberg-Horton, personal

communication, 2015). Subsurface banded fertilizer applications can reduce volatilization, nutrient run-off, and pathogen losses in run-off (Pote et al., 2011), and several studies have demonstrated crop yield increases with subsurface banded fertilizer applications compared with broadcast fertilizer applications (Blackshaw et al., 2004; Rassmussen, 2002; Tewolde et al., 2009). While subsurface banding poultry litter may reduce environmental concerns, typical fertilizer boxes on no-till planters may not deliver a high enough volume of poultry litter to provide for maximum corn yields. Other organic fertilizer materials, such as feather meal and blood meal, are available to organic producers. These materials have a higher N concentration per unit volume, do not provide P and K, and can lead to higher N mineralization rates compared with poultry litter (Gaskell and Smith, 2007). Nitrogen availability for the subsequent crop is often improved with commercial organic fertilizers because N is more concentrated compared to composts and legume N release, and these fertilizer materials can be particularly important for late season N management (Gaskell and Smith, 2007). Feather meal and blood meal products can be purchased in pelletized form, allowing for a subsurface banded application with common no-till planting equipment on organic farms. While these commercial organic fertilizers have the benefits of increased N concentration and reduced environmental risk, these fertilizer materials are significantly more expensive per unit N than poultry litter materials.

High levels of N fertility may allow for maximum corn yield to be achieved, however N applications in excess of corn N uptake needs can exacerbate weed competition with the commercial crop. Some weed species have a stronger response at high N rates than the crop (Barker et al., 2006; Carlson and Hill, 1985). Blackshaw and Brandt (2008) reported that

high-N responsive weed species, such as redroot pigweed (*Amaranthus retroflexus)*, had improved competiveness at higher N rates, while low-N demanding weed species had no response to increased N rates. This may be attributed to greater plasticity of some weed species in response to available resources compared with crops (Barker et al., 2006). Smith et al. (2011) found a stimulatory effect of banded corn gluten meal on weed competition in soybean production with a rye cover crop mulch, presumably due to additional N available to the weeds from the corn gluten meal. Other studies have demonstrated no effect on weed interference at increasing nitrogen rates (Satorre & Snaydon, 1991), and other studies have shown improved corn competitiveness with weeds in high nitrogen environments (Abouziena et al., 2007; Evans et al., 2003).

In addition to nitrogen fertilizer rate, fertilizer application method may also have an influence on weed competition. Blackshaw et al. (2004) generally reported reduced weed biomass with subsurface banded N applications compared to surface broadcast N applications. Blackshaw (2005) also observed that subsurface fertilizer applications improved wheat competitiveness against weeds when compared to a broadcast application. In another study, liquid manure injection reduced weed biomass compared with a broadcasted manure application (Rasmussen, 2002). These studies suggest that weed suppression may be improved when using subsurface banded fertility applications compared to surface broadcast fertility applications.

Organic corn producers are often limited to pre-plant N fertility management. Equipment capable of delivering a subsurface fertilizer application at sidedress in no-till production has been developed by the USDA-ARS (Tewolde et al., 2009), however investing

in new equipment could be economically limiting to organic producers. Subsurface banded fertilizer applications using dry fertilizer boxes on existing no-till planting equipment is one viable option for N management that can potentially improve weed suppression and increase corn grain yields, however it is possible that these dry fertilizer boxes cannot deliver enough N to maximize corn yield. The objective of this study was to evaluate the effects of different starter fertilizer materials and fertilizer application methods on both weed competition and grain yield in organic rotational no-till corn production using a cover crop mulch for weed suppression.

MATERIALS AND METHODS

Research was conducted at three locations including the USDA-ARS Beltsville Agricultural Research Center in Beltsville, MD, the Caswell Research Station in Kinston, NC, and the Piedmont Research Station in Salisbury, NC. Experiments were conducted during the 2013 and 2014 corn growing seasons at all locations. The combination of year and location will be referred to as an environment. The Beltsville trials were conducted on a Hatboro Silt Loam (fine-loam, mixed, active, mesic Fluvaquentic Endoaquepts). The Kinston 2013 trial was conducted on a Pocalla Loamy Sand (loamy, siliceous, subactive, thermic Arenic Plinthic Paleudults) and the Kinston 2014 trial was conducted on a Johns Sandy Loam (fine-loamy over sandy, siliceous, semiactive, thermic Aquic Hapludults). The Salisbury 2013 and 2014 trials were conducted on a Mecklenburg Clay Loam (fine, mixed, active, thermic Ultic Hapludalfs). The Beltsville environments were certified organic. The Kinston and Salisbury environments were managed organically with one exception of a single pre-emergence herbicide application at corn planting to the weed-free plots. These locations were selected to represent a range of growing conditions which might be experienced by organic corn producers in the mid-Atlantic and Southeastern USA regions.

A cereal rye and hairy vetch cover crop mixture was established in early fall uniformly across all treatments (Table 1). Seeding rates for cereal rye and hairy vetch were 101 and 16.8 kg ha^{-1}, respectively. Seeding rates were selected based on previous cereal rye and hairy vetch cover crop mixture studies which indicated that these seeding rates would maximize the benefits of each cover crop species in the mixture (Poffenbarger et al., In review). At the Beltsville environments, rye was of the cultivar ‘Aroostook’ and vetch of the

cultivar ‘Groff’. At the Kinston and Salisbury environments, rye was of the cultivar ‘Wrens Abruzzi’ and vetch of the cultivar ‘Purple Bounty’. Rye and vetch were thoroughly mixed together prior to planting, and were planted into a clean-tilled seedbed using a John Deere 450 grain drill at the Beltsville environments and a Hege 1000 series cone planter at the Kinston and Salisbury environments. Cover crops were terminated using a roller-crimper, and one, two, or three roller-crimping events occurred depending on environment (Table 1). In the Kinston 2013 and Kinston 2014 environments, the second and third roller-crimping event, respectively, occurred following corn planting near corn emergence (Table 1). Cover crop termination was targeted to align with rye growth stage Zadoks 65 and early pod set for vetch.

Corn was planted in 76.2 cm rows parallel to cover crop drilling direction at the first or second cover crop roller-crimping event, depending on environment (Table 1). Corn was planted using a no-till planter (Model 7200 Max Emerge, Conservation Tillage, John Deere, Moline, IL) equipped with additional custom residue slicers (Pequea Planter Llc., Gap, PA) and Yetter Shark Tooth residue managers (Yetter Profitable Solutions, Colchester, IL) attached to an added front toolbar to assist with planting into high cover crop biomass. Corn variety ‘Blue River 51B57’ was planted at the Beltsville 2013 environment, variety ‘Blue River 56M30’ was planted at the Beltsville 2014 environment, and variety ‘Doeblers N630’ was planted at the Kinston and Salisbury environments. Corn varieties were certified organic and were selected for adaption to regional growing conditions.

Treatments were arranged in a spilt-plot design with three replications at the Beltsville environments, six replications at the Kinston 2013, Kinston 2014, and Salisbury

2014 environments, and four replications at the Salisbury 2013 environment. Main plot factor was fertility treatment and subplot factor was weed-free and weedy conditions. Fertility treatments included 1) high rate broadcast poultry litter (HBPL), 2) low rate broadcast poultry litter and a subsurface banded pelletized poultry litter application using the dry fertilizer boxes on the planter (LBPL+SBPL), 3) subsurface banded pelletized feather meal application using the dry fertilizer boxes on the planter (SBFM), 4) subsurface banded pelletized poultry litter application using the dry fertilizer boxes on the planter (SBPL), and 5) no added fertility (no starter). Additional information on each fertility treatment is available in Table 2. All fertility treatments were applied at corn planting. The HBPL fertility treatment was not employed at the Beltsville environments and the LBPL+SBPL fertility treatment was not employed at the Kinston 2013 and Salisbury 2013 environments.

Pelleted poultry litter (3-2-3) was used for the broadcast and subsurface poultry litter applications (microSTART60, Perdue AgriRecycle, Llc., Seaford, DE). Pelleted litter was used for the broadcast applications in this study due to ease of obtaining materials. It is likely that most organic producers would utilize loose poultry litter for a broadcast application, and therefore when calculating the cost of fertility treatments the price of the broadcast applications are based on the price of loose poultry litter (Table 2). The pelletized feather meal product was a Blending Base Fertilizer (13-0-0) obtained from Nature Safe Company and was certified organic (Cold Spring, KY). Dry fertilizer boxes on the planter were adjusted for maximum fertilizer delivery, allowing for ~645-700 kg pelleted material ha^{-1}. A tractor speed between 1.6 and 4.8 km h^{-1} was maintained during subsurface banded fertilizer applications to prevent clogging of the fertilizer hoses.

At the Beltsville environments, weed-free conditions were maintained by hand weeding. At the Kinston and Salisbury environments, weed-free plots received a single pre-emergence application of Medal II ATZ at 4.9 (4.0 kg ai ha^{-1} atrazine + 3.1 kg ai ha^{-1} S-metolachlor) and 6.0 (4.9 kg ai ha^{-1} atrazine + 3.8 kg ai ha^{-1} S-metolachlor) L ha^{-1}, respectively. Subsequent hand weeding was performed to maintain weed-free conditions at the Kinston and Salisbury environments. Plot size was 6.1 m by 9.1 m at the Beltsville environments, 6.1 m by 7.6 m at the Kinston 2013 and Salisbury 2013 environments, and 6.1 m by 12.2 m at the Kinston 2014 and Salisbury 2014 environments. Data collected includes cover crop biomass, cover crop tissue elemental C and N, soil inorganic N (NO_3-N+NH_4-N), SPAD readings, corn biomass, corn tissue elemental C and N, visual weed coverage ratings, weed biomass, corn populations, and corn grain yield.

Cover crop biomass was collected at the first cover crop roller-crimping event directly following roller-crimping using a 0.5-m^2 quadrat. At four of the six environments, cover crop species were separated in the field, dried at 65ºC to obtain dry weight, and ground to pass a 2-mm sieve in preparation for elemental C and N analysis. In the Kinston and Salisbury 2013 environments, cover crop species were not separated prior to drying and grinding. Ground cover crop biomass was analyzed for elemental C and N using a LECO CHN-2000 elemental analyzer (LECO Inc., St. Joseph, MI) for the Beltsville environments and a PerkinElmer 2400 CHN elemental analyzer (PerkinElmer, Waltham, MA) for the Kinston and Salisbury environments.

