Winter Annual Cover Crops Interseeded into Soybean in Eastern Virginia: Influence on Soil Nitrogen, Corn Yield, and In-Season Soil Nitrogen Tests

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Crop and Soil Environmental Sciences

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December 8, 2014
Blacksburg, VA

Keywords: interseed, cover crops, hairy vetch, cereal rye, nitrogen management, no-till corn, agronomic optimum nitrogen rate, Solvita®, presidedress nitrate test

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Abstract

The diverse cropping system of eastern Virginia's coastal plain offers limited opportunity to establish winter annual cover crops (WCC) for nitrogen (N) scavenging. The winter fallow niche after double-crop or full-season soybean (Glycine max L. Merr.) encompasses the majority of acres left fallow. Our objective was to evaluate interseeded WCC N scavenging performance following soybean and N supplying capacity to subsequent corn (*Zea mays* L.). Field studies were conducted at four different locations in each of the two study years. The experimental design was split plot with cereal rye, hairy vetch, and RV mix WCC as main plots and ten fertilizer nitrogen (FN) rates in a factorial arrangement (0 and 45 kg FN ha^{-1} as starter; and 0, 45, 90, 135, and 180 kg FN ha^{-1} at sidedress) to corn as subplots. The highest N uptake for cereal rye at winter dormancy was 18 kg N ha^{-1}, but the average was 6-7 kg N ha^{-1}. At WCC termination average N uptake for cereal rye was 35 and 40 kg N ha^{-1} in 2013 and 2014, respectively. Average biomass dry matter (DM) at WCC termination for cereal rye, cereal rye + hairy vetch mix (RV mix), and hairy vetch was 2356, 2000, and 1864 kg ha^{-1} in 2013; and 2055, 2701, and 692 kg ha^{-1} in 2014, respectively. Average cereal rye N uptake was 35 kg N ha^{-1} in 2013 and 40 kg N ha^{-1} in 2014. Significant differences for residual soil nitrogen were most apparent for soil nitrate (NO_3-N) at lower depths (15-30 and 30-60 cm) during WCC termination and in the upper 0-15 cm during corn growth stage (GS) V4 of both years. Corn grain yield plateau following hairy vetch WCC was 0.7 and 0.6 Mg ha^{-1} higher than when following cereal rye WCC at zero and 45 kg ha^{-1} starter FN, respectively. Average agronomic optimum FN rates (AONR) were 26 and 9 kg ha^{-1} lower following hairy vetch than cereal rye WCC at zero and 45 kg ha^{-1} starter FN, respectively. Estimated hairy vetch FN reductions by FN replacement and AONR difference methods were 48 and 18 kg FN ha^{-1} in plots receiving zero starter FN; and 58 and -43 kg FN ha^{-1} in plots receiving 45 kg ha^{-1} starter FN. In-season soil N tests did not offer adequate information in order to predict sidedress FN reductions. These findings suggest that cereal rye and RV mix have the potential to scavenge and conserve residual soil N and hairy vetch is more than capable to supply PAN to subsequent corn when interseeded into soybean.

Acknowledgements

I am sincerely grateful to my advisor for, Dr. Wade Thomason, for giving me the opportunity to advance my education and gain experience in a field that I am deeply interested in and intend on growing professionally. Your patience, pragmatism, and work ethic are an inspiration. I would also like to thank Drs. Greg Evanylo and Mark Reiter. You both have offered me valuable advice that has helped me in my research.

I would like to thank everyone who has helped me with field and lab work. Especially Bee Khim Chim, Harry Behl, Steve Nagle, Stephanie Kulesza, Devin Rippner, Martin Battalgia, Kevin Bamber, Madalyn Lynch, Tri Nguyen, Tyler Black, and Emma Flemmig. I would also like to thank Liz Hokanson for help with planning and always smiling.

I would also like to thank extension agents Keith Balderson and David Moore for answering my many questions and providing field support. I am indebted to the cooperating farmers who were willing to take time out of their busy day to assist with project activities. Without their cooperation, the scope of this project would not have been possible. Thank you - Jimmy Brizendine, Buck Richardson, John Hundley, George Carlton, Roger Calhoun, and Peel Dillard.

I am grateful to my family for their support and instilling in me patience and determination which has given me the strength to sustain me through this process. Finally, I thank my wonderful wife Emily for always encouraging me to aim high and shoot for the stars. Without all of your help in the lab and support at home, this final stretch would have been much less bearable.

Partial funding for this project was provided by Virginia Department of Environmental Quality.

“This land was made for you and me.”
Woody Guthrie

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List of Abbreviations

AONR	Agronomic Optimum Nitrogen Rate
C	Carbon
DM	Aboveground Dry Matter
FN	Fertilizer Nitrogen
GS	Growth Stage
N	Nitrogen
PAN	Plant Available Nitrogen
PMN	Potentially Mineralizable Nitrogen
R	Cereal Rye
RV	Cereal Rye + Hairy Vetch Mixture
SOM	Soil Organic Matter
TC	Total Carbon
TN	Total Nitrogen
UAN	Urea Ammonium Nitrate
V	Hairy Vetch
WCC	Winter Annual Cover Crop

1. Literature Review

1.1 Introduction

Virginia encompasses 34% of the Chesapeake Bay's total watershed and is the source of approximately 27% of the nitrogen (N) discharged into the Chesapeake Bay annually (Chesapeake Bay Program, 2009; USEPA, 2010). In 2013, Virginia identified winter annual cover crops (WCC) as an agricultural best management practice (BMP) for improving soil and water quality in the Chesapeake Bay watershed (Virginia Department of Conservation and Recreation, 2012). In order to have significant reductions in nonpoint source N loading into the Chesapeake Bay, substantial increases in cropland planted to WCC are needed; however, adoption in current cropping systems has plateaued. One niche that could be suitable for implementation of WCC is the winter fallow period between soybean [*Glycine max* (L.) Merr.] and corn (*Zea mays* L.). Currently, limited acres are planted into WCC during this period due to late soybean harvest and the short window of time remaining to establish sufficient biomass to achieve significant results. Although it is well documented that early-planted WCC have long-term benefits for the environment and crop production, benefits of WCC interseeded into standing soybean are not well-known, and adoption remains low. Research is needed to identify how WCC interseeded into standing soybean affects residual soil N conservation, N supply to corn, corn yield, and soil-based N tests for corn recommendations.

1.2 Winter Annual Cover Crop's Influence on Soil Nitrogen and Corn Yield

Winter cover crops provide surface protection, increase soil organic matter (SOM), and both supply and recycle nutrients (Brady and Weil, 2007; Dabney et al., 2001). Additional soil benefits are extensive and include: increase microbial activity and their services, increase water infiltration, reduce surface crusting, reduce evaporation, and reduce extreme changes in temperature and moisture (Brady and Weil, 2007; Dabney et al., 2001). Conversely, WCC slow soil warmth in the spring may reduce plant available water in dry years, may contribute to N immobilization and volatilization losses, and may require initial costs such as seed and labor that are more obvious than future savings (Cabezas et al., 2004; Dabney et al., 2001).

Decomposition of plant residue increases SOM, which is well known for its positive effect on many biogeochemical properties that are indicators of soil quality (Sequeira and Alley, 2011). Most notably, SOM is positively correlated with soil structure, water holding capacity, cation exchange capacity, biological activity, pH buffering, and many other important biogeochemical reactions (Stevenson, 1994; Weil and Magdoff, 2004). Many studies have demonstrated that arable land with high SOM is often more productive than land with low SOM (Franzluebbers, 2004; Spargo et al., 2008a). In fact, agronomic management practices that reduce oxidation of SOM and increase residue inputs (e.g., no-till, crop rotation, cover crops) can increase SOM of arable land (Franzluebbers, 2002; Franzluebbers, 2004).

Surface residues buffer the soil surface from extreme weather events and are a key source of mineralizable nutrients. Plant tissue is composed of organic compounds that are broken down by microorganisms for metabolites and energy. The decay of organic residue occurs at different stages depending on the organic molecules within the residues and the microbial communities acting upon them. Larger molecular substances, such as cellulose, are initially broken down and metabolized. Simultaneously, at a much slower rate, resistant compounds such as lignin are decomposed by actinomycetes and fungi. Organic intermediates created during residue decomposition are further degraded into smaller organic molecules. Byproducts of these steps are carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulfide (H_2S), organic acids, and organic intermediates. The process of further degrading of organic intermediates polymerizes them into more resistant, higher molecular weight compounds that are the building blocks of humic substances (Stevenson, 1994). The rate with which these compounds decompose is primarily related to microbial activity, the organic compounds structure, and its interaction with soil colloids. Studies have shown that in temperate climates, approximately one-third of the C in plant residues remain in the soil after the first growing season as a component of SOM (Stevenson, 1994). Three major fractions relating to SOM decay rate have been identified with their respective turnover rates: 1) active fraction=two to four years; 2) protected fraction=20 to 50 years; and 3) stable fraction=800 to 1200 years (Parton et al., 1988).

Plant residues, specifically lignocellulose, provide a majority of the organic carbon compounds utilized by microorganisms for energy and biosynthesis (Wagner and Wolf, 1998). Lignocellulose is found in the cell walls of plants and is a complex structure of lignin, cellulose, and hemicellulose. Decomposition of lignocellulose material is carried out by a wide range of microorganisms. Lignin degradation is most commonly performed aerobically by white-rot fungi (*P. chrysosporium*) (Wong, 2009). Lignin degradation exposes polysaccharides and smaller biopolymers that are further degraded by various bacteria. Cellulose decomposition is catalyzed by a group of enzymes generally known as cellulase (or cellobiases). Different components of cellulase enzymes are secreted by different bacteria and fungi. Cellulase enzymes work on various parts of the cellulose structure, depending on the individual enzyme, to cleave the cellulose microfibril into monosaccharide units (e.g., glucose). Hemicellulose degradation is similar to that of cellulose and is also broken down into monosaccharide units (Paul, 2006). Monosaccharide units are utilized by heterotrophic microorganisms to initiate complex respiratory metabolic processes.

Several important microbial cellular constituents (e.g., proteins, nucleic acids, and cell walls) require N assimilation with the carbonaceous intermediates produced during the tricarboxylic acid (TCA) cycle. Soil microorganisms can satisfy this need by consuming organic polymers rich in N (direct assimilation) or inorganic N. Ammonium (NH_4^+) is the preferred source of inorganic N; however microorganisms can uptake NO_3^- if NH_4^+ concentrations are too low (Paul, 2006). Nitrate uptake is less efficient for microorganisms because it must be reduced to nitrite (NO_2^-) and then to NH_4^+ by nitrate reductase and nitrite reductase, respectively (McCarty and Bremner, 1992; Richardson et al., 2001). Assimilatory NO_3^- reduction is regulated at normal agricultural soil concentrations of NH_4^+ (Rice and Tiedje, 1989). Ammonium assimilation into glutamate or glutamine is enzymatically catalyzed by glutamate dehydrogenase or glutamine synthase, respectively (Myrold and Bottomley, 2008). Microorganisms can also directly take up organic N monomers of amino acids, nucleotides, and amino sugars (Barraclough, 1997). The monomers can be utilized for direct biosynthesis and excess N is deaminized and excreted. This pathway differs from the more traditional mineralization-immobilization turnover (MIT) pathway, where secreted enzymes deaminize NH_4^+ from organic residues in the soil matrix and are subsequently consumed (Mengel, 1996).

It is estimated that approximately 90% of N found in surface soils is in organic forms. Cultivated soils have been found to contain 0.06 to 0.5% total N (Bremner, 1996; Stevenson, 1994). Approximately 1 to 4% of soil organic N mineralizes per year to NH_4^+ (Havlin et al., 2005). A large proportion of the NH_4^+ ions become fixed in clays and humic substances (Stevenson, 1994). Soil organic N has been delineated into different empirical and theoretical fractions. The primary identifiable soil organic N compounds are amino acid-N and amino sugar-N. Approximately 50% of the N found in humic substances is accounted for in the amino acid-N fraction (Stevenson, 1994). Other commonly used fractions are soluble organic N (SON) and dissolved organic N (DON) (Murphy et al., 2000). Murphy et al. (2000) emphasizes that SON and DON are different pools of different composition and size. Soluble organic N is partially composed of easily mineralizable N, which may play a significant role in the cycling of NH_4^+ and NO_3^- (Mengel et al., 1999). Concentrations of SON in soil are comparable to inorganic N (Murphy, et al., 2000). Dissolved organic N is considered to be relatively stable and susceptible to leaching (Jones et al., 2005; Smith, 1987).

Amino acids and amino sugars are the most important sources of mineralizable N (Mengel, 1996). Nitrogen mineralization is driven by heterotrophic microorganisms that secrete enzymes in order to hydrolyze and deaminize N containing compounds. Amino acid hydrolysis and deamination are catalyzed by the enzymes proteases and deaminases. Although peptides are readily hydrolyzed into amino acids, it is suggested that a substantial quantity of these free amino acids are susceptible to bridging complexes with clay and humus (Loll and Bollag, 1983). Amino sugar polymers of glucosamine, muramic acid, and galactosamine are released from microbial and fungi cell walls (e.g., peptidoglycan, teichoic acid, chitin) (Roberts and Jones, 2012). Peptidoglycan and chitin are degraded by enzymes, releasing amino sugar polymers that are quickly mineralized to glucose and NH_3, which is rapidly hydrolyzed to NH_4^+ at pH levels below 7. Amino sugars have been estimated to contribute 5 to 12% of the total soil organic N (Knicker, 2011; Stevenson, 1994).

Predatory soil fauna also contribute significantly to N mineralization. Predatory N mineralization has been reported to be between 10 to 25% of total N mineralization (Hassink and Neutel, 1994), and has been shown to enhance total N mineralization (Kuikman et al., 1990). Microfauna (e.g., protozoa) excrete readily available NH_4^+, whereas macrofauna (e.g., earthworms) excrete urea, which requires enzymatic degradation. Urea hydrolysis is catalyzed by urease yielding ammonia and bicarbonate (Krajewska, 2009). Urea hydrolysis increases soil pH, which can result in ammonia volatilization if the soil pH is greater than 7.

Net mineralization and/or immobilization (assimilation) is attributed to the substrate quality, most notably the substrate's C:N ratio. Microorganisms require one N molecule to metabolize eight C molecules (Jansson and Persson, 1982). However, only 1/3 of the C molecules consumed are metabolized (Brady and Weil, 2007). Therefore, microorganisms require 20-30 C molecules for every N molecule consumed (Havlin et al., 2005). If the C:N ratio of the residue is lower than 20, net mineralization occurs and excess NH_3 is excreted by microorganisms (Havlin et al., 2005). Conversely, if the C:N ratio is above 30, net immobilization occurs and inorganic N from the soil is scavenged by microorganisms and used to continue metabolizing carbonaceous materials (Havlin et al., 2005).

Nitrification occurs simultaneously with N mineralization, where chemolithoautotrophic ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) (primarily the genera of *nitrosomonis* and *nitrobacter*, respectively) oxidize NH_3 to NO_3^-. Nitrifying bacteria oxidize N to obtain energy to run the Calvin-Benson-Bassham (CBB) cycle and fix C from CO_2 via the enzymatic reaction with ribulose1,5-biphosphate carboxylase/oxygenase (RubisCO) (Norton, 2008; Prosser, 1989). Energy in the form of ATP is generated when the accepted electrons are utilized in their electron transport system. Nitrification is a two-step process where NH_3 is first oxidized to NO_2 by AOB and then oxidized to NO_3^- by NOB. Ammonia-oxidizing bacteria use two enzymes during a series of redox reaction: ammonia monoxidiase and hydroxylamine oxidase. Nitrite-oxidizing bacteria accomplish N oxidation via enzymatic reactions with nitrite oxidoreductase. Nitrification lowers pH as two moles of H^+ are produced for every mole of

NH_4^+ oxidized (Havlin et al., 2005). Under anaerobic conditions some species of nitrifying bacteria are able to obtain their energy by reducing NO_3^- (Wrage et al., 2004).

Ammonium and NO_3^- transformations in the soil are dependent on soil physical and chemical properties and agricultural management practices. Generally, ammonification and nitrification processes are optimized at conditions that favor plant growth: temperatures between 20° to 35°C, water-filled pore space of approximately 60%, atmospheric concentrations of oxygen (O_2), near neutral pH, and an ample supply of both microorganisms and nitrogenous compounds (Brady and Weil, 2007). Management practices that favor these conditions will stimulate microbial activity and plant available nitrogen (PAN) production

Ammonium and NO_3^- ions react differently in soils. At agronomic pH ranges, soil is net negatively charged and, consequently, repulsive forces dominate soil-NO_3^- interactions. This phenomenon is responsible for the high mobility of NO_3^- in soil solution and its susceptibility to leaching. Significant leaching in corn production systems in North America can range from between 11-107 kg N ha^{-1} (Bjorneberg et al., 1996). In eastern United States, a majority of NO_3^- leaching occurs during the winter months when evapotranspiration is at its lowest (Staver and Brinsfield, 1998). Not all fertilizer N (FN) applied in a year leaches below the root zone within the same year; a majority remains immobilized in the organic fraction (Di and Cameron, 2002). One study indicated that FN accounted for 13, 19, and 4% of the NO_3^- leachate in the first, second, and third years after fertilization, respectively (Baker and Timmons, 1994).

The opposite can be said for NH_4^+, a counterion, which is attracted to negatively charged soil colloids. Ammonium, however, due to its hydrated radii, does not compete well with other cations for exchange sites and is, therefore, easily exchangeable and readily available for plant uptake (Bohn et al., 2001). Under certain conditions, NH_4^+ is able to migrate into ditrigonal cavities (hexagonal holes) within the interlayer of vermiculite or illite and become “fixed” and essentially unavailable for plant uptake (Bohn et al., 2001). Ammonium fixation is not considered to be agriculturally significant (Havlin et al., 2005).

In addition to erosion control and SOM accumulation, WCC have been promoted for the ability to capture leachable NO_3^- and supply PAN to subsequent cash crops. Winter cover crop’s N scavenging performance is highly related to soil N availability, cover crop growth vigor, and plant biomass (Meisinger et al., 1991). In Virginia, WCC grow slowly in the fall, become dormant in the winter, and begin rapid growth in early spring. Small grain WCC should be seeded earlier than two weeks prior to the first killing frost in to improve NO_3^- scavenging capacity (Simpson and Weammert, 2009). However, for best results WCC should be seeded six weeks before hard frost (Clark, 2007).

Various WCC monocultures and bicultures have been tested for their N scavenging and supplying ability. Studies have demonstrated that cereal rye (*Secale cereale* L.) routinely scavenges more N than other small grain WCC (Clark et al., 1994; Ditsch et al., 1993; Ranells and Wagger, 1997; Sainju et al., 1998; Wagger et al., 1998). In two separate lysimeter studies, NO_3^- concentrations in groundwater under cereal rye were 62 and 72 percent lower than concentrations under fallow ground (Karraker et al., 1950; Morgan et al., 1942). Staver and Brinsfield (1990), observed soil NO_3^- concentrations ranged from 58 kg ha^{-1} in a fallow treatment to 13 kg ha^{-1} in a cereal rye treatment following corn fertilized with approximately 170 kg FN ha^{-1}. In one study cereal rye was able to capture 62.5 kg N ha^{-1} of residual N when planted by October 1 (Brinsfield and Staver, 1991). However, when planting was delayed until November, cereal rye was only able to capture 13.4 kg N ha^{-1} (Brinsfield and Staver, 1991). Shipley et al. (1992) reported percent recoveries of fall applied FN in aboveground dry matter

(DM) were 45% for cereal rye, 27% for annual ryegrass (*Lolium multiflorum* Lam.), 10% for hairy vetch (*Vicia villosa* Roth subsp. *villosa*), 8% for crimson clover *(Trifolium incarnatum* L.), and 8% for native weed cover. Conversely, Ritter et al. (1998) found no significant difference between N leaching or corn grain yields regardless of cover crop treatment on either no-till or conventional-till soil. Ritter et al. (1998) concluded that winter cover crop establishment following corn was too late to adequately capture excess soil N in the sandy soils of the Delmarva Peninsula. Ritter et al. (1998) suggest aerial seeding methods for earlier cover crop establishment.

Leguminous WCC are not as effective as small grain WCC at N scavenging (Meisinger et al., 1991). However, they are capable of N-fixation and supplying significant quantities of PAN to subsequent cash crops. Legume N-fixation is a process of the symbiotic relationship between rhizobia bacteria (both *Rhizobium* and *Bradyrhizobia*) and legume plants. Rhizobia infect the root hairs of legume plants, forming nodules where the rhizobium is protected and nourished. Legumes provide the rhizobia with carbohydrates for energy, and rhizobia reciprocate with PAN. Rhizobia use the nitrogenase enzyme to reduce inert atmospheric N_2 and produce NH_3, which react with organic acids to produce amino acids and proteins in the host plant (Havlin et al., 2005).

Various species within the genera of Rhizobium and Bradyrhizobium infect specific legume species as their host. For example, *Bradyrhizobium japonicum* will specifically pair with soybean but not with hairy vetch (Brady and Weil, 2007). Vetch species (and pea species) require *Rhizobium leguminosarum biovar viceae* for N-fixation (Brady and Weil, 2007). Legume seed inoculation is advised when required rhizobia populations in the soil are too low for adequate N-fixation.

Legume WCC in temperate regions typically fix 60 to 150 kg ha^{-1} yr^{-1}, which accounts for approximately 75% of their own N requirement (Havlin et al., 2005). However, soils high in PAN lead to low N-fixation, because the legumes will choose to scavenge PAN before they expend energy to stimulate rhizobia to biologically fix N (Clark, 2007). Generally, aboveground biomass can be associated with N fixed by rhizobia, whereas belowground biomass is what was scavenged by the legume plant (Clark, 2007). Rhizobia have a high requirement for molybdenum (MoO_4^{2-}), iron (Fe^{2+} and Fe^{3+}), phosphorus ($H_2PO_4^-$ and HPO_4^{2-}), and sulfur (SO_4^{2-}) (Brady and Weil, 2007; Clark, 2007). Soils with low concentrations of these nutrients will result in low N-fixation and will likely lead to reduced legume crop yield.

In the mid-Atlantic region hairy vetch is prized for its high biomass, N-fixation, and N supplying capacity to subsequent cash crops (Clark, 2007). Clark et al. (1994) demonstrated that hairy vetch fixed more N and the subsequent corn yielded higher than when following cereal rye and cereal rye-hairy vetch biculture. Holderbaum et al. (1990) found that when compared to crimson clover, hairy vetch had less fall growth and winter soil cover, but had higher winter survival and spring growth which led to higher biomass and total N in the top growth. Ranells and Wagger (1996) found that 132 kg N ha^{-1} was released by hairy vetch eight weeks after termination over a two year study. McVay et al. (1989) demonstrated that hairy vetch was able to replace two-thirds (123 kg ha^{-1}) the FN required for corn production. In a five-year study, corn grain yields following hairy vetch was on average 2.5 Mg ha^{-1} greater than when following cereal rye or corn residue with no N fertilizer (Ebelhar et al., 1984). Ebelhar et al. (1984) further concluded that hairy vetch supplied biologically fixed N equivalent to 90 to 100 kg ha^{-1} FN annually to no-till corn. A meta-analysis conducted by Tonitto et al. (2006) indicated that legume aboveground N content ≥110 kg N ha^{-1} was required to produce similar corn grain yields as produced by conventional systems.

According to Teasdale et al. (2004), approximately 900 growing degree days (GDD) (base 4°C) are required for hairy vetch to develop approximately 4000 kg ha^{-1}. Hairy vetch containing such biomass contains approximately 140 kg N ha^{-1} (assuming 3.5% N) and is sufficient for corn agronomic optimum N rate. In eastern Virginia, WCC are typically seeded from mid-September (after corn) to mid-October (after soybean) but can sometimes be as late as mid-November. Aerially seeding WCC can provide a head start to accumulate GDD after soybean harvest in November. Thirty-year average temperatures indicate very little GDD accumulation from December through late February and accelerating GDD accumulation after mid-March (Figure 1.1). Assuming very little GDD are accumulated under soybean canopy, hairy vetch interseeded into standing soybean will accumulate a majority of their GDD in the spring for biomass production (Figure 1.1). Therefore, hairy vetch termination should be delayed until approximately early to mid-May to achieve 900 GDD (Figure 1.1).

Small grain-legume bicultures can optimize legume N-fixation in soils with high concentrations of PAN (Creamer et al., 1997). Small grains establish faster in the fall and are able to scavenge residual N early in the spring, while legumes begin rapid growth and N-fixation later in the spring when PAN concentrations are lower (Creamer et al., 1997). Generally, small grains dominate when PAN is high, and legumes dominate when PAN is low. Small grain-legume bicultures are able to satisfy a “dual purpose” by conserving fall residual N and supplying high concentrations of mineralized N to the succeeding corn crop (Clark et al., 2007b). In one two-year study Ranells and Wagger (1996) estimated N release from winter cover crop residue eight weeks after desiccation to be 24, 60, 132, 48, and 108 kg ha^{-1} for cereal rye, crimson clover, hairy vetch, cereal rye-crimson clover mix, and cereal rye-hairy vetch mix, respectively. Ranells and Wagger (1997) indicated that cereal rye-legume bicultures scavenged 44% and 15% soil inorganic N compared to cereal rye which scavenged 62% and 37% in the same years. Ranells and Wagger (1996) demonstrated that small grain-legume bicultures can provide substantial concentrations of PAN for subsequent cash crops. Additionally, Mitchell and Teel (1977) showed that no-tillage systems with winter biculture WCC before corn can produce grain yields comparable to those obtained by the application of 112 kg FN ha^{-1}.

Small grain N uptake rate from soil decreases substantially after the boot stage (Clark et al., 1997a; Shipley et al., 1992; Vaughan and Evanylo, 1998). Boot growth stage also marks the time when biomass production increases rapidly (Vaughan and Evanylo, 1998). Consequently, desiccation after boot growth stage results in higher C:N ratio residue, which can contribute to slow decomposition and N-immobilization (Vaughan and Evanylo, 1998). This is not the case with legumes, as their N-fixation and N accumulation increases later in the season and is highest just before flowering (Vaughan and Evanylo, 1998). Total N concentrations and biomass in small grain and legume monocultures are highest at later kill dates (Clark et al., 1994; Wagger, 1989b). Wagger (1989b) demonstrated that the substantially higher concentrations of N in later killed WCC were offset by the slower rate of N release, especially for cereal rye. Vaughan and Evanylo (1998) noted similar results, stating that cereal rye and cereal rye-hairy vetch bicultures should be terminated several weeks prior to corn planting, while hairy vetch monoculture termination should be delayed as late as possible to minimize N leaching and maximize PAN. Attention to termination time is important to improve the synchrony with winter cover crop N release and corn N uptake to increase N use efficiency (NUE) and reduce N fertilizer costs (Delgado et al., 2001; Wagger, 1989b).

1.3 Virginia Coastal Plain Cropping System

In the Virginia coastal plain a common crop rotation is no-till corn–wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.)/double-crop soybean. No-till corn and soybean have been planted in Virginia since the 1980's (Spargo et al., 2008a). Increased popularity can be attributed to less labor and energy use, improved soil quality, and higher yield (Reicosky et al., 1977). Conversely, no-till fields warm later than conventionally tilled fields and delay planting approximately one week (Kladivko et al., 1986; Thomason et al., 2009). Studies have indicated that after three to six years on coastal plain soils in Maryland, no-till systems achieve greater yields than conventional tillage (Bandel, 1983). When compared after four-years of continuous tillage treatments, no-till had higher mean corn grain yield than both moldboard plow-disc and chisel plow treatments (Cassel et al., 1995). Another study found corn yields in a cereal rye-corn rotation to be higher in no-till treatments relative to conventional till (Moschler et al., 1972).

Improved corn yields can be attributed to improved soil quality, including but not limited to SOM accumulation, and consequently increased mineralizable soil N. After nine years of no-till production, mineralizable soil N was approximately 45% greater than soils disk tilled (Franzluebbers et al., 1994). In another study microbial biomass N (MBN) and potentially mineralizable N (PMN) of the surface 0-7.5 cm averaged 13-45 and 12-122 kg N ha^{-1} greater in no-till than conventionally tilled soil, respectively (Doran, 1987). Continuous no-till systems have the ability to conserve approximately 22 to 28 kg N ha^{-1} $year^{-1}$ (Franzluebbers, 2004; Spargo et al., 2008b). Conserved N in these relatively labile fractions of SOM can provide subsequent cash crops with PAN during the growing season and inherently improve NUE.

Although increased PMN leads to higher concentrations of leachable NO_3^-, studies have indicated that soil NO_3^- leaching actually decreases in continuous no-till soils (Tyler and Thomas, 1977). Due to improved soil structure and increased preferential flow, NO_3^- in the soil matrix is bypassed by preferential flow. On the other hand, NO_3^- in surface runoff or in macropores will have increased leaching potential in continuous no-till soils (Tyler and Thomas, 1977). These differences are more significant in fine textured soils than in coarse sandy soils (Tyler and Thomas, 1977).

Planting date is a strong determinant of corn yield, as earlier planted corn has more biomass to utilize sunlight during the high growing degree days of June and July. Early planted corn often dries in the field, and consequently has lower grain drying costs (Alley et al., 2009b). Additionally, early planted corn usually is harvested earlier, which allows growers to seed small grains earlier in the fall (Alley et al., 2009b).