Soil samples were collected across all fertility treatments in the weed-free plots at corn growth stages: VE, V2, and V5. Eight to ten soil cores were collected from each plot (0-

to 30-cm depth) using a soil auger at the Kinston and Salisbury environments, and a soil probe at the Beltsville environments. Soil cores from each plot were thoroughly mixed prior to transfer into a cooler where samples were stored moist at 4ºC for 1-3 d. Soil samples were then sieved (6-mm) and air-dried. Following air drying, soil samples were sieved to pass a 1-mm sieve and stored prior to inorganic N analysis. Inorganic N was determined by extracting 2 g soil with 20 mL 1 *M* KCl at the Beltsville environments and by extracting 5 g of soil with 50 mL 1 *M* KCl at the Kinston and Salisbury environments. A SEAL AutoAnalyzer 3 HR (Seal Analytical, Milwaukee, WI) was used to determine NO_3-N and NH_4-N concentration in the KCl extract.

Visual weed coverage ratings and weed biomass were obtained at various corn growth stages depending on level of weed competition at each environment. Visual weed ratings were obtained on a percent basis, with 0% corresponding to no weed coverage and 100% corresponding to total weed coverage. Weed biomass was collected using a 0.5-m^2 quadrat randomly placed within the plot. All weeds within the quadrat were harvested together and dried at 65ºC to obtain dry weight.

SPAD readings were obtained using a Konica Minolta SPAD-502 leaf chlorophyll meter (Ramsey, NJ). A SPAD reading is a representative value of leaf chlorophyll content, which is an indicator of leaf N content (Hunt and Daughtry, 2014). Six corn leaves were randomly selected within each plot and three SPAD measurements were obtained from each leaf (n=18). SPAD readings were obtained from the newest leaf with a mature collar between the margin and the mid-vein of the corn leaf. SPAD readings were collected at corn growth stages V5, V8, and V10.

Corn biomass was collected from each plot at corn growth stages V5, V8, R1, and R6. At each sampling event, six randomly selected plants within each plot were harvested by cutting the plant at the soil surface. Samples were dried at 65ºC to obtain dry weight, and subsequently ground to pass a 2-mm sieve in preparation for elemental C and N analysis. Ground corn biomass was analyzed for elemental C and N using a LECO CHN-2000 elemental analyzer (LECO Inc., St. Joseph, MI) for the Beltsville environments and a PerkinElmer 2400 CHN elemental analyzer (PerkinElmer, Waltham, MA) for the Kinston and Salisbury environments. Sample dry weight, corn population, and % N were used to estimate corn N content in kg ha^{-1}.

Corn was harvested at the Beltsville environments using a small plot combine and harvest length ranged from 10.7-15.3 linear m. At the Kinston and Salisbury environments, two 3.05 linear m sections were designated between corn growth stages V2 and V8 for corn grain yield harvest. Sections were selected avoiding large gaps and to prevent subsequent destructive biomass sampling from occurring in designated corn grain yield areas. Corn was hand harvested and shelled using an Agriculex SXS-2 Corn Sheller (Agriculex Inc., Guelph, Ontario) at the Kinston and Salisbury environments. Corn grain yield data was adjusted to 15.5% moisture content. Corn population data was obtained by counting the number of plants in the designated yield sections.

Analysis of variance was conducted using PROC MIXED in SAS 9.3. (SAS Institute Inc., Cary, NC) to test the effect of fertility treatment and weeds on SPAD readings, corn N content, and corn grain yield, and to test the effect of fertility treatment on soil inorganic N, weed coverage, and weed biomass. Treatment means were reported using least square mean

values. Means were separated using Fisher's Protected LSD test at $P<0.05$. Square root transformations were performed on weed coverage, weed biomass, and SPAD readings to correct for homogeneity of variance violations. Due to different weed communities and weed coverage at each environment, weed coverage and weed biomass data failed homogeneity of variance tests for a combined analysis and environments were analyzed individually. Soil inorganic N, corn N content, and corn grain yield data met model assumptions. Combined analyses across all environments were attempted for soil inorganic N, SPAD readings, corn N content, and corn grain yield. When a two or three way interaction between fertility treatment, weeds, and environment had a P-value<0.1 for a combined analysis of all six environments, a combined analysis of four environments was attempted (Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014) to evaluate if combining over these four environments was justified. The Beltsville 2013 and Kinston 2013 environments typically had different trends compared with the other four environments, and therefore were removed from the combined analysis of four environments. When pooling was justified across the four environments, the Beltsville 2013 and Kinston 2013 environments were analyzed individually. If the combined analysis of four environments resulted in a two or three way interaction between fertility treatment, weeds, and environment with a P-value<0.1, all environments were analyzed individually.

RESULTS AND DISCUSSION

Cover Crop: Biomass, C:N ratio, and Management. Cover crop biomass was greater than 9,000 kg ha^{-1} at four of the six environments (Table 3), indicating that the rye/vetch cover crop mixture proportions used in this study have high biomass production potential. High rye seeding rates and early fall establishment of the cover crop can help explain the high biomass levels obtained from this mixture (Table 1), as these cover crop management strategies are associated with high cover crop biomass production (Mirsky et al., 2011; Reberg-Horton et al., 2012). The Kinston 2013 environment had the lowest cover crop biomass, averaging only 6,343 kg ha^{-1} (Table 3). The Kinston 2013 environment was on a Coastal Plain soil and had the lowest baseline fertility of all the environments. In a previous rye/vetch cover crop mixture study from a Coastal Plain soil with low N availability, rye production was reduced and vetch production dominated (Clark et al., 1994). If rye growth was inhibited by low N availability at the Kinston 2013 environment, it could explain the lower levels of cover crop biomass obtained at this environment, as rye is known for producing more biomass than vetch (Reberg-Horton et al., 2012). The Kinston 2013 environment also had the earliest cover crop termination date of all the environments (Table 1), which may have restricted cover crop biomass from reaching maximum potential as delaying cover crop termination has been shown to increase cover crop biomass (Nord et al., 2011).

Large differences in average cover crop mixture C:N ratios were observed across environments (Table 3). The Beltsville 2013 environment had the highest cover crop mixture C:N ratio (48:1), and the highest proportion of rye in the cover crop mixture of those environments where cover crop biomass was separated by species prior to harvest (Table 3).

The Kinston 2014 environment had the lowest cover crop mixture C:N ratio (25:2), and the highest proportion of vetch in the mixture across environments where cover crop biomass was separated by species prior to harvest (Table 3). Vetch has a lower C:N ratio than rye (Ranells and Wagger, 1997), and this can explain why lower C:N ratios are generally observed at environments where a higher proportion of cover crop biomass is comprised of vetch. The Beltsville and Salisbury environments both have a long term history of manure application, and residual soil N levels were higher at these environments compared with the Kinston environments, which have been primarily managed with synthetic N fertilizers. High levels of soil N favor cereal production in mixture with a legume, whereas environments with low soil N favor legume production in a mixture with cereals (Jensen, 1996). This can help explain the higher rye biomass production and C:N ratios observed at the Beltsville and Salisbury environments, compared to those observed at the Kinston environments (Table 3). Winter temperatures, date of cover crop establishment, and date of cover crop termination also influence species performance in a cover crop mixture, and can lead to significant year to year variability in C:N ratios (Hayden et al., 2015; Reberg-Horton et al., 2012). The variability in cover crop mixture C:N ratios observed across environments in this study illustrates the importance of having starter fertilizer recommendations available for producers in environments where a high C:N ratio prohibits adequate cover crop N release for corn N demand.

Terminating cover crops via roller-crimping one to four weeks prior to corn planting, and then roller-crimping again at planting, generally provided the best results for effective corn planting. This may be attributed to replenished soil moisture prior to corn planting when

planting is delayed following cover crop termination. Delaying planting after cover crop termination has been recommended to improve cash crop planting efficiency into high cover crop biomass (Price et al., 2009). Extensive cover crop regrowth between the first and second cover crop roller-crimping events was not observed in this study, but has been identified as a potential risk when cover crop roller-crimping occurs prior to corn planting (Mirsky et al., 2013).

Soil inorganic N (NO_3-N + NH_4-N). Soil samples for soil inorganic N analysis were collected from the weed-free treatment across fertility treatments. At corn emergence and corn growth stage V5, a combined analysis of six environments resulted in a P-value <0.1 for the fertility treatment by environment interaction, therefore a combined analysis of four environments occurred and two environments were analyzed individually (Table 4). At corn growth stage V2, the interaction between fertility treatment and environment was not significant, allowing for a combined analysis across all environments (Table 4). In all the combined analyses, fertility treatment significantly affected soil inorganic N levels (Table 4). The general trend in soil inorganic N levels across combined analyses and corn growth stages was that the HBPL fertility treatment had the highest soil inorganic N levels, followed by the LBPL+SBPL fertility treatment (Figure 1). The SBFM, SBPL, and no starter fertility treatments had lower and generally similar soil inorganic N levels (Figure 1).

At the Kinston 2013 environment, fertility treatment significantly affected soil inorganic N levels at corn emergence and corn growth stage V5 (Table 5). The highest soil inorganic N levels were observed in the HBPL fertility treatment (Table 8). At corn emergence, the SBFM, SBPL, and no starter fertility treatments had similar soil inorganic N

levels, however by corn growth stage V5 the SBFM fertility treatment had higher soil inorganic levels than the no starter fertility treatment (Table 8). This observation may be attributed to slow N release of the feather meal material (Hadas & Kautsky, 1994).

Weed competition. Fertility treatment did not affect weed coverage or weed biomass at five of the six environments (Table 7). Results from these environments are similar to those from previous research efforts which report little difference in weed competition among N fertilizer rates (Chikoye et al., 2008) and application techniques (Cochran et al., 1990). Alternatively, these results disagree with studies that report increasing N rate (Abouziena et al., 2007; Blackshaw et al., 2003) and application method (Blackshaw et al., 2004; Rasmussen, 2002) affect weed competition; however these studies were conducted in environments without cover crop mulches. At the Kinston 2014, Salisbury 2013, and Salisbury 2014 environments, weed coverage was less than 10% across all fertility treatments, and less than 15% across all fertility treatments in the Beltsville 2013 environment. These environments had cover crop biomass greater than 9,000 kg ha^{-1} (Table 3). Previous research has reported consistent weed management from cover crop mulches when cover crop biomass levels exceed 8,000 kg ha^{-1}, which can explain the high levels of weed suppression achieved at these environments (Teasdale and Mohler, 2000; Mirsky et al., 2013).