Corn requires temperatures above 10°C to germinate but will not begin rapid growth until temperatures reach 15.6°C (Brann et al., 2000). According to 30 year air temperature averages, the Virginia coastal plain often experiences a cold front in the second week of April (Alley et al., 2009b). Recommendations from this report are to plant no-till corn during the first week of April if air and soil temperatures are adequate and the one to two-week forecast does not indicate a cold front moving in. Otherwise, planting should be delayed to reduce risk of seedling damage.

Corn requires significant inputs of N fertilizer. In Virginia, N fertilizer rates are based on farmer yield goals and/or yield potential of the soil series. Corn typically emerges six to ten days after planting and after an additional seven days develops two fully-expanded leaves and a primary root system (Alley et al., 2009a; Hoeft et al., 2000). By this time the nutrients provided by the seed are exhausted and the plant must source nutrients from the soil (Hoeft et al., 2000). After the first two leaves, each subsequent leaf fully develops after 65 GDD and physiological maturity occurs after 2700 GDD for most mid-season maturity corn hybrids (Hoeft et al., 2000). Maximum growth and N uptake are highest approximately one month before silking and tasselling (30 to 45 days after emergence; after approximately 400 GDD) (Alley et al., 2009a; Evanylo and Alley, 1998). Corn grain yield of 9.4 Mg ha^{-1} will remove approximately 146 kg N ha^{-1} from the soil (Martin et al., 2006). A rate of 18 to 20 g FN kg $yield^{-1}$ is recommended for corn production in Virginia (Thomason et al., 2009).

Corn NUE can be increased with split application of one-third at planting and two-thirds applied at sidedress (Thomason et al., 2009). Starter fertilizer should be band applied 5 x 5 cm below and to the side of the seed to minimize salt injury, and sidedress is applied when corn is 15 to 45 cm tall at the whorl. In Virginia, it is recommended to band 34-45 kg FN ha^{-1} as a starter fertilizer and to sidedress FN between rows for higher NUE (Alley et al., 2009a; Thomason et al., 2009). Optimum sidedress FN rates vary dramatically and should be determined based on in-season soil and/or plant analysis (Alley et al., 2009a). Corn grain is harvested in September through November depending on the kernel moisture content. In eastern Virginia corn is typically followed with soft red winter wheat, barley, or WCC.

Soft red winter wheat is seeded on 109,000 ha acres in Virginia (USDA-NASS, 2012). In the Virginia coastal plain winter wheat is typically seeded from October 15 to November 15 and harvested from late June to early July. Following winter wheat are double-crop soybean, which are no-till planted into wheat stubble preferably no later than June 10 in eastern Virginia (Brann et al., 2000). Winter wheat harvest can often delay double-crop soybean planting and thus decrease yield. However, studies indicate that economic returns are greater in wheat/double-crop soybean systems than full-season soybean systems (Kyei-Boahen and Zhang, 2006). Double-crop soybean dry-down and are harvested later than full-season soybean. After harvest, soybean residues decompose and mineralize rapidly leaving the soil surface exposed to erosion and residual N susceptible to leaching (Broder and Wagner, 1988; Zhu and Fox, 2003). Furthermore, Zhu and Fox (2003) concluded in a Pennsylvania study that there was no significant difference between NO_3^- leaching after soybean than after corn in a corn-soybean rotation when recommended FN rates are applied to corn. Angle (1990) concluded similarly but also noted that NO_3^- leaches almost exclusively after soybean residue decomposition, whereas in corn NO_3^- is lost at various points throughout the season.

Establishment of WCC after soybean in eastern Virginia is typically by either no-till drilling or aerial application methods. No-till drilling occurs after harvest and is often too late for adequate fall biomass growth for successful N scavenging. Aerial and broadcast seeding may occur after harvest or into standing soybean (interseeding). The latter has not shown to reduce soybean yield (Johnson et al., 1998). Interseeding has been used in Virginia for many years and is generally met with mixed reviews. Preliminary studies have shown potential benefits with interseeding WCC into standing soybean. Janke et al. (1987) had success interseeding grass and legume WCC into standing soybean at leaf-yellowing stage in late summer. Unpublished recommendations indicate that best results occur when interseeding into soybean between 50% leaf yellow and 50% leaf drop (Robinson, 2012). Leaf drop provides a mulch layer for the WCC seed and improves germination (Johnson et al., 1998). Winter cover crops like white clover (*Trifolium repens* L.), annual ryegrass, cereal rye, hairy vetch, crimson clover, red clover (*Trifolium pretense* L.), and sweet clover [*Melilotus officinalis* (L.) Lam.] that can tolerate early shading do best (Clark, 2007). After soybean harvest winter cover crop seedlings undergo rapid growth until winter dormancy. Spring regrowth is similar to that found in no-till drill seeded WCC. In one Midwestern study, spring oat (*Avena sativa* L.), cereal rye, and spring oat-cereal rye mixture were interseeded with a tractor-mounted drop spreader at various dates from late July until leaf drop in mid-September (Johnson et al., 1998). Johnson et al. (1998) indicated that interseeded WCC did not reduce soybean yield regardless of planting date and that fall biomass was greater than post-harvest seeded WCC. In this study soybean had dropped 90% of leaves by middle of September and were harvested at the end of September in 1993. Additionally, it was noted that cereal rye and spring oat-cereal rye mixture significantly reduced subsequent corn yields, while spring oat did not (Johnson et al., 1998). Spring oats do not overwinter and deplete spring soil moisture or contribute to N-immobilization as much as cereal rye. Another study that investigated the interseeding of various WCC into full season soybean at last cultivation indicated that fall cover crop growth can achieve heights that interfere with soybean harvest (Hively and Cox, 2001). Although interseeded WCC hold promise as a seeding technique following double-crop soybean, research is needed to compare seeding techniques with respect to N scavenging and supplying capacity to subsequent corn crop.

1.4 Nitrogen Tests for Corn

Corn producers in the humid mid-Atlantic region have primarily relied on the presidedress nitrate test (PSNT) to measure soil NO_3-N concentrations to predict corn yield response to sidedress N in soils high in PMN. The PSNT is a valuable tool to measure soil NO_3-N immediately before maximum corn growth and N uptake. This methodology works well because it measures the net soil NO_3-N that is available for corn uptake after maximum gains and losses occur (Magdoff, 1991; Rozas et al., 2000). A critical NO_3^- concentration of 18 mg NO_3-N kg^{-1} soil has been identified in Virginia (Evanylo and Alley, 1997). Presidedress nitrate test

NO_3-N concentrations greater than 18 mg N kg^{-1} soil require no additional sidedress N fertilizer to achieve a realistic yield goal. Presidedress nitrate test NO_3-N concentrations less than the critical concentration require sidedress rates based on criteria outlined in section VAC 5-15-150.A.2.e of the Virginia Nutrient Management Training and Certification Regulations (Virginia Department of Conservation and Recreation, 2005).

Efficiency of the PSNT has been analyzed by numerous studies to determine if modifications are warranted in different situations. Several studies tested sampling depth to 60 cm and analysis for both NH_4-N and NO_3-N, and concluded that neither modification significantly improved PSNT predictive ability in the humid eastern region of the United States (Magdoff et al., 1984; Sims et al., 1995). Vaughan and Evanylo (1999) demonstrated that sampling to 15 cm on no-till cropping systems is adequate when a majority of PAN is supplied by WCC. Vaughan and Evanylo (1999) also noted that soil sampling in these systems may be delayed by up to two weeks after the standard PSNT sampling period.

The PSNT is especially important in no-till winter cover crop systems that have high concentrations of PMN. The PSNT is valuable when a substantial quantity of N may become available via mineralization and/or FN application is at sidedress. It has been further indicated that PSNT is applicable when starter banded or broadcast FN does not exceed 50 kg FN ha^{-1}(Bundy and Meisinger, 1994). In instances where starter FN is banded, soil should be sampled between rows to avoid fertilizer bands. The PSNT is also limited in that FN recommendations may be incorrect when (1) soil NO_3^- accumulates within the root zone below 30 cm in porous soils; (2) NO_3^- losses occur between sampling and sidedress application; and (3) substantial N mineralization occurs between sampling and sidedress application (Magdoff, 1991). Other authors have noted similar limitations (Bundy et al., 1992; Grove, 1992).

Use of the PSNT has shown to increase profits associated with lower fertilizer inputs while maintaining optimum yields (Babcock and Blackmer, 1992; Musser et al., 1995). However, profits are often modest and may not offset the burdens of additional tasks when time may be better spent on other profit driven activities (i.e., soybean planting). The PSNT requires soil sampling, analysis, and fertilizer procurement and application to occur within a narrow window of two to three weeks. This has spurred research and development of alternative tests that claim similar results.

Potentially mineralizable N is associated with the labile fraction of SOM and is considered the amount of N that will mineralize in an infinite amount of time at an optimum temperature and moisture (Curtin and Campbell, 2007). Stanford and Smith (1972) were some of the early investigators of PMN. They developed a 30-week aerobic incubation of soil:sand mixture at optimum moisture and temperature. Though considered the standard in estimating PMN, the Stanford and Smith (1972) method is too time consuming for practical application. Additionally, tests that only measure PMN or inorganic N have limited success at predicting corn FN response (Bundy and Meisinger, 1994). Waring and Bremner (1964) developed the 7-day anaerobic incubation and residual N test (IRNT) to account for both residual NO_3^- and NH_4^+, and PMN. Williams et al. (2007) compared the IRNT, Illinois soil N test (ISNT) (Khan et al., 2001), and gas pressure test (GPT) (Picone et al., 2002), and found that the ISNT and GPT had better precision and are better correlated to mineralizable and residual soil N than the IRNT. Keeney and Bremner (1966) developed a more practical 7-day anaerobic incubation, but this method has received mixed results when compared with field tests (Christensen et al., 1999). Anaerobic incubations may not effectively represent natural conditions as some NH_3 represents lysed aerobic bacteria and does not account for the entire MIT process as aerobic incubations do (Bundy and Meisinger, 1994).

Indirect methods that measure CO_2 evolution through C mineralization have been well correlated with N mineralization (Haney et al., 2008b). Three popular methods for measuring CO_2 release by active soil organisms are the alkali (NaOH or KOH) absorption method, the gas chromatography (GC), and the dual-channel infrared gas analyzer (IRGA). The IRGA has been shown to detect twice the amount of alkali absorption method (Cropper et al., 1985). Head space gas regulation tends to be a major influence on C mineralization. The O_2/CO_2 ratios must be kept at atmospheric concentrations. Ammonia oxidation has been shown to be reduced in incubations with NaOH traps when CO_2 concentrations are maintained below 0.1 ml L^{-1} (Kinsbursky and Saltzman, 1990). Haney et al. (2008a) have developed a simple method that measures CO_2 respiration after 24 hours (Haney-Brinton method). The Haney-Brinton method has been reported to be highly correlated with both the alkali absorption method and the IRGA method (Haney et al., 2008a). Haney et al. (2008b) reported that the Haney-Brinton method was highly related to 28-day N mineralization incubation (R^2=0.82) and initial water-extractable organic N and C (R^2=0.91 and 0.76, respectively). Haney et al. (2008b) concluded that the Haney-Brinton method was a good indicator of PMN and better suited to predict 28-day N mineralization than the titration method (R^2 values not reported). This method uses a patented gel paddle to detect CO_2 evolution from 40 g of rewetted soil (50% water-filled pore space) in a 250 ml sealed jar at 25 °C after 24 hours (Haney et al., 2012). The flush of CO_2 after rewetting is inferred to simulate microbial respiration after natural soil drying and rewetting. These test methods may be sufficient to calculate PMN in ideal laboratory settings; however natural conditions are not easily simulated in vitro.

Bundy and Meisinger (1994) indicate that air dried, sieved, and rewetted samples may increase microbial activity and overestimate mineralizable N concentrations in no-till soil. Conversely, Franzluebbers (1999) concluded that composite soil samples are more practical and do not bias results with regard to microbial biomass or activity in southeastern U.S. soils. Biological based soil tests have high spatiotemporal variability and are not well studied for FN recommendations in no-till winter cover crop systems. More research is required to determine if the Haney-Brinton test is suitable for predicting PAN and can be used to make N fertilizer recommendations to farmers in eastern Virginia.

1.5 Summary

The diverse cropping system of eastern Virginia's coastal plain offers limited opportunity to establish WCC; however, with improved seeding techniques producers are capable of aerially seeding WCC into standing soybean. The success of aerially seeded WCC depends on the producer's goals (i.e., SOM regeneration, N conservation, and/or N supply) and several important factors: soil moisture at seeding, soybean leaf drop, soybean harvest date, winter temperatures, and cover crop termination date. Considering that the winter fallow niche after double-crop or full-season soybean encompasses the majority of acres left bare in the Chesapeake Bay watershed, FN leaches over several seasons (Baker and Timmons, 1994), residual soil N following soybean and corn are not significantly different (Zhu and Fox, 2003), and immobilized residual soil N from a small grain WCC preceding corn becomes available after corn harvest (Kessavalou and Walters, 1999); it is imperative that research is conducted to fully understand how WCC following soybean affect residual soil N in eastern Virginia's diverse crop rotation. Furthermore, legume-based fertilizer systems have the potential to meet corn N requirements while reducing nitrate leaching potential from the soil profile (Tonitto et al., 2006).

Even when used to scavenge N, WCC biomass acts as mulch during the corn growing season which can reduce moisture stress and increase corn yield when N is not limiting (Clark et al., 1997a; Clark et al., 1995; Decker et al., 1994; Ebelhar et al., 1984). The majority of the research that exists was conducted on WCC following corn. Fewer studies have been published with results on WCC N scavenging and N supplying capacity following soybean. With added interest in protecting the Chesapeake Bay from nonpoint source agricultural pollution and the inevitable increase of FN costs, it is important to understand the role of WCC on N scavenging and N supplying capacity in all major rotations, including the period following soybean. Refined knowledge in these areas will allow policy makers to develop programs to meet realistic water quality goals and provide producers with tools to estimate FN credits from legume WCC.

Soil N is very dynamic and difficult to effectively measure for the purpose of providing accurate FN recommendations. The PSNT is the most commonly relied upon soil N test for corn production in the eastern United States. However, producers typically only use the PSNT after applying manures - when high concentrations of PMN are available. The Haney-Brinton test has received a lot of attention in recent years and has producers wondering about its value as a tool to predict sidedress FN recommendations. The Haney-Brinton test needs further calibration to be recommended to corn producers in Virginia.

1.6 Research Objectives

The overall goal of this research is to assess the influence of grass, legume, and mixed grass-legume WCC on soil N cycling and N supply to corn in a wheat/double-crop soybean–corn rotation. Although significant research has been conducted regarding WCC, there is a need for further research on WCC grown during the winter fallow period between double-crop soybean and corn in the mid-Atlantic region. Furthermore, the research will address N availability and corn yield following the various WCC, and will provide data for calibration of corn sidedress FN rate recommendations based on the PSNT and Haney-Brinton test.

1.6.1 Specific objectives:

Objective 1: *To determine the impact of small grain, legume, and mixed cover crop systems on soil N during the cover crop and corn growing season;*

Objective 2: *To determine the performance and N supplying capacity of small grain, legume, and mixed cover crop systems for the subsequent corn crop; and*

Objective 3: *To evaluate soil chemical and biological testing methods for predicting N cycling from WCC and the effect on sidedress N needs for corn*

1.7 References

Alley, M.M., M.E.J. Martz, P.H. Davis and J.L. Hammons. 2009a. Nitrogen and phosphorus fertilization of corn. Publ. no. 424-027. Virginia Coop. Ext., Blacksburg, VA.

Alley, M.M., J. Roygard and D. Brann. 2009b. Corn planting dates in the virginia coastal plain: How early is early? Publ. no. 424-033. Virginia Coop. Ext., Blacksburg, VA.

Angle, J.S. 1990. Nitrate leaching losses from soybeans (Glycine-max L Merr). Agric. Ecosyst. Environ. 31: 91-97.

Babcock, B.A. and A.M. Blackmer. 1992. The value of reducing temporal input nonuniformities. J. Agric. Res. Econ. 17: 335-347.

Baker, J.L. and D.R. Timmons. 1994. Fertilizer Management Effects on Leaching of Labeled Nitrogen for No-Till Corn in Field Lysimeters. J. Environ. Qual. 23: 305-310.

Bandel, V.A. 1983. No-tillage for corn: Effects of fertilizer practices and time. Better Crops Plant Food. 67: 23-25.

Barraclough, D. 1997. The direct or MIT route for nitrogen immobilization: A 15N mirror image study with leucine and glycine. Soil Biol. Biochem. 29: 101-108.

Bjorneberg, D.L., R.S. Kanwar and S.W. Melvin. 1996. Seasonal changes in flow and nitrate-N loss from subsurface drains. Trans. ASAE. 39: 961-967.

Bohn, H.L., B.L. Mcneal and G.A. O'Connor. 2001. Soil chemistry. 3rd ed. John Wiley & Sons, Inc., New York, NY.

Brady, N.C. and R.R. Weil. 2007. The nature and properties of soil. 14th ed. Prentice-Hall Inc., Upper Saddle River, NJ.

Brann, D.E., A.O. Abaye and P.R. Peterson. 2000. Crop description. In: D. E. Brann, D. L. Holshouser and G. L. Mullins, editors, Agronomy Handbook. Publ. no. 424-100, Virginia Coop. Ext., Blacksburg, VA. p. 1-30.

Bremner, J.M. 1996. Nitrogen - total. In: D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston and M. E. Sumner, editors, Methods of Soil Analysis. Part 3. Chemical Methods. SSSA Book Ser. 5. SSSA, Madison, WI. p. 1085-1121.

Brinsfield, R. and K. Staver. 1991. Role of cover crops in reduction of cropland nonpoint source pollution. Final report to USDA/SCS, Cooperative Agreement #25087.

Broder, M.W. and G.H. Wagner. 1988. Microbial colonization and decomposition of corn, wheat, and soybean residue. Soil Sci. Soc. Am. J. 52: 112-117.

Bundy, L., M. Schmitt and G. Randall. 1992. Predicting N fertilizer needs for corn in humid regions: Advances in the upper midwest. In: Y. Bull, editor, Predicting N fertilizer need for corn in humid regions. Natl. Fertilizer and Environ. Res., Muscle Shoals, AL. p. 73-89.

Bundy, L.G. and J.J. Meisinger. 1994. Nitrogen availability indices. In: P. J. Bottomley, J. S. Angle and R. W. Weaver, editors, Methods of Soil Analysis. Part 2: Microbiological and Biochemical Properties. SSSA book series 5.2. SSSA, Madison, WI. p. 951-984.

Cabezas, W.A.R.L., B.J.R. Alves, S.S.U. Caballero and D.G.d. Santana. 2004. Influence of the previous winter crop and nitrogen fertilization to corn productivity in notillage and conventional tillage. Cienc. Rural. 34: 1005-1013.

Cassel, D.K., C.W. Raczkowski and H.P. Denton. 1995. Tillage effects on corn production and soil physical conditions. Soil Sci. Soc. Am. J. 59: 1436-1443.

Chesapeake Bay Program. 2009. 2011 milestones for reducing nitrogen and phosphorus. Chesapeake Bay Program, Annapolis, MD.

Christensen, N., M. Qureshi, D. Baloch and R. Karow. Assessing nitrogen mineralization in a moist xeric environment. 1999. p. 83-90.

Clark, A. 2007. Managing cover crops profitably. 3rd ed. Handb. Ser. Book 9. Sust. Agric. Network, Beltsville, MD.

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.
Clark, A.J., A.M. Decker, J.J. Meisinger and M.S. McIntosh. 1997. Kill date of vetch, rye, and a vetch-rye mixture: I. cover crop and corn nitrogen. Agron. J. 89: 427-434.
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., J.J. Meisinger, A.M. Decker and F.R. Mulford. 2007. Effects of a grass-selective herbicide in a vetch–rye cover crop system on nitrogen. Agron. J. 99: 36-42.
Creamer, N.G., M.A. Bennett and B.R. Stinner. 1997. Evaluation of cover crop mixtures for use in vegetable production systems. HortScience 32: 866-870.
Cropper, J., W. P., K.C. Ewel and J.W. Raich. 1985. The measurement of soil CO2 evolution in situ. Pedobiologia 28: 35-40.
Curtin, D. and C. Campbell. 2007. Mineralizable nitrogen. In: M. R. Carter and E. G. Gregorich, editors, Soil sampling and methods of analysis. 2nd ed. CRC Press, Boca Raton, FL. p. 599-606.
Dabney, S.M., J.A. Delgado and D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32: 1221-1250.
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.
Delgado, J.A., R.J. Ristau, M.A. Dillon, H.R. Duke, A. Stuebe, R.F. Follett, M.J. Shaffer, R.R. Riggenbach, R.T. Sparks, A. Thompson, L.M. Kawanabe, A. Kunugi and K. Thompson. 2001. Use of innovative tools to increase nitrogen use efficiency and protect environmental quality in crop rotations. Commun. Soil Sci. Plant Anal. 32: 1321-1354.
Di, H. and K. Cameron. 2002. Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. Nutr. Cycling Agroecosyst. 64: 237-256.
Ditsch, D., M. Alley, K. Kelley and Y. Lei. 1993. Effectiveness of winter rye for accumulating residual fertilizer N following corn. J. Soil Water Conserv. 48: 125-132.
Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distributions in no-tillage and plowed soils. Biol. Fertil. Soils. 5: 68-75.
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.
Evanylo, G.K. and M.M. Alley. 1997. Presidedress soil nitrogen test for corn in Virginia. Commun. Soil Sci. Plant Anal. 28: 1285-1301.
Evanylo, G.K. and M.M. Alley. 1998. Nitrogen soil testing for corn in Virginia. Publ. no. 418-016,. Virginia Coop. Ext., Blacksburg, VA.
Franzluebbers, A.J. 1999. Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. Soil Biol. Biochem. 31: 1083-1090.
Franzluebbers, A.J. 2002. Soil organic matter stratification ratio as an indicator of soil quality. Soil and Tillage Research 66: 95-106.
Franzluebbers, A.J. 2004. Tillage and residue management effects on soil organic matter. In: F. Magdoff and R. R. Weil, editors, Soil organic matter in sustainable agriculture. CRC Press Inc., Boca Raton, FL. p. 227-268.
Franzluebbers, A.J., F.M. Hons and D.A. Zuberer. 1994. Long-term changes in soil carbon and nitrogen pools in wheat management systems. Soil Sci. Soc. Am. J. 58: 1639-1645.
Grove, J. 1992. Application of soil nitrate testing to corn production: field verification. In: K. L. Wells and W. R. Thompson Jr., editors, Current Viewpoints on the Use of Soil Nitrate Tests in the South. ASA, Madison, WI. p. 33-42.
Haney, R., A. Franzluebbers, V. Jin and M.V. Johnson. 2012. Soil organic C: N vs. water-extractable organic C: N. Open J. Soil Sci.
Haney, R.L., W.F. Brinton and E. Evans. 2008a. Soil CO2 respiration: comparison of chemical titration, CO2 IRGA analysis and the Solvita gel system. Renew. Agric. Food Syst. 23: 171-176.

Haney, R.L., W.H. Brinton and E. Evans. 2008b. Estimating soil carbon, nitrogen, and phosphorus mineralization from short-term carbon dioxide respiration. Commun. Soil Sci. Plant Anal. 39: 2706-2720.

Hassink, J. and A. Neutel. 1994. C and N mineralization in sandy and loamy grassland soils: the role of microbes and microfauna. Soil Biol. Biochem. 26: 1565-1571.

Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson. 2005. Soil fertility and fertilizers: An introduction to nutrient management. 7th ed. Pearson Prentice Hall, Upper Saddle River, NJ.

Hively, W.D. and W.J. Cox. 2001. Interseeding cover crops into soybean and subsequent corn yields. Agron. J. 93: 308-313.

Hoeft, R.G., E.D. Nafziger, S.R. Aldrich and R.R. Johnson. 2000. Modern corn and soybean production. 1st ed. MCSP Publ., Champaign, IL.

Holderbaum, J.F., A.M. Decker, J.J. Messinger, F.R. Mulford and L.R. Vough. 1990. Fall-seeded legume cover crops for no-tillage corn in the humid east. Agron. J. 82: 117-124.

Janke, R., R. Hofstetter, B. Volak and J. Radke. 1987. Legume interseeding cropping systems research at the Rodale Research Center. In: J. F. Power, editor, Proc. Soil Conservation Soc. Amer. Natl. Conf. Athens, GA. 1987. Soil Conservation Soc. Amer. Ankeny, IA. p. 90-91.

Jansson, S.L. and J. Persson. 1982. Mineralization and immobilization of soil nitrogen. In: F. J. Stevenson, editor, Nitrogen in Agricultural Soils. Agron. Monogr. 22. ASA-CSA-SSSA, Madison, WI. p. 229-252.

Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak and S.D. Logsdon. 1998. Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. J. Soil Water Conserv. 53: 276-279.

Jones, D.L., J.R. Healey, V.B. Willett, J.F. Farrar and A. Hodge. 2005. Dissolved organic nitrogen uptake by plants—an important N uptake pathway? Soil Biol. Biochem. 37: 413-423.

Karraker, P.E., C.E. Bartner and E.N. Fergus. 1950. Nitrogen balance in lysimeters as affected by growing Kentucky bluegrass and certain legumes separately and together. Kentucky Agr. Exp. Sta. Bul. 557: 1-16, Lexington, KY.

Keeney, D.R. and J.M. Bremner. 1966. Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. Agron. J. 58: 498-503.

Kessavalou, A. and D.T. Walters. 1999. Winter rye cover crop following soybean under conservation tillage: residual soil nitrate. Agron. J. 91: 643-649.

Khan, S.A., R.L. Mulvaney and R.G. Hoeft. 2001. A simple soil test for detecting sites that are nonresponsive to nitrogen fertilization. Soil Sci. Soc. Am. J. 65: 1751-1760.

Kinsbursky, R.S. and S. Saltzman. 1990. CO2-nitrification relationships in closed soil incubation vessels. Soil Biol. Biochem. 22: 571-572.

Kladivko, E.J., D.R. Griffith and J.V. Mannering. 1986. Conservation tillage effects on soil properties and yield of corn and soya beans in Indiana. Soil Tillage Res. 8: 277-287.

Knicker, H. 2011. Soil organic N-An under-rated player for C sequestration in soils? Soil Biol. Biochem. 43: 1118-1129.

Krajewska, B. 2009. Ureases I. Functional, catalytic and kinetic properties: A review. J. Mol. Catal. B: Enzym. 59: 9-21.

Kuikman, P.J., A.G. Jansen, J.A. Veen and A.J.B. Zehnder. 1990. Protozoan predation and the turnover of soil organic carbon and nitrogen in the presence of plants. Biol. Fertil. Soils 10: 22-28.

Kyei-Boahen, S. and L. Zhang. 2006. Early-maturing soybean in a wheat–soybean double-crop system. Agron. J. 98: 295-301.

Loll, M.J. and J.-M. Bollag. 1983. Protein transformation in soil. Adv. Agron. 36: 351-382.

Magdoff, F. 1991. Understanding the Magdoff pre-sidedress nitrate test for corn. J. Prod. Agric. 4: 297-305.

Magdoff, F.R., D. Ross and J. Amadon. 1984. A soil test for nitrogen availability to corn. Soil Sci. Soc. Am. J. 48: 1301-1304.

Martin, J.H., R.P. Waldren and D.L. Stamp. 2006. Principles of field crop production. 4th ed. Pearson Prentice Hall, Upper Saddle River, NJ.