Kinston 2013 was the only environment to demonstrate a significant effect of fertility treatment on weed coverage and weed biomass (Table 7). Weed coverage and weed biomass were lowest in the HBPL fertility treatment across all corn growth stages (Figure 2). This was presumably due to improved corn competiveness with weeds from high PAN in the

HBPL fertility treatment compared to the other fertility treatments (Table 2). Similar results were observed in previous research which demonstrated that increasing N rates resulted in improved corn competitiveness with weeds (Abouziena et al., 2007; Evans et al., 2003). These results disagree with Blackshaw et al., 2002 who reported that subsurface banded N led to greater weed suppression compared with surface broadcast N when both application techniques were applied at similar N rates; however the authors attributed this to increased crop competitiveness against weeds with the subsurface banded fertilizer application. The HBPL fertility treatment in this study supplied substantially more PAN than the subsurface banded fertility treatments (Table 2) and had the highest soil inorganic N availability at this environment (Table 8), therefore corn competiveness was likely improved with the HBPL fertility treatment, ultimately leading to greater weed suppression in this fertility treatment. Similar weed coverage and weed biomass levels were generally achieved with the SBFM and SBPL fertility treatments at earlier corn growth stages in the Kinston 2013 environment, despite comparatively large PAN availability from the SBFM fertility treatment (Figure 2; Table 2). Poultry litter has been reported to have more rapid N mineralization following application compared with other pelletized organic fertilizer materials (Wild et al., 2011) and soil inorganic N levels were similar among the subsurface banded fertility treatments at corn growth stage V5 (Table 8), which could explain the similar crop competitiveness against weeds between the SBFM and SBPL fertility treatments early in the corn growing season. Significant differences in weed coverage between the subsurface banded fertility treatments was only observed at corn growth stage R6, where more weed competition occurred in the SBPL fertility treatment compared to the SBFM fertility treatment (Figure 2). Corn nitrogen

uptake typically occurs from seeding development until 3 to 5 weeks after silking (Cathcart & Swanton, 2004), therefore a large window is available for the plant to capitalize on slower and more consistent N release from the feather meal material (Wild et al., 2011). This could explain the late season increased crop competitiveness against weeds experienced with the SBFM fertility treatment at the Kinston 2013 environment. The highest weed coverage and weed biomass levels were observed in the no starter fertility treatment at the Kinston 2013 environment (Figure 2), which can likely be attributed to reduced corn competitiveness against weeds. Research from a sandy loam soil demonstrated that green foxtail intensified the effect of low N rate on corn development (Cathcart & Swanton, 2004), and Evans et al. (2003) reported more extensive reductions in corn height and leaf area at reduced N rates. It is likely that reduced corn competiveness is responsible for higher weed coverage in the low N fertility treatments at this environment.

Corn N uptake. At corn growth stages V8 and V10 for SPAD readings and corn growth stage R6 for corn N content, a combined analysis of all six environments resulted in the interaction between fertility treatment and environment having a P-value<0.1, and therefore a combined analysis of four environments occurred and two environments were analyzed individually (Table 5, Table 6). For these combined analyses, fertility treatment but not weeds significantly affected SPAD readings and corn N content (Table 5, Table 6). The trend for these combined analyses was that highest SPAD readings and corn N content were observed in the HBPL fertility treatment, followed by the LBPL+SBPL and SBFM fertility treatments, and the lowest results occurred in the SBPL and no starter fertility treatments (Figure 3, Figure 4). The only difference in results between these analyses was higher SPAD

readings were observed in the SBPL fertility treatment compared to the no starter fertility treatment at corn growth stage V10 (Figure 3). Previous research has demonstrated that SPAD readings collected later in the corn growing season can provide a more accurate estimation of N stress in N deficient treatments (Hawkins et al., 2007), and this could explain the detected difference in SPAD readings between the SBPL and no starter fertility treatments at corn growth stage V10.

At the Kinston 2013 environment, both fertility treatment and weeds had a significant effect on SPAD readings at corn growth stages V8 and V10 and corn N content at corn growth stage R6 (Table 5, Table 6). SPAD readings were highest in the HBPL and SBFM fertility treatments, followed by the SBPL and no starter fertility treatments (Table 9). Similar results were observed at corn growth stage R6 for corn N content, however corn N content was higher with the HBPL fertility treatment compared to the SBFM fertility treatment (Table 10). The large amount of PAN available early in the corn growing season with the HBPL fertility treatment likely allowed for a more competitive corn crop throughout the growing season, allowing for higher corn biomass accumulation and ultimately higher corn N content in the HBPL fertility treatment, even if similar SPAD readings were observed between the HBPL and SBFM fertility treatments. Weeds had a large impact on SPAD readings and corn N content at this environment in all fertility treatments except the HBPL fertility treatment (Table 9, Table 10). The HBPL fertility treatment had the lowest weed coverage and weed biomass of all the fertility treatments (Figure 2), thus explaining the lack of differences observed in SPAD readings and corn N content at these corn growth stages between the weed-free and weedy plots for this fertility treatment (Table 9, Table 10). In the

SBFM, SBPL, and no starter fertility treatments at this environment, strong weed competition resulted in high levels of N competition between the corn crop and weeds, leading to generally reduced SPAD readings and lower corn N content in the weedy treatments (Table 9, Table 10). A significant effect of weeds on corn N uptake was not present at this environment until corn growth stage R6 (Table 6), however an effect of weeds on SPAD readings was present at corn growth stages V8 and V10 (Table 5). SPAD readings are known to be affected by other crop stresses (Hawkins et al., 2007; Zhu et al., 2011), and it is possible that the presence of weeds had an impact on other crop stresses in addition to N deprivation at earlier corn growth stages, leading to reduced SPAD readings in the weedy treatment of those fertility treatments.

At the Beltsville 2013 environment, neither fertility treatment nor weeds affected SPAD readings or corn N content across all corn growth stages, with the exception of corn N content at corn growth stage R1 (Table 5, Table 6). This trend is similar to that observed for soil inorganic N at the Beltsville 2013 environment (Table 4). It is plausible that manuring history at this environment coupled with a history of legume use precipitated any effect that varying fertility treatments would provide on these variables due to high nitrogen carryover.

Corn grain yield. A significant three-way interaction between fertility treatment, weeds, and environment restricted combing corn grain yield across all six environments (Table 7), therefore a combined analysis occurred across four environments, and two environments were analyzed individually (Table 7). Fertility treatment had a significant effect on corn grain yield in the combined analysis, but weeds did not (Table 7). These results are not surprising as weed coverage was very low in the environments included in the combined analysis.

Yields were highest with the HBPL fertility treatment, but not statistically different from the LBPL+SBPL and SBFM fertility treatments (Figure 5). The slower N release of the feather meal material can help explain similar yields achieved with the SBFM fertility treatment compared with the HBPL fertility treatment (Gaskell et al., 2006), despite higher PAN availability from the HBPL fertility treatment (Table 2). This may be attributed to more timely N release for corn N demands with the feather meal material. Lower yields were observed with the SBPL and no starter fertility treatments (Figure 5). Previous research conducted on a loam soil in Iowa reported similar results, where corn grain yield was reduced with no N fertilizer application, but increasing N rate beyond 85 kg ha^{-1} did not increase corn grain yield (Al-Kaisi and Kwaw-Mensah, 2007). Corn grain yield results for the combined analysis are similar to those observed in the combined analyses for SPAD readings at corn growth stage V8 and corn N content at corn growth stage R6 (Figure 3, Figure 4), however the HBPL fertility treatment had significantly higher SPAD readings and corn N content than the LBPL+SBPL and SBFM fertility treatments (Figure 3, Figure 4). SPAD readings are unable to predict N availability in excess of crop need (Bullock and Anderson, 2008), and therefore these results indicate that the HBPL fertility treatment provided excessive N to maximize corn grain yield. The low amount of PAN delivered through the SBPL fertility treatment proved to be inadequate to improve corn grain yield statistically above that of the no starter fertility treatment in the combined corn grain yield analysis (Table 2, Figure 5).

Both fertility treatment and weeds had a significant effect on corn grain yield at the Kinston 2013 environment (Table 7). The highest yields were observed with the HBPL fertility treatment and yields were lower with the SBFM fertility treatment (Table 11),

whereas in the combined analysis these two fertility treatments had similar corn grain yield (Figure 5). Higher N rates are typically necessary to maximize corn yield on loamy sand or sandy loam soils, compared with silt loam or silty clay loam soils (Oberle and Keeney, 1990). This environment was on a loamy sand with a lack of manuring history, which is likely the reason that higher PAN was required to maximize corn grain yield. Corn grain yield did not differ between the weed-free and weedy treatments in the HBPL fertility treatment at the Kinston 2013 environment (Table 11), due to reduced weed competition in the HBPL fertility treatment from non-limiting N (Figure 2). The two subsurface fertility treatments had similar yields in the weed-free treatments (Table 11). Statistically lower grain yields were observed with the no starter fertility treatment at this environment (Table 11), indicating that at a low fertility environment even the small amount of PAN available through the SBPL fertility treatment was beneficial for improving corn grain yield. Weeds had a large impact on grain yield in the SBFM, SBPL, and no starter fertility treatments at the Kinston 2013 environment (Table 11), with corn grain yield reductions of 48%, 35%, and 46%, respectively, compared to the weed-free treatments. Weed competition has been shown to have a greater impact on corn yield at low N rates (Tollenaar et al., 1994), which can help explain the large reduction in corn grain yield from weeds in the lower N fertility treatments at this environment. This environment had the lowest cover crop biomass of all the environments included in this study, and in lieu of low cover crop biomass, providing enough nitrogen to ensure a competitive corn crop against weeds was an important tool to supplement weed suppression from the cover crop mulch. This environment could be

representative of an organic farm with low soil fertility or which has recently been transitioned from conventional to organic production.

Neither fertility treatment nor weeds had a significant effect on corn grain yield at the Beltsville 2013 environment (Table 7). Similar trends were generally observed across corn growth stages for soil inorganic N, SPAD readings, and corn N content at this environment (Table 4, Table 5, Table 6). Cover crop biomass was very high at this environment conferring to very low weed pressure (Table 3). Cover crop C:N ratio was 48:1 at this environment which may favor initial N immobilization, however cover crop termination occurred 3 weeks prior to corn planting (Table 1), and therefore it is plausible that N release from the high cover crop biomass obtained at this environment could have aligned with corn N demand. This coupled with the manuring history of the site likely provided adequate nitrogen carryover N to maximize corn yields in absence of additional fertilizer application. Of the environments included in the study, this environment may most closely represent that of a very high fertility organic farm, therefore indicating that in environments having high levels of nitrogen carryover and high cover crop biomass, supplemental N fertilizer applications may not be necessary to reach maximum corn yields. Additional research at high fertility sites is necessary to confirm results from this environment.

CONCLUSIONS

Results from this study demonstrate that adequate weed suppression in organic corn production can be obtained by roller-crimping a rye/vetch cover crop mixture when cover crop biomass levels in excess of 9,000 kg ha^{-1} are achieved. At five of the six environments in this study, starter fertilizer materials were necessary to maximize corn yields. Results from a combined corn grain yield analysis of four moderate fertility environments indicate that producers have flexibility when selecting starter fertilizer materials and application methods, and that subsurface banding feather meal fertilizer is a viable option to obtain high corn grain yield for producers who are limited in their ability to use poultry litter. In the combined corn grain yield analysis, the SBPL fertility treatment did not have significantly higher corn grain yield than the no starter fertility treatment, and both treatments provided for lower corn grain yield than the other fertility treatments. At the lowest fertility environment, providing high PAN through the HBPL fertility treatment was required to ensure corn competiveness to suppress weeds and to reach high corn grain yield. In one environment from this study which had very high cover crop biomass and a long term history of manure and legume use, similar corn grain yields were achieved across all fertility treatments, indicating that maximum corn grain yield can be achieved without starter fertilizer input if cover crop biomass and N carryover are very high. Further research is necessary on the effects of starter fertilizer materials and application methods on corn grain yield in very high fertility environments, and to evaluate the economic and environmental impacts of different starter fertilizer materials and application methods in organic rotational no-till corn production.

LITERATURE CITED

Abouziena, H.F., M.F. El-Karmany, M. Singh, and S.D. Sharma. 2007. Effect of nitrogen rates and weed control treatments on maize yield and associated weeds in sandy soils. Weed Technology, 21:1049-1053.

Al-Kaisi, M., and D. Kwaw-Mensah. 2007. Effect of tillage and nitrogen rate on corn yield and nitrogen and phosphorus uptake in a corn-soybean rotation. Agron. J., 99:1548-1558.

Ashford, D.L., and D.W. Reeves. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. Am. J. of Alternative Agric., 18:37-45.

Barker, D.C., S.Z. Knezevic, A.R. Martin, and J.L. Lindquist. 2006. Effect of nitrogen addition on the comparative productivity of corn and velvetleaf (*Abutilon theophrasti*). Weed Sci., 54: 354-363.

Blackshaw, R.E., and R.N. Brandt. 2008. Nitrogen fertilizer rate effects on weed competitiveness is species dependent. Weed Sci., 56:743-747.

Blackshaw, R.E. 2005. Nitrogen fertilizer, manure, and compost effects on weed growth and competition with spring wheat. Agron. J., 97:1612-1621.

Blackshaw, R.E., L.J. Molnar, and H.H. Janzen. 2004. Nitrogen fertilizer timing and application method affect weed growth and competition with spring wheat. Weed Sci., 52:614-622.

Blackshaw, R.E., R.N Brandt, H.H. Janzen, T. Entz, C.A. Grant, and D.A. Derksen. 2003. Differential response of weed species to added nitrogen. Weed Sci., 51:532-539.

Blackshaw, R.E., G. Semach, and H.H. Janzen, 2002. Fertilizer application method affects nitrogen uptake in weeds and wheat. Weed Sci., 50:634-641.

Bullock, D.G., and D.S. Anderson. 2008. Evaluation of the Minolta SPAD-502 chlorophyll meter for nitrogen management in corn. Journal of Plant Nutrition, 21:741-755.

Carlson, H.L., and J.E. Hill. 1985. Wild oat (*Avena fatua*) competition with spring wheat: effects on nitrogen fertilization. Weed Sci., 34:29-33.

Cathcart, R.J., and C.J. Swanton. 2004. Nitrogen and green foxtail (*Setaria viridis*) competition effects on corn growth and development. Weed Sci., 52:1039-1049.

Chikoye, D., A.F. Lum, R. Abaidoo, A. Menkir, A. Kamara, F. Ekeleme, and N. Sanginga.

2008. Response of corn genotypes to weed interference and nitrogen in Nigeria. Weed Sci., 56:424-433.

Clark, A.J., A.M. Decker, J.J. Meisinger, and M.S. McIntosh. 1997. Kill date of vetch, rye, and a vetch-rye mixture: II. Soil moisture and corn yield. Agron. J., 89:434-441.

Clark, A.J., A.M Decker, J.J. Meisinger, F.R. Mulford, and M.S. McIntosh. 1995. Hairy vetch kill date effects on soil water and corn production. Agron. J., 87:579-585.

Clark, A.J., A.M. Decker, and J.J. Meisinger. 1994. Seeding rate and kill date effects on hairy vetch-cereal rye cover crop mixtures for corn production. Agron. J., 86:1065-1070.

Cochran, V.L., L.A. Morrow, and R.D. Schirman. 1990. The effect of N placement on grass weeds and winter wheat responses in three tillage systems. Soil & Tillage Research, 18:347-355.

Cook, J.C., R.S. Gallagher, J.P. Kaye, J. Lynch, and B. Bradley. 2010. Optimizing vetch nitrogen production and corn nitrogen accumulation under no-till management. Agron. J., 102:1491-1499.

Davis, A. 2010. Cover-crop roller-crimper contributes to weed management in no-till soybean. Weed Sci., 58:300-309.

Decker, A.M., A.J. Clark, J.J. Meisinger, F.R. Mulford, and M.S. McIntosh. 1994. Legume cover crop contributions to no-tillage corn production. Agron. J., 86:126-135.

Delate, K., D. Cwach, and C. Chase. 2011. Organic no-tillage system effects on soybean, corn, and irrigated tomato production and economic performance in Iowa, USA. Renewable Agriculture and Food Systems, 27:49-59.

Ebelhar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from legume cover crops for no-tillage corn. Agron. J., 76:51-55.

Endale, D.M., H.H. Schomberg, M.B. Jenkins, D.H. Franklin, and D.S. Fisher. 2010. Management implications of conservation tillage and poultry litter use for Southern Piedmont USA cropping systems. Nutrient Cycling Agroecosystems, 88:299-313.

Evans, S.P., S.Z. Knezevic, J.L. Lindquist, C.A. Shapiro, and E.E. Blankenship. 2003. Nitrogen applications influences the critical period for weed control in corn. Weed Sci., 51:408-417.

Gaskell, M., and R. Smith. 2007. Nitrogen sources for organic vegetable crops. HortTechnology, 17:431-441.

Gaskell, M., R. Smith, J. Mitchell, S.T. Koike, C. Foucher, T. Hartz, W. Horwath, and L. Jackson. 2006. Soil fertility management for organic crops. Univ. California Publ. 7429.

Grandy, A.S., G.P. Robertson, and K.D. Thelen. 2006. Do productivity and environmental trade-offs justify periodically cultivating no-till cropping systems? Agron. J., 98:1377-1383.

Hadas, A., and L. Kautsky. 1994. Feather meal, a semi-slow-release nitrogen fertilizer for organic farming. Fertilizer Research, 38:165-170.

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. Weed Sci., 50:688-699.

Hawkins, J.A., J.E. Sawyer, D.W. Barker, and J.P. Lundvall. 2007. Using relative chlorophyll meter values to determine nitrogen application rates for corn. Agron. J., 99:1034-1040.

Hayden, Z.D., M. Ngouajio, and D.C. Brainard. 2015. Planting date and staggered seeding of rye-vetch mixtures: biomass, nitrogen, and legume winter survival. Agron. J., 103:33-40.

Hayden, Z.D., D.C. Brainard, B. Henshaw, and M. Ngouajio. 2012. Winter annual weed suppression in rye-vetch cover crop mixtures. Weed Tech., 26:818-825.

Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems, and Environment, 103:1-25.

Hunt, R.E. Jr., and C.S.T. Daughtry. 2014. Chlorophyll meter calibrations for chlorophyll content using measured and stimulated leaf transmittances. Agron. J., 106:931-939.

Koger, C.H., and K.N. Reddy. 2005. Effects of hairy vetch (*Vicia villosa*) cover crop and banded herbicides on weeds, grain yield, and economic returns in corn (*Zea mays*). Journal of Sustainable Agriculture, 26:107-124.

Jensen, E.K. 1996. Grain yield, symbiotic N_2 fixation and interspecific competition for inorganic N in pea-barley intercrops. Plant and Soil, 182:25-38.

MacDonald, J.M. 2008. The economic organization of U.S. broiler production. Economic Information Bulletin, Number 38. Economic Research Service, United States Department of Agriculture.

McVay, K.A., D.E. Radcliffe, and W.L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Sci. Soc. Am. J., 53:1856-1862.

Mirsky, S.B., M.R. Ryan, J.R. Teasdale, W.S. Curran, S.C. Reberg-Horton, J.T. Spargo, M.S. Wells, C.L. Keene, and J.W. Moyer. 2013. Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the eastern United States. Weed Tech., 27:193-203.

Mirsky, S.B., M.R. Ryan, W.S. Curran, J.R. Teasdale, J. Maul, J.T. Spargo, J. Moyer, A.M. Grantham, D. Weber, T.R. Way, and G.G. Camargo. 2012. Conservation tillage issues: cover crop-based organic rotational no-till grain production in the mid-Atlantic region, USA. Renewable Agriculture and Food Systems, 27:31-40.

Mirsky, S.B., W.S. Curran, D.M. Mortensen, M.R. Ryan, and D.L. Shumway. 2011. Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. Weed Sci., 59:380-389.

Mischler, R., S.W. Duiker, W.S. Curran, and D. Wilson. 2010. Hairy vetch management for no-till organic corn production. Agron. J., 102:355-362.

Mitchell, J.P., P.N. Singh, W.W. Wallender, D.S. Munk, W.R. Horwath, P. Hogan, R. Roy, and B.R. Hanson. 2012. No-tillage and high-residue practices reduce soil water evaporation. California Agriculture, 66:55-61.

Nord, E.A., W.S. Curran, D.A. Mortensen, S.B. Mirsky, and B.P. Jones. 2011. Integrating multiple tactics for managing weeds in high residue no-till soybean. Agron. J., 103:1542-1551.

Oberle, S.L., and D.R. Keeney. 1990. Soil type, precipitation, and fertilizer N effects on corn yield. Journal of Production Agriculture, 3:522-527.

Parr, M., J.M. Grossman, S.C. Reberg-Horton, C. Brinton, and C. Crozier. 2011. Nitrogen delivery from legume cover crops in no-till organic corn production. Agron. J., 103:1578-1590.

Peigné, J., B.C. Ball, J. Roger-Estrade, and C. David. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use and Management, 23:129-144.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science, 267:1117-1123.

Poffenbarger, H.J., S.B. Mirsky, J.E. Maul, R.R. Weil, M. Kramer, J.T. Spargo, and M.A. Cavigelli. In review. Biomass and nitrogen accumulation of hairy vetch-cereal rye cover crop mixtures as influenced by species proportions. Agron. J.

Pote, D.H., T.R. Way, P.J.A. Kleinman, P.A. Moore Jr., J.J. Meisinger, K.R. Sistani, L.S. Saporito, A.L. Allen, and G.W. Feyereisen. 2011. Subsurface application of poultry litter in pasture and no-till soils. J. Environ. Qual., 40:402-4011.

Price, A.J., F.J. Arriaga, R.L. Raper, K.S. Balkcom, T.S. Kornecki, and D.W. Reeves. 2009. Comparison of mechanical and chemical winter cereal cover crop termination systems and cotton yield in conservation agriculture. J. of Cotton Sci., 13:238-245.

Ranells, N.N., and M.G. Wagger. 1997. Grass-legume bicultures as winter annual cover crops. Agron. J., 89:659-665.

Ranells, N.N. and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crop monocultures and bicultures. Agron. J., 88:777-782.