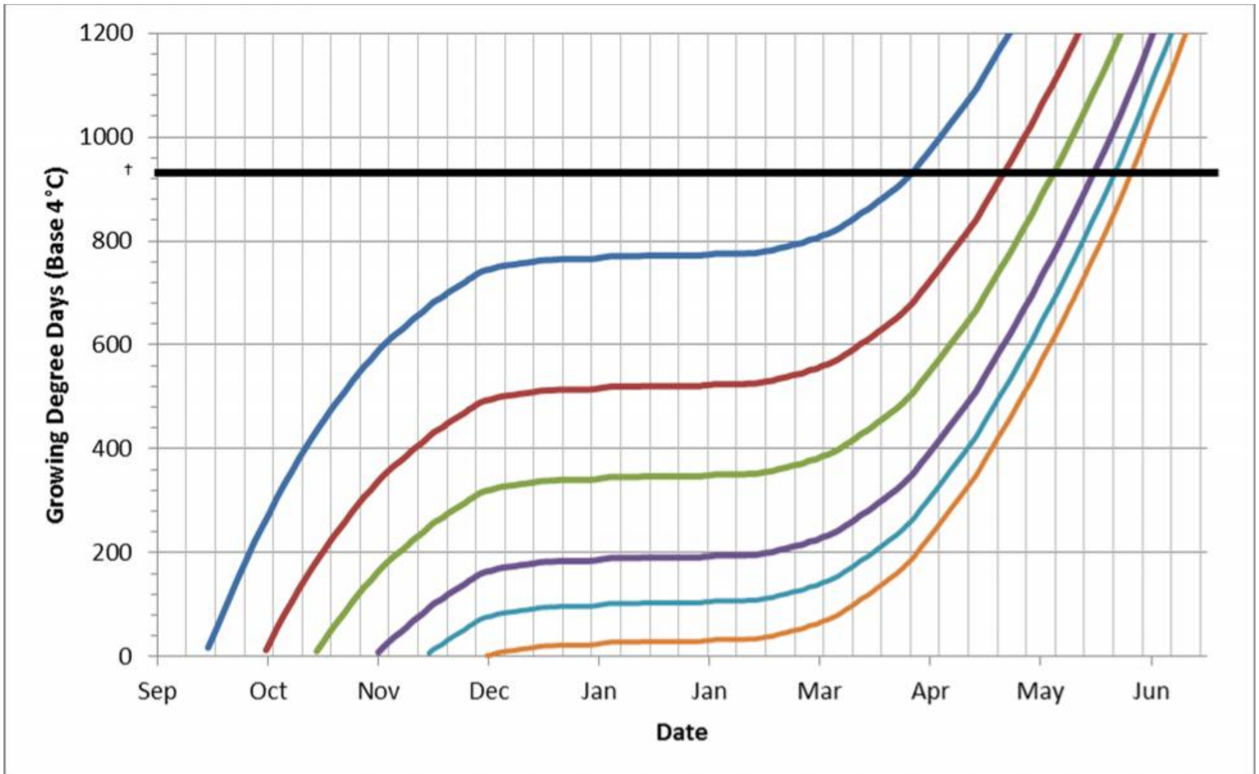
McCarty, G.W. and J.M. Bremner. 1992. Regulation of assimilatory nitrate reductase activity in soil by microbial assimilation of ammonium. Proceedings of the National Academy of Sciences of the United States of America. 89: 453-456.
McVay, K.A., D.E. Radcliffe and W.L. Hargrove. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Sci. Soc. Am. J. 53: 1856-1862.
Meisinger, J., W. Hargrove, R. Mikkelsen, J. Williams and V. Benson. 1991. Effects of cover crops on groundwater quality. In: W. L. Hargrove, editor, Cover crops for clean water. Soil and Water Conserv. Soc., Jackson, TN. p. 57-68.
Mengel, K. 1996. Turnover of organic nitrogen in soils and its availability to crops. Plant Soil 181: 83-93.
Mengel, K., B. Schneider and H. Kosegarten. 1999. Nitrogen compounds extracted by electroultrafiltration (EUF) or CaCl2 solution and their relationships to nitrogen mineralization in soils. J. Plant Nutr. Soil Sci. 162: 139-148.
Mitchell, W.H. and M.R. Teel. 1977. Winter-annual cover crops for no-tillage corn production. Agron. J. 69: 569-573.
Morgan, M.F., H.G.M. Jacobson and S.B. LeCompte. 1942. Drainage water losses from a sandy soil as affected by cropping and cover crops. Conn. Agric. Exp. Stn. Bull. 466: 731-759.
Moschler, W.W., G.M. Shear, D.C. Martens, G.D. Jones and R.R. Wilmouth. 1972. Comparative yield and fertilizer efficiency of no-tillage and conventionally tilled corn. Agron. J. 64: 229-231.
Murphy, D.V., A.J. Macdonald, E.A. Stockdale, K.W.T. Goulding, S. Fortune, J.L. Gaunt, P.R. Poulton, J.A. Wakefield, C.P. Webster and W.S. Wilmer. 2000. Soluble organic nitrogen in agricultural soils. Biol. Fertil. Soils 30: 374-387.
Musser, W.N., J.S. Shortle, K. Kreahling, B. Roach, W.-C. Huang, D.B. Beegle and R.H. Fox. 1995. An economic analysis of the pre-sidedress nitrogen test for Pennsylvania corn production. Rev. Agric. Econ. 17: 25-35.
Myrold, D. and P. Bottomley. 2008. Nitrogen mineralization and immobilization. In: J. S. Schepers, W. R. Raun, R. F. Follett, R. H. Fox and G. Randall, editors, Nitrogen in Agricultural Systems. Agron. Monogr. 49. ASA-CSA-SSSA, Madison, WI. p. 157-172.
Norton, J.M. 2008. Nitrification in agricultural soils. In: J. S. Schepers and W. R. Raun, editors, Nitrogen in Agricultural Systems. Agron. Monogr. 49. ASA-CSA-SSSA, Madison, WI. p. 173-199.
Parton, W.J., J.W.B. Stewart and C.V. Cole. 1988. Dynamics of C, N, P and S in grassland soils: a model. Biogeochemistry 5: 109-131.
Paul, E.A. 2006. Soil microbiology, ecology and biochemistry. Academic press, New York, NY.
Picone, L.I., M.L. Cabrera and A.J. Franzluebbers. 2002. A rapid method to estimate potenially mineralizable nitrogen in soil. Soil Sci. Soc. Am. J. 66: 1843-1847.
Prosser, I.I. 1989. Autotrophic nitrification in bacteria. In: A. H. Rose, editor, Advances in Microbial Physiology. Academic press, San Diego, CA. p. 125.
Ranells, N.N. and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crop monocultures and bicultures. Agron. J. 88: 777-882.
Ranells, N.N. and M.G. Wagger. 1997. Winter annual grass-legume bicultures for efficient nitrogen management in no-till corn. Agric. Ecosyst. Environ. 65: 23-32.
Reicosky, D.C., D.K. Cassel, R.L. Blevins, W.R. Gill and G.C. Naderman. 1977. Conservation tillage in the southeast. J. Soil Water Conserv. 32: 13-19.
Rice, C.W. and J.M. Tiedje. 1989. Regulation of nitrate assimilation by ammonium in soils and in isolated soil microorganisms. Soil Biol. Biochem. 21: 597-602.
Richardson, D.J., B.C. Berks, D.A. Russell, S. Spiro and C.J. Taylor. 2001. Functional, biochemical and genetic diversity of prokaryotic nitrate reductases. Cell. Mol. Life Sci. 58: 165-178.
Ritter, W.F., R.W. Scarborough and A.E.M. Chirnside. 1998. Winter cover crops as a best management practice for reducing nitrogen leaching. J. Contam. Hydrol. 34: 1-15.
Roberts, P. and D.L. Jones. 2012. Microbial and plant uptake of free amino sugars in grassland soils. Soil Biol. Biochem. 49: 139-149.

Robinson, D. 2012. Plant cover crops: Learning about the benefits of planting cover crops. Available at http://plantcovercrops.com/cover-crops-areial-applied-into-soybeans-and-corn-any-difference-in-emergence-time/. (verified 10 Feb. 2013).
Rozas, H.S., H.E. Echeverría, G.A. Studdert and G. Domínguez. 2000. Evaluation of the presidedress soil nitrogen test for no-tillage maize fertilized at planting. Agron. J. 92: 1176-1183.
Sainju, U.M., B.P. Singh and W.F. Whitehead. 1998. Cover crop root distribution and its effects on soil nitrogen cycling. Agron. J. 90: 511-518.
Sequeira, C.H. and M.M. Alley. 2011. Soil Organic Matter Fractions as Indices of Soil Quality Changes. Soil Sci. Soc. Am. J. 75: 1766-1773.
Shipley, P.R., J.J. Messinger and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84: 869-876.
Simpson, T.W. and S.E. Weammert. 2009. Developing best management practice definitions and effectiveness estimates for nitrogen, phosphorus and sediment in the Chesapeake Bay watershed. Mid-Atlantic Water Program, Univ. of Maryland, College Park, MD.
Sims, J.T., B.L. Vasilas, K.L. Gartley, B. Milliken and V. Green. 1995. Evaluation of soil and plant nitrogen tests for maize on manured soils of the Atlantic coastal plain. Agron. J. 87: 213-222.
Smith, S. 1987. Soluble organic nitrogen losses associated with recovery of mineralized nitrogen. Soil Sci. Soc. Am. J. 51: 1191-1194.
Spargo, J.T., M.M. Alley, R.F. Follett and J.V. Wallace. 2008a. Soil carbon sequestration with continuous no-till management of grain cropping systems in the Virginia coastal plain. Soil Tillage Res. 100: 133-140.
Spargo, J.T., M.M. Alley, R.F. Follett and J.V. Wallace. 2008b. Soil nitrogen conservation with continuous no-till management. Nutr. Cycling Agroecosyst. 82: 283-297.
Stanford, G. and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. J. 36: 465-472.
Staver, K. and R. Brinsfield. 1990. Patterns of soil nitrate availability in corn production systems: Implications for reducing groundwater contamination. J. Soil Water Conserv. 45: 318-323.
Staver, K.W. and R.B. Brinsfield. 1998. Using cereal grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plain. J. Soil Water Conserv. 53: 230-240.
Stevenson, F.J. 1994. Humus chemistry, genesis, composition, reactions. 2nd ed. John Wiley & Sons, Inc., New York, NY.
Teasdale, J.R., T.E. Devine, J.A. Mosjidis, R.R. Bellinder and C.E. Beste. 2004. Growth and development of hairy vetch cultivars in the northeastern United States as influenced by planting and harvesting date. Agron. J. 96: 1266-1271.
Thomason, W.E., R.R. Youngman, S.E. Hagood and M.M. Alley. 2009. Successful no-tillage corn production. Publ. no. 424-030. Virginia Coop. Ext., Blacksburg, VA.
Tonitto, C., M.B. David and L.E. Drinkwater. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agric. Ecosyst. Environ. 112: 58-72.
Tyler, D.D. and G.W. Thomas. 1977. Lysimeter measurements of nitrate and chloride losses from soil under conventional and no-tillage corn. J. Environ. Qual. 6: 63-66.
USDA-NASS. 2012. Quick stats 1.0 crop estimates database. Available at http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats_1.0/index.asp#top. (verified 10 Feb. 2013).
USEPA. 2010. Chesapeake Bay TMDL executive summary. Available at http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/CBayFinalTMDLSection4_final.pdf. (verified 26 Feb. 2013).
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.
Vaughan, J.D. and G.K. Evanylo. 1999. Soil nitrogen dynamics in winter cover crop-corn systems. Commun. Soil Sci. Plant Anal. 30: 31-52.

Virginia Department of Conservation and Recreation. 2005. Virginia nutrient management standards and criteria. Richmond, VA.
Virginia Department of Conservation and Recreation. 2012. Program year 2013, Virginia agricultural cost share (VACS), BMP manual. Richmond, VA.
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.
Wagger, M.G., M.L. Cabrera and N.N. Ranells. 1998. Nitrogen and carbon cycling in relation to cover crop residue quality. J. Soil Water Conserv. 53: 214-218.
Wagner, G. and D. Wolf. 1998. Carbon transformations and soil organic matter formation. In: D. Sylvia, J. Fuhrmann, P. Hartel and D. A. Zuberer, editors, Principles and applications of soil microbiology. Prentice Hall, Upper Saddle River, NJ.
Waring, S. and J. Bremner. 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature 201: 951-952.
Weil, R.R. and F. Magdoff. 2004. Significance of soil organic matter to soil quality and health. In: R. R. Weil and F. Magdoff, editors, Soil Organic Matter In Sustainable Agriculture. CRC Press Inc., Boca Raton, FL. p. 1-43.
Williams, J.D., C.R. Crozier, J.G. White, R.P. Sripada and D.A. Crouse. 2007. Comparison of Soil Nitrogen Tests for Corn Fertilizer Recommendations in the Humid Southeastern USA. Soil Sci. Soc. Am. J. 71: 171-180.
Wong, D.S. 2009. Structure and action mechanism of ligninolytic enzymes. Appl. Biochem. Biotechnol. 157: 174-209.
Wrage, N., G. Velthof, H. Laanbroek and O. Oenema. 2004. Nitrous oxide production in grassland soils: assessing the contribution of nitrifier denitrification. Soil Biol. Biochem. 36: 229-236.
Zhu, Y. and R.H. Fox. 2003. Corn–soybean rotation effects on nitrate leaching. Agron. J. 95: 1028-1033.

1.8 Figures

Figure 1.1. 30 year average growing degree day (base 4°C) accumulation by seeding date for Richmond, VA



† Bold horizontal line indicates critical GDD (926 GDD) for hairy vetch to accumulate 120 to 144 kg N ha^{-1} (Teasdale et al., 2004).

2. Winter Annual Cover Crops Interseeded into Soybean in Eastern Virginia: Influence on Soil Nitrogen.

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2.1 Abstract

The diverse cropping system of eastern Virginia's coastal plain offers limited opportunity to establish winter annual cover crops (WCC) for nitrogen (N) scavenging. The winter fallow niche after double-crop or full-season soybean (Glycine max L. Merr.) encompasses the majority of acres left fallow. Our objective was to evaluate interseeded WCC N scavenging performance following soybean and influence on residual soil N throughout the subsequent corn (*Zea mays* L.) growing season. Field studies were conducted at four different locations in each of the two study years. The highest N uptake for cereal rye at winter dormancy was 18 kg N ha^{-1}, but the average was 6-7 kg N ha^{-1}. At WCC termination average N uptake for cereal rye was 35 and 40 kg N ha^{-1} in 2013 and 2014, respectively. Average biomass dry matter (DM) at WCC termination for cereal rye, cereal rye + hairy vetch mix (RV mix), and hairy vetch was 2356, 2000, and 1864 kg ha^{-1} in 2013; and 2055, 2701, and 692 kg ha^{-1} in 2014, respectively. Significant differences for residual soil nitrogen were most apparent for soil nitrate (NO_3-N) at lower depths (15-30 and 30-60 cm) during WCC termination and in the upper 0-15 cm during corn growth stage (GS) V4 of both years. At corn harvest significant differences in residual soil NO_3-N in fertilize N (FN) control plots (0 kg FN ha^{-1}) were observed but were biologically insignificant. Residual soil NO_3-N was highest in hairy vetch and/or RV mix treatments with high FN rates; and residual soil NH_4-N and inorganic N was highest in cereal rye and/or RV mix treatments with high FN rates at most locations. These findings suggest that cereal rye and RV mix have the potential to scavenge and conserve residual soil N when interseeded into soybean similarly as when drilled after corn.

2.2 Introduction

The Chesapeake Bay Agreement of 1987 set nutrient reduction at the forefront of water quality regulations in the Chesapeake Bay watershed (Boesch et al., 2001). In 2009, Executive Order 13508 established the Federal Leadership Committee for the Chesapeake Bay to oversee and coordinate efforts in reaching water quality goals by 2025 (Federal Register, 2009). Total maximum daily loads (TMDL) and watershed implementation plans (WIP) were established for each State in the Chesapeake Bay watershed in 2010. With cover crops identified as one of five "priority" best management practices (BMP) for improving water quality in Virginia there is increased interest in reducing the portion of cropland left fallow during winter months.

Virginia encompasses 34% of the Chesapeake Bay's total watershed and is the source of approximately 27% nitrogen (N) discharged into the Chesapeake Bay annually (Chesapeake Bay Program, 2009; USEPA, 2010). According to the U.S. Environmental Protection Agency, Virginia's agriculture industry contributes 20% of the overall N load (USEPA, 2010). Virginia has adopted cover crops as an agricultural priority BMP for improving soil and water quality in the Chesapeake Bay watershed (Virginia Department of Conservation and Recreation, 2012). The U.S. Department of Agriculture National Agriculture Statistic Service's 2012 census reported 122,198 ha planted into cover crops on Virginia cropland (USDA-NASS, 2012). The 2012 census indicated approximately 10% of Virginia's cropland planted with cover crops, which indicated that considerable cropland in Virginia is allocated for winter small grain commodity crop production. For example, in eastern Virginia two common rotations are corn (*Zea mays* L.)–winter wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.)/double-crop soybean [*Glycine max* (L.) Merr.]–winter fallow, or corn–small grain winter annual cover crops (WCC)–full season soybean–winter fallow.

Various WCC monocultures and bicultures have been tested for their N scavenging capacity. Effectiveness of N scavenging depends on many factors including residual soil N, climate, cover crop species, and cover crop management (Brinsfield and Staver, 1991; Meisinger et al., 1991; Shipley et al., 1992). Numerous studies have concluded that cereal rye out-competes other WCC in N scavenging performance in the mid-Atlantic region (Shipley et al., 1992; Clark et al., 1994; Ranells and Wagger, 1997; Sainju et al., 1998; Staver and Brinsfield, 1998; Wagger et al., 1998; Vaughan and Evanylo, 1999). For example, Shipley et al. (1992) reported percent recoveries of fall applied fertilizer N (FN) in spring aboveground dry matter (DM) to be 45% for cereal rye, 27% for annual ryegrass (*Lolium multiflorum* Lam.), 10% for hairy vetch (*Vicia villosa* Roth subsp. *villosa*), 8% for crimson clover *(Trifolium incarnatum* L.), and 8% for native weed cover. Staver and Brinsfield (1998) also reported significant annual reductions of groundwater nitrate (60%) during a long-term watershed-scale study after cereal rye was continually seeded following no-till corn. Both studies were performed in Maryland coastal plain soils that are similar to those in eastern Virginia.

Although considerable research was conducted in the past twenty years, few studies investigated residual soil N losses after soybean. Angle (1990) reported nitrate-nitrogen (NO_3-N) in leachate following soybean to be comparable with that following corn. Kessavalou and Walters (1999) examined cereal rye's uptake and influence on residual soil N following corn in a soybean-cereal rye-corn rotation and concluded that the residual soil N after soybean was immobilized by cereal rye during the corn growing season and released in the fall following corn harvest. These results imply that, in addition to the N released from the immediately harvested crop, a portion of the N immobilized by the preceding crop may also become available to leach.

In order to have significant reductions in nonpoint source N loading into the Chesapeake Bay, substantial increases in land planted to WCC are needed; however, incorporation into current cropping systems has plateaued. One period that offers the potential for increased use of WCC is the winter fallow between soybean and corn. Currently, too few acres are planted into WCC during this period due the short window of time remaining after soybean harvest to establish sufficient biomass.

Although it is well documented that WCC have long-term benefits for the environment and crop production, benefits of interseeded WCC into standing soybean are not well-known. Research is needed to identify how interseeded WCC into standing soybean affects residual soil N conservation throughout the WCC and subsequent corn growing seasons. The specific objectives were to (i) evaluate WCC DM production when interseeded into standing soybean; (ii) evaluate the effectiveness of interseeded WCC on conserving residual soil N following soybean; (iii) determine the effects of WCC on residual soil N following corn harvest.

2.3 Materials and Methods

2.3.1 Experimental Design

Research was conducted at four locations in 2012-2013 and at four different locations in 2013-2014 in the Virginia coastal plain region in USDA hardiness zone 7b. Average annual temperature of the region is 14°C and precipitation is 112 cm yr^{-1}. All locations had a history of using both inorganic and organic N sources. Location coordinates and soil physical descriptions are listed in table 2.1. All locations, with exception of JHE2, were in no-till corn–winter wheat or barley/double-crop soybean rotation. Location JHE2 was in corn–small grain WCC–full season soybean rotation. Winter cover crops were interseeded into standing soybean, with the exception of CCM1 which was broadcast seeded shortly after soybean harvest (Table 2.2).

The experimental design was a split-plot with four replications at each location. Three WCC treatments were main plots and ten corn FN rates arranged in a full factorial were subplots. Main plots were seeded with cereal rye, hairy vetch, and winter rye-hairy vetch mix WCC. Seeding rates, agronomic relevant dates, and WCC and corn hybrid varieties are listed in table 2.2. Subplots received two starter FN and five sidedress FN rates arranged in a full factorial. Fertilizer N rates were in increments of 45 kg ha^{-1} (0, 45, 90, 135, and 180 kg ha^{-1}) as liquid ammonium nitrate (UAN) dribble banded either 5 cm to the side of the furrow or between corn rows at planting and sidedress, respectively. Main plots were 75 x 15 m; subplots were 9 m length by 4 rows (3.1 m). Production practices followed recommendations of Virginia Cooperative Extension (Brann et al., 2000).

2.3.2 Sample Analysis

Composite soil samples were collected to depths of 0-15, 15-30, and 30-60 cm using a 1.9 cm diameter probe from each experimental unit at all locations at cover crop planting, winter dormancy, cover crop termination, corn growth stage V4 (0-15 and 0-30 cm), and after corn harvest. Soil samples were air dried, sieved through a 2 mm screen, and extracted with 2 M KCL (Bremner and Keeney, 1966) prior to analysis for NH_3-N and NO_3-N. Ammonia-N and NO_3-N concentrations were determined using automated injection flow analysis (Lachat Instruments, Milwaukee, WI) with QuickChem sodium salicylate method 12-107-06-2-A (Hofer, 2001) and QuickChem 12-107-04-1-B using Cd reduction (Knepel, 2003), respectively. Soil samples were further processed using pestle and mortar for analysis of total C and N by dry combustion (VarioMax CNS macro elemental analyzer, Elementar, Hanau, Germany). Routine soil tests were also conducted by the Virginia Tech soil testing laboratory on surface (0-15 cm) soil samples in the fall of study years (Table 2.3) (Maguire and Heckendorn, 2011).

Cover crop aboveground DM was hand clipped from a 0.1 m^2 area during winter dormancy and immediately before termination. Dry matter samples were dried at 60°C for 48 hours in a forced air oven, ground to pass a 2 mm screen using a Wiley sample mill (Thomas Scientific, Swedesboro, NJ) and total C and N determined via dry combustion (VarioMax CNS macro elemental analyzer, Elementar, Hanau, Germany).

2.3.3 Statistical Analysis

Statistical analyses were performed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, 2012). All variables were analyzed by location due to significant interaction between location and treatments. Mean comparisons using Tukey's Honestly Significant Difference (HSD) (α=0.05) were made to separate treatment effects when F tests indicated that significant differences existed (p<0.05).

2.4 Results and Discussion

2.4.1 Aboveground Dry Matter Yield and N Content

Winter Dormancy

Growth and N content of interseeded WCC experienced significant interactions between location and WCC during both years (Table 2.4). At winter dormancy cereal rye and cereal rye + hairy vetch mixture (RV mix) DM were both significantly higher than hairy vetch at three of the eight locations, but were not significantly different from each other at any location (Table 2.5). Only three of the eight sites had fall cereal rye or RV mix DM>300 kg ha^{-1}, which was similar to results reported by Wilson et al. (2013). Johnson et al. (1998) interseeded cereal rye into standing soybeans in mid-August in Iowa, and reported DM of 410 kg ha^{-1} at winter dormancy, which was twice as high as reported in this study. Differences in our results are most likely due to the later seeding and earlier termination dates in this study. Mean aboveground DM during winter dormancy was 229, 250, and 56 kg ha^{-1} in 2012, and 204, 217, and 32 kg ha^{-1} in 2013 for cereal rye, RV mix, and hairy vetch in, respectively (Table 2.5).

Significant differences in aboveground N content were observed among WCC at BRM1, JBE1, and CCM2 (Table 2.5). Differences generally reflected respective DM differences, with either cereal rye or RV mix having highest aboveground N content. Cereal rye scavenged 18 kg N ha^{-1} at BRM1, but the average cereal rye aboveground N content at all locations was approximately 6-9 kg N ha^{-1} before winter dormancy (Table 2.5). Mean aboveground N content for cereal rye, RV mix, and hairy vetch was 9, 10, and 3 kg N ha^{-1} in 2013; and 6, 7, and 2 kg N ha^{-1} in 2014, respectively. Differences in C:N ratio were observed at four of eight locations. Cereal rye and RV mix had similar C:N ratios at three of the four locations where differences were observed. Cereal rye C:N ratio was significantly higher than hairy vetch in three of the four locations where differences were observed.

WCC Termination

At WCC termination significant DM differences were observed at three of the eight locations, with cereal rye or RV mix having highest DM (Table 2.5). Winter cover crops growing season length was in the order of BRM1, JBE2, JBE1, JHE2, CCM2, BRM2, and CCM1, respectively (Table 2.2). With the exception of November 2012 and January 2014, WCC growing season monthly temperature and precipitation means were not abnormal (Figures 2.1 and 2.2). Locations CCM1 and PDE1 experienced lowest DM yield in year 1 due to dry conditions during establishment and lower seeding rates, respectively (Table 2.2; Figure 2.2). Year 2 experienced well below 30-year average temperatures in the month of January (Figure 2.1). Low temperatures may have factored into the significantly lower hairy vetch DM relative to other WCC treatments at the four locations in 2014. Both years experienced slightly lower average monthly temperatures in February and March (Figure 2.2). Mean aboveground DM at WCC termination was 2356, 2000, and 1864 kg ha^{-1} in 2012, and 2055, 2701, and 692 kg ha^{-1} in 2014 for cereal rye, RV mix, and hairy vetch, respectively (Table 2.5). Cereal rye aboveground DM yields at termination observed in our study were similar to when interseeded in to soybeans (Johnson et al., 1998) or drilled following corn harvest (Staver and Brinsfield, 1998). Conversely, Vaughan and Evanylo (1999) observed considerably higher cereal rye and RV mix DM in the first year of their study than was observed in either year of this study, which was perhaps a result of seeding method – drilled into tilled soil following corn.

Significant differences in aboveground N content of WCC were observed at four of the eight locations. Hairy vetch N content was only higher than other WCC at one of the eight locations, BRM1 (Table 2.5). First year results are similar to those reported by Clark et al. (1997), who reported hairy vetch N content to be two to three times greater than that of cereal rye. Location BRM1 had the highest cereal rye N content at 91 kg N ha^{-1}. Average cereal rye N content was 37.4 kg N ha^{-1}, which is consistent with other studies when WCC are planted late in the fall (Clark et al., 1997; Decker et al., 1994; Kessavalou and Walters, 1997; Staver and Brinsfield, 1998). Cereal rye mean C:N ratios were 26:1 and 21:1, while RV mix and hairy vetch were 20:1 and 18:1, and 11:1 and 12:1, at WCC termination in 2013 and 2014, respectively (Table 2.5). Locations BRM1, JBE1, PDE1, and JBE2 were the only locations to have cereal rye C:N ratios at WCC termination ≥25:1 (Table 2.5), which can indicate potential N immobilization. Locations JBE1 and JBE2 also had RV mix C:N ratios at WCC termination ≥25:1.

2.4.2 Residual Soil Nitrogen

Winter Dormancy

Residual soil NO_3-N was only significantly different at 0-15 cm at PDE1 with hairy vetch having significantly higher residual soil NO_3-N than cereal rye (Tables 2.6 and 2.7). At 30-60 cm, residual soil NO_3-N was higher with hairy vetch (PDE1) or RV mix (BRM2) than cereal rye. Hairy vetch had significantly higher residual soil NH_4-N than cereal rye at 0-15 and 30-60 cm at BRM2 (Table 2.8). Conversely, at 30-60 cm at CCM2 cereal rye had higher residual soil NH_4-N (Table 2.8). Residual soil inorganic N was lowest in cereal rye than hairy vetch and RV mix at 30-60 cm at BRM2 (Table 2.9). Hairy vetch DM at BRM2 and CCM2 was significantly lower than other WCC treatments; however, no WCC DM differences were observed at PDE1 (p=0.279) (Table 2.5). Although significant differences in residual soil NH_4-N and inorganic N were observed at BRM2 and CCM2, these differences were minimal. The largest difference between means was between hairy vetch and cereal rye at PDE1: 2.5 mg NO_3-N kg^{-1} (Table 2.7).

WCC Termination

When averaged across depths and locations, mean residual soil NO_3-N values for cereal rye, RV mix, and hairy vetch were respectively 1.4, 1.7, and 2.1 in 2013; and 1.1, 1.3, and 3.8 in 2014. Differences in residual soil NO_3-N were observed at 15 of the 24 location-by-depth combinations (Table 2.6). Of these, the majority were observed at the 15-30 and 30-60 cm depths and during the second study year. Hairy vetch had higher residual soil NO_3-N than cereal rye and RV mix at 13 and 12 of the 24 location-by-depth combinations, respectively (Table 2.6). Cereal rye and hairy vetch had similar residual soil NO_3-N at only CCM2 at 30-60 cm and JBE2 at 0-15 cm (Table 2.7). Hairy vetch and RV mix had similar residual soil NO_3-N at CCM1, PDE1, and JHE2 at 30-60 cm (Table 2.7). Cereal rye and RV mix residual soil NO_3-N was not different at any location-by-depth combination (Table 2.7). Location BRM2 had dramatic WCC treatment effects with residual soil NO_3-N values of 18.2, 4.4, and 4.2 mg kg^{-1} in hairy vetch treatments at 0-15, 15-30, and 30-60 cm, respectively (Table 2.7). In addition, BRM2 exhibited relatively low NH_4-N values (Table 2.8). Winter cover crops at BRM2 were terminated approximately 2 weeks after the other three locations in year 2, which resulted in soils sampled during warmer weather and possibly increased soil nitrification. During the second year significant WCC effects were observed at 0-15 cm at every location except CCM2 (Table 2.6). Location CCM2 had cereal rye spring DM$<$1000 kg ha^{-1}, which was identified by Hively et al. (2009) as a critical concentration of biomass to achieve reductions in residual soil NO_3-N. This may explain why there were no WCC effects on residual soil NO_3-N at 0-15 cm; however CCM2 did have significant WCC effects at 15-30 and 30-60 cm (Tables 2.5 and 2.7). Locations CCM1 and PDE1 also had cereal rye spring DM<1000 kg ha^{-1}, and both locations had WCC treatment effects at lower depths (Tables 2.5 and 2.7). Vaughan et al. (2000) reported similar trends and residual soil N values for cereal rye, RV mix, and hairy vetch.