Rasmussen, K. 2002. Influence of liquid manure application method on weed control in spring cereals. Weed Res., 42:287-298.

Reberg-Horton, S.C., J.M. Grossman, T.S. Kornecki, A.D. Meijer, A.J. Price, G.T. Place, and T.M. Webster. 2012. Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern USA. Renewable Agriculture and Food Systems, 27:41-48.

Reberg-Horton, S., J. Burton, D. Danehower, G. Ma, D. Monks, J. Murphy, et al. 2005. Changes over time in the allelochemical content of ten cultivars of rye (*Secale cereale L.*). J. Chem. Ecol., 31:179-193.

Satorre, E.H., and R.W. Snaydon. 1991. A comparison of root and shoot competition between spring cereals and *Avena fatua* L. Weed Res., 32:45-55.

Smith, A.N., S.C. Reberg-Horton, G.T. Place, A.D. Meijer, C. Arellano, and J.P. Mueller. 2011. Rolled rye mulch for weed suppression in organic no-till soybeans. Weed Sci., 59:224-231.

Sullivan, P.G., D.J. Parrish, and J.M. Luna. 1991. Cover crop contributions to N supply and water conservation in corn production. American Journal of Alternative Agriculture, 6:101-113.

Teasdale, J.R., S.B. Mirsky, J.T. Spargo, M.A. Cavigelli, and J.E. Maul. 2012. Reduced-tillage organic corn production in a hairy vetch cover crop. Agron. J., 104:621-628.

Teasdale, J.R., C.B. Coffman, and R.W. Mangum. 2007. Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agron. J., 99:1297-1305.

Teasdale, J.R. and C.L. Mohler. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci., 48:385-392.

Teasdale J.R. and A.A. Abdul-Baki. 1998. Comparison of mixtures vs. monoculture of cover crops for fresh-market tomato production with and without herbicide use. HortScience, 33:1163-1166.

Teasdale, J.R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J., 85:673-680.

Teasdale, J.R., C. E. Beste, and W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci., 39:195-199.

Tewolde, H., S. Armstrong, T.R. Way, D.E. Rowe, and K.R. Sistani. 2009. Cotton response to poultry litter applied by subsurface banding relative to surface broadcasting. Soil Sci. Soc. Am. J., 73:384-389.

Tollenaar, M., A. Aguilera, S.F. Weise, and C.J. Swanton. 1994. Effect of weed interference and soil nitrogen on four maize hybrids. Agron. J., 86:596-601.

Triplett, Jr. G.B., and W.A. Dick. 2008. No-tillage crop production: A revolution in agriculture! Agron. J., 100:153-165.

Vaughan, J.D., and G.K. Evanylo. 1998. Corn response to cover crop species, spring desiccation time, and residue management. Agron. J., 90:536-544.

Wagger, M.G. 1989. Time of desiccation effects on plant composition and subsequent nitrogen release from several winter annual cover crops. Agron. J., 81:236-241.

Webb, J., H. Menzi, B.F. Pain, T.H. Misselbrook, U. Dammgen, H. Hendriks, and H. Dohler. 2005. Managing ammonia emissions from livestock production in Europe. Environmental Pollution, 135:399-406.

Wells, M.S., S.C. Reberg-Horton, A.N. Smith, and J.M. Grossman. 2013. The reduction of plant-available nitrogen by cover crop mulches and subsequent effects on soybean performance and weed interference. Agron. J., 105:539-545.

Wild, P.L., C. van Kessel, J. Lundberg, and B.A. Linquist. 2011. Nitrogen availability from

poultry litter and pelletized organic amendments for organic rice production. Agron. J., 103:1284-1291.

Young, B.G. 2006. Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. Weed Tech., 20:301-307.

Zhu, J., N. Tremblay, and Y. Liang. 2011. A corn nitrogen status indicator less affected by soil water content. Agron. J., 103:890-898

Table 1. Dates for cover crop and corn management for individual environments.

	Cover Crop			Corn	
Environment	Planting	Roller-Crimping 1	Roller-Crimping 2	Planting	Harvest
Beltsville 2013	September 15, 2012	May 31, 2013	June 21, 2013	June 21, 2013	December 3, 2013
Beltsville 2014	September 27, 2013	June 5, 2014	June 19, 2014	June 19, 2014	November 13, 2014
Kinston 2013	October 11, 2012	May 8, 2013	May 16, 2013	May 8, 2013	August 29, 2013
Kinston 2014†	September 27, 2013	May 12, 2014	May 20, 2014	May 20, 2014	September 16, 2014
Salisbury 2013	September 27, 2012	May 15, 2013	May 28, 2013	May 29, 2013	September 19, 2013
Salisbury 2014	September 18, 2013	May 14, 2014	May 22, 2014	May 22, 2014	September 9, 2014

† A third roller-crimping event occurred at this environment on May 28, 2014 to prevent cover crop regrowth.

Table 2. Fertility rate, assumed fertility N content, plant available nitrogen (PAN), cost per hectare, and number of environments employed for individual fertility treatments.

Fertility Treatment	Fertility Rate (Mg ha^{-1})	N Content (%)	PAN (kg ha^{-1}) ‡	Cost ($ ha^{-1})§	Environments¶
HBPL	9.0	3	~160	~300	4
LBPL+SBPL	3.4+0.6-0.7	3	~72	~280-300	4
SBFM	0.6-0.7	13	~80	~710-770	6
SBPL	0.6-0.7	3	~12	~170-185	6
No Starter	0	0	0	0	6

† Abbreviations: PAN, plant available nitrogen; HBPL, high rate broadcast poultry litter; LBPL+SBPL, low rate broadcast poultry litter plus subsurface banded poultry litter; SBFM, subsurface banded feather meal; SBPL, subsurface banded poultry litter.

‡ PAN estimated using guidelines from The Mid-Atlantic Nutrient Management Handbook (2006).

§ Price estimates for each material obtained through personal communication. Prices used for cost calculations include: $30/T loose litter for broadcast applications (Reberg-Horton, 2015), $240/T pelleted poultry litter (Reberg-Horton, 2015), $1000/T Nature Safe (13-0-0) feather meal material (Newman, 2014).

¶ Number of environments at which each fertility treatment was employed. The HBPL fertility treatment was not employed at the Beltsville 2013 and Beltsville 2014 environments, and the LBPL+SBPL fertility treatment was not employed at the Kinston 2013 and Salisbury 2013 environments.

Table 3. Average cover crop biomass, average cover crop mixture C:N ratio, and average corn populations for individual environments.

Environment	Total CC Biomass	Rye Biomass	Vetch Biomass	CC C:N Ratio	Corn Population
	---------- kg ha^{-1} ----------				----- plants ha^{-1} ----
Beltsville 2013	15,472	14,228	1,244	48.1	60,969
Beltsville 2014	7,499	5,398	2,101	43.0	65,044
Kinston 2013	6,343	—	—	26.6	80,076
Kinston 2014	9,654	6,011	3,643	25.2	74,797
Salisbury 2013	9,790	—	—	39.2	87,553
Salisbury 2014	10,155	7,840	2,315	28.0	72,792

† Abbreviations: CC, cover crop.

‡ Data not presented (—) because cover crop species were not separated at cover crop biomass collection, therefore only total cover crop biomass is presented.

Table 4. ANOVA results for the effect of fertility (F), environment (E), and their interaction on soil inorganic N levels (NO_3-N + NH_4-N) at corn growth stages: Emergence (VE), V2, and V5 for combined analyses and the relevant individual environment analyses.

				Environment					
CGS	Source	Combined 6 environments	Combined 4 environments‡	Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
		P>*F*							
VE	F	<0.001	<0.001	NS	—	<0.001	—	—	—
	E	0.003	0.003	—	—	—	—	—	—
	F*E	NS	NS	—	—	—	—	—	—
V2	F	<0.001	—	—	—	—	—	—	—
	E	0.003	—	—	—	—	—	—	—
	F*E	NS	—	—	—	—	—	—	—
V5	F	<0.001	<0.001	NS	—	<0.001	—	—	—
	E	0.001	0.007	—	—	—	—	—	—
	F*E	0.04	NS	—	—	—	—	—	—

† Abbreviations: CGS, corn growth stage; F, fertility; E, environment; NS, nonsignificant at the 0.05 level.

‡ The four environments in the combined analysis include: Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014.

§ Data not presented (—) because environments were included in a combined analysis or source pertains only to a combined analysis.

Table 5. ANOVA results for the effect of fertility (F), weeds (W), environment (E), and the relevant interactions on SPAD readings at corn growth stages V5, V8, and V10 for both combined analyses and the relevant individual environment analyses.

				Environment					
CGS	Source	Combined 6 Environments	Combined 4 Environments‡	Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
		P>*F*							
V5	F	0.002	0.01	NS	NS	<0.001	<0.001	0.002	<0.001
	W	NS	NS	NS	NS	NS	0.001	NS	NS
	E	<0.001	0.001	—	—	—	—	—	—
	F*W	NS	NS	NS	NS	NS	NS	NS	NS
	F*E	<0.001	0.001	—	—	—	—	—	—
	W*E	NS	0.03	—	—	—	—	—	—
	F*W*E	NS	NS	—	—	—	—	—	—
V8	F	0.001	<0.001	NS	—	<0.001	—	—	—
	W	NS	NS	NS	—	0.001	—	—	—
	E	<0.001	0.004	—	—	—	—	—	—
	F*W	NS	NS	NS	—	NS	—	—	—
	F*E	0.001	NS	—	—	—	—	—	—
	W*E	NS	NS	—	—	—	—	—	—
	F*W*E	0.01	NS	—	—	—	—	—	—
V10	F	<0.001	<0.001	NS	—	<0.001	—	—	—
	W	NS	NS	NS	—	0.001	—	—	—
	E	0.001	0.003	—	—	—	—	—	—
	F*W	NS	NS	NS	—	0.05	—	—	—
	F*E	0.05	NS	—	—	—	—	—	—
	W*E	NS	NS	—	—	—	—	—	—
	F*W*E	0.05	NS	—	—	—	—	—	—

† Abbreviations: CGS, corn growth stage; F, fertility; W, weeds; E, environment; NS, nonsignificant at the 0.05 level.

‡ The four environments in the combined analysis include: Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014.

§ Data not presented (—) because environments were included in a combined analysis or source pertains only to a combined analysis.

Table 6. ANOVA results for the effect of fertility (F), weeds (W), environment (E), and the relevant interactions on corn N content at corn growth stages V5, V8, R1, and R6 for both combined analyses and the relevant individual environment analyses.