Corn Growth Stage V4

Significant differences in residual soil NO_3-N among WCC treatments were observed at four of the eight locations and two of the eight locations at 0-15 and 0-30 cm, respectively (Table 2.6). Residual soil NO_3-N in hairy vetch plots was significantly higher than cereal rye in all location-by-depth combinations where significant differences were observed. Hairy vetch and RV mix had similar values in three of the six location-by-depth combinations where significant differences where observed. Cereal rye and RV mix had similar values in three of the six locations-by-depth combinations where significant differences where observed. Mean residual soil NO_3-N concentrations at 0-15 cm for cereal rye, RV mix, and hairy vetch were 7.0, 7.8, and 10.5 in 2013; and 11.6, 13.6, and 18.7 in 2014 (Table 2.7). Mean residual soil NO_3-N concentrations at 0-30 cm for cereal rye, RV mix, and hairy vetch were 6.1, 7.7, and 8.1 in 2013; and 11.9, 12.2, and 17.5 in 2014 (Table 2.7). Vaughan and Evanylo (1999) also reported significantly higher NO_3-N concentrations in hairy vetch than cereal rye treatments and concentrations in RV mix that were generally not different than cereal rye treatments.

Residual soil NH_4-N was different at two of the eight locations at 0-15 cm (Table 2.8). At both locations, residual soil NH_4-N in WCC treatments cereal rye and hairy vetch were not significantly different, and RV mix had the lowest values. Four of eight locations had significant differences among WCC treatments for residual inorganic N at 0-15 cm (Table 2.9). At each of these locations, hairy vetch plots had highest residual inorganic N. Residual soil N parameters were not correlated with hairy vetch or cereal rye aboveground N content (data not presented).

However, residual soil NO_3-N and inorganic N at depths 0-15 and 0-30 cm was positively correlated with RV mix aboveground N content (data not presented). The poor relationship between hairy vetch aboveground N content and residual soil N parameters at V4 may be due to high rate of N release within 4-5 weeks of WCC termination (Ranells and Wagger, 1996) and PAN losses due to corn N uptake, NO_3-N leaching, and NH_3-N volatilization.

Corn Harvest

In check plots receiving 0 FN, significant differences among WCC treatments were observed for residual soil NO_3-N and inorganic N (Table 2.6). At BRM1, residual soil NO_3-N at 0-cm was lowest in RV mix treatments (Table 2.7). At JBE1, residual soil NO_3-N at 15-30 cm was lowest in hairy vetch treatment (Table 2.7). Hairy vetch had lower residual soil NO_3-N at 30-60 cm than both cereal rye and RV mix at BRM1 and RV mix at CCM1. Although significant differences were observed, these differences are minimal. When averaged by WCC treatment, residual soil NO_3-N values for cereal rye, RV mix, and hairy vetch were 4.6, 5.2, and 4.4; 1.6, 1.3, and 1.3; and 1.0, 1.0, and 0.7 mg kg^{-1} at 0-15, 15-30, and 30-60 cm, respectively. These values are similar to those collected after soybean harvest (Table 2.3), which is consistent with research conducted by Zhu and Fox (2003).

Treatment effects for residual soil NO_3-N were observed at one out of 12 location-by-depth combinations (Table 2.11). In general, residual soil NO_3-N concentrations did not vary considerably regardless of WCC treatment or sidedress FN rate. Mean NO_3-N concentrations were 4.9, 1.3, and 1.0 mg kg^{-1} at 0-15, 15-30, and 30-60 cm, respectively (Table 2.11). Standard deviations of the means were 0.5, 0.2, and 0.5 mg kg^{-1} for the respective three depths (Table 2.11). Similar studies comparing corn grown with either hairy vetch or synthetic FN also reported negligible differences in residual soil N (McCrackin et al., 1994; and Seo et al., 2006).

However, Kessavalou and Walters (1999) observed higher residual soil NO_3-N following corn harvest in cereal rye relative to fallow treatments. They also suggested that a build-up of previously immobilized N from cereal rye WCC may become available for leaching in the fall of the same year (Kessavalou and Walters, 1999).

Treatment effects for residual soil NH_4-N and inorganic N were observed at two out of the four and one out of the four locations in 2013, respectively (Tables 2.12 and 2.13). Hairy vetch treatment combinations had lower residual soil NH_4-N and inorganic N concentrations relative to either cereal rye or RV mix where statistical differences were observed (Tables 2.12 and 2.13). However, similar to residual soil NO_3-N, residual soil NH_4-N and inorganic N concentrations did not vary considerably regardless of WCC treatment or sidedress FN rate (Tables 2.12 and 2.13). These results indicate that PAN from hairy vetch in combination with appropriate rates of sidedress FN did not lead to increased residual soil N concentrations at corn harvest relative to either cereal rye or RV mix with or without FN. However, since our study only compared differences among WCC and not with fallow, we cannot conclude that these WCC systems would either increase or decrease residual soil N losses relative to winter fallow systems.

Overall Residual Soil Nitrogen

Throughout the WCC and corn growing seasons, residual soil NO_3-N at 0-30 cm was below 5 mg kg^{-1} with the exception of the corn GS V4 sampling period in June when residual soil NO_3-N increased (Figure 2.4). This observation was expected due to increased soil microbial activity prior to accelerated corn growth and nutrient uptake (Karlen et al., 1987). Differences in residual soil NO_3-N were primarily observed in April (WCC termination) during the second year (Figure 2.4). In general, where hairy vetch DM was significantly lower than either cereal rye or RV mix at termination, residual soil NO_3-N in hairy vetch plots was significantly higher than either cereal rye or RV mix (data not presented). Higher residual soil NO_3-N with hairy vetch is most likely the result of reduced N uptake due to significantly lower second year hairy vetch DM accumulation relative to cereal rye and/or RV mix (Table 2.5). The only location with no significant differences in WCC DM in 2014 was CCM2 (Table 2.5), which interestingly also had the highest *p*-value (p=0.0479) for residual soil NO_3-N at WCC termination. Cereal rye mean residual soil NO_3-N reductions (0-60 cm) were 34 and 43% when compared to hairy vetch at WCC termination in 2013 and 2014, respectively (Table 2.7). Residual soil NO_3-N reductions between cereal rye and RV mix were 10 and 12%, and between RV mix and hairy vetch were 27 and 36% at WCC termination in 2013 and 2014, respectively (Table 2.7). These results suggest that a RV mix is nearly as effective at scavenging residual soil NO_3-N as cereal rye, and both are much more effective than hairy vetch. Similar results were reported by (Ranells and Wagger, 1997). In the first year of this study, significant differences among various residual soil N parameters were found after corn harvest, however these differences are very small and unlikely to indicate relative differences in residual soil N losses among WCC-by-sidedress FN treatments (Tables 2.6-2.13). However, it is important to note that residual soil N was similar after corn harvest and soybean harvest at 0-15 cm at respective locations (Tables 2.3, 2.7, 2.8, and 2.9). These findings suggest that cereal rye and RV mix have the potential to scavenge and conserve residual soil N when interseeded into soybean similarly as when drilled after corn.

2.5 Conclusion

Residual soil N concentrations in surface soils were similar after corn harvest and soybean harvest. This finding illustrates the importance of establishing successful WCC stands during the winter fallow niche following soybean. In general cereal rye and RV mix had greater DM and resulted in lower soil residual N than hairy vetch alone during the WCC and corn growing season. Delaying hairy vetch termination until late April to May increases aboveground N content and can potentially provide subsequent corn with plant available N as indicated by higher residual soil N during corn GS V4 in most hairy vetch treatments. However, hairy vetch is not as hardy as cereal rye and is sensitive to abnormal low temperatures, which reduces early spring biomass and N accumulation. At corn harvest, residual soil N was generally similar among all WCC-by-sidedress FN treatments and location-by-depth combinations. These findings infer that high N legume WCC residue does not add to the soil N pool following corn harvest, and therefore does not increase fall residual soil NO_3-N leaching losses relative to small grain and legume-small grain mix WCC. However based on this research, conclusions cannot be drawn on WCC effects on residual soil N relative to winter fallow. More research is needed to determine optimum dates for interseeding WCC into standing soybeans, and the influence of soybean harvest date on WCC growth.

2.6 References

Angle, J.S. 1990. Nitrate leaching losses from soybeans (Glycine-max L Merr). Agric. Ecosyst. Environ. 31: 91-97.

Boesch, D.F., R.B. Brinsfield and R.E. Magnien. 2001. Chesapeake bay eutrophication: Scientific understanding, ecosystem restoration, and challenges for agriculture. J. Environ. Qual. 30: 303-320.

Brann, D.E., A.O. Abaye and P.R. Peterson. 2000. Crop description. In: D. E. Brann, D. L. Holshouser and G. L. Mullins, editors, Agronomy Handbook. Publ. no. 424-100, Virginia Coop. Ext., Blacksburg, VA. p. 1-30.

Bremner, J.M. and D.R. Keeney. 1966. Determination and isotope-ratio analysis of different forms of nitrogen in soils: 3. Exchangeable ammonium, nitrate, and nitrite by extraction-distillation methods. Soil Sci. Soc. Am. Proc. 30: 577-582.

Brinsfield, R. and K. Staver. 1991. Role of cover crops in reduction of cropland nonpoint source pollution. Final report to USDA/SCS, Cooperative Agreement #25087.

Chesapeake Bay Program. 2009. 2011 milestones for reducing nitrogen and phosphorus. Chesapeake Bay Program, Annapolis, MD.

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.

Clark, A.J., A.M. Decker, J.J. Meisinger and M.S. McIntosh. 1997. Kill date of vetch, rye, and a vetch-rye mixture: I. cover crop and corn nitrogen. Agron. J. 89: 427-434.

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.

Federal Register. 2009. Executive Order 13508. Draft strategy for protecting and restoring the Chesapeake Bay. Federal Register 74:22098-23104. Washington, D.C.

Hively, W.D., M. Lang, G.W. McCarty, J. Keppler, A. Sadeghi and L.L. McConnell. 2009. Using satellite remote sensing to estimate winter cover crop nutrient uptake efficiency. Journal of soil and water conservation 64: 303-313.

Hofer, S. 2001. QuikChem Method 12-107-06-2-A: Determination of ammonia (salicylate) in 2 *M* KCl soil extracts by flow injection analysis. Lachat Instrum., Milwaukee, WI.

Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak and S.D. Logsdon. 1998. Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. J. Soil Water Conserv. 53: 276-279.

Karlen, D.L., R.L. Flannery, and E.J. Sadler. 1987. Fertilizer use efficiency: Nutrient and dry matter accumulation rates for high yielding maize. J. Plant. Nutr. 10:1409-1417.

Kessavalou, A. and D.T. Walters. 1997. Winter Rye as a Cover Crop Following Soybean under Conservation Tillage. Agron. J. 89: 68-74.

Kessavalou, A. and D.T. Walters. 1999. Winter rye cover crop following soybean under conservation tillage: residual soil nitrate. Agron. J. 91: 643-649.

Knepel, K. 2003. QuikChem Method 12-107-04-1-B: Determination of nitrate in 2*M* KCl soil extracts by flow injection analysis. Lachat Instrum., Milwaukee, WI.

Maguire, R.O., and S.E. Heckendorn. 2011. Soil test recommendations for Virginia. Virginia Coop. Ext., Blacksburg, VA. Available at http://www.soiltest.vt.edu/PDF/lab-procedures.pdf. (verified Dec. 12, 2014).

McCracken, D.V., S.J. Corak, M.S. Smith, W.W. Frye and R.L. Blevins. 1989. Residual Effects of Nitrogen Fertilization and Winter Cover Cropping on Nitrogen Availability. Soil Sci. Soc. Am. J. 53: 1459-1464.
Meisinger, J., W. Hargrove, R. Mikkelsen, J. Williams and V. Benson. 1991. Effects of cover crops on groundwater quality. In: W. L. Hargrove, editor, Cover crops for clean water. Soil and Water Conserv. Soc., Jackson, TN. p. 57-68.
Ranells, N.N. and M.G. Wagger. 1997. Winter annual grass-legume bicultures for efficient nitrogen management in no-till corn. Agric., Ecosyst. Environ. 65: 23-32.
Sainju, U.M., B.P. Singh and W.F. Whitehead. 1998. Cover crop root distribution and its effects on soil nitrogen cycling. Agron. J. 90: 511-518.
Seo, J.-H., J.J. Meisinger and H.-J. Lee. 2006. Recovery of Nitrogen-15–Labeled Hairy Vetch and Fertilizer Applied to Corn. Agron. J. 98: 245-254.
Shipley, P.R., J.J. Messinger and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84: 869-876.
Staver, K.W. and R.B. Brinsfield. 1998. Using cereal grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plain. J. Soil Water Conserv. 53: 230-240.
USDA-NASS. 2012. Quick Stats 2.0. Available at http://quickstats.nass.usda.gov/results/ABCF232F-4877-32B5-B3C1-3E8D19E41D5E. (verified Sept. 12, 2014).
USDA-NRCS. 2008. Web soil survey. Available at http://websoilsurvey.nrcs.usda.gov/app/. (verified Oct. 07, 2014).
USEPA. 2010. Sources of nitrogen, phosphorus and sediment to the Chesapeake bay. In: Chesapeake bay total maximum daily load for nitrogen, phosphorus and sediment. Washington, D.C.
Vaughan, J.D. and G.K. Evanylo. 1999. Soil nitrogen dynamics in winter cover crop-corn systems. Commun. Soil Sci. Plant Anal. 30: 31-52.
Vaughan, J.D., G.D. Hoyt and A.G. Wollum, II. 2000. Cover crop nitrogen availability to conventional and no-till corn: soil mineral nitrogen, corn nitrogen status, and corn yield. Commun. Soil Sci. Plant Anal. 31: 1017-1041.
Virginia Department of Conservation and Recreation. 2005. Virginia nutrient management standards and criteria. Richmond, VA.
Virginia Department of Conservation and Recreation. 2012. Program year 2013, Virginia agricultural cost share (VACS), BMP manual. Richmond, VA.
Wagger, M.G., M.L. Cabrera and N.N. Ranells. 1998. Nitrogen and carbon cycling in relation to cover crop residue quality. J. Soil Water Conserv. 53: 214-218.
Wilson, M.L., J.M. Baker and D.L. Allan. 2013. Factors Affecting Successful Establishment of Aerially Seeded Winter Rye. Agron. J. 105: 1868-1877.
Zhu, Y. and R.H. Fox. 2003. Corn–soybean rotation effects on nitrate leaching. Agron. J. 95: 1028-1033.

2.7 Tables

Table 2.1. Experimental location, soil series, and select soil characteristics for study years 2012-2013 and 2013-2014.

Year	Location	Latitude	Longitude	Soil Series[†]	Surface Texture[†]	Drainage Class[†]	Hydrologic Group[†]	Land Capability[†]	Corn Productivity Group[‡]	Nitrogen Loss Risk[‡]
2012-2013	BRM1	37.66	-76.68	Bethera/Daleville	L	Poorly	C/D	4w	V	L
	CCM1	37.63	-76.68	Suffolk	LS	Well	B	1	IIIb	M
	JBE1	37.82	-76.88	Kempsville	FSL	Well	B	1	IIIa	M
	PDE1	37.81	-76.80	Kempsville	FSL	Well	B	1	IIIa	M
2013-2014	BRM2	37.67	-76.70	Bama	FSL	Well	B	2e	IIIa	M
	CCM2	37.69	-76.72	Kempsville	FSL	Well	B	1	IIIa	M
	JBE2	37.78	-76.87	Kempsville	FSL	Well	B	1	IIIa	M
	JHE2	37.79	-76.78	Atlee	SiL	Moderately well	C	2w	IIIa	L

[†] Published in USDA-NRCS (2008)
[‡] Published in Virginia Department of Conservation and Recreation (2014)

Table 2.2. Experimental locations, agronomic significant dates, winter annual cover crop (WCC) seeding rates, WCC cultivars, and corn hybrid varieties.

Year	Location	WCC Seeding Date	Soybean Harvest Date	Corn Planting Date	WCC Termination Date	Rye Seeding Rate	RV[†] Mix (Rye Component) Seeding Rate	RV Mix (Vetch Component) Seeding Rate	Vetch Seeding Rate	Rye Cultivar	Vetch Cultivar	Corn Hybrid
						------------------------kg ha^{-1}------------------------						
2012-2013	BRM1	26-Sep	20-Nov	14-May	14-May	101	67	22	28	Abruzzi	VNS	Syngenta N68B-3111
	CCM1	14-Nov	10-Nov	18-Apr	22-Apr	101	67	22	28	Abruzzi	VNS	Pioneer 35F50AM
	JBE1	28-Sep	26-Oct	15-Apr	17-Apr	101	67	17	34	Abruzzi	VNS	Pioneer 0912HR
	PDE1	1-Oct	25-Oct	15-Apr	17-Apr	101	67	17	22	Abruzzi	VNS	Pioneer 1184HR
2013-2014	BRM2	5-Nov	22-Dec	5-May	6-May	101	67	22	28	VNS[‡]	VNS	Syngenta N68B-3111
	CCM2	18-Oct	14-Nov	14-Apr	14-Apr	101	67	22	28	VNS	VNS	Doeblers 747AM
	JBE2	14-Oct	15-Nov	21-Apr	25-Apr	101	67	17	22	VNS	VNS	Pioneer 0210HR
	JHE2	14-Oct	25-Oct	24-Apr	5-May	101	67	17	22	VNS	VNS	Pioneer 1105AM

[†] RV mix: cereal rye + hairy vetch mixture.
[‡] VNS: Variety not stated.

Table 2.3. Initial soil analysis of pH, primary Mehlich-I extractible macronutrients, KCL extractable NO_3-N and NH_4-N, total N, total C, and soil organic matter for experimental locations in study years 2012-2013 and 2013-2014.

Year	Location	pH[†]	P[‡]	K[‡]	NO_3-N[§]	NH_4-N[§]	Total N[¶]	Total C[¶]	Soil Organic Matter[#]
			-------------mg kg^{-1}-------------				----------g kg-1----------		
2012-2013	BRM1	6.7	48.5	169	5.4	3.9	0.92	9.3	17.8
	CCM1	6.3	17.3	107	3.4	5.2	0.91	11	17.5
	JBE1	6.0	11.8	116	4.2	4.6	0.94	9.1	15.8
	PDE1	6.1	15.0	135	2.9	3.4	1.1	9.9	18.5
2013-2014	BRM2	6.7	13.8	174	3.0	4.3	0.93	8.8	17.8
	CCM2	6.0	10.5	70.3	5.4	3.0	1.0	12	22.3
	JBE2	6.3	7.75	73.8	4.3	2.1	0.93	8.7	16.8
	JHE2	5.8	16.5	62.5	5.3	3.9	1.1	11	21.3

[†] pH: 1:1 soil:water.
[‡] P and K: Mehlich I.
[§] NH_4-N and NO_3-N: 2 M KCL; automated flow injection analysis.
[¶] Total C and total N: dry combustion.
[#] Soil Organic Matter: Walkley-Black method.

Table 2.4. Analysis of variance for winter annual cover crops (WCC) effects on aboveground dry matter (DM) yield, N content, and C:N ratio at winter dormancy and WCC termination sampling periods for experimental locations in study years 2012-2013 and 2013-2014.

Sample period		Winter Dormancy			WCC Termination		
Variable		DM yield	N Content	C:N ratio	DM yield	N Content	C:N ratio
2012-2013	BRM1	*	*	*	ns	ns	*
	CCM1	ns	ns	ns	ns	ns	*
	JBE1	ns	ns	ns	ns	*	*
	PDE1	ns	ns	ns	ns	ns	***
2013-2014	BRM2	**	ns	ns	**	*	**
	CCM2	*	*	**	ns	ns	***
	JBE2	ns	ns	***	***	*	***
	JHE2	ns	ns	***	***	***	***

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
ns Nonsignificant at the 0.05 probability level.

Table 2.5. Least square means for winter annual cover crops (WCC) aboveground dry matter (DM) yield, N content, and C:N ratio at winter dormancy and WCC termination sampling periods for experimental locations in study years 2012-2013 and 2013-2014.

Sample period			Winter Dormancy						WCC Termination					
Variable			DM yield		N Content		C:N ratio		DM yield		N Content		C:N ratio	
Year	Site	WCC	---------- kg ha^{-1} ----------						---------- kg ha^{-1} ----------					
2012-2013	BRM1	R	495	a[†]	18	a	11	a	6254	a	91	a	29	a
		RV	431	ab	16	ab	11	ab	5000	a	150	a	16	b
		V	65	b	3	b	8	b	5088	a	146	a	14	b
	CCM1	R	68	a	3	a	10	a	779	a	14	a	22	a
		RV	47	ab	2	a	9	a	922	a	19	a	19	a
		V	25	b	1	a	9	a	635	a	23	a	11	b
	JBE1	R	174	ab	8	ab	10	a	1532	a	21	b	27	a
		RV	427	a	16	a	12	a	1338	a	18	b	29	a
		V	72	b	3	b	10	a	1102	a	48	a	10	b
	PDE1	R	179	a	6	a	11	a	858	a	13	b	25	a
		RV	97	a	6	a	10	a	743	a	18	b	17	b
		V	61	a	4	a	10	a	633	a	24	a	11	c
2013-2014	BRM2	R	291	a	8	a	15	a	2608	ab	58	b	19	a
		RV	293	a	8	a	15	a	4591	a	153	a	13	b
		V	0	-	-	-	-	-	950	b	36	b	11	b
	CCM2	R	70	ab	2	b	18	a	692	a	16	a	18	a
		RV	116	a	3	a	18	a	1179	a	37	a	13	b
		V	30	b	2	b	11	b	619	a	20	a	13	b
	JBE2	R	323	a	10	a	13	b	2887	b	40	ab	30	a
		RV	366	a	12	a	13	a	3512	a	53	a	27	a
		V	27	a	2	a	11	c	778	c	25	b	13	b
	JHE2	R	132	a	4	a	11	b	2034	a	46	a	18	b
		RV	92	a	3	a	12	b	1523	b	32	b	19	a
		V	70	a	2	a	13	a	422	c	14	c	12	c
2012-2013	Mean	R	229		9		11		2356		35		26	
		RV	250		10		10		2000		51		20	
		V	56		3		9		1864		60		12	
2013-2014	Mean	R	204		6		14		2055		40		21	
		RV	217		7		14		2701		69		18	
		V	32		2		12		692		24		12	

[†]Means within each column and location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 2.6. Analysis of variance for winter annual cover crops (WCC) effects on residual soil NO3-N, NH4-N, and inorganic nitrogen at three soil depths during four sampling periods at eight locations.

Sample period		Winter Dormancy			WCC Termination			Corn GS V4		Corn Harvest		
Depth, cm		0-15	15-30	30-60	0-15	15-30	30-60	0-15	0-30	0-15	15-30	30-60
					Residual soil NO_3-N, mg kg^{-1}							
2012-2013	BRM1	ns	ns	ns	ns	ns	*	**	ns	**	ns	*
	CCM1	ns	ns	ns	ns	ns	*	ns	**	ns	ns	*
	JBE1	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns
	PDE1	*	ns	*	ns	***	*	***	ns	ns	ns	ns
2013-2014	BRM2	ns	ns	*	**	***	**	***	ns	-	-	-
	CCM2	ns	ns	ns	ns	**	*	**	*	-	-	-
	JBE2	ns	ns	ns	**	***	***	ns	ns	-	-	-
	JHE2	ns	ns	ns	**	**	**	ns	ns	-	-	-
					Residual soil NH_4-N, mg kg^{-1}							
2012-2013	BRM1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	CCM1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	JBE1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	PDE1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
2013-2014	BRM2	*	ns	***	ns	ns	ns	ns	ns	-	-	-
	CCM2	ns	ns	**	*	ns	ns	ns	ns	-	-	-
	JBE2	ns	ns	ns	*	ns	ns	*	ns	-	-	-
	JHE2	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-
					Residual inorganic nitrogen, mg kg^{-1}							
2012-2013	BRM1	ns	ns	ns	ns	ns	ns	**	ns	*	ns	ns
	CCM1	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns
	JBE1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	PDE1	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
2013-2014	BRM2	ns	ns	**	**	*	ns	***	ns	-	-	-
	CCM2	ns	ns	*	*	ns	ns	ns	ns	-	-	-
	JBE2	ns	ns	ns	*	ns	ns	*	ns	-	-	-
	JHE2	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.

Table 2.7. Least square means for residual soil NO_3-N at three soil depths during four sampling periods at eight locations for plots receiving no fertilizer nitrogen.

Sample period			Winter Dormancy						WCC Termination						Corn GS V4				Corn Harvest					
Depth, cm			0-15		15-30		30-60		0-15		15-30		30-60		0-15		0-30		0-15		15-30		30-60	
Year	Site	WCC	Residual soil NO_3-N, mg kg^{-1}																					
2012-2013	BRM1	R	5.7	a†	3.3	a	3.0	a	2.0	a	0.6	a	0.5	b	4.1	b	4.5	a	1.7	a	0.8	a	0.8	a
		RV	4.5	a	2.7	a	2.7	a	4.1	a	0.7	a	0.5	b	8.1	a	10.5	a	0.8	b	0.6	a	0.8	a
		V	5.6	a	2.9	a	2.7	a	4.2	a	0.9	a	0.8	a	10.7	a	9.0	a	1.4	a	0.6	a	0.5	b
	CCM1	R	6.1	a	1.4	a	1.3	a	1.2	a	1.1	a	0.7	b	6.8	a	4.3	b	6.1	a	1.8	a	0.7	b
		RV	6.3	a	1.4	a	1.3	a	1.5	a	1.2	a	0.8	ab	6.4	a	4.8	b	8.5	a	1.4	a	1.1	a
		V	5.8	a	1.4	a	1.1	a	2.1	a	0.9	a	1.1	a	8.7	a	6.2	a	5.5	a	1.6	a	0.7	b
	JBE1	R	5.0	a	1.7	a	2.5	a	3.4	a	0.8	a	1.1	a	8.2	a	7.3	a	5.8	a	1.1	a	0.8	a
		RV	2.4	a	1.2	a	1.9	a	3.0	a	1.0	a	0.9	a	9.4	a	6.1	a	5.3	a	1.0	a	0.6	a
		V	5.2	a	1.4	a	1.9	a	3.4	a	1.4	a	1.4	a	12.2	a	8.6	a	4.9	a	0.9	b	0.6	a
	PDE1	R	1.5	b	1.2	a	1.3	b	2.7	a	1.5	b	1.0	b	9.1	b	8.2	a	4.7	a	2.7	a	1.8	a
		RV	2.8	ab	2.0	a	1.7	ab	3.6	a	1.9	b	1.3	ab	7.3	c	8.7	a	6.3	a	2.2	a	1.3	a
		V	4.0	a	2.0	a	1.8	a	3.0	a	3.6	a	1.8	a	10.4	a	8.6	a	6.0	a	2.1	a	0.9	a
2013-2012	BRM2	R	3.2	a	1.6	a	2.3	b	1.9	b	1.0	b	0.7	b	13.4	c	18.7	a	-	-	-	-	-	-
		RV	3.5	a	1.6	a	2.5	a	5.7	b	0.9	b	0.7	b	18.4	b	19.2	a	-	-	-	-	-	-
		V	3.6	a	1.6	a	2.4	ab	18.2	a	4.4	a	4.2	a	29.6	a	25.8	a	-	-	-	-	-	-
	CCM2	R	1.5	a	1.0	a	1.6	a	2.1	a	1.0	b	0.8	ab	12.2	b	7.7	c	-	-	-	-	-	-
		RV	1.9	a	0.8	a	1.5	a	2.4	a	0.8	b	0.6	b	12.3	b	10.9	b	-	-	-	-	-	-
		V	2.4	a	1.3	a	1.0	a	3.6	a	1.8	a	1.4	a	18.8	a	16.4	a	-	-	-	-	-	-
	JBE2	R	1.7	a	0.6	a	0.6	a	2.8	b	0.5	b	0.6	b	11.6	a	12.8	a	-	-	-	-	-	-
		RV	1.6	a	0.6	a	0.8	a	1.9	b	0.6	b	0.6	b	14.5	a	9.4	a	-	-	-	-	-	-
		V	1.7	a	0.6	a	0.6	a	4.0	a	1.7	a	1.4	a	16.9	a	18.1	a	-	-	-	-	-	-
	JHE2	R	1.4	a	1.6	a	2.8	a	0.7	b	0.6	b	0.8	b	9.5	a	8.3	a	-	-	-	-	-	-
		RV	1.4	a	1.0	a	3.0	a	0.8	b	0.6	b	0.6	b	9.2	a	9.2	a	-	-	-	-	-	-
		V	1.3	a	1.5	a	3.1	a	1.4	a	1.4	a	2.6	a	9.5	a	11.9	a	-	-	-	-	-	-
2012-2013	Mean	R	4.6		1.9		2.0		2.4		1.0		0.8		7.0		6.1		4.6		1.6		1.0	
		RV	4.0		1.8		1.9		3.1		1.2		0.9		7.8		7.7		5.2		1.3		1.0	
		V	5.2		1.9		1.9		3.2		1.7		1.3		10.5		8.1		4.4		1.3		0.7	
2013-2014	Mean	R	1.9		1.2		1.8		1.9		0.8		0.7		11.6		11.9		-		-		-	
		RV	2.1		1.0		2.0		2.7		0.7		0.6		13.6		12.2		-		-		-	
		V	2.2		1.3		1.7		6.8		2.3		2.4		18.7		17.5		-		-		-	

†Means within each column and location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 2.8. Least square means for residual soil NH_4-N at three soil depths during four sampling periods at eight locations for plots receiving no fertilizer nitrogen.

Sample period			Winter Dormancy						WCC Termination						Corn GS V4				Corn Harvest					
Depth, cm			0-15		15-30		30-60		0-15		15-30		30-60		0-15		0-30		0-15		15-30		30-60	
Year	Site	WCC	Residual soil NH_4-N, mg kg^{-1}																					
2012-2013	BRM1	R	4.1	a[†]	1.1	a	0.7	a	3.1	a	2.1	a	1.5	a	4.1	a	2.7	a	3.9	a	2.1	a	2.9	a
		RV	1.6	a	0.8	a	0.6	a	4.5	a	1.7	a	1.9	a	4.9	a	5.4	a	3.5	a	2.5	a	2.1	a
		V	1.2	a	1.0	a	0.5	a	3.9	a	2.3	a	2.3	a	3.8	a	3.3	a	2.4	a	1.9	a	1.8	a
	CCM1	R	1.9	a	0.5	a	0.4	a	3.3	a	3.5	a	2.6	a	4.9	a	3.4	a	6.1	a	5.2	a	4.0	a
		RV	2.8	a	1.1	a	1.1	a	4.1	a	4.0	a	3.7	a	4.8	a	4.7	a	3.8	a	1.7	a	3.5	a
		V	2.3	a	1.0	a	0.7	a	4.4	a	3.5	a	3.2	a	4.5	a	3.9	a	3.4	a	2.7	a	2.1	a
	JBE1	R	3.3	a	2.9	a	1.8	a	10.5	a	8.3	a	6.3	a	5.1	a	5.3	a	2.5	a	1.5	a	2.8	a
		RV	5.9	a	4.8	a	8.9	a	9.9	a	8.0	a	6.8	a	3.0	a	4.6	a	2.4	a	1.8	a	1.8	a
		V	8.8	a	5.0	a	6.2	a	4.9	a	7.3	a	5.4	a	5.3	a	4.1	a	1.7	a	1.6	a	1.7	a
	PDE1	R	4.6	a	6.3	a	0.7	a	7.6	a	5.1	b	5.4	a	5.1	a	5.9	a	9.6	a	12.3	a	8.7	a
		RV	5.5	a	1.8	a	1.2	a	9.5	a	6.4	ab	5.6	a	5.9	a	5.3	a	8.2	a	7.5	a	7.3	a
		V	3.2	a	1.6	a	0.9	a	7.1	a	8.4	a	5.9	a	5.7	a	5.4	a	8.1	a	5.7	a	4.1	a
2013-2014	BRM2	R	1.4	b	1.1	a	1.0	b	5.0	a	3.2	a	3.0	a	7.6	a	15.4	a	-	-	-	-	-	-
		RV	1.4	b	1.1	a	1.3	a	4.2	a	3.9	a	3.5	a	9.6	a	11.8	a	-	-	-	-	-	-
		V	1.6	a	1.1	a	1.2	a	5.8	a	3.2	a	3.7	a	10.3	a	9.4	a	-	-	-	-	-	-
	CCM2	R	1.5	a	1.1	a	1.4	a	14.8	ab	16.9	a	18.3	a	6.3	a	5.8	a	-	-	-	-	-	-
		RV	1.7	a	1.3	a	1.3	a	14.0	b	14.8	a	17.4	a	12.3	a	7.7	a	-	-	-	-	-	-
		V	1.5	a	1.4	a	1.0	b	19.2	a	18.0	a	19.2	a	9.8	a	10.2	a	-	-	-	-	-	-
	JBE2	R	1.5	a	0.9	a	1.1	a	17.8	a	14.5	a	17.3	a	4.1	ab	7.4	a	-	-	-	-	-	-
		RV	1.5	a	1.5	a	1.0	a	13.8	b	14.1	a	22.8	a	3.4	b	3.4	a	-	-	-	-	-	-
		V	1.4	a	1.1	a	1.1	a	12.4	b	14.0	a	18.6	a	6.0	a	8.8	a	-	-	-	-	-	-
	JHE2	R	1.5	a	1.2	a	1.2	a	18.5	a	18.8	a	19.1	a	10.0	a	5.7	a	-	-	-	-	-	-
		RV	1.2	a	1.0	a	1.3	a	15.2	a	20.5	a	21.7	a	3.8	b	7.9	a	-	-	-	-	-	-
		V	1.4	a	0.9	a	1.1	a	16.2	a	15.3	a	20.7	a	6.4	ab	7.9	a	-	-	-	-	-	-
2012-2013	Mean	R	3.5		2.7		0.9		6.1		4.7		4.0		4.8		4.3		5.5		5.3		4.6	
		RV	4.0		2.1		2.9		7.0		5.0		4.5		4.6		5.0		4.5		3.4		3.6	
		V	3.9		2.2		2.1		5.1		5.4		4.2		4.8		4.2		3.9		3.0		2.4	
2013-2014	Mean	R	1.5		1.1		1.2		14.0		13.3		14.4		7.0		8.6		-		-		-	
		RV	1.5		1.2		1.2		11.8		13.3		16.3		7.2		7.7		-		-		-	
		V	1.4		1.1		1.1		13.4		12.6		15.5		8.1		9.1		-		-		-	

[†]Means within each column and location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 2.9. Least square means for residual soil inorganic nitrogen at three soil depths during four sampling periods at eight locations for plots receiving no fertilizer nitrogen.

Sample period			Winter Dormancy						WCC Termination						Corn GS V4				Corn Harvest					
Depth, cm			0-15		15-30		30-60		0-15		15-30		30-60		0-15		0-30		0-15		15-30		30-60	
Year	Site	WCC	Residual soil inorganic nitrogen, mg kg^{-1}																					
2012-2013	BRM1	R	9.8	a†	4.3	a	3.7	a	5.1	a	2.7	a	2.1	a	8.1	b	7.2	a	5.6	a	2.9	a	3.7	a
		RV	6.1	a	3.5	a	3.3	a	8.7	a	2.4	a	2.4	a	10.4	b	15.9	a	4.3	ab	3.1	a	2.8	a
		V	6.8	a	3.9	a	3.2	a	8.1	a	3.2	a	3.0	a	16.3	a	12.3	a	3.8	b	2.5	a	2.4	a
	CCM1	R	8.0	a	2.0	a	1.8	a	4.5	a	4.6	a	3.3	a	10.5	b	7.7	a	12.2	a	6.9	a	4.7	a
		RV	9.1	a	2.5	a	2.4	a	5.6	a	5.1	a	4.4	a	11.2	b	10.1	a	12.4	a	3.1	a	4.6	a
		V	8.1	a	2.4	a	1.8	a	6.5	a	4.4	a	4.3	a	14.1	a	10.1	a	8.8	a	4.3	a	2.7	a
	JBE1	R	8.4	a	4.6	a	4.3	a	14.0	a	9.1	a	7.4	a	13.3	a	12.6	a	8.2	a	2.6	a	3.5	a
		RV	8.3	a	6.1	a	10.8	a	12.8	a	9.1	a	7.7	a	14.6	a	10.7	a	7.7	a	2.8	a	2.4	a
		V	14.0	a	6.4	a	8.1	a	8.3	a	8.8	a	6.8	a	17.4	a	12.7	a	6.6	a	2.5	a	2.3	a
	PDE1	R	6.2	a	7.5	a	2.0	a	10.3	a	6.6	b	6.3	a	15.2	a	14.1	a	14.3	a	15.0	a	10.4	a
		RV	8.3	a	3.8	a	2.9	a	13.1	a	8.3	b	7.0	a	13.7	a	14.0	a	14.5	a	9.6	a	8.6	a
		V	7.1	a	3.7	a	2.7	a	10.1	a	12.0	a	7.7	a	16.1	a	14.0	a	14.1	a	7.7	a	5.0	a
2013-2014	BRM2	R	4.6	a	2.7	a	3.3	b	6.8	b	4.2	b	3.8	a	21.0	b	34.0	a	-	-	-	-	-	-
		RV	5.0	a	2.7	a	3.8	a	9.9	b	4.8	ab	4.2	a	28.0	b	31.0	a	-	-	-	-	-	-
		V	5.2	a	2.7	a	3.6	a	23.9	a	7.6	a	7.9	a	39.8	a	35.1	a	-	-	-	-	-	-
	CCM2	R	3.1	a	2.1	a	2.9	a	16.9	b	17.8	a	19.1	a	18.5	a	13.5	a	-	-	-	-	-	-
		RV	3.5	a	2.1	a	2.9	a	16.4	b	15.7	a	18.0	a	27.2	a	18.6	a	-	-	-	-	-	-
		V	3.8	a	2.6	a	2.0	a	22.8	a	19.7	a	20.5	a	28.6	a	24.6	a	-	-	-	-	-	-
	JBE2	R	3.1	a	1.5	a	1.8	a	20.6	a	15.1	a	17.9	a	15.7	b	20.2	a	-	-	-	-	-	-
		RV	3.1	a	2.1	a	1.8	a	15.7	b	14.7	a	23.4	a	14.5	b	12.8	a	-	-	-	-	-	-
		V	3.1	a	1.7	a	1.6	a	16.3	b	15.7	a	19.9	a	22.9	a	26.9	a	-	-	-	-	-	-
	JHE2	R	2.8	a	2.7	a	4.0	a	19.2	a	19.3	a	19.9	a	19.5	a	14.1	a	-	-	-	-	-	-
		RV	2.6	a	2.0	a	4.3	a	16.0	a	21.1	a	22.3	a	16.2	a	17.1	a	-	-	-	-	-	-
		V	2.7	a	2.4	a	4.2	a	17.6	a	16.7	a	23.3	a	15.8	a	19.7	a	-	-	-	-	-	-
2012-2013	Mean	R	8.1		4.6		2.9		8.5		5.7		4.8		11.8		10.4		10.1		6.8		5.6	
		RV	7.9		4.0		4.8		10.0		6.2		5.4		12.5		12.7		9.7		4.7		4.6	
		V	9.0		4.1		4.0		8.2		7.1		5.4		16.0		12.2		8.3		4.3		3.1	
2013-2014	Mean	R	3.4		2.2		3.0		15.9		14.1		15.2		18.7		20.4		-		-		-	
		RV	3.5		2.2		3.2		14.5		14.1		17.0		21.5		19.9		-		-		-	
		V	3.7		2.3		2.8		20.1		14.9		17.9		26.8		26.6		-		-		-	

†Means within each column and location followed by the same uppercase letter are not significantly different (P > 0.05)

Table 2.10. Analysis of variance for WCC and FN effects on residual soil NO_3-N, NH_4-N, and inorganic N at three soil depths and at eight locations at corn harvest.

Variable		Residual soil NO_3-N			Residual soil NH_4-N			Residual soil inorganic nitrogen		
Depth, cm		0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
Year	Effect									
2012-2013	loc†	***	***	***	***	***	***	***	***	***
	wcc‡	**	***	***	***	***	***	***	***	***
	loc*wcc	*	***	***	***	***	***	***	***	***
	pre§	ns	ns	ns	ns	ns	ns	ns	ns	ns
	loc*pre	ns	**	ns	ns	ns	ns	ns	ns	ns
	pre*wcc	ns	ns	ns	ns	ns	ns	ns	ns	ns
	loc*pre*wcc	ns	ns	ns	ns	ns	ns	ns	ns	ns
	sdn¶	ns	**	***	ns	**	*	ns	ns	***
	loc*sdn	**	***	***	***	ns	ns	***	ns	ns
	sdn*wcc	**	***	***	ns	ns	***	*	**	***
	loc*sdn*wcc	**	***	***	ns	*	***	**	***	***
	pre*sdn	*	ns	*	ns	*	***	ns	ns	*
	loc*pre*sdn	***	**	ns	*	*	***	***	**	**
	pre*sdn*wcc	***	ns	ns	ns	*	**	***	*	ns
	loc*pre*sdn*wcc	***	ns	ns	***	***	***	***	**	***

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
ns Nonsignificant at the 0.05 probability level.
† Location.
‡ Winter cover crop.
§ Starter fertilizer nitrogen.
¶ Sidedress fertilizer nitrogen.

Table 2.11. Least square means for winter annual cover crops (WCC) and sidedress FN effects on residual soil NO3-N at three soil depths and at four locations at corn harvest in 2012-2013.

	Location	BRM1			CCM1			JBE1			PDE1		
	Depth, cm	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
WCC	Sidedress FN	Residual NO_3-N, mg kg^{-1}											
R[‡]	0	1.8 a[†]	0.7 a	0.8 a	5.8 abc	1.7 a	1.2 a	6.5 a	1.0 a	0.9 a	5.7 a	2.2 a	1.2 a
R	45	1.3 a	0.6 a	0.7 a	8.0 ab	1.7 a	0.9 a	5.7 a	1.0 a	0.6 a	6.0 a	2.4 a	1.5 a
R	90	1.1 a	0.7 a	0.8 a	6.0 abc	1.5 a	0.9 a	7.2 a	0.9 a	0.6 a	5.6 a	1.4 a	1.3 a
R	135	1.0 a	0.6 a	0.7 a	6.7 abc	1.8 a	0.9 a	6.8 a	0.9 a	0.7 a	5.1 a	1.8 a	1.3 a
R	180	0.9 a	0.6 a	0.7 a	5.5 abc	1.9 a	1.5 a	4.8 a	1.1 a	0.6 a	6.3 a	1.9 a	1.5 a
RV[§]	0	0.8 a	0.6 a	0.9 a	7.8 abc	1.6 a	0.8 a	4.8 a	1.0 a	0.6 a	6.9 a	2.0 a	0.9 a
RV	45	0.8 a	0.6 a	0.6 a	5.2 bc	1.8 a	1.0 a	5.8 a	0.9 a	0.6 a	7.2 a	2.3 a	0.9 a
RV	90	1.0 a	0.6 a	0.7 a	4.7 cde	1.5 a	0.9 a	4.7 a	1.3 a	0.6 a	5.8 a	2.1 a	1.0 a
RV	135	0.8 a	0.5 a	0.7 a	8.0 ab	1.7 a	0.9 a	4.9 a	1.4 a	1.6 a	5.3 a	2.3 a	1.4 a
RV	180	1.7 a	0.7 a	1.6 a	5.8 abc	1.8 a	1.5 a	5.2 a	2.5 a	6.3 a	6.0 a	2.2 a	1.5 a
V[¶]	0	1.2 a	0.6 a	0.6 a	6.2 abc	1.2 a	0.8 a	5.1 a	1.0 a	0.7 a	6.0 a	2.0 a	1.0 a
V	45	1.5 a	0.8 a	0.6 a	6.4 abc	1.3 a	0.7 a	4.9 a	1.1 a	0.7 a	5.9 a	2.1 a	0.9 a
V	90	1.6 a	0.6 a	0.5 a	7.5 abc	1.5 a	0.9 a	6.9 a	1.0 a	0.9 a	5.8 a	1.9 a	0.9 a
V	135	1.6 a	0.6 a	0.6 a	9.2 a	1.5 a	0.9 a	6.6 a	1.1 a	1.1 a	6.6 a	2.1 a	0.9 a
V	180	2.0 a	1.7 a	0.7 a	6.4 abc	1.1 a	0.8 a	6.4 a	2.1 a	1.4 a	6.0 a	0.0 a	0.0 a

[†]Means within each column and experimental location followed by the same lowercase letter are not significantly different ($P > 0.05$)

[‡] Cereal rye.

[§] Cereal rye + hairy vetch mixture.

[¶]Hairy vetch.

Table 2.12. Least square means for winter annual cover crops (WCC) and sidedress FN effects on residual soil NH_4-N at three soil depths and at four locations at corn harvest in 2012-2013.

	Location	BRM1			CCM1			JBE1			PDE1		
	Depth, cm	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
WCC	Sidedress FN	Residual NH_4-N, mg kg^{-1}											
R[‡]	0	3.8 a[†]	2.1 a	2.7 a	5.3 ab	3.7 a	3.9 ab	2.3 a	1.5 a	2.5 a	11.9 ab	9.5 ab	8.4 ab
R	45	3.2 a	1.8 a	1.9 a	6.5 a	3.0 a	3.9 ab	2.7 a	1.8 a	1.5 a	10.8 abc	7.8 bcd	5.9 bcdef
R	90	3.0 a	2.6 a	2.3 a	4.6 ab	3.3 a	4.3 ab	2.1 a	1.7 a	1.7 a	13.6 a	10.5 a	5.8 bcdef
R	135	3.0 a	2.1 a	2.6 a	5.0 ab	3.5 a	4.2 ab	2.3 a	1.7 a	2.4 a	9.8 bcd	8.6 abc	9.9 a
R	180	3.1 a	2.4 a	2.1 a	4.8 ab	4.1 a	5.3 a	2.5 a	1.9 a	1.7 a	10.7 abc	8.3 abcd	6.8 bcde
RV[§]	0	4.0 a	2.5 a	3.3 a	3.9 ab	2.9 a	3.0 ab	2.4 a	1.9 a	2.4 a	8.6 cde	8.4 abc	6.7 bcde
RV	45	4.3 a	2.4 a	2.3 a	2.9 b	2.7 a	2.6 b	2.6 a	1.9 a	2.4 a	8.6 cde	7.3 bcdef	7.1 bcd
RV	90	3.7 a	2.6 a	2.9 a	2.9 b	2.9 a	3.2 ab	2.6 a	1.8 a	2.0 a	10.8 abc	7.4 bcde	8.2 ab
RV	135	4.1 a	2.6 a	3.0 a	3.3 b	2.6 a	2.8 b	2.5 a	1.7 a	2.2 a	8.2 cde	7.9 bcd	7.5 abc
RV	180	4.0 a	3.7 a	4.5 a	3.1 b	2.3 a	2.7 b	2.7 a	1.7 a	1.8 a	10.6 abc	8.9 abc	8.4 ab
V[¶]	0	2.7 a	1.8 a	1.9 a	3.2 b	2.7 a	2.5 b	2.3 a	1.8 a	1.8 a	7.4 de	5.6 ef	4.7 def
V	45	2.3 a	1.7 a	1.4 a	3.8 b	3.1 a	2.9 b	2.2 a	1.7 a	1.9 a	6.6 e	5.3 f	5.6 cdef
V	90	2.7 a	2.1 a	1.4 a	3.3 b	3.0 a	2.4 b	2.9 a	2.0 a	2.3 a	7.1 e	5.8 def	4.5 def
V	135	2.7 a	2.5 a	1.5 a	3.4 b	3.1 a	2.7 b	2.4 a	1.7 a	1.9 a	6.4 e	5.9 def	4.3 f
V	180	2.6 a	1.5 a	1.4 a	3.1 b	2.7 a	2.2 b	2.5 a	1.6 a	1.8 a	7.2 de	7.0 cdef	5.0 def

[†]Means within each column and experimental location followed by the same lowercase letter are not significantly different ($P > 0.05$)

[‡] Cereal rye.

[§] Cereal rye + hairy vetch mixture.

[¶]Hairy vetch.

Table 2.13. Least square means for winter annual cover crops (WCC) and sidedress FN effects on residual soil inorganic nitrogen at three soil depths and at at corn harvest in 2012-2013.

	Location	BRM1						CCM1						JBE1						PDE1					
	Depth, cm	0-15		15-30		30-60		0-15		15-30		30-60		0-15		15-30		30-60		0-15		15-30		30-60	
WCC	Sidedress FN	Residual inorganic N, mg kg^{-1}																							
R[‡]	0	5.6	a[†]	2.8	a	3.5	a	11.1	a	5.3	a	4.7	a	8.8	a	2.6	a	3.3	ab	18.0	ab	10.5	abc	10.5	a
R	45	4.6	a	2.5	a	2.6	a	13.9	a	4.2	a	5.2	a	8.4	a	2.8	a	2.2	b	18.0	abc	9.8	bcd	7.3	abcde
R	90	4.1	a	3.2	a	3.1	a	10.5	a	4.5	a	5.0	a	8.5	a	2.8	a	2.5	b	22.3	a	12.8	a	7.6	abcde
R	135	4.4	a	2.7	a	3.2	a	11.7	a	5.0	a	5.1	a	9.1	a	2.7	a	3.3	ab	15.2	bc	10.0	bcd	9.4	ab
R	180	4.8	a	2.9	a	2.7	a	10.3	a	5.6	a	6.1	a	7.9	a	3.2	a	2.8	b	17.0	bc	10.5	abcd	7.4	abcde
RV[§]	0	4.7	a	3.0	a	4.1	a	12.1	a	4.7	a	3.7	a	7.2	a	2.8	a	3.2	ab	15.5	bc	10.6	ab	8.0	abcde
RV	45	5.2	a	2.9	a	2.9	a	8.0	a	4.4	a	3.5	a	8.4	a	2.9	a	3.0	b	15.8	bc	11.3	ab	8.6	abcd
RV	90	4.6	a	3.1	a	3.6	a	8.3	a	4.4	a	4.0	a	7.1	a	2.7	a	2.6	b	17.4	abc	9.2	bcde	10.0	a
RV	135	4.8	a	3.1	a	3.7	a	11.5	a	4.4	a	3.8	a	8.0	a	2.6	a	2.9	b	13.5	c	9.7	bcde	8.7	abc
RV	180	5.5	a	4.6	a	6.7	a	8.8	a	4.1	a	4.0	a	7.8	a	2.7	a	2.9	b	16.8	bc	10.3	abcd	10.0	a
V[¶]	0	3.9	a	2.4	a	2.5	a	9.4	a	4.2	a	3.3	a	7.4	a	2.7	a	2.4	b	13.4	c	7.6	e	5.6	e
V	45	3.7	a	2.5	a	2.0	a	11.9	a	4.9	a	3.9	a	7.2	a	2.6	a	2.6	b	13.1	c	7.6	de	6.5	bcde
V	90	3.9	a	2.6	a	1.8	a	10.0	a	4.8	a	3.3	a	9.8	a	3.3	a	3.0	b	12.9	c	7.8	cde	5.4	e
V	135	4.4	a	3.1	a	2.1	a	12.8	a	4.8	a	3.6	a	9.0	a	3.2	a	4.1	ab	12.9	c	8.2	cde	5.8	de
V	180	4.5	a	2.2	a	3.1	a	9.8	a	4.5	a	4.2	a	9.3	a	3.9	a	7.8	a	13.2	c	9.1	bcde	6.6	bcde

[†]Means within each column and experimental location followed by the same lowercase letter are not significantly different (P > 0.05)

[‡] Cereal rye.

[§] Cereal rye + hairy vetch mixture.

[¶]Hairy vetch.

2.8 Figures

Figure 2.1. 2012-2013 and 2013-2012 and 30 year monthly mean temperature for Tappahannock, VA.

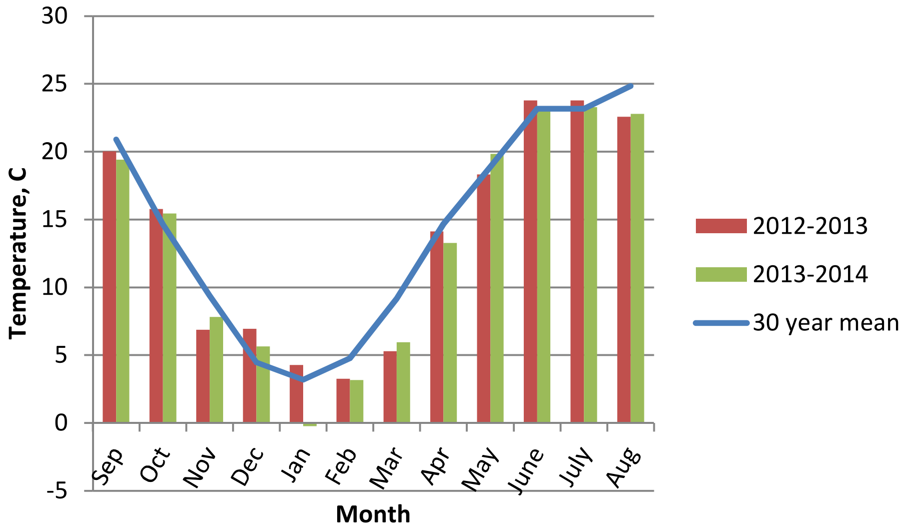


Figure 2.2. 2012-2013 and 2013-2012 and 30 year monthly cumulative precipitation for Tappahannock, VA.

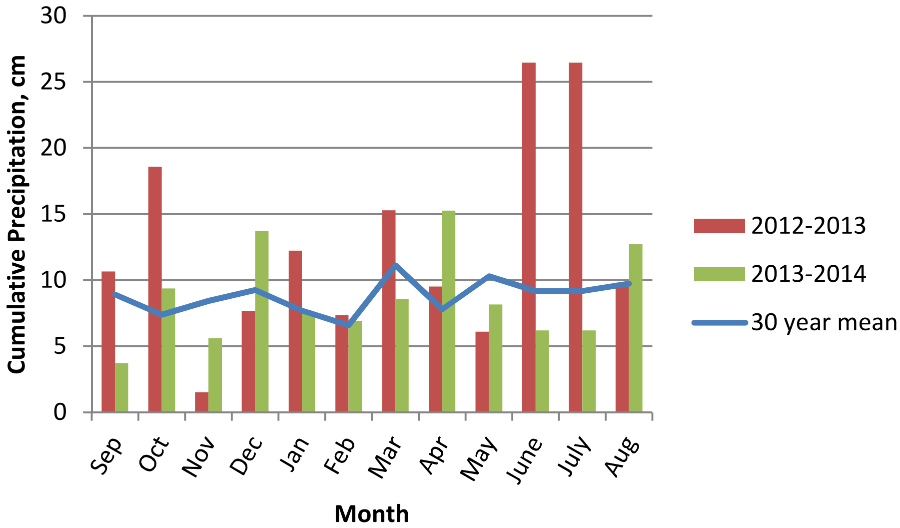
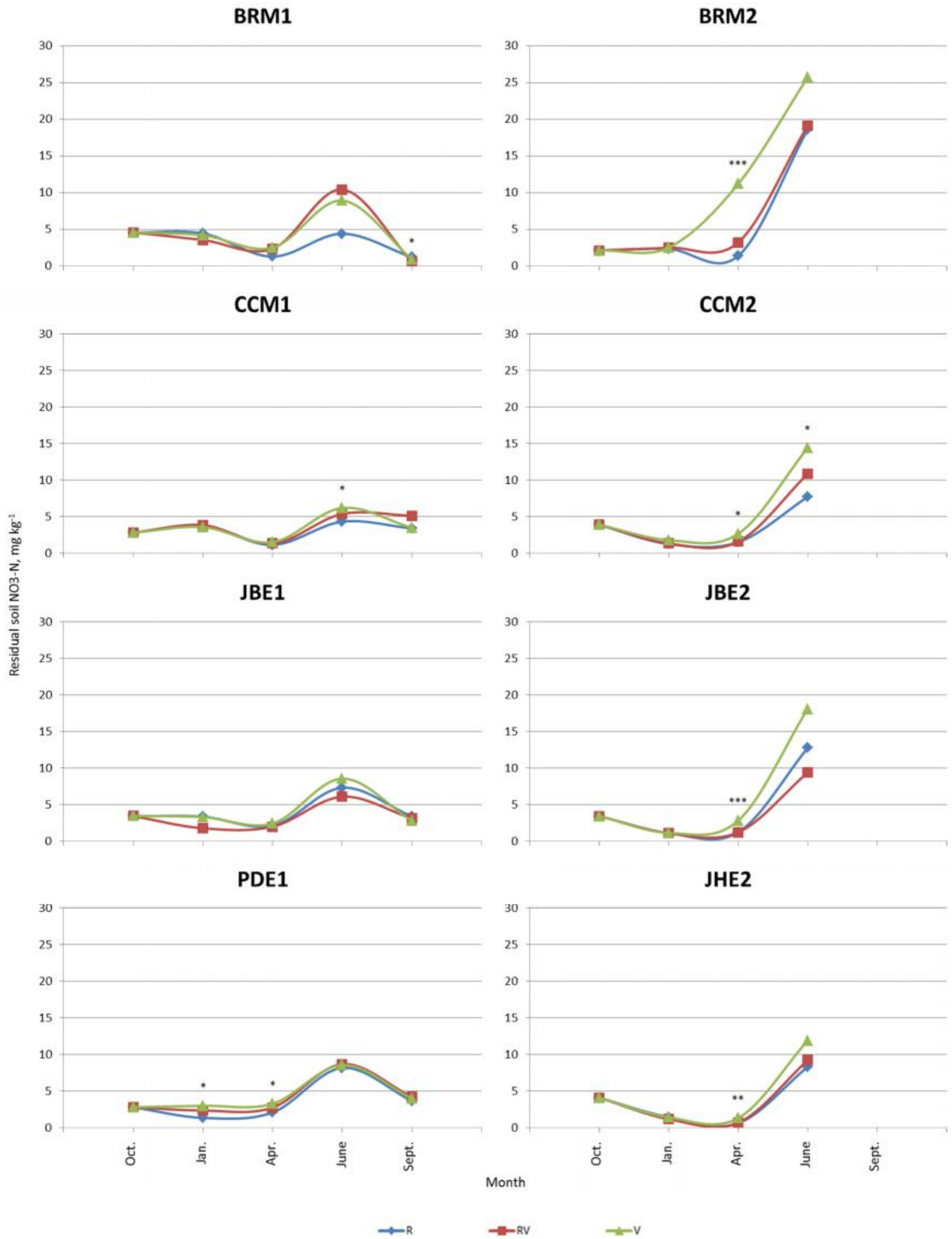


Figure 2.3. Winter cover crop growing degree days (base 4°C) by location and year from winter annual cover crops (WCC) seeding to termination and from soybean harvest to termination.