				Environment					
CSG	Source	Combined 6 environments	Combined 4 environments‡	Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
				P>*F*					
V5	F	0.001	0.004	NS	0.001	0.001	0.001	0.001	0.001
	W	NS	NS	NS	NS	NS	NS	NS	NS
	E	<0.001	0.001	—	—	—	—	—	—
	F*W	NS	NS	NS	NS	NS	NS	NS	NS
	F*E	<0.001	0.002	—	—	—	—	—	—
	W*E	0.01	0.02	—	—	—	—	—	—
	F*W*E	NS	NS	—	—	—	—	—	—
V8	F	<0.001	<0.001	NS	NS	<0.001	<0.001	<0.001	<0.001
	W	NS	NS	NS	NS	NS	NS	NS	NS
	E	<0.001	<0.001	—	—	—	—	—	—
	F*W	NS	NS	NS	NS	NS	NS	NS	NS
	F*E	0.02	NS	—	—	—	—	—	—
	W*E	NS	NS	—	—	—	—	—	—
	F*W*E	NS	NS	—	—	—	—	—	—
R1	F	<0.001	0.02	0.02	NS	<0.001	<0.001	0.001	<0.001
	W	NS	NS	0.01	NS	NS	NS	NS	NS
	E	<0.001	0.01	—	—	—	—	—	—
	F*W	NS	NS	NS	NS	NS	NS	NS	NS
	F*E	0.001	0.001	—	—	—	—	—	—
	W*E	NS	NS	—	—	—	—	—	—
	F*W*E	NS	NS	—	—	—	—	—	—
R6	F	<0.001	0.001	NS	—	<0.001	—	—	—
	W	NS	NS	NS	—	0.002	—	—	—
	E	<0.001	0.001	—	—	—	—	—	—
	F*W	NS	NS	NS	—	NS	—	—	—
	F*E	NS	NS	—	—	—	—	—	—
	W*E	NS	NS	—	—	—	—	—	—
	F*W*E	NS	NS	—	—	—	—	—	—

† Abbreviations: CGS, corn growth stage; F, fertility; W, weeds; E, environment; NS, nonsignificant at the 0.05 level.

‡ The four environments in the combined analysis include: Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014.

§ Data not presented (—) because environments were included in a combined analysis or source pertains only to a combined analysis.

Table 7. ANOVA results for the effect of fertility (F), weeds (W), environment (E), and the relevant interactions on corn grain yield for combined analyses and the relevant individual environment analyses, and on weed coverage and weed biomass across corn growth stages at individual environments.

					Environment					
	CGS	Source	Combined 6 Environments	Combined 4 Environments‡	Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
			P>*F*							
Yield	--	F	<0.001	<0.001	NS	--	<0.001	--	--	--
	--	W	0.01	NS	NS	--	<0.001	--	--	--
	--	E	<0.001	0.007	--	--	--	--	--	--
	--	F*W	NS	NS	NS	--	NS	--	--	--
	--	F*E	NS	NS	--	--	--	--	--	--
	--	W*E	NS	NS	--	--	--	--	--	--
	--	F*W*E	0.005	NS	--	--	--	--	--	--
Weed Coverage										
	V5	F	--	--	NS	NS	0.001	--	--	--
	V8	F	--	--	NS	NS	0.001	--	NS	--
	V10	F	--	--	NS	NS	0.002	--	NS	NS
	R1	F	--	--	NS	NS	0.001	--	NS	NS
	R6	F	--	--	--	--	<0.001	NS	--	NS
Weed Biomass										
	V2	F	--	--	NS	--	--	--	--	--
	V5	F	--	--	NS	NS	--	--	--	--
	V8	F	--	--	NS	NS	0.001	--	--	--
	R1	F	--	--	NS	NS	0.001	--	--	--

† Abbreviations: CGS, corn growth stage; F, fertility; W, weeds; E, environment; NS, nonsignificant at the 0.05 level.
‡ The four environments in the combined analysis include: Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014.
§ Data not presented (--) because data was not collected, environments were included in a combined analysis, and source pertains only to a combined analysis. Weed data is presented by environment only.

Table 8. Soil inorganic N levels (NO_3-N + NH_4-N) as affected by fertility treatment at corn growth stages Emergence (VE), V2, and V5.

		Environment					
CGS	Fertility TRT	Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
		kg ha^{-1}					
VE	HBPL	—	—	54a	75a	96a	56a
	LBPL+SBPL	48a	30a	—	39b	—	46b
	SBFM	39ab	21b	34b	30b	51b	27c
	SBPL	32b	28ab	31b	29b	58b	32c
	No Starter	37ab	25b	29b	31b	54b	28c
V2	HBPL	—	—	86a	86a	125a	58a
	LBPL+SBPL	46a	38a	—	48b	—	51a
	SBFM	40ab	32a	46b	39b	59b	33b
	SBPL	30b	27a	41b	41b	58b	29b
	No Starter	35ab	30a	39b	37b	56b	32b
V5	HBPL	—	—	42a	102a	128a	58a
	LBPL+SBPL	47ab	48a	—	69b	—	40b
	SBFM	53a	30b	31b	54bc	64b	34bc
	SBPL	27b	33b	28bc	48bc	73b	31bc
	No Starter	38ab	30b	26c	45c	70b	28c

† Abbreviations: CGS, corn growth stage; TRT, treatment; HBPL, high rate broadcast poultry litter; LBPL+SBPL, low rate broadcast poultry litter plus subsurface banded poultry litter; SBFM, subsurface banded feather meal; SBPL, subsurface banded poultry litter.

‡ Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

§ Data not presented (—) because treatments went not employed at that environment.

Table 9. SPAD readings as affected by fertility treatment and weeds at corn growth stages V5, V8, and V10 for individual environments.

			Environment					
CGS	Fertility TRT	Weed TRT	Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
V5	HBPL	Weed-Free	—	—	43a	53ab	53a	47abc
		Weedy	—	—	43a	53ab	52a	48ab
	LBPL+SBPL	Weed-Free	44a	50a	—	53a	—	45bc
		Weedy	43a	49a	—	51bc	—	44c
	SBFM	Weed-Free	40a	46ab	36b	53ab	52a	49ab
		Weedy	42a	48ab	36b	52abc	53a	50a
	SBPL	Weed-Free	41a	46ab	40a	50c	45bc	39d
		Weedy	41a	47ab	39ab	47d	47b	38d
	No Starter	Weed-Free	43a	45b	27c	47d	43bc	34e
		Weedy	40a	46ab	28c	46d	42c	37de
V8	HBPL	Weed-Free	—	—	48ab	55a	52a	54a
		Weedy	—	—	48ab	55ab	51ab	53ab
	LBPL+SBPL	Weed-Free	49a	56a	—	53c	—	51c
		Weedy	45abc	53abc	—	53bc	—	52bc
	SBFM	Weed-Free	48ab	53abc	50a	53abc	50ab	52abc
		Weedy	49a	56ab	48b	54abc	51ab	51c
	SBPL	Weed-Free	43c	51c	41c	50d	49bc	48d
		Weedy	46abc	52c	38de	49d	47cd	48d
	No Starter	Weed-Free	45abc	53bc	39cd	50d	47cd	48d
		Weedy	44bc	53bc	36e	49d	45d	48d
V10	HBPL	Weed-Free	—	—	50a	55a	53ab	50a
		Weedy	—	—	50a	54ab	54a	51a
	LBPL+SBPL	Weed-Free	53a	47a	—	53ab	—	47bc
		Weedy	49a	46a	—	53ab	—	48b
	SBFM	Weed-Free	54a	47a	48ab	52ab	52ab	47bcd
		Weedy	52a	47a	47b	52b	50bc	48b
	SBPL	Weed-Free	49a	44a	44c	49c	48bc	45cde
		Weedy	52a	44a	40d	49c	48c	44e
	No Starter	Weed-Free	49a	42a	39d	46d	48cd	44e
		Weedy	49a	42a	35e	48cd	44d	45de

† Abbreviations: CGS, corn growth stage; TRT, treatment; HBPL, high rate broadcast poultry litter; LBPL+SBPL, low rate broadcast poultry litter plus subsurface banded poultry litter; SBFM, subsurface banded feather meal; SBPL, subsurface banded poultry litter.

‡ Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

§ Data not presented (—) because treatments went not employed at that environment.

Table 10. Corn N content as affected by fertility treatment and weeds at corn growth stages V5, V8, R1, and R6 for individual environments.

CGS	Fertility TRT	Weed TRT	Environment					
			Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
			kg ha^{-1}					
V5	HBPL	Weed-Free	--	--	12a	25a	35a	10b
		Weedy	--	--	12a	25ab	32ab	13a
	LBPL+SBPL	Weed-Free	7a	13a	--	24ab	--	9b
		Weedy	4b	11ab	--	20cd	--	9b
	SBFM	Weed-Free	4ab	6d	5bcd	22bc	24bc	9b
		Weedy	5ab	7cd	4cde	19de	25bc	11ab
	SBPL	Weed-Free	5ab	8cd	8b	20cd	12de	6c
		Weedy	4ab	9bc	6bc	16ef	17cd	5c
	No Stater	Weed-Free	5ab	8cd	2e	15fg	8e	3c
		Weedy	4ab	8cd	2de	13g	11de	4c
V8	HBPL	Weed-Free	--	--	51a	109a	136a	60a
		Weedy	--	--	48a	112a	130a	61a
	LBPL+SBPL	Weed-Free	23a	36ab	--	95ab	--	45b
		Weedy	17ab	40a	--	91bc	--	48b
	SBFM	Weed-Free	17ab	16b	34b	84bcd	96bc	41bc
		Weedy	15ab	24ab	25bc	82bcd	102b	43bc
	SBPL	Weed-Free	12ab	25ab	22c	73cd	80bcd	32cd
		Weedy	14ab	29ab	20cd	69d	71d	27d
	No Starter	Weed-Free	15ab	23b	11de	67d	75cd	24d
		Weedy	10b	24b	10e	50e	67d	25d
R1	HBPL	Weed-Free	--	--	103a	170ab	308a	106a
		Weedy	--	--	110a	183a	276a	100a
	LBPL+SBPL	Weed-Free	74a	73a	--	130cd	--	74b
		Weedy	48bcd	67ab	--	134cd	--	76b
	SBFM	Weed-Free	63abc	53ab	62b	146bc	180bc	74b
		Weedy	60abc	58ab	54bc	135cd	204b	77b
	SBPL	Weed-Free	65ab	50b	57b	126cde	154bc	65bc
		Weedy	53bcd	59ab	49bc	111def	119c	56c
	No Starter	Weed-Free	45cd	45b	39cd	84f	141bc	53c
		Weedy	40d	53ab	29d	97ef	125c	62bc
R6	HBPL	Weed-Free	--	--	113a	234a	297a	167a
		Weedy	--	--	114a	222ab	278ab	166a
	LBPL+SBPL	Weed-Free	108a	106ab	--	184bcd	--	146a
		Weedy	95ab	113a	--	215ab	--	150a
	SBFM	Weed-Free	93ab	78d	87b	217ab	213bc	113b
		Weedy	97ab	101abc	62c	198abc	204c	146a
	SBPL	Weed-Free	80ab	78cd	74bc	168cd	164cd	102b
		Weedy	87ab	91bcd	59c	194abcd	134d	109b
	No Starter	Weed-Free	71b	81cd	57c	151d	206bcd	104b
		Weedy	93ab	78cd	31d	183bcd	134d	104b

† Abbreviations: CGS, corn growth stage; TRT; treatment; HBPL, high rate broadcast poultry litter; LBPL+SBPL, low rate broadcast poultry litter plus subsurface banded poultry litter; SBFM, subsurface banded feather meal; SBPL, subsurface banded poultry litter.