Figure 2.4. Residual soil NO3-N throughout winter annual cover crops (WCC) and corn growing seasons at depth 0-30 cm.



* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

3. Winter Annual Cover Crops Interseeded into Soybean in Eastern Virginia: Influence on Corn Yield and Corn Nitrogen Nutrition.

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3.1 Abstract

Fertilizer nitrogen (FN) demand for corn (*Zea mays* L.) production is expected to increase with global population growth, and alternative sources for plant available nitrogen (PAN) will need to be optimized. Hairy vetch (*Vicia villosa* Roth) winter annual cover crop (WCC) has been shown to supply subsequent corn with substantial PAN. However, common corn-soybean (*Glycine max* L. Merr.) rotations leave fields fallow following soybeans. Our objective was to evaluate hairy vetch's capacity to supply PAN to subsequent corn following soybeans in the mid-Atlantic coastal plain region of the United States. Eight sites were seeded into standing soybeans with rye (*Secale cereale* L.), hairy vetch, and a mixture of the two in the fall of study years. The experimental design was a split-plot with WCC species as the main plot and ten FN rates in a full factorial arrangement as subplots. Maximum corn grain yield following hairy vetch WCC was 0.7 and 0.6 Mg ha^{-1} higher than when following cereal rye WCC at zero and 45 kg ha^{-1} starter FN, respectively. Average agronomic optimum FN rates (AONR) were 26 and 9 kg ha^{-1} lower following hairy vetch than cereal rye WCC at zero and 45 kg ha^{-1} starter FN, respectively. At location BRM1 hairy vetch WCC achieved aboveground N content of 146 kg N ha^{-1} and yield plateau of subsequent corn was 2.9 Mg ha^{-1} higher than when following cereal rye. Relative to cereal rye, estimated hairy vetch FN reductions by FN replacement and AONR difference methods were 48 and 18 kg N ha^{-1} in plots receiving zero starter FN; and 58 and -43 kg N ha^{-1} in plots receiving 45 kg ha^{-1} starter FN. Highest relative net returns where achieved by the AONR difference method and when comparing corn following hairy vetch versus cereal rye.

3.2 Introduction

By 2050, annual global grain and fertilizer nitrogen (FN) demand are both projected to increase by 60% to $3x10^9$ and $150x10^6$ Mg, respectively, due to emerging markets' increased consumption of grain-fed meat (Alexandratos and Bruinsma, 2012). In the ten year period from 2003 to 2013, urea (460 g N kg^{-1}) fertilizer prices in the United States have increased approximately 130 percent from US$0.62 to US$1.42 kg^{-1} FN (USDA-ERS, 2013). These trends suggest future increases in FN prices are inevitable unless technological advances reduce production costs.

Meeting future caloric demands also brings environmental challenges. Increasing yields per hectare on currently cultivated cropland (intensification) through advances in technology and management in an environmentally sensitive manner has been coined 'sustainable intensification' and is considered the preferred method to meet future demands (Burney et al., 2010; Foley et al., 2011; Garnett et al., 2013; Tilman et al., 2011). Burney et al. (2010) suggested that intensive agriculture has the potential to mitigate future greenhouse gas emissions, especially if extensive (i.e., expanding cropland) practices are avoided and conservation practices are implemented. Legume winter annual cover crops (WCC) are one recommended conservation practice that can help meet future grain demands while mitigating environmental impacts (Godfray et al., 2010; Tilman et al., 2011). In addition to beneficial ecosystem services, Tonitto et al. (2006) estimated that legume N based cropping systems have the potential to reduce fossil fuel consumption by approximately 55% compared to conventionally fertilized fields. Additionally, legume N based cropping systems potentially reduce N leaching and denitrification losses as excess N is retained in the organic soil fraction, which consequently mitigates eutrophication and greenhouse gas emissions (Drinkwater et al., 1998; Tonitto et al., 2006).

Legume WCC effects on corn grain yield are largest at low FN application rates and decrease as FN rates increase, but are typically positive over all FN levels (Miguez and Bollero, 2005). At zero FN, corn following legume WCC has the ability to achieve similar yields as corn with optimum FN rates if legume biomass is sufficient. Meta-analysis conducted by Tonitto et al. (2006) indicated that when legume WCC biomass provides ≥ 110 kg N ha^{-1}, relative corn yields were 10% lower, but not significantly different than corn yields following bare fallow and at recommended FN rates. Delaying legume WCC termination until corn planting will maximize biomass and N content (Clark et al., 1997b; Clark et al., 1995; Corak et al., 1991; Decker et al., 1994; Vaughan and Evanylo, 1998). In addition, studies by Clark, et al. (1995; 1997b; 2007b) in Maryland reported higher corn yields following hairy vetch killed in late-April/early-May than in early-April. Clark et al. (1997b) suggested that soil moisture conservation benefits from increased residue mulch associated with delayed termination outweighed any soil moisture depleted during spring legume WCC growth.

In the eastern United States, hairy vetch (*Vicia villosa* Roth) routinely produces more spring biomass and N content per hectare than other legume WCC (Clark, 2007; Ebelhar et al., 1984; Holderbaum et al., 1990; Ranells and Wagger, 1996; Ranells and Wagger, 1997). When compared to crimson clover (*Trifolium incarnatum* L), hairy vetch had less fall growth and winter soil cover, but had higher winter survival and spring growth that led to higher biomass and aboveground total N (Holderbaum et al., 1990). Ranells and Wagger (1996) indicated that hairy vetch produced more biomass and N content than crimson clover when grown alone and in a biculture with cereal rye (*Secale cereale* L.). In a 10 year study, hairy vetch treatments consistently resulted in highest net revenues and highest maximum corn grain yield with 16% to 26% less FN than the control treatment (Roberts et al., 1998). Another study demonstrated that hairy vetch was able to replace two-thirds (123 kg ha^{-1}) the FN required for corn production (McVay et al., 1989). Similar results have been published by other researchers throughout eastern U.S.A. (Blevins et al., 1990; Clark et al., 1994; Clark et al., 2007a; Decker et al., 1994; Ebelhar et al., 1984; Frye et al., 1985; Holderbaum et al., 1990; Tyler et al., 1987).

Although cereal rye WCC potentially immobilizes residual soil N, corn grain yield plateaus are often similar to those following fallow at comparable agronomic optimum nitrogen rates (AONR) (Miguez and Bollero, 2005; Tonitto et al., 2006; Utomo et al., 1990; Vaughan et al., 2000). Corn grain yields following cereal rye WCC are normally depressed at low FN rates due to N immobilization; however, comparable yields were attained and annual nitrate (NO_3-N) leaching was reduced by 70% at standard FN rates (Tonitto et al., 2006).

Throughout much of the U.S., FN recommendations for corn are based on realistic yield goals, where yield goal equals the average yield from the best three out of five most recent years, or when historical data is not available, based on local research. Fertilizer N recommendations equal the yield goal multiplied by a FN factor (~20 kg N Mg^{-1} corn grain) and corrected for N credits. Nitrogen credits are predicted from previous legume and residual soil N. Most legume-based FN equivalency experiments focus on the FN recovery or replacement methods. The FN recovery method compares the difference between corn N uptake yield in plots with and without legume WCC (Lory et al., 1995). The FN replacement method utilizes nitrogen response curves to determine the FN level where corn grain following fallow yields the same as that following a legume WCC without FN (Lory et al., 1995). The FN replacement method is the traditional method for developing N credits, where the FN replaced by the legume WCC is reduced from the producers standard FN rate (Lory et al., 1995). The traditional FN credit method does not account for positive non-N rotation effects that result in increased yield plateaus (Lory et al., 1995). Positive non-N rotation effects have been attributed to improved soil biological and physical properties (McVay et al., 1989; Sainju et al., 2003), weed suppression (Clark, 2007), and reduced soil moisture evaporation (Clark et al., 1997b).

Many studies reported corn following legume WCC typically required similar FN rates as corn following fallow to achieve yield plateau, however due to non-N rotation effects, corn yield plateaus following legume WCC are typically higher than those following fallow (Blevins et al., 1990; Clark et al., 1997b; Corak et al., 1991; Decker et al., 1994; Ebelhar et al., 1984; Frye et al., 1985; Holderbaum et al., 1990; Miguez and Bollero, 2005; Tonitto et al., 2006; Utomo et al., 1990; Vaughan et al., 2000; Wagger, 1989a). For example, Decker et al. (1994) and Vaughan et al. (2000) reported average non-N rotation effects of approximately 2 Mg ha^{-1} in Maryland coastal plain and in western North Carolina, respectively.

To account for these non-N rotational effects, Smith et al. (1987) introduced the difference method FN credit technique. The difference method is the difference between economic optimum nitrogen rates (EONR) of corn in rotation with a legume WCC versus that of corn following fallow (Smith et al., 1987). In a comparison of the two methods, Lory et al. (1995), recommends using the difference method, because the difference method is designed to achieve economic optimum yields. Unfortunately, studies have shown poor correlation between predicted EONR and actual yield at EONR (Kachanoski et al., 1996; Lory and Scharf, 2003).

Others suggested the use of corn grain N content or concentration for determining N credits (Hargrove, 1986; McVay et al., 1989). Both Hargrove (1986) and McVay et al. (1989) suggested the use of corn grain N content (kg N ha^{-1} removed) for estimating FN contribution from legumes, because corn grain yield response was less predictive than corn grain N content when following legumes. However, research conducted by Cerrato and Blackmer (1990) concluded that use of corn grain N concentration was not satisfactory to discriminate between optimum and excessive FN rates; therefore, it would appear to be a poor tool to predict AONR. Brouder et al. (2000) suggests that corn grain N concentration is better suited to determine N deficiency vs. sufficiency. The reported critical corn grain N concentration was 13.1 g kg^{-1} and had a success rate of 73% in predicting non responsive sites (Brouder et al., 2000).

Although it is well known that WCC have direct effects on subsequent corn grain yields, few studies have investigated these benefits when WCC have been interseeded into standing soybeans. Research is needed to identify how interseeded WCC into standing soybean affects subsequent corn grain yield and optimum FN rates. The specific objectives were to (i) determine the effects of interseeded WCC on subsequent corn grain yield; (ii) evaluate the effectiveness of interseeded WCC supplying N to subsequent corn; and (iii) refine sidedress FN credit recommendations of hairy vetch WCC for corn grain producers in eastern Virginia.

3.3 Materials and Methods

3.3.1 Experimental Design

Research was conducted at four locations in 2012-2013 and at four different locations in 2013-2014 in the Virginia coastal plain region in USDA hardiness zone 7b. Average annual temperature of the region is 14°C and precipitation is 112 cm yr^{-1}. All locations had a history of using both inorganic and organic N sources. Location coordinates and soil physical descriptions are listed in Table 3.1. All locations, with the exception of JHE2, were in no-till corn–winter wheat or barley/double-crop soybean rotation. Location JHE2 was in corn–small grain WCC–full season soybean rotation. Winter cover crops were interseeded into standing soybean, with the exception of CCM1 that was broadcast seeded shortly after soybean harvest (Table 3.2).

The experimental design was a split-plot with four replications at each location. Three WCC treatments were main plots and ten corn FN rates were subplots. Main plots were seeded with cereal rye, hairy vetch, and winter rye-hairy vetch mix WCC. Seeding rates, agronomic relevant dates, and WCC and corn hybrid varieties are listed in table 2.2. Subplots received two starter FN and five sidedress FN rates arranged in a full factorial. Fertilizer N rates were in increments of 45 kg ha^{-1} (0, 45, 90, 135, and 180 kg ha^{-1}) as liquid ammonium nitrate (UAN) dribble banded either 5 cm to the side of the furrow or between corn rows at planting and sidedress, respectively. Main plots were 75 x 15 m; subplots were 9 m length by 4 rows (3.1 m). Production practices followed recommendations of Virginia Cooperative Extension (Brann et al., 2000).

3.3.2 Sample Analysis

Cover crop aboveground DM was hand clipped from a 0.1 m^2 area immediately before termination in April or May of study years. Dry matter samples were dried at 60°C for 48 hours in a forced air oven, ground to pass a 2 mm screen using a Wiley sample mill (Thomas Scientific, Swedesboro, NJ) and total C and N determined via dry combustion (VarioMax CNS macro elemental analyzer, Elementar, Hanau, Germany). Corn ear leaves were harvested at corn GS R1 from 12 plants from the center two rows of each plot. Corn ear leaves were dried in a forced air oven at 60°C, ground to pass a 2 mm screen using a Wiley sample mill (Thomas Scientific, Swedesboro, NJ) and analyzed for total N concentration via dry combustion evaluate crop N status. Corn was harvested from the center two rows of each plot with a small plot combine, and grain yield, moisture, and test weight determined using a Graingage™ system (Juniper Systems, Logan, UT). Grain yields from all trials are reported at 155 g kg^{-1} moisture content. Grain N was analyzed using Foss NIR Systems Rapid Content Analyzer (Foss NIR Systems, Silver Spring, MD).

3.3.3 Statistical Analysis

Statistical analyses were performed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, 2012). All variables were analyzed by location, year, and starter FN rate due to significant interaction between location and treatments. Mean comparisons using Tukey's Honestly Significant Difference (HSD) (α=0.05) were made to separate treatment effects when F tests indicated that significant differences existed (p<0.05). Response curves were developed using the NLIN procedure to analyze relationships between sidedress FN rates and corn grain yield, corn grain N content, and corn ear leaf N concentration. The quadratic-plus-plateau or linear-plus-plateau models were selected based on R^2 values, model p-values, and whether model convergence criterion was met. Parameter coefficients were adjusted until convergence criterion was met in most models. Nitrogen credit estimates were calculated based on the traditional method (fertilizer N replacement method) or the difference method (AONR difference method)

(Lory et al., 1995) for both corn yield and corn N content using quadratic-plus-plateau and the linear-plus-plateau models as appropriate. The fertilizer N replacement was calculated by substituting the y-intercept from the hairy vetch regression equation with y in either cereal rye or RV mix regression equations and solving for x (sidedress FN rate). The AONR difference method was calculated by determining the difference between agronomic optimum FN rates between hairy vetch and either cereal rye or RV mix regression curves. Net returns were calculated using 5-year average (2009-2013) corn grain and FN (urea-N) prices (USDA-ERS, 2013; USDA-ERS, 2014); net return=((corn yield x corn price)-(FN used x FN price))-WCC seed price.

3.4 Results and Discussion

3.4.1 WCC Aboveground Nitrogen Content and C:N Ratio

Table 3.4 shows WCC dry matter yield (DM), N content, and C:N ratio of cereal rye, RV mix, and hairy vetch. Location BRM1 was the only location where hairy vetch aboveground N content was >110 kg N ha^{-1}, which according to Tonitto et al. (2006) is the critical value required to achieve statistically similar yield plateaus as corn following fallow and fertilized at AONR. Location BRM1 had terminated WCC approximately 1 month later than the other locations in 2013 (Table 3.2). The 2013-2014 growing season experienced colder than normal January temperatures (Figure 3.1) that resulted in relatively low DM yields at termination for all locations. Mean hairy vetch N content, averaged over locations was 60 and 24 kg N ha^{-1} in 2013 and 2014, respectively (Table 3.4). Carbon:N ratios were above 20 for cereal rye at BRM1, CCM1, JBE1, PDE1, and JBE2; and for RV mix at JBE1 and JBE2.

3.4.2 Corn Grain Yield

Weather conditions during both growing seasons were conducive for corn grain production (Figures 3.1 and 3.2). Year 2013 had abundant precipitation and above average corn yields throughout the study area. Winter cover crops had significant effects on corn yield at all locations except JBE1 and PDE1 (Table 3.5). Sidedress FN was significant at all locations, while WCC-by-sidedress FN interaction was only significant at BRM2 (Table 3.5). Winter cover crop-by-starter FN-by-sidedress FN interaction was not significant at all locations with exception for BRM1 (Table 3.5). When pooled over sidedress FN rates, corn grain yield differences were significant at only BRM1 and JHE1 at both starter FN rates (data not presented). At both locations corn yield following hairy vetch was significantly greater than corn yield following cereal rye. In the case of JHE2, these results may be due to N immobilization rather than N mineralization in hairy vetch plots since hairy vetch N content was only 14 kg N ha^{-1} (Table 3.4). Hairy vetch WCC biomass DM at JHE was minimized due to substantial weed competition.

Regression equations for corn grain yield as a function of sidedress FN were developed for each WCC-by-location-by-starter FN (Table 3.7). The quadratic-plus-plateau model was reported in most instances, because the model was a better fit for the data than the linear-plus-plateau model, which generally had similar yield plateau and AONR results. Hairy vetch WCC generally had higher y-intercepts and lower linear and quadratic coefficients, which indicated lower response to sidedress FN (Table 3.7). On average, hairy vetch treatments had slightly higher yield plateaus and lower AONR than cereal rye in both years (Table 3.7). Mean corn grain yield plateau was similar between RV mix and hairy vetch and had similar AONR in the first year and lower AONR in the second year (Table 3.7). Hairy vetch mean yield plateau was 0.7 and 0.6 Mg ha^{-1} higher than cereal rye for both years at zero and 45 kg ha^{-1} starter FN, respectively (Table 3.7). Mean differences in AONR between cereal rye and hairy vetch were 26 and 9 kg ha^{-1} sidedress FN at 0 and 45 kg ha^{-1} starter FN rates, respectively. At BRM1, where higher differences were expected due to high hairy vetch WCC biomass, hairy vetch yield plateau and AONR were 2.9 Mg ha^{-1} and 22 kg FN ha^{-1} higher than cereal ryes, respectively (Table 3.7). Decker et al. (1994) also observed greatest yield plateaus in legume WCC relative to small grain WCC, biculture WCC, or winter fallow. They concluded these results were due to synergistic effects of improved rainwater infiltration, moisture conservation, and increased yield potentials due to earlier improved N supply (Decker et al., 1994). Decker et al. (1994) hypothesized improved soil moisture conservation in hairy vetch treatments due to vetch's more consistent matted residue structure – especially early in the corn growing season. Clark et al.

(1997b) measured and reported higher soil moisture under hairy vetch than cereal rye residues, and included it as one of the important factors increasing corn grain yield plateau in hairy vetch relative to cereal rye treatments.

Nitrogen immobilization from cereal rye was not directly measured in this study. However, differences in corn grain yield at zero sidedress FN for both starter FN rates (delta check yield) correlated with aboveground WCC N content (data not presented). Delta check yields for both cereal rye and RV mix were positively correlated (p=0.32 and 0.11 for cereal rye and RV mix, respectively) with aboveground N content, while hairy vetch was negatively correlated (p=0.46). Although these relationships were not significant, they do indicate a relationship between biomass and responsiveness to starter FN. For cereal rye and RV mix there is a greater response to FN as WCC N content increases. However for cereal rye and RV mix, their relationship is also dependent on residue C:N ratio. Correlations between WCC DM and delta check yield for cereal rye and RV mix accounted for their respective C:N ratios and improved the model (p=0.18 and 0.06 for cereal rye and RV mix, respectively). The negative relationship observed in hairy vetch treatments is logical. Since hairy vetch has a low C:N ratio, net mineralization and reduced response to FN is expected as aboveground WCC N content increases.

Assuming 5-year average corn grain an FN prices (US\$207 Mg corn^{-1} and US\$1.11 kg FN^{-1}) and US\$20 difference in 2013 WCC seed costs (US\$30 cereal rye seed ha^{-1} and US\$50 hairy vetch seed ha^{-1}) relative net returns at BRM1 would be approximately US\$576 and US\$741 ha^{-1} higher with corn at AONR following hairy vetch than cereal rye for zero and 45 kg ha^{-1} starter FN, respectively. Mean net returns for corn following hairy vetch relative to cereal rye in 2013 and 2014 at AONR were US\$150 and US\$183 ha^{-1} at zero starter FN, and US\$86 and

US\$190 ha^{-1} at 45 kg ha^{-1} starter FN. When compared to RV mix (US\$58 RV mix seed ha^{-1}), hairy vetch relative net returns at AONR in 2013 and 2014 were US\$129 and US\$25 ha^{-1} at zero starter FN, and US\$18 and US\$74 ha^{-1} at 45 kg ha^{-1} starter FN. Interestingly, location BRM1 had the highest relative net returns and hairy vetch aboveground N content of any other location (data not presented). Similarly, Clark et al. (1997b) reported best corn grain yields when hairy vetch termination was delayed allowing time for aboveground N accumulation. Research on Maryland coastal plain soils reported best returns (US\$120 ha^{-1}) from no-till corn when following hairy vetch relative to winter wheat when receiving the same topdress FN rate (134 kg FN ha^{-1}) (Decker et al., 1994; Hanson et al., 1993). When comparing returns at respective AONR and 5-year average corn and FN prices (2009-2013), net returns of corn grain following hairy vetch was US\$270 and US\$540 ha^{-1} compared to winter wheat (US\$26 winter wheat seed ha^{-1}) and fallow (-US\$50), respectively (adapted from Decker et al. 1994). However, average hairy vetch above ground N content in the Decker et al. (1994) study was considerably higher (206 kg N ha^{-1}) than what was observed in this study.

3.4.3 Corn Nitrogen Nutrition

Corn grain N concentration response to sidedress FN was less pronounced than yield response in cereal rye and RV mix plots (Table 3.8). However, corn grain N concentration following hairy vetch had similar response as corn grain yield to sidedress FN. Corn grain N concentrations were less than the 13.1 g kg^{-1} critical concentration defined by Brouder et al. (2000) at only BRM1 in cereal rye plots with ≤90 and ≤45 kg ha^{-1} sidedress FN at zero and 45 kg ha^{-1} starter FN, respectively (Table 3.8). The only other locations where corn grain N concentration was close to the critical concentration (<14 g kg^{-1}) were CCM1, CCM2, JBE2 and JHE2; the remaining location-by-starter FN combinations had corn grain N concentrations above

14 g kg^{-1} at most sidedress FN indicating that most location-by-starter FN combinations had corn with suitable N status (Table 3.8).

Corn grain N content was more responsive to sidedress FN effects than either corn grain yield or N concentration. Cereal rye, RV mix, and hairy vetch responded to sidedress FN at 100, 88, and 88% of the locations with zero starter FN; and 88, 88, and 63% of the locations with 45 kg ha^{-1} sidedress FN, respectively. These results complement those published by Hargrove (1986) who concluded that corn grain N content was a better index to determine corn response to N. Mean corn N content for cereal rye, RV mix, and hairy vetch at zero FN (starter and sidedress) was 75, 104, and 114 kg N ha^{-1} in 2013; and 81, 96, and 109 kg N ha^{-1} in 2014, respectively (Table 3.9). These results indicate that hairy vetch supplied corn 39 and 28 kg N ha^{-1} greater than cereal rye in 2013 and 2014, respectively (Table 3.9).

Corn ear leaf N concentration in cereal rye, RV mix, and hairy vetch treatments increased with sidedress FN rates in 75, 75, and 38% of the locations with zero starter FN; and 63, 50, and 25% of the locations with 45 kg ha^{-1} sidedress FN, respectively (Table 3.10). A majority of the treatment combinations in both years had corn ear leaf N concentration less than the published critical concentration of 27.5 g kg^{-1}, which indicates that corn in most treatment combinations had below optimum N nutrition status at corn GS VT (Schepers et al., 1992). Corn following cereal rye, RV mix, and hairy vetch had corn ear leaf N concentrations above the critical concentration in 21, 34, and 45% of the location-by-starter FN-by-sidedress FN combinations, respectively (Table 3.10). Typically in cereal rye treatments, corn ear leaf N concentrations greater than the critical concentration occurred when sidedress FN rates were above 135 kg ha^{-1}, with the exception of BRM2 where N concentrations were above the critical concentration at all sidedress FN levels. Location BRM1 had corn ear leaf N concentrations below the critical concentration in cereal rye at all FN levels, which parallels their highly responsive corn yield data (Tables 3.6 and 3.10). Conversely, both RV mix and hairy vetch at BRM1 corn yield was not responsive to sidedress FN, however corn ear leaf N concentration in low sidedress FN rates were below 27.5 g kg^{-1} (Tables 3.6 and 3.10). These results are not exclusive to BRM1, similar trends where corn ear leaf N concentrations are below the critical value but corn yield data is not responsive occur at most locations (Tables 3.6 and 3.10). These results may indicate either maximum yields were not achieved in certain treatment combinations or that the corn ear leaf critical concentration is too high for our study.

3.4.4 Hairy Vetch Sidedress Fertilizer Nitrogen Credit

Corn grain yield response to sidedress FN was used to determine hairy vetch nitrogen credits since corn grain N concentration and content on average had lower R^2 and higher *p*-values. In addition, corn grain yield response to sidedress FN had more reliable AONR between WCC and starter FN combinations. Two different methods were used to estimate sidedress FN credits following hairy vetch. These methods were used to compare yield differences between hairy vetch with either cereal rye or RV mix (Table 3.12). Hairy vetch FN credit method 2 (AONR difference) is relative to AONR for cereal rye or RV mix. Hairy vetch FN credit comparison to a fallow treatment was not determined in this study since published literature indicates that corn grain yield plateaus following cereal rye WCC are similar to those following fallow (Miguez and Bollero, 2005; Tonitto et al., 2006; Utomo et al., 1990; Vaughan et al., 2000).

The AONR difference method generally had positive FN credits which indicated hairy vetch treatments required more sidedress FN to reach AONR relative to cereal rye (Table 3.12). Corn following hairy vetch WCC with applied FN credit (AONR difference method) had yield plateaus 1.4 Mg ha^{-1} higher than when following cereal rye in both 2013 and 2014, respectively (Table 3.12). When compared to RV mix these differences were 1.1 and -0.3 Mg ha^{-1}, respectively. When compared to cereal rye, highest average sidedress FN reductions were generally observed with FN replacement method at both starter FN rates in 2013 and and 45 kg ha^{-1} sidedress FN in 2014 (Table 3.12).

Table 3.13 summarizes net returns of the three FN credit methods. When compared to cereal rye, the AONR difference method provided highest net returns in all four year-by-starter FN combinations (Table 3.13). These results are due to the higher yield plateaus in hairy vetch treatments that were observed in nine out of the 16 location-by-starter FN combinations (Table 3.7). With zero starter FN, the hairy vetch FN credit (AONR difference) reduces FN by 1 and 35 kg ha^{-1}, and results in net returns of US$243 and US$117 relative to cereal rye in 2013 and 2014, respectively (Table 3.13). With 45 kg ha^{-1} starter FN, the AONR difference method increases FN in hairy vetch treatments relative to cereal rye treatments, but also results in US$238 and US$216 relative net returns in 2013 and 2014, respectively (Table 3.13). Compared to RV mix, hairy vetch FN credit trends are not consistent with respect to determination methods. Based on these results farmers should not reduce sidedress FN, because potential profits would not be met.

3.5 Conclusion

Results from this study showed that hairy vetch interseeded into standing soybeans can accumulate required DM and aboveground N content to increase corn grain yields relative to cereal rye. Corn grain yield increased with increasing sidedress FN rates in hairy vetch treatments at most locations. Therefore, instead of decreasing sidedress FN requirement, hairy vetch increased corn grain yield plateaus beyond which could be explained with addition of N (non-N rotation effect). Corn grain yield plateaus were generally in the order of hairy vetch > RV mix > cereal rye. Hairy vetch N credits were calculated using two different methods: FN replacement and AONR difference. Hairy vetch N credit varied considerably, likely due to WCC DM, N content, and C:N ratio. The AONR difference method resulted in highest relative net returns. Net returns were highest at locations with high hairy vetch DM and N content. Delayed hairy vetch termination and corn planting in normal climatic years can increase hairy vetch N contribution to corn and subsequently increase net returns when appropriate FN rates are applied. This research did not find justification for sidedress FN reductions since reduced sidedress FN lowered profits and did not reduce residual soil N following corn harvest (Chapter 2). Benefits of hairy vetch on corn grain yield appear to be directly proportional to hairy vetch aboveground DM and N content. Further research is needed to determine if similar results are obtained in abnormal climatic years. In addition, meta-analysis should be performed on larger datasets to refine hairy vetch FN credits in the mid-Atlantic region.

3.6 References

Alexandratos, N. and J. Bruinsma. 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO.

Blevins, R.L., J.H. Herbek and W.W. Frye. 1990. Legume cover crops as a nitrogen source for no-till corn and grain sorghum. Agron. J. 82: 769-772.

Brann, D.E., A.O. Abaye and P.R. Peterson. 2000. Crop description. In: D. E. Brann, D. L. Holshouser and G. L. Mullins, editors, Agronomy Handbook. Publ. no. 424-100, Virginia Coop. Ext., Blacksburg, VA. p. 1-30.

Brouder, S.M., D.B. Mengel and B.S. Hofmann. 2000. Diagnostic efficiency of the blacklayer stalk nitrate and grain nitrogen tests for corn. Agron. J. 92: 1236-1247.

Burney, J.A., S.J. Davis and D.B. Lobell. 2010. Greenhouse gas mitigation by agricultural intensification. Proc. Natl. Acad. Sci. USA. 107: 12052-12057.

Cerrato, M.E. and A.M. Blackmer. 1990. Relationships between grain nitrogen concentrations and the nitrogen status of corn. Agron. J. 82: 744-749.

Clark, A. 2007. Managing cover crops profitably. 3rd ed. Handb. Ser. Book 9. Sust. Agric. Network, Beltsville, MD.

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.

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., J.J. Meisinger, A.M. Decker and F.R. Mulford. 2007. Effects of a grass-selective herbicide in a vetch–rye cover crop system on corn grain yield and soil moisture. Agron. J. 99: 43-48.

Corak, S.J., W.W. Frye and M.S. Smith. 1991. Legume mulch and nitrogen fertilizer effects on soil water and corn production. Soil Sci. Soc. Am. J. 55: 1395-1400.

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.

Drinkwater, L.E., P. Wagoner and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396: 262-265.

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.

Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, N.D. Mueller, C. O'Connell, D.K. Ray and P.C. West. 2011. Solutions for a cultivated planet. Nature 478: 337-342.

Frye, W.W., W.G. Smith and R.J. Williams. 1985. Economics of winter cover crops as a source of nitrogen for no-till corn. J. Soil Water Conserv. 40: 246-249.

Garnett, T., M. Appleby, A. Balmford, I. Bateman, T. Benton, P. Bloomer, B. Burlingame, M. Dawkins, L. Dolan and D. Fraser. 2013. Sustainable intensification in agriculture: Premises and policies. science 341: 33-34.

Godfray, H.C.J., J.R. Beddington, I.R. Crute, L. Haddad, D. Lawrence, J.F. Muir, J. Pretty, S. Robinson, S.M. Thomas and C. Toulmin. 2010. Food security: The challenge of feeding 9 billion people. science 327: 812-818.

Hanson, J.C., E. Lichtenberg, A.M. Decker and A.J. Clark. 1993. Profitability of no-tillage corn following a hairy vetch cover crop. J. Prod. Agric. 6: 432-436.

Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no-till grain sorghum. Agron. J. 78: 70-74.

Holderbaum, J.F., A.M. Decker, J.J. Messinger, F.R. Mulford and L.R. Vough. 1990. Fall-seeded legume cover crops for no-tillage corn in the humid east. Agron. J. 82: 117-124.

Kachanoski, R., I. O'Halloran, D. Aspinall and P. Von Bertoldi. 1996. Delta yield: mapping fertilizer nitrogen requirement for crops. Better Crops Plant Food 80: 20-23.

Lory, J.A., M.P. Russelle and T.A. Peterson. 1995. A comparison of two nitrogen credit methods: traditional vs. difference. Agron. J. 87: 648-651.

Lory, J.A. and P.C. Scharf. 2003. Yield goal versus delta yield for predicting fertilizer nitrogen need in corn. Agron. J. 95: 994-999.

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.

Miguez, F.E. and G.A. Bollero. 2005. Review of corn yield response under winter cover cropping systems using meta-analytic methods. Crop Sci. 45: 2318-2329.

Ranells, N.N. and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crop monocultures and bicultures. Agron. J. 88: 777-882.

Ranells, N.N. and M.G. Wagger. 1997. Winter annual grass-legume bicultures for efficient nitrogen management in no-till corn. Agric. Ecosyst. Environ. 65: 23-32.

Roberts, R.K., J.A. Larson, D.D. Tyler, B.N. Duck and K.D. Dillivan. 1998. Economic analysis of the effects of winter cover crops on no-tillage corn yield response to applied nitrogen. J. Soil Water Conserv. 53: 280-284.

Sainju, U., W. Whitehead and B. Singh. 2003. Cover crops and nitrogen fertilization effects on soil aggregation and carbon and nitrogen pools. Can. J. Soil Sci. 83: 155-165.

Schepers, J.S., D.D. Francis, M. Vigil and F.E. Below. 1992. Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. Commun. Soil. Sci. Plant Anal. 23: 2173-2187.

Smith, M.S., W.W. Frye and J.J. Varco. 1987. Legume winter cover crops. Adv. Soil Sci. 7: 95-139.

Tilman, D., C. Balzer, J. Hill and B.L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. USA. 108: 20260-20264.

Tonitto, C., M.B. David and L.E. Drinkwater. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agric. Ecosyst. Environ. 112: 58-72.

Tyler, D., B. Duck, J. Graved and J. Bowen. 1987. Estimating response curves of legume nitrogen contribution to no-till corn. In: J. Power, editor, The role of legumes in conservation tillage systems. Soil Conserv. Soc. Am., Ankeny, IA. p. 50–51.

USDA-ERS. 2013. Average U.S. farm prices of selected fertilizers, 1960-2013. Available at http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx#26727. (verified Dec. 17, 2014). Washington, DC.

USDA-ERS. 2014. Corn, sorghum, barley, and oats: Planted acreage, harvested acreage, production, yield, and farm price. Available at http://www.ers.usda.gov/data-products/feed-grains-database/feed-grains-yearbook-tables.aspx#26766. (verified Dec. 17, 2014).

USDA-NRCS. 2008. Web soil survey. Available at http://websoilsurvey.nrcs.usda.gov/app/. (verified 10/07/2014).

Utomo, M., W.W. Frye and R.L. Blevins. 1990. Sustaining soil nitrogen for corn using hairy vetch cover crop. Agron. J. 82: 979-983.

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.

Vaughan, J.D., G.D. Hoyt and A.G. Wollum, II. 2000. Cover crop nitrogen availability to conventional and no-till corn: soil mineral nitrogen, corn nitrogen status, and corn yield. Commun. Soil Sci. Plant Anal. 31: 1017-1041.

Virginia Department of Conservation and Recreation. 2005. Virginia nutrient management standards and criteria. Richmond, VA.

Wagger, M.G. 1989. Cover crop management and nitrogen rate in relation to growth and yield of no-till corn. Agron. J. 81: 533-538.

3.7 Tables

Table 3.1. Experimental location, soil series, and select soil characteristics for experimental locations in study years 2012-2013 and 2013-2014.

Year	Location	Latitude	Longitude	Soil Series†	Surface Texture†	Drainage Class†	Hydrologic Group†	Land Capability†	Corn Productivity Group‡	Nitrogen Loss Risk‡
2012-2013	BRM1	37.66	-76.68	Bethera/Daleville	L	Poorly	C/D	4w	V	L
	CCM1	37.63	-76.68	Suffolk	LS	Well	B	1	IIIb	M
	JBE1	37.82	-76.88	Kempsville	FSL	Well	B	1	IIIa	M
	PDE1	37.81	-76.80	Kempsville	FSL	Well	B	1	IIIa	M
2013-2014	BRM2	37.67	-76.70	Bama	FSL	Well	B	2e	IIIa	M
	CCM2	37.69	-76.72	Kempsville	FSL	Well	B	1	IIIa	M
	JBE2	37.78	-76.87	Kempsville	FSL	Well	B	1	IIIa	M
	JHE2	37.79	-76.78	Atlee	SiL	Moderately well	C	2w	IIIa	L

† Published in USDA-NRCS (2008)
‡ Published in Virginia Department of Conservation and Recreation (2014)

Table 3.2. Experimental locations, agronomic significant dates, winter annual cover crop (WCC) seeding rates, WCC cultivars, and corn hybrid varieties.

Year	Location	WCC Seeding Date	Soybean Harvest Date	Corn Planting Date	WCC Termination Date	Rye Seeding Rate	RV[†] Mix (Rye Component) Seeding Rate	RV Mix (Vetch Component) Seeding Rate	Vetch Seeding Rate	Rye Cultivar	Vetch Cultivar	Corn Hybrid
						------------------------kg ha^{-1}------------------------						
2012-2013	BRM1	26-Sep	20-Nov	14-May	14-May	101	67	22	28	Abruzzi	VNS	Syngenta N68B-3111
	CCM1	14-Nov	10-Nov	18-Apr	22-Apr	101	67	22	28	Abruzzi	VNS	Pioneer 35F50AM
	JBE1	28-Sep	26-Oct	15-Apr	17-Apr	101	67	17	34	Abruzzi	VNS	Pioneer 0912HR
	PDE1	1-Oct	25-Oct	15-Apr	17-Apr	101	67	17	22	Abruzzi	VNS	Pioneer 1184HR
2013-2014	BRM2	5-Nov	22-Dec	5-May	6-May	101	67	22	28	VNS[‡]	VNS	Syngenta N68B-3111
	CCM2	18-Oct	14-Nov	14-Apr	14-Apr	101	67	22	28	VNS	VNS	Doeblers 747AM
	JBE2	14-Oct	15-Nov	21-Apr	25-Apr	101	67	17	22	VNS	VNS	Pioneer 0210HR
	JHE2	14-Oct	25-Oct	24-Apr	5-May	101	67	17	22	VNS	VNS	Pioneer 1105AM

[†] RV mix: cereal rye + hairy vetch mixture.
[‡] VNS: Variety not stated.

Table 3.3. Initial soil analysis of pH, primary Mehlich-I extractible macronutrients, KCL extractable NO_3-N and NH_4-N, total N, total C, and soil organic matter for experimental locations in study years 2012-2013 and 2013-2014.

Year	Location	pH†	P‡	K‡	NO_3-N§	NH_4-N§	Total N¶	Total C¶	Soil Organic Matter#
			-------------mg kg^{-1}-------------				----------g kg-1----------		
2012-2013	BRM1	6.7	48.5	169	5.4	3.9	0.92	9.3	17.8
	CCM1	6.3	17.3	107	3.4	5.2	0.91	11	17.5
	JBE1	6.0	11.8	116	4.2	4.6	0.94	9.1	15.8
	PDE1	6.1	15.0	135	2.9	3.4	1.1	9.9	18.5
2013-2014	BRM2	6.7	13.8	174	3.0	4.3	0.93	8.8	17.8
	CCM2	6.0	10.5	70.3	5.4	3.0	1.0	12	22.3
	JBE2	6.3	7.75	73.8	4.3	2.1	0.93	8.7	16.8
	JHE2	5.8	16.5	62.5	5.3	3.9	1.1	11	21.3

† pH: 1:1 soil:water.
‡ P and K: Mehlich I.
§ NH_4-N and NO_3-N: 2 M KCL; automated flow injection analysis.
¶ Total C and total N: dry combustion.
# Soil Organic Matter: Walkley-Black method.

Table 3.4. Least square means for winter annual cover crops (WCC) aboveground dry matter (DM) yield, N content, and C:N ratio WCC termination sampling periods for experimental locations in study years 2012-2013 and 2013-2014.

Sample period			WCC Termination					
Variable			DM yield		N Content		C:N ratio	
Year	Site	WCC	---------- kg ha^{-1}	----------				
2012-2013	BRM1	R	6254[†]	a	91	a	29	a
		RV	5000	a	150	a	16	b
		V	5088	a	146	a	14	b
	CCM1	R	779	a	14	a	22	a
		RV	922	a	19	a	19	a
		V	635	a	23	a	11	b
	JBE1	R	1532	a	21	b	27	a
		RV	1338	a	18	b	29	a
		V	1102	a	48	a	10	b
	PDE1	R	858	a	13	b	25	a
		RV	743	a	18	b	17	b
		V	633	a	24	a	11	c
2013-2014	BRM2	R	2608	ab	58	b	19	a
		RV	4591	a	153	a	13	b
		V	950	b	36	b	11	b
	CCM2	R	692	a	16	a	18	a
		RV	1179	a	37	a	13	b
		V	619	a	20	a	13	b
	JBE2	R	2887	b	40	ab	30	a
		RV	3512	a	53	a	27	a
		V	778	c	25	b	13	b
	JHE2	R	2034	a	46	a	18	b
		RV	1523	b	32	b	19	a
		V	422	c	14	c	12	c
2012-2013	Mean	R	2356		35		26	
		RV	2000		51		20	
		V	1864		60		12	
2013-2014	Mean	R	2055		40		21	
		RV	2701		69		18	
		V	692		24		12	

[†]Means within each column and location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 3.5. Analysis of variance for corn grain yield, corn grain N concentration, corn grain N content, and corn ear leaf N at eight locations.

	Corn grain yield				Corn grain N concentration				Corn grain N content				Corn ear leaf N concentration			
	2012-2013															
	BRM1	CCM1	JBE1	PDE1	BRM1	CCM1	JBE1	PDE1	BRM1	CCM1	JBE1	PDE1	BRM1	CCM1	JBE1	PDE1
wcc[†]	***	**	ns	ns	***	*	ns	ns	***	**	ns	ns	***	***	***	***
pre[‡]	***	***	**	***	ns	**	ns	ns	***	***	**	***	ns	***	ns	ns
wcc*pre	ns	*	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	**	ns	*
sdn[§]	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
wcc*sdn	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	**
pre*sdn	ns	**	ns	ns	ns	ns	ns	*	ns	**	ns	ns	*	*	ns	ns
wcc*pre*sdn	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	2013-2014															
	BRM2	CCM2	JBE2	JHE2	BRM2	CCM2	JBE2	JHE2	BRM2	CCM2	JBE2	JHE2	BRM2	CCM2	JBE2	JHE2
wcc	***	*	**	***	*	*	**	ns	***	**	**	***	***	***	*	**
pre	***	ns	***	ns	ns	**	*	ns	***	*	***	ns	ns	ns	*	ns
wcc*pre	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
sdn	***	***	***	***	**	***	***	***	***	***	***	***	ns	***	***	***
wcc*sdn	***	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
pre*sdn	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
wcc*pre*sdn	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
ns Nonsignificant at the 0.05 probability level.
[†] Winter annual cover crops.
[‡] Starter fertilizer nitrogen.
[§] Sidedress fertilizer nitrogen.

Table 3.6. Least square means for corn grain yield at eight locations, three WCC treatments, and 10 FN rates.

		Location															
WCC	Sidedress FN rate, kg ha^{-1}	BRM1				CCM1				JBE1				PDE1			
		Starter FN rate, kg ha^{-1}															
		0		45		0		45		0		45		0		45	
		Corn grain yield Mg ha^{-1}															
R	0	3.9	k†	5.5	ijk	5.4	j	6.7	hij	4.9	d	7.4	abcd	6.1	j	6.7	ij
R	45	5.2	jk	6.5	hijk	7.4	ghij	8.8	defgh	7.0	bcd	7.9	abcd	8.1	ghi	9.0	bcdefghi
R	90	6.5	ghijk	8.2	efghij	9.0	defg	10.2	abcde	8.4	abcd	11.0	ab	9.7	abcdefgh	10.2	abcde
R	135	8.8	cdefghij	10.4	abcdefgh	10.3	abcd	11.8	ab	11.7	ab	11.6	ab	10.0	abcdefg	10.5	abcd
R	179	9.9	abcdefgh	9.7	abcdefgh	11.2	abc	11.6	abc	11.9	ab	12.5	a	10.1	abcdef	11.3	a
RV	0	6.6	ghijk	8.6	defghij	6.7	hij	6.8	hij	5.9	cd	7.9	abcd	7.6	hij	8.3	efghi
RV	45	7.5	fghijk	8.8	cdefghij	8.1	efgh	10.0	abcdef	8.7	abcd	8.8	abcd	8.3	fghi	9.7	abcdefgh
RV	90	9.4	abcdefghi	9.3	bcdefghij	10.3	abcd	10.4	abcd	10.4	abc	11.2	ab	9.2	bcdefgh	10.0	abcdefg
RV	135	10.7	abcdefg	9.3	abcdefghij	11.1	abc	11.1	abc	10.2	abc	12.0	a	10.9	ab	10.2	abcdef
RV	179	8.4	efghij	12.9	abc	11.9	a	11.3	abc	10.6	abc	12.5	a	10.8	abc	10.8	abc
V	0	10.0	abcdefgh	10.3	abcdefgh	5.8	ij	7.7	ghi	7.3	abcd	8.3	abcd	7.0	ij	8.5	defghi
V	45	10.7	abcdefg	11.3	abcdef	7.7	fghi	9.7	bcdef	9.6	abcd	10.4	abc	8.8	cdefghi	9.3	abcdefgh
V	90	11.8	abcde	12.6	abcd	9.6	cdef	10.1	abcde	10.6	abc	10.8	abc	9.5	abcdefgh	10.1	abcdef
V	135	12.0	abcde	13.5	a	10.9	abcd	11.6	abc	10.9	abc	10.1	abcd	9.4	abcdefgh	11.0	ab
V	179	13.0	ab	13.8	a	12.2	a	12.5	a	10.8	ab	10.6	abc	10.7	abc	10.7	abc
		BRM2				CCM2				JBE2				JHE2			
R	0	6.0	j	7.5	ij	6.1	c	6.5	bc	5.9	ef	6.6	def	4.4	m	4.2	m
R	45	8.9	hi	10.6	efgh	7.9	abc	8.7	abc	7.9	cdef	9.1	abcd	6.7	ghijklm	6.6	hijklm
R	90	10.5	fgh	11.7	defg	9.2	abc	8.4	abc	8.3	bcdef	9.5	abcd	8.0	defghij	7.4	fghijkl
R	135	11.8	cdefg	12.7	bcdef	8.8	abc	9.6	abc	10.2	abc	11.1	abc	8.5	bcdefgh	10.2	abcde
R	179	13.1	abcd	12.4	bcdef	9.0	abc	9.6	abc	9.7	abcd	10.8	abc	10.6	abc	9.7	abcdef
RV	0	7.1	ij	10.2	gh	6.6	bc	8.2	abc	5.6	f	8.1	bcdef	5.6	ijklm	5.0	lm
RV	45	10.2	gh	11.5	defg	8.9	abc	8.6	abc	8.3	bcdef	9.1	abcde	7.2	fghijkl	8.1	cdefghi
RV	90	11.7	defg	12.6	bcdef	8.7	abc	8.6	abc	9.2	abcde	10.6	abc	9.2	abcdef	9.2	abcdef
RV	135	13.0	abcd	13.2	abcd	9.5	abc	8.1	abc	10.8	abc	11.6	ab	10.7	ab	10.6	abc
RV	179	13.6	abcd	14.1	ab	9.8	ab	9.5	abc	11.9	a	11.8	a	10.7	ab	11.1	a
V	0	9.8	gh	13.1	abcd	7.1	abc	8.0	abc	6.4	def	8.9	abcdef	5.4	klm	5.5	jklm
V	45	12.6	bcdef	12.8	bcde	8.6	abc	9.2	abc	8.6	abcdef	9.7	abcd	7.5	fghijk	7.7	efghijk
V	90	13.1	abcd	14.4	ab	9.1	abc	9.8	abc	10.7	abc	9.8	abcd	9.6	abcdef	8.4	bcdefgh
V	135	13.9	abc	14.1	ab	9.9	ab	10.3	ab	10.4	abc	11.7	ab	10.3	abcd	10.9	ab
V	179	14.2	ab	15.0	a	10.5	a	9.5	abc	10.2	abc	10.1	abcd	10.5	abcd	10.9	ab

†Means within each location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 3.7. Quadratic-plus-plateau regression variables for corn grain yield at eight locations and three winter annual cover crop (WCC) treatments.

Year	Location	WCC[†]	Yield Plateau	FN rate at Yield Plateau[‡]	Quadratic (a)	Slope (b)	Yield at FN rate=0 (c)	R^2	P-value
					Starter=0 kg FN ha^{-1}				
2013	BRM1	R	9.9	157	0.00011	0.020	3.9	0.73	***
	BRM1	RV	9.7	96	0.00030	0.003	6.7	0.34	*
	BRM1	V	12.8	179	0.00000	0.015	10.2	0.41	*
	CCM1	R	11.2	178	-0.00008	0.048	5.4	0.93	***
	CCM1	RV	11.9	165	-0.00008	0.046	6.5	0.85	***
	CCM1	V	12.2	173	-0.00007	0.050	5.6	0.88	***
	JBE1	R	11.9	141	0.00015	0.028	5.0	0.71	***
	JBE1	RV	10.4	71	0.00000	0.063	5.9	0.36	*
	JBE1	V	10.6	67	0.00010	0.034	7.9	0.23	ns
	PDE1	R	9.9	86	0.00000	0.044	6.1	0.77	***
	PDE1	RV	10.8	135	0.00012	0.008	7.6	0.75	***
	PDE1	V	9.8	67	0.00010	0.036	7.0	0.65	***
					Starter=45 kg FN ha^{-1}				
	BRM1	R	10.1	125	0.00019	0.014	5.5	0.64	***
	BRM1	RV	12.3	179	0.00010	0.005	8.2	0.47	**
	BRM1	V	13.8	147	-0.00002	0.027	10.2	0.64	***
	CCM1	R	11.6	135	-0.00005	0.042	6.9	0.85	***
	CCM1	RV	10.9	57	0.00010	0.067	6.8	0.82	***
	CCM1	V	12.2	179	-0.00006	0.035	7.9	0.79	***
	JBE1	R	13.3	172	0.00002	0.032	7.2	0.76	***
	JBE1	RV	13.3	169	0.00000	0.033	7.8	0.49	**
	JBE1	V	10.4	23	0.00000	0.095	8.3	0.09	ns
	PDE1	R	10.9	113	0.00001	0.027	7.8	0.62	***
	PDE1	RV	10.3	63	0.00010	0.026	8.3	0.54	**
	PDE1	V	10.8	130	0.00001	0.018	8.5	0.67	***
					Starter=0 kg FN ha^{-1}				
2014	BRM2	R	13.0	179	-0.00012	0.060	6.2	0.95	***
	BRM2	RV	13.1	165	-0.00022	0.073	7.1	0.84	***
	BRM2	V	13.7	62	0.00000	0.063	9.8	0.78	***
	CCM2	R	9.0	69	0.00010	0.034	6.1	0.45	**
	CCM2	RV	9.3	53	0.00010	0.045	6.6	0.54	**
	CCM2	V	10.5	179	-0.00006	0.028	7.2	0.36	*
	JBE2	R	9.7	135	0.00000	0.025	6.4	0.55	**
	JBE2	RV	11.9	179	-0.00008	0.048	5.8	0.93	***
	JBE2	V	10.4	76	0.00010	0.047	6.3	0.45	**
	JHE2	R	10.5	179	-0.00004	0.039	4.6	0.83	***
	JHE2	RV	10.7	118	0.00010	0.032	5.6	0.88	***
	JHE2	V	10.4	108	-0.00002	0.049	5.4	0.91	***
					Starter=45 kg FN ha^{-1}				
	BRM2	R	12.2	67	0.00010	0.064	7.5	0.79	***
	BRM2	RV	14.1	174	-0.00004	0.030	10.1	0.73	***
	BRM2	V	15.0	160	0.00020	-0.020	13.1	0.28	ns
	CCM2	R	9.2	54	0.00010	0.045	6.5	0.40	*
	CCM2	RV	9.0	179	0.00000	0.005	8.1	0.07	ns
	CCM2	V	9.9	75	0.00000	0.023	8.1	0.19	ns
	JBE2	R	10.6	135	-0.00013	0.046	6.8	0.65	***
	JBE2	RV	11.8	142	0.00001	0.025	8.1	0.64	***
	JBE2	V	9.6	4	0.00010	0.176	8.9	0.01	ns
	JHE2	R	9.8	135	0.00010	0.025	4.7	0.86	***
	JHE2	RV	10.6	168	-0.00019	0.065	5.1	0.84	***
	JHE2	V	10.9	140	0.00003	0.033	5.7	0.80	***

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

ns Nonsignificant at the 0.05 probability level.

[†] WCC: cereal rye (R), cereal rye + hairy vetch mixture (RV), hairy vetch (V).

[‡] Agronomic optimum sidedress FN rate (AONR)

Table 3.8. Least square means for corn grain N concentration at eight locations, three WCC treatments, and 10 FN rates.

WCC	Sidedress FN rate, kg ha^{-1}	BRM1 Starter 0	BRM1 Starter 45	CCM1 Starter 0	CCM1 Starter 45	JBE1 Starter 0	JBE1 Starter 45	PDE1 Starter 0	PDE1 Starter 45
		Corn grain N concentration g kg^{-1}							
R	0	12.9 ef†	12.7 f	14.3 de	14.4 de	14.4 c	15.3 abc	16.3 cde	16.7 abcde
R	45	12.6 f	12.5 f	14.4 de	14.9 abcde	15.7 abc	14.9 abc	16.4 bcde	17.6 abcde
R	90	13.0 def	13.6 cdef	14.4 de	15.7 abcde	14.6 bc	15.4 abc	16.7 abcde	17.4 abcde
R	135	15.4 abcdef	14.2 bcdef	15.8 abcde	17.3 a	16.8 abc	16.6 abc	18.8 abcde	18.4 abcde
R	179	15.0 abcdef	14.6 abcdef	16.3 abcd	17.0 ab	17.8 a	17.6 ab	19.0 abcde	19.5 abc
RV	0	14.7 abcdef	14.5 abcdef	15.5 abcde	14.7 cde	14.2 c	14.8 bc	17.6 abcde	16.6 bcde
RV	45	13.6 cdef	14.7 abcdef	15.3 abcde	16.5 abcd	14.9 abc	16.0 abc	16.2 cde	17.2 abcde
RV	90	14.8 abcdef	15.0 abcdef	15.2 abcde	15.8 abcde	15.5 abc	15.9 abc	16.4 bcde	17.3 abcde
RV	135	16.0 abcdef	16.5 abcdef	15.8 abcde	16.5 abcd	16.3 abc	17.5 ab	19.6 ab	18.9 abcde
RV	179	16.6 abcde	17.4 abc	17.1 ab	17.0 ab	17.6 ab	17.3 abc	19.2 abcd	20.0 a
V	0	14.7 abcdef	15.4 abcdef	13.4 e	13.7 e	15.5 abc	14.9 abc	16.6 bcde	15.9 e
V	45	16.4 abcdef	16.9 abcd	14.8 bcde	15.3 abcde	14.9 abc	15.7 abc	16.1 de	17.2 abcde
V	90	16.9 abcd	17.6 ab	14.9 abcde	16.1 abcde	15.9 abc	16.3 abc	17.0 abcde	18.0 abcde
V	135	15.9 abcdef	17.3 abcd	16.4 abcd	16.1 abcde	16.0 abc	17.3 abc	20.0 a	18.6 abcde
V	179	17.9 ab	18.3 a	16.8 abc	16.3 abcd	16.2 abc	16.9 abc	20.1 a	20.2 a
		BRM2 0	BRM2 45	CCM2 0	CCM2 45	JBE2 0	JBE2 45	JHE2 0	JHE2 45
R	0	16.5 a	18.3 a	13.4 f	14.0 ef	13.2 d	13.6 bcd	14.4 cde	14.8 bcde
R	45	15.8 a	15.7 a	15.0 bcdef	15.2 bcdef	14.3 bcd	13.4 cd	14.0 de	14.8 bcde
R	90	16 a	18.9 a	15.4 abcdef	15.8 abcdef	13.5 bcd	15.3 abcd	15.7 abcde	14.8 bcde
R	135	17.6 a	20.9 a	17.0 abcdef	17.4 abcde	15.2 abcd	15.2 abcd	17.7 abc	16.4 abcde
R	179	18.7 a	20.7 a	17.6 abcde	17.8 abcde	15.9 abcd	17.1 ab	15.9 abcde	17.9 ab
RV	0	17.2 a	16.4 a	15.3 abcdef	14.5 def	13.4 cd	13.8 bcd	14.9 bcde	14.2 de
RV	45	19.8 a	17.1 a	15.2 bcdef	16.4 abcdef	13.9 bcd	14.2 bcd	14.8 bcde	14.8 bcde
RV	90	18.9 a	18.5 a	17.1 abcdef	16.7 abcdef	15.2 abcd	15.0 abcd	14.8 bcde	15.3 abcde
RV	135	17.7 a	19.3 a	17.2 abcdef	18.5 ab	15.6 abcd	16.0 abc	18.3 a	17.1 abcd
RV	179	20.9 a	18.5 a	18.0 abcd	19.1 ab	16.2 ab	15.9 abc	16.6 abcde	17.5 abc
V	0	18.6 a	19.2 a	13.2 f	14.5 def	13.8 bcd	13.9 bcd	13.9 de	13.7 e
V	45	18.3 a	19.5 a	14.9 cdef	16.1 abcdef	13.8 bcd	15.8 abcd	13.6 e	14.8 bcde
V	90	19.1 a	19.0 a	15.7 abcdef	18.3 abc	14.7 abcd	15.7 abcd	15.3 abcde	14.8 bcde
V	135	18.8 a	20.5 a	17.0 abcdef	18.1 abcd	16.1 ab	15.5 abcd	16.0 abcde	15.6 abcde
V	179	19.1 a	20.1 a	17.3 abcde	19.3 a	16.2 ab	17.1 a	16.6 abc	17.8 abc

†Means within each location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 3.9. Least square means for corn grain N content at eight locations, three WCC treatments, and 10 FN rates.