‡ Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

§ Data not presented (--) because fertility treatment was not employed at individual environment.

Table 11. Corn grain yield as affected by fertility treatment and weeds at individual environments.

		Environment					
Fertility TRT	Weed TRT	Beltsville 2013	Beltsville 2014	Kinston 2013	Kinston 2014	Salisbury 2013	Salisbury 2014
		kg ha^{-1}					
HBPL	Weed-Free	—	—	7,077a	10,098a	13,212a	8,241ab
	Weedy	—	—	6,356a	10,445a	12,875ab	8,330a
LBPL+SBPL	Weed-Free	9,091a	9,839a	—	9,870a	—	7,310abc
	Weedy	6,036b	8,560b	—	8,657ab	—	6,419c
SBFM	Weed-Free	7,423ab	8,578ab	4,275b	9,812a	11,274abc	6,991bc
	Weedy	7,619ab	7,522b	2,240d	7,680bc	9,778cd	7,087abc
SBPL	Weed-Free	6,246b	8,026b	3,584bc	7,920bc	9,219cde	4,206d
	Weedy	6,634b	7,187b	2,359cd	5,549d	8,092de	4,702d
No Starter	Weed-Free	5,955b	7,243b	1,614de	6,535cd	10,626bc	4,148d
	Weedy	5,922b	7,637b	869e	5,479d	6,492e	4.391d

† Abbreviations: TRT, treatment; HBPL, high rate broadcast poultry litter; LBPL+SBPL, low rate broadcast poultry litter plus subsurface banded poultry litter; SBFM, subsurface banded feather meal; SBPL, subsurface banded poultry litter.

‡ Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

§ Data not presented (—) because fertility treatment was not employed at individual environment.

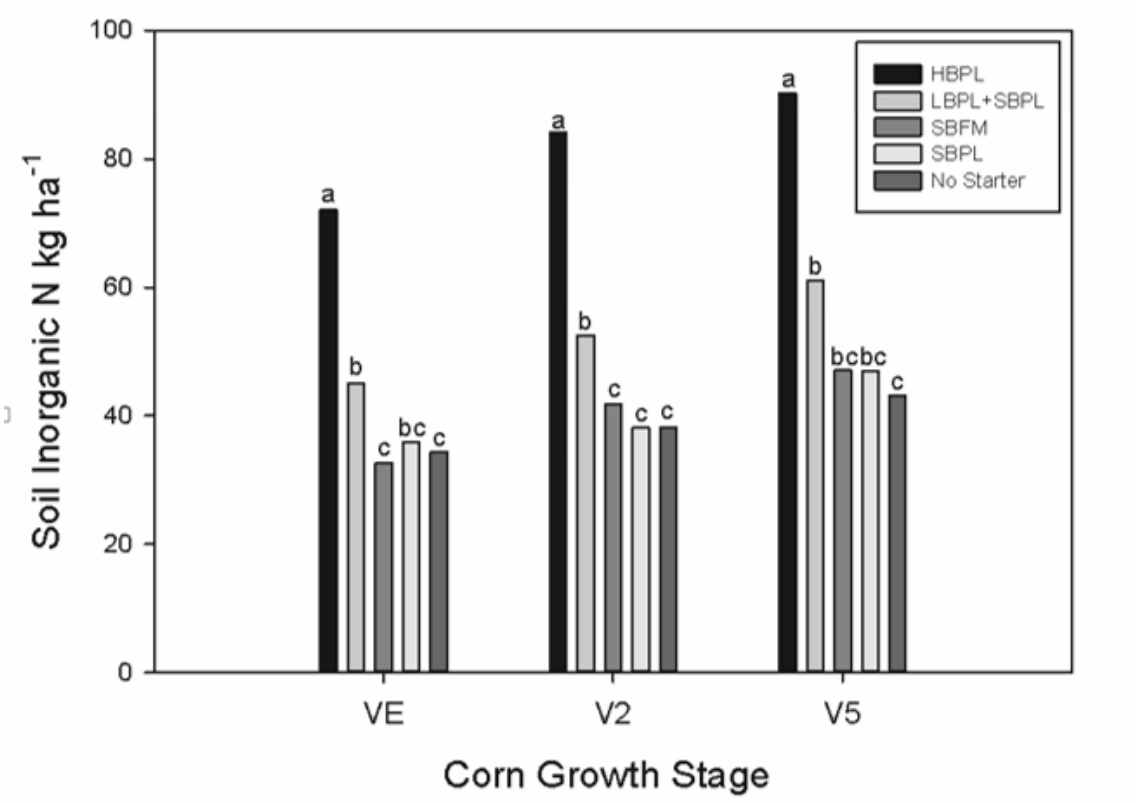

Figure 1. The effect of fertility treatment on soil inroganic N (NO_3-N and NH_4-N) at corn growth stages emergence (VE),V2 and V5. A combined analysis of six environments occurred for corn growth stage V2, and in this combined analysis mean values for the HBPL fertility treatment were averagerd across Kinston 2013, Kinston 2014, Salisbury 2013, and Salisbury 2014, mean values for the LBPL+SBPL fertility treatment were averaged across Beltsivlle 2013, Beltsville 2014, Kinston 2014, and Salisbury 2014, and mean values for the remainding fertility treatments were averaged acorss all environments. A combined analysis of four environments occurred for corn growth stages VE and V5, and in these combined analyses mean values were averaged across Kinston 2014, Salisbury 2013, and Salisbury 2014 for the HBPL fertility treatment, mean values were averaged across the Beltsville 2014, Kinston 2014, and Salisbury 2014 environments for the LBPL+SBPL fertility treatment, and mean values were averaged across the Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014 environments for the SBFM, SBPL, and no starter fertility treatments. Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

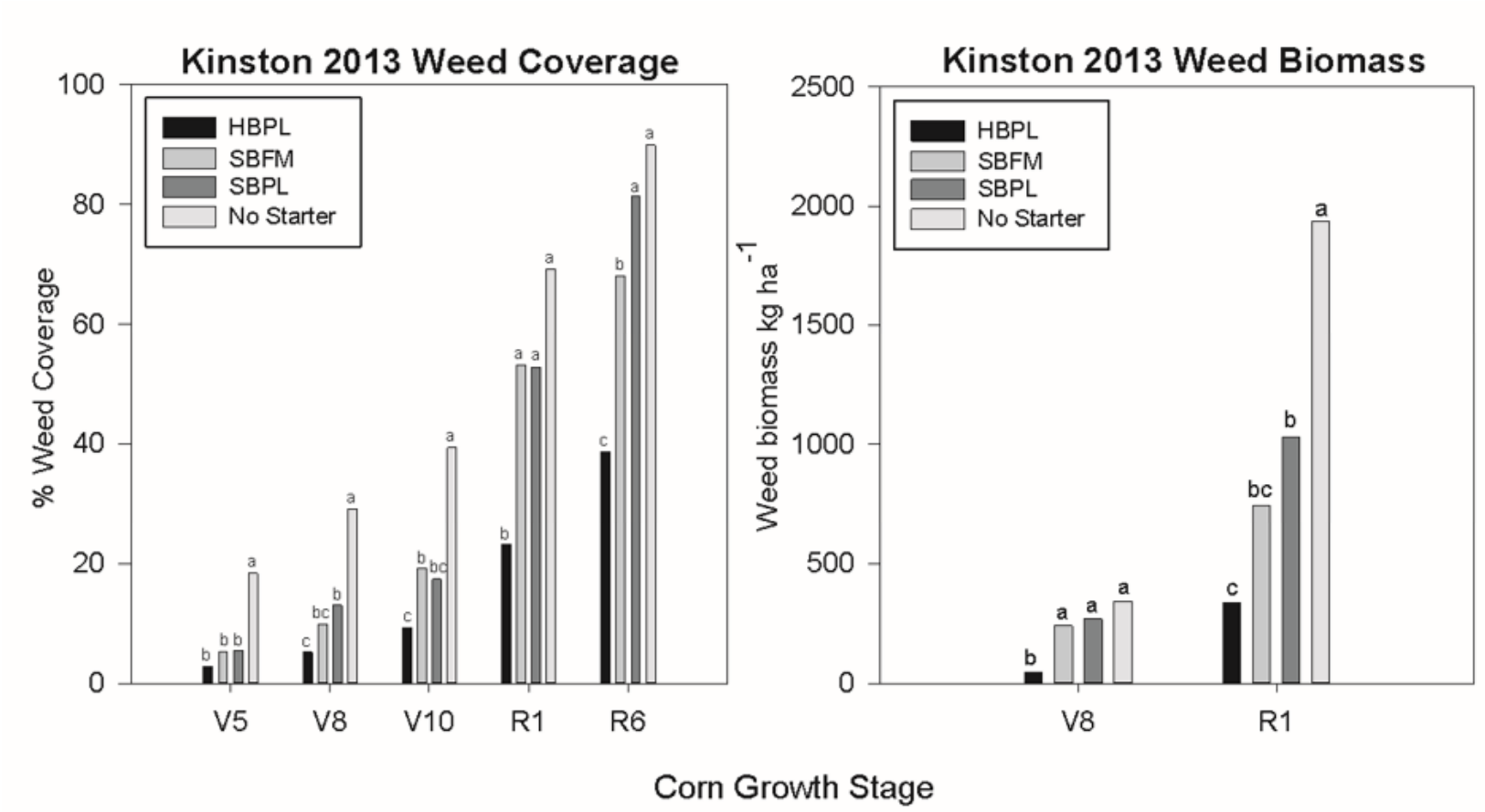

Figure 2. Weed coverage and weed biomass as affected by fertility treatment across corn growth stages at the Kinston 2013 environment. Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