		Location															
WCC	Sidedress FN rate, kg ha-1	BRM1				CCM1				JBE1				PDE1			
		Starter FN rate, kg ha-1															
		0		45		0		45		0		45		0		45	
		Corn grain N content kg ha-1															
R	0	51	j†	69	hij	78	i	97	hi	69	e	114	bcde	100	i	110	hi
R	45	67	ij	81	ghij	106	hi	132	fgh	110	cde	118	bcde	135	fghi	158	bcdefghi
R	90	86	ghij	111	fghij	130	fgh	160	cdef	122	bcde	169	abcd	160	bcdefgh	179	abcdefg
R	135	134	efghi	149	cdefgh	162	bcdef	204	a	196	abc	193	abc	188	abcdef	193	abcd
R	179	150	cdefgh	143	defghi	183	abcde	197	abc	212	ab	222	a	192	abcde	221	a
RV	0	97	fghij	124	efghij	104	hi	99	hi	83	de	118	bcde	133	ghi	138	efghi
RV	45	102	fghij	133	efghi	124	fgh	165	abcdef	129	abcde	140	abcde	134	fghi	167	abcdefgh
RV	90	141	efghi	140	efghi	156	def	165	abcdef	161	abcd	178	abc	151	cdefghi	173	abcdefg
RV	135	172	bcdef	154	bcdefgh	176	abcde	183	abcde	169	abcd	211	ab	214	ab	192	abcde
RV	179	135	efghi	224	abc	202	ab	192	abdc	185	abc	217	ab	208	ab	216	ab
V	0	148	cdefgh	158	bcdefg	77	i	105	hi	114	bcde	122	bcde	116	hi	134	fghi
V	45	178	abcdef	193	abcde	112	ghi	149	efg	143	abcde	163	abcd	141	defghi	159	bcdefgh
V	90	199	abcde	221	abcd	132	fgh	164	abcdef	169	abcd	177	abc	161	bcdefgh	182	abcdefg
V	135	192	abcde	233	ab	181	abcde	186	abcde	174	abcd	173	abcd	187	abcdefg	204	abc
V	179	232	ab	253	a	205	a	202	abc	177	abc	179	abc	216	ab	216	ab
		BRM2				CCM2				JBE2				JHE2			
R	0	100	i	137	ghi	82	f	91	ef	78	f	90	ef	63	jk	62	k
R	45	140	ghi	168	efghi	118	abcdfe	132	abcdfe	113	def	123	cdef	94	ghijk	97	fghijk
R	90	166	efghi	222	bcdef	141	abcdfe	132	abcdfe	120	cdef	145	abcde	125	cdefgh	110	fghijk
R	135	208	cdefg	263	abc	147	abcde	167	abc	155	abcd	168	abcd	149	abcdef	167	abcd
R	179	245	abcde	256	abcd	156	abcd	170	ab	161	abcd	173	abc	167	abcd	173	abc
RV	0	124	hi	165	fghi	101	cdef	118	bcdef	75	f	113	def	83	hijk	70	ijk
RV	45	202	cdefg	194	cdefgh	136	abcdfe	140	abcdfe	115	cdef	129	bcdef	107	fghijk	120	defghi
RV	90	222	bcdef	233	abcdef	148	abcde	146	abcdfe	140	abcde	159	abcd	136	bcdefg	141	bcdefg
RV	135	229	abcdef	256	abcd	165	abcd	148	abcde	168	abcd	184	ab	213	a	180	ab
RV	179	286	ab	261	abc	176	ab	185	a	193	a	187	ab	175	abc	194	a
V	0	182	defgh	251	abcd	93	def	130	abcdfe	86	ef	124	cdef	74	hijk	76	hijk
V	45	231	abcdef	248	abcd	128	abcdfe	146	abcde	119	cdef	151	abcd	102	fghijk	114	efghij
V	90	250	abcd	241	abc	142	abcdfe	179	ab	158	abcd	155	abcd	147	abcdef	125	cdefgh
V	135	260	abc	289	ab	167	abc	182	a	166	abcd	189	ab	166	abcde	181	ab
V	179	270	abc	301	a	205	a	183	a	166	abcd	172	abc	173	abc	194	a

†Means within each location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 3.10. Least square means for corn ear leaf N concentration at eight locations, three WCC treatments, and 10 FN rates.

		Location															
		BRM1				CCM1				JBE1				PDE1			
		Starter FN rate, kg ha^{-1}															
WCC	Sidedress FN rate, kg ha^{-1}	0		45		0		45		0		45		0		45	
		Corn ear leaf nitrogen concentration g kg^{-1}															
R	0	16.6	f[†]	18.5	ef	14.5	g	17.4	fg	16.1	g	17.6	efg	19.7	d	24.3	bcd
R	45	21.6	cdef	18.8	ef	19.1	defg	19.5	cdefg	18.4	defg	20.7	abcdefg	23.2	cd	26.1	abcd
R	90	23.7	abcdef	22.6	bcdef	20.9	bcdef	24.9	abc	21.3	abcdefg	20.6	abcdefg	24.7	abcd	27.4	abcd
R	135	24.7	abcde	23.3	abcdef	23.8	abcde	23.7	abcde	22.9	abcdef	22.6	abcdef	28.8	abc	28.3	abc
R	179	23.6	abcdef	24.3	abcde	22.9	abcdef	28.1	a	23.4	abcde	25.7	abc	28.3	abc	29.9	abc
RV	0	20.8	def	24.7	abcde	18.5	efg	19.4	defg	16.6	fg	20.2	bcdefg	26.3	abcd	25.9	abcd
RV	45	23.5	abcdef	23.0	bcdef	19.6	cdefg	22.2	abcdef	21.8	abcdefg	22.8	abcdef	26.6	abcd	26.0	abcd
RV	90	27.7	abcd	25.7	abcde	24.7	abcd	23.6	abcde	23.2	abcde	24.5	abcd	29.3	abc	30.2	abc
RV	135	27.8	abcd	26.5	abcde	26.7	ab	22.6	abcdef	26.8	a	26.0	ab	30.2	abc	31.7	ab
RV	179	28.8	abcd	29.7	ab	26.2	ab	26.0	ab	26.2	ab	25.5	abc	32.8	a	32.4	ab
V	0	23.4	abcdef	27.4	abcd	18.4	defg	21.8	bcdef	19.9	bcdefg	19.5	cdefg	27.4	abcd	30.9	abc
V	45	26.6	abcd	28.0	abcd	20.5	bcdef	24.6	abcd	23.9	abcd	22.2	abcdefg	31.0	abc	23.5	bcd
V	90	30.9	a	29.7	ab	23.0	abcd	24.1	abcde	23.0	abcde	25.2	abc	32.8	a	31.2	abc
V	135	28.9	abcd	28.5	abcd	23.9	abcde	25.7	ab	23.2	abcde	24.9	abc	28.2	abc	26.8	abcd
V	179	29.9	ab	29.2	abc	24.5	abcd	27.0	ab	24.8	abc	23.3	abcde	31.3	abc	28.1	abc
		BRM2				CCM2				JBE2				JHE2			
R	0	27.6	a	28.3	a	20.5	hi	20.3	i	16.9	g	20.9	efg	13.2	k	13.9	ijk
R	45	28.2	a	25.8	a	23.2	ghi	24.3	fghi	25.2	bcdef	24.4	bcdefg	18.3	defghijk	19.2	bcdefghij
R	90	27.7	a	30.3	a	26.1	efgh	24.4	fghi	27.3	abcde	27.8	abcde	20.8	abcdefgh	18.7	cdefghijk
R	135	26.8	a	29.7	a	26.5	defg	26.6	defg	27.9	abcd	30.3	ab	22.6	abcde	25.8	a
R	179	30.0	a	28.0	a	25.8	efghi	26.8	cdefg	32.7	a	30.2	ab	24.1	abcd	22.8	abcde
RV	0	31.1	a	25.8	a	22.3	ghi	24.7	fghi	17.6	g	19.3	fg	13.4	jk	15.0	hijk
RV	45	29.5	a	28.6	a	25.6	efghi	27.1	bcdefg	23.7	bcdefg	22.2	cdefg	19.5	bcdefghi	21.2	abcdefg
RV	90	27.9	a	30.3	a	27.2	bcdefg	29.7	abcdef	28.1	abcd	25.7	bcdef	21.6	abcdef	24.0	abcd
RV	135	30.5	a	29.4	a	29.7	abcdef	29.0	abcdef	26.5	abcde	28.8	abc	24.0	abcd	24.4	abc
RV	179	29.9	a	31.6	a	29.5	abcdef	31.1	abcde	27.7	abcde	26.8	abcde	23.3	abcde	26.0	a
V	0	32.2	a	31.7	a	27.0	bcdefg	27.1	bcdefg	19.1	fg	21.2	defg	15.4	ghijk	15.9	fghijk
V	45	30.9	a	30.2	a	30.9	abcde	32.6	ab	22.0	cdefg	26.3	abcde	21.2	abcdefg	17.9	efghijk
V	90	29.0	a	31.2	a	32.0	abcd	32.9	ab	25.0	bcdef	26.6	abcde	24.0	abcd	21.2	abcdefg
V	135	29.7	a	32.2	a	32.2	abcd	31.3	abcde	27.9	abcd	29.2	ab	24.7	abc	24.8	ab
V	179	32.5	a	30.5	a	33.8	a	32.5	abc	27.7	abcde	30.4	ab	23.0	abcde	24.7	ab

[†]Means within each location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 3.11. Quadratic-plus-plateau regression variables for corn grain nitrogen concentration at eight locations and three winter annual cover crop (WCC) treatments.

Year	Location	WCC†	Yield Plateau	FN rate at Plateau	Quadratic (a)	Slope (b)	Yield at FN rate=0 (c)	R^2	P-value
					Starter=0 kg FN ha^{-1}				
2013	BRM1	R	14.9	135	0.00028	-0.023	12.9	0.56	**
	BRM1	RV	16.6	145	0.00028	-0.028	14.6	0.28	ns
	BRM1	V	16.9	55	0.00010	0.035	14.7	0.29	ns
	CCM1	R	16.3	151	0.00017	-0.013	14.4	0.55	**
	CCM1	RV	18.2	179	0.00014	-0.017	15.6	0.70	***
	CCM1	V	16.8	155	0.00009	0.007	13.7	0.64	***
	JBE1	R	17.8	178	0.00009	0.001	14.6	0.58	***
	JBE1	RV	17.6	179	0.00006	0.008	14.3	0.63	***
	JBE1	V	16.1	96	0.00039	-0.031	15.5	0.22	ns
	PDE1	R	19.0	141	0.00022	-0.014	16.4	0.53	**
	PDE1	RV	19.2	135	0.00052	-0.059	17.7	0.67	***
	PDE1	V	20.5	142	0.00043	-0.034	16.6	0.71	***
					Starter=45 kg FN ha^{-1}				
	BRM1	R	14.4	111	0.00029	-0.017	12.7	0.54	**
	BRM1	RV	17.4	162	0.00014	-0.005	14.5	0.40	**
	BRM1	V	17.7	69	0.00000	0.034	15.4	0.30	**
	CCM1	R	17.0	135	0.00010	0.005	14.6	0.70	***
	CCM1	RV	16.4	26	0.00010	0.065	14.7	0.45	**
	CCM1	V	16.1	67	0.00010	0.025	14.0	0.49	**
	JBE1	R	17.6	157	0.00020	-0.017	15.3	0.37	*
	JBE1	RV	17.3	135	0.00005	0.010	15.0	0.43	**
	JBE1	V	17.0	135	0.00000	0.015	15.0	0.59	***
	PDE1	R	20.0	179	0.00006	0.004	16.8	0.44	**
	PDE1	RV	20.2	179	0.00009	0.003	16.7	0.46	**
	PDE1	V	20.2	179	0.00001	0.020	16.0	0.76	***
					Starter=0 kg FN ha^{-1}				
2014	BRM2	R	18.1	87	0.00079	-0.051	16.5	0.11	ns
	BRM2	RV	19.3	22	0.00010	0.094	17.2	0.15	ns
	BRM2	V	18.8	0	0.00000	-0.006	18.4	0.00	*
	CCM2	R	17.6	161	0.00001	0.024	13.5	0.48	**
	CCM2	RV	17.7	100	0.00047	-0.023	15.3	0.59	***
	CCM2	V	17.3	153	-0.00004	0.033	13.3	0.66	***
	JBE2	R	16.8	183	0.00002	0.016	13.1	0.41	**
	JBE2	RV	16.2	162	-0.00001	0.019	13.3	0.62	***
	JBE2	V	16.2	137	0.00017	-0.005	13.7	0.75	***
	JHE2	R	16.8	105	0.00054	-0.035	14.4	0.39	**
	JHE2	RV	17.0	135	0.00010	0.005	14.6	0.37	**
	JHE2	V	16.6	148	0.00013	0.000	13.8	0.56	**
					Starter=45 kg FN ha^{-1}				
	BRM2	R	20.8	102	0.00144	-0.123	18.3	0.41	**
	BRM2	RV	18.9	100	0.00016	0.009	16.4	0.27	ns
	BRM2	V	19.9	74	0.00010	0.001	19.2	0.04	ns
	CCM2	R	17.8	149	0.00006	0.016	14.1	0.71	***
	CCM2	RV	19.0	162	-0.00003	0.031	14.7	0.60	***
	CCM2	V	18.7	95	0.00056	-0.027	16.1	0.23	ns
	JBE2	R	16.2	178	0.00002	0.012	13.4	0.41	**
	JBE2	RV	15.9	127	0.00010	0.004	13.8	0.61	***
	JBE2	V	16.9	179	-0.00003	0.018	14.3	0.40	**
	JHE2	R	17.9	169	0.00020	-0.015	14.8	0.62	***
	JHE2	RV	17.5	147	0.00014	0.001	14.3	0.61	***
	JHE2	V	17.8	171	0.00009	0.007	14	0.57	***

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
ns Nonsignificant at the 0.05 probability level.
† WCC: cereal rye (R), cereal rye + hairy vetch mixture (RV), hairy vetch (V).

Table 3.12. Hairy vetch N credit relative to corn grain yield following cereal rye and RV mix using FN replacement and AONR difference methods.

	Location	HV N Content	FN Replacement (Method 1)[†]		AONR Difference (Method 2)[‡]		FN Replacement (Method 1)[†]		AONR Difference (Method 2)[‡]		Model
WCC		kg ha^{-1}	----------------R----------------				----------------------RV----------------------				
Year						Starter FN=0 kg ha^{-1}					
2013	BRM1	146	-157[§]	(0.2)[¶]	22	(2.9)	-96	(0.3)	83	(3.1)	#
	CCM1	23	-4	(1.0)	-5	(1.0)	20	(0.3)	8	(0.3)	#
	JBE1	48	ns	ns	ns	ns	ns	ns	ns	ns	ns
	PDE1	24	-20	(-0.1)	-20	(-0.1)	-46	(-1.0)	-68	(-1.0)	#
						Starter FN=45 kg ha^{-1}					
	BRM1	146	-125	(-0.1)	22	(3.7)	-120	(-0.5)	-32	(1.6)	#
	CCM1	23	-26	(-0.7)	48	(0.6)	-16	(-1.7)	126	(1.3)	#
	JBE1	48	ns	ns	ns	ns	ns	ns	ns	ns	ns
	PDE1	24	-26	(-0.9)	16	(-0.1)	-6	(-0.8)	67	(0.5)	#
						Starter FN=0 kg ha^{-1}					
2014	BRM2	36	-71	(0.7)	-120	(0.5)	-43	(0.6)	-103	(0.6)	#
	CCM2	20	-29	(-0.7)	118	(1.5)	-12	(-1.0)	134	(1.2)	#
	JBE2	25	-6	(0.7)	-54	(0.6)	-7	(-1.5)	-81	(-1.5)	††
	JHE2	14	-20	(-0.1)	-84	(-0.7)	6	(-0.3)	-10	(-0.3)	#
						Starter FN=45 kg ha^{-1}					
	BRM2	36	-67	(0.4)	110	(2.5)	-107	(0.7)	19	(-0.8)	††
	CCM2	20	ns	ns	ns	ns	ns	ns	ns	ns	ns
	JBE2	25	ns	ns	ns	ns	ns	ns	ns	ns	ns
	JHE2	14	-36	(-1.3)	5	(0.4)	-8	(0.3)	-29	(0.3)	#
Year						Starter FN=0 kg ha^{-1}					
2013	Mean	60	-60	(0.4)	-1	(1.3)	-43	(-0.1)	8	(0.6)	
2014	Mean	24	-31	(0.1)	-35	(0.5)	-14	(-0.6)	-15	(0.0)	
						Starter FN=45 kg ha^{-1}					
2013	Mean	60	-60	(-0.5)	29	(1.4)	-48	(-1.0)	54	(1.1)	
2014	Mean	24	-56	(-0.5)	57	(1.4)	-58	(0.5)	-5	(-0.3)	

[†] FN replacement method determined by solving cereal rye N response regression equation by substituting hairy vetch y-int value for f(x).

[‡] AONR difference method determined by subtracting AONR of corn following hairy vetch from corn following cereal rye.

[§] Negative values represent FN reductions to corn following hairy vetch relative to either cereal rye or RV mix (hairy vetch N credit).

[¶] Difference in corn grain yield in hairy vetch treatments when hairy vetch N credit is applied relative to cereal rye or RV mix yield plateau.

[#] Quadratic-plus-plateau model.

†† Linear-plus-plateau model.

ns Both models nonsignificant at the 0.05 probability level.

Table 3.13. Net returns (US$) of corn following hairy vetch with applied hairy vetch N credit methods relative to corn grain plateau yields following either cereal rye or RV mix.

	Location	HV N Content	FN Replacement (Method 1)	AONR Difference (Method 2)	FN Replacement (Method 1)	AONR Difference (Method 2)	Model
WCC			----------R----------		----------RV----------		
Year				Starter FN=0 kg ha^{-1}			
2013	BRM1	146	196	556	184	558	#
	CCM1	23	191	193	48	61	#
	JBE1	48	ns	ns	ns	ns	ns
	PDE1	24	-19	-19	-148	-124	#
				Starter FN=45 kg ha^{-1}			
	BRM1	146	98	721	38	375	#
	CCM1	23	-136	51	-326	137	#
	JBE1	48	ns	ns	ns	ns	ns
	PDE1	24	-177	-58	-151	37	#
				Starter FN=0 kg ha^{-1}			
2014	BRM2	36	204	217	180	247	#
	CCM2	20	-133	160	-186	108	#
	JBE2	25	132	164	-295	-213	††
	JHE2	14	-19	-72	-61	-43	#
				Starter FN=45 kg ha^{-1}			
	BRM2	36	137	375	272	-179	††
	CCM2	20	ns	ns	ns	ns	ns
	JBE2	25	ns	ns	ns	ns	ns
	JHE2	14	-249	57	79	102	#
Year				Starter FN=0 kg ha^{-1}			
2013	Mean	60	123	243	28	165	
2014	Mean	24	46	117	-90	25	
				Starter FN=45 kg ha^{-1}			
2013	Mean	60	-71	238	-146	183	
2014	Mean	24	-51	216	175	-38	

† Net returns calculated with 5-year average corn price=US$207 Mg^{-1}; 5-year average FN=US$1.11 kg^{-1}; cereal rye seed=US$30 ha^{-1}; hairy vetch seed=US$50 ha^{-1}; RV mix seed=US$58 ha^{-1}.

Quadratic-plus-plateau model.

†† Linear-plus-plateau model.

ns Nonsignificant at the 0.05 probability level.

3.8 Figures

Figure 3.1. 2012-2013 and 2013-2012 and 30 year monthly mean temperature for Tappahannock, VA.

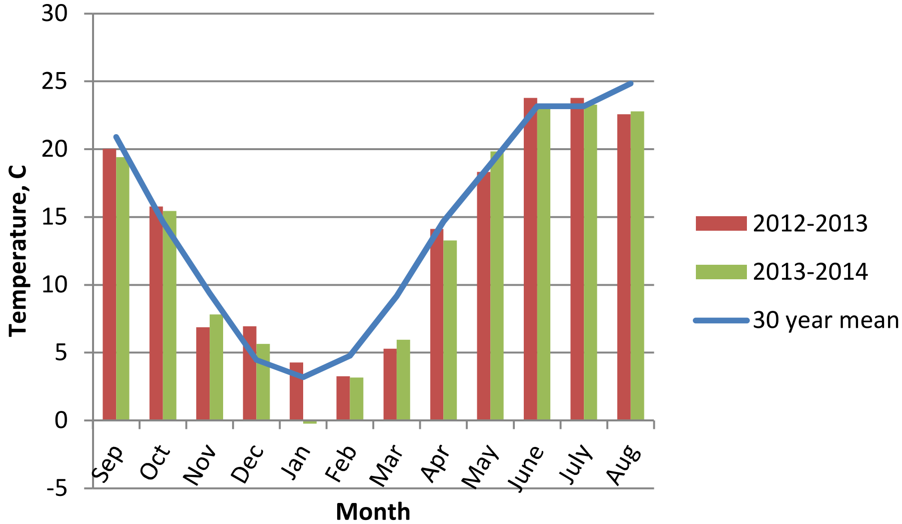
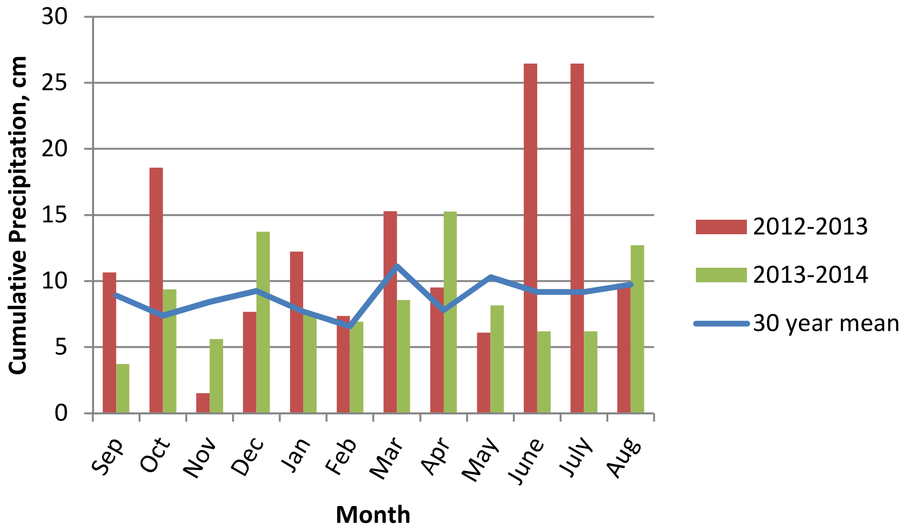


Figure 3.2. 2012-2013 and 2013-2012 and 30 year monthly cumulative precipitation for Tappahannock, VA.



4. Winter Annual Cover Crops Interseeded into Soybean in Eastern Virginia: Influence on In-season Soil Nitrogen Tests for Corn.

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4.1 Abstract

Environmental and economic goals have encouraged the use of soil nitrogen (N) tests to improve fertilizer N (FN) management in corn (*Zea mays* L.). However, many producers still rely on expected yields for FN management instead of in-season soil N tests. Recent attention has been given to the Solvita® 1-day CO_2 burst test as an alternative tool for FN recommendations based on soil potentially mineralizable N (PMN). Our objective is to evaluate the Solvita® test and compare it with the already calibrated presidedress nitrate test (PSNT) in a typical crop rotation in the mid-Atlantic coastal plain that includes winter annual cover crops (WCC). Winter annual cover crop effects were observed at 1:8, 0:8, 4:8, and 2:8 locations for preplant Solvita®, V4 Solvita®, and V4 NO_3-N at 0-15 and 0-30 cm, respectively. Coefficient of determination for soil N test parameters relationship with relative corn yields were 0.33, 0.25, 0.28, and 0.27; for preplant Solvita®, V4 Solvita®, and V4 NO_3-N at 0-15 and 0-30 cm, respectively. Both V4 NO_3-N at 0-15 and 0-30 cm were positively correlated with corn check yields (R^2=0.45 respectively). Solvita® did not provide additional information relative to either PSNT. The advantages observed for the Solvita® test was its simplicity, speed of analysis, and lower CV relative to the standard PSNT (V4 NO_3-N at 0-30 cm). The V4 NO_3-N at 0-15 cm appears to be a better test for no-till corn following legume WCC.

4.2 Introduction

Improving corn fertilizer nitrogen (FN) rate recommendations has economic and environmental implications. Unfortunately, corn producers in eastern Virginia have few reliable soil-based options to predict adjustments to sidedress FN rates. The PSNT is a valuable tool to measure soil NO_3-N immediately before maximum corn growth and N uptake. Presidedress NO_3-N concentrations above 20 mg NO_3-N kg^{-1} are adequate to meet corn N requirements in most instances (Evanylo and Alley, 1997). The PSNT has been successfully used by producers who apply manures or have soils with high levels of soil organic matter (SOM). Most corn producers in eastern Virginia have coarse textured soils with low SOM, and often forgo the PSNT and rely on past experiences and yield goals to determine FN rates.

Use of the PSNT was shown to increase profits associated with lower fertilizer inputs while maintaining optimum yields (Babcock and Blackmer, 1992; Musser et al., 1995). However, increased profits are often modest and may not offset the burden of additional tasks when time may be better spent on other profit driven activities (i.e., soybean planting). The PSNT requires soil sampling, analysis, fertilizer procurement, and application to occur within a narrow window of approximately two weeks. In addition, some grain producers lack confidence in the PSNT due to confounding results. Occasionally residual soil NO_3-N may be lost after PSNT sampling which can cause inaccurate sidedress FN recommendations (Magdoff, 1991). In addition, plant available nitrogen (PAN) supplied by legume WCC may not be fully released by PSNT sampling time. It takes approximately 8 weeks for the majority of hairy vetch (*Vicia villosa* Roth subsp. *villosa*) aboveground N to become plant available (Ranells and Wagger, 1996) and PSNT sampling typically occurs 4-6 weeks after corn planting (and likely WCC termination). The dynamic nature of soil N and the practicality of the PSNT have spurred research and development for alternative tests with a faster turnaround time and more precise results.

Haney et al. (2008a) developed a simple indirect method that measures CO_2 respiration after 24 hours (Haney-Brinton method). Haney et al. (2008b) reported that the Solvita® 1-day CO_2 burst method was highly correlated to a 28-day aerobic N mineralization incubation (R^2=0.82). The Solvita® test uses a patented gel paddle to detect the flush of CO_2 after rewetting and is inferred to simulate microbial respiration after natural soil drying and rewetting. Bundy and Meisinger (1994) hypothesized that dried, sieved, and rewetted samples may increase microbial activity and overestimate mineralizable N concentrations in no-till soil. Conversely, Franzluebbers (1999) concluded that dried composite soil samples are more practical and do not bias results with regard to microbial biomass or activity in southeastern U.S. soils.

Biological based soil tests have increasingly gained attention by grain producers and regulators since the late 1990's. The USDA-NRCS soil quality test kit includes a microbial respiration component, which Solvita® is alternatively referenced (USDA-NRCS, 2001). More recently, the Solvita® test in conjunction with water extractable organic carbon (C) and N have been promoted to calculate PMN that may be available to a summer cash crop (Woods End Laboratory, 2014). However, calibration of the Solvita® in Virginia has yet to be performed. Consequently, FN recommendations based on Solvita® recommendations to no-till corn in the diverse cropping systems common to eastern Virginia must be investigated. Our objective was to compare the Solvita® 1-day burst test with the PSNT for establishing corn FN recommendations.

4.3 Materials and Methods

4.3.1 Experimental Design

Research was conducted at four locations in 2012-2013 and at four different locations in 2013-2014 in the Virginia coastal plain region in USDA hardiness zone 7b. Average annual temperature of the region is 14°C and precipitation is 112 cm yr^{-1}. Location coordinates and soil physical descriptions are listed in table 4.1. All locations, with exception to JHE2, were in no-till corn–winter wheat or barley/double-crop soybean rotation. Location JHE2 was in corn–small grain WCC–full season soybean rotation. Winter cover crops were interseeded into standing soybean, with the exception of CCM1 which was broadcast seeded shortly after soybean harvest (Table 4.2).

The experimental design was a split-plot with four replications at each location. Three WCC treatments were main plots and ten corn FN rates were subplots. Main plots were seeded with cereal rye, hairy vetch, and winter rye-hairy vetch mix WCC. Seeding rates, agronomic relevant dates, and WCC and corn hybrid varieties are listed in table 2.2. Subplots received two starter FN (0 or 45 kg FN ha^{-1}) and five sidedress FN rates arranged in a full factorial. Fertilizer N rates were in increments of 45 kg FN ha^{-1} (0, 45, 90, 135, and 180 kg FN ha^{-1}) as liquid ammonium nitrate (UAN) dribble banded 5 cm to the side of the furrow or between corn rows at planting and sidedress, respectively. Main plots were 75 x 15 m; subplots were 9 m length by 4 rows (3.1 m). Production practices followed recommendations of Virginia Cooperative Extension (Brann et al., 2000).

4.3.2 Sample Analysis

Composite soil samples were collected to depths of 0-15 cm using a 1.9 cm diameter probe from each experimental unit at all locations prior to cover crop seeding, at cover crop termination, and at corn growth stage V4 (0-15 and 0-30 cm). Soil samples were either dried at 40°C in a forced air oven or at ambient air temperature, depending on the analysis performed. Dried soil was sieved through a 2 mm screen prior to analysis