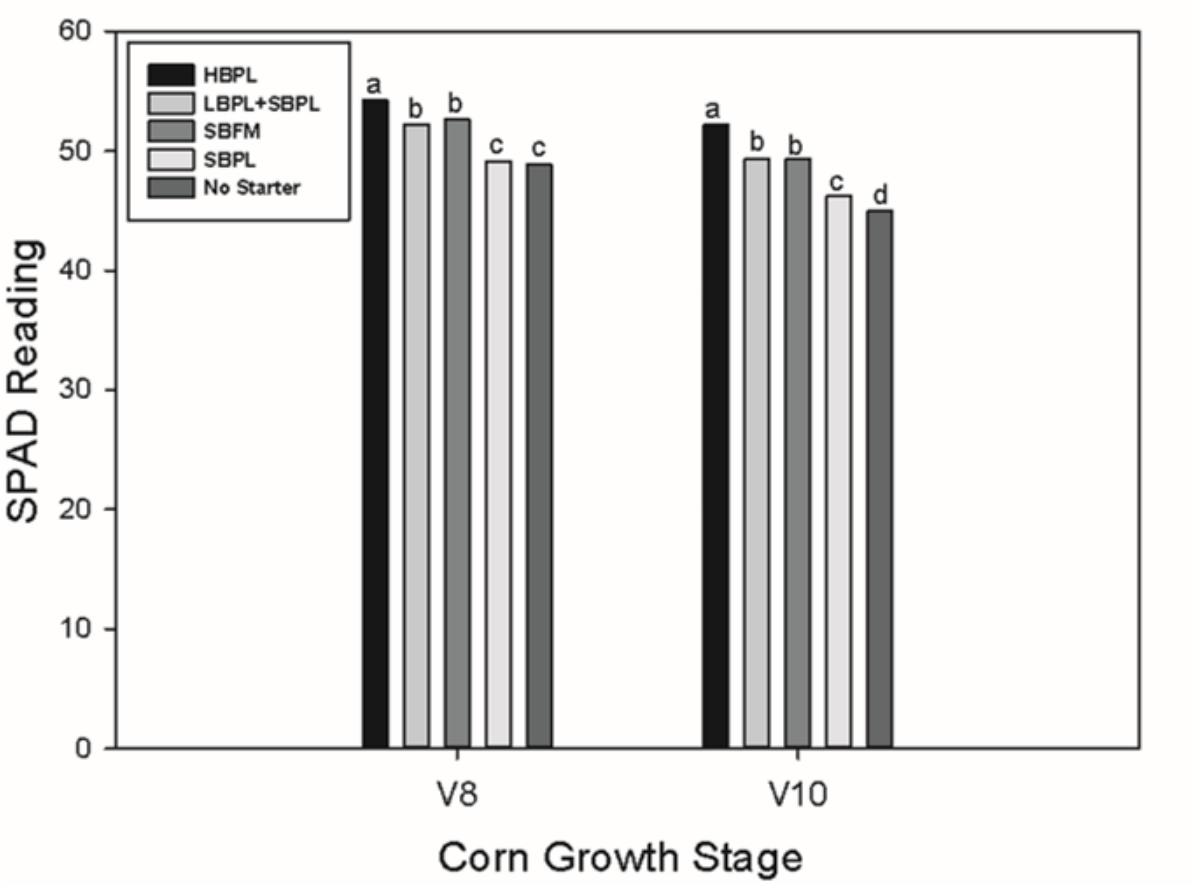

Figure 3. The effect of fertility treatment on SPAD readings for a combined analysis of four environments at corn growth stages V8 and V10. Mean values averaged across Kinston 2014, Salisbury 2013, and Salisbury 2014 for the HBPL fertility treatment, mean values averaged across the Beltsville 2014, Kinston 2014, and Salisbury 2014 environments for the LBPL+SBPL fertility treatment, and mean values averaged across the Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014 environments for the SBFM, SBPL, and no starter fertility treatments. Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

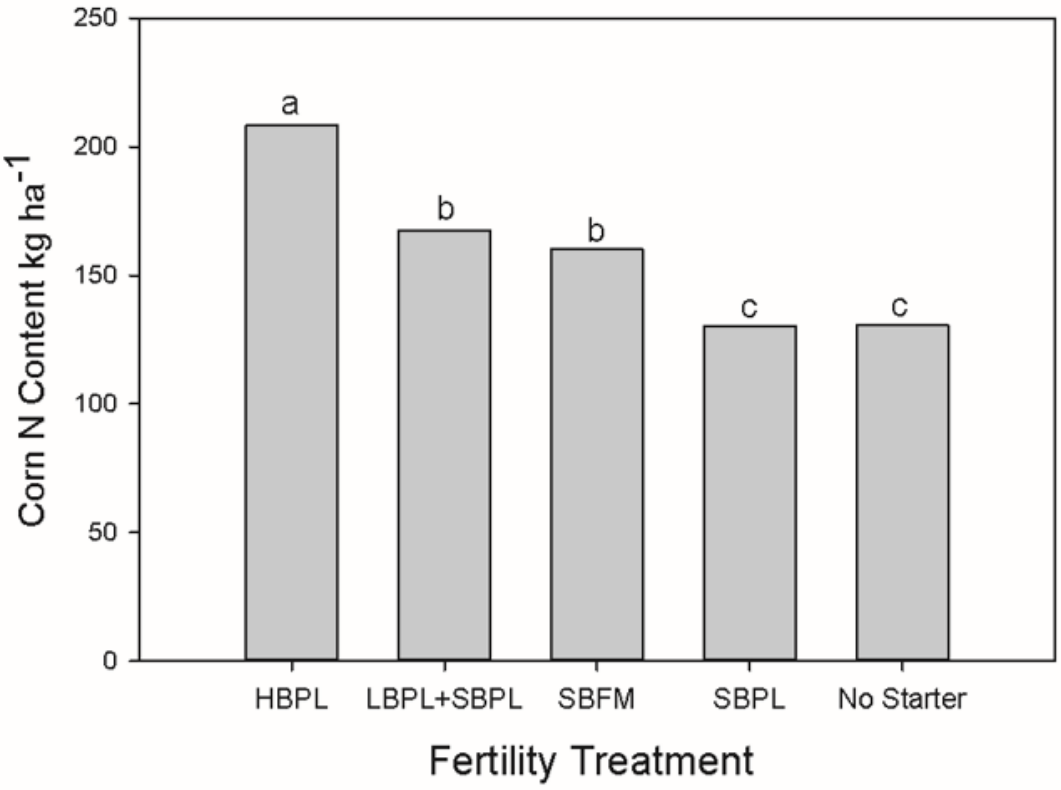

Figure 4. The effect of fertility treatment on corn N content at corn growth stage R6 for a combined analysis of four environments. Mean values averaged across Kinston 2014, Salisbury 2013, and Salisbury 2014 for the HBPL fertility treatment, mean values averaged across the Beltsville 2014, Kinston 2014, and Salisbury 2014 environments for the LBPL+SBPL fertility treatment, and mean values averaged across the Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014 environments for the SBFM, SBPL, and no starter fertility treatments. Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.

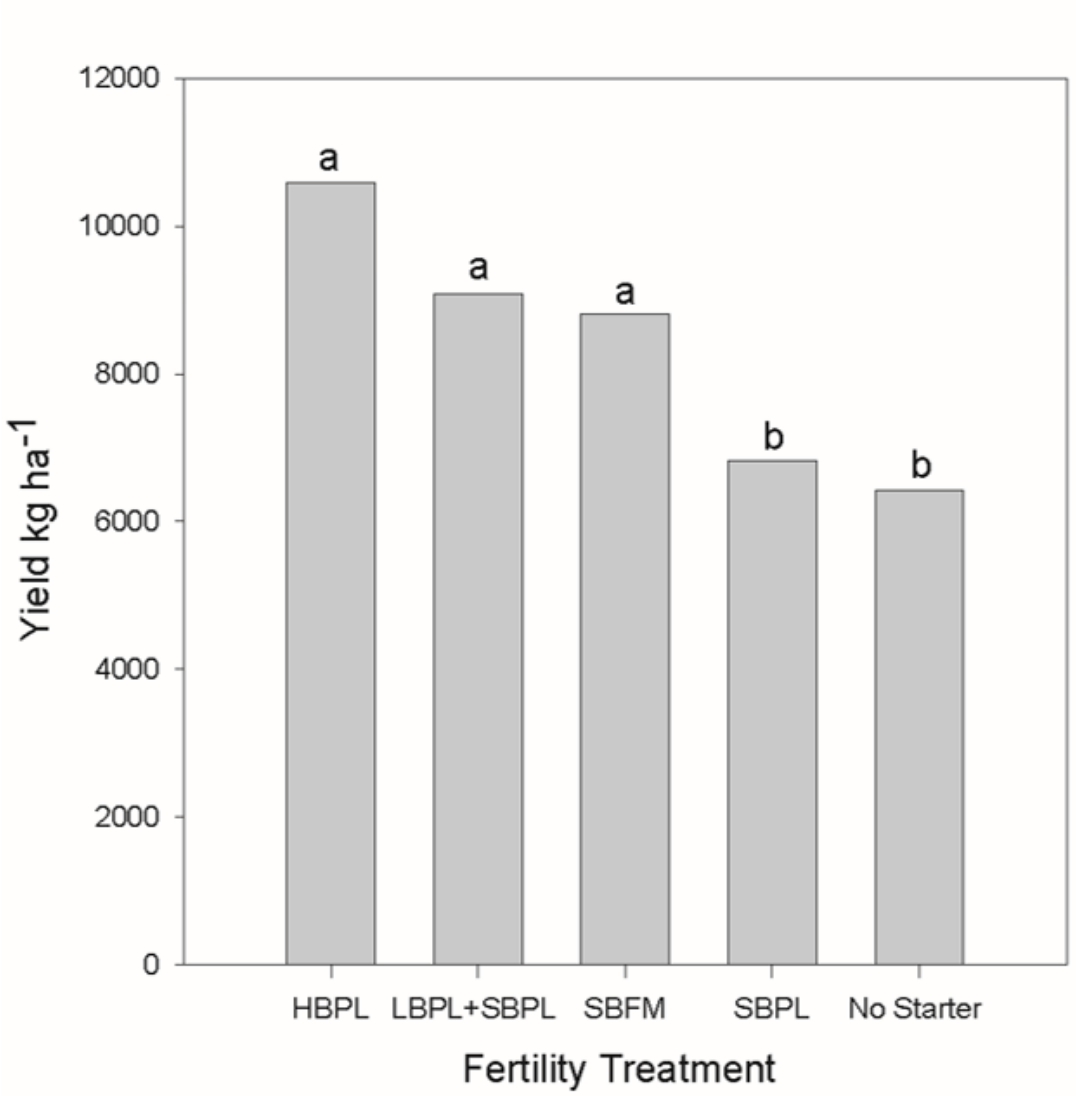

Figure 5. The effect of fertility treatment on corn grain yield for a combined analysis of four environments. Mean values averaged across Kinston 2014, Salisbury 2013, and Salisbury 2014 for the HBPL fertility treatment, mean values averaged across the Beltsville 2014, Kinston 2014, and Salisbury 2014 environments for the LBPL+SBPL fertility treatment, and mean values averaged across the Beltsville 2014, Kinston 2014, Salisbury 2013, and Salisbury 2014 environments for the SBFM, SBPL, and no starter fertility treatments. Means followed by the same letter are not significantly different at $P < 0.05$ based on Fisher's Protected LSD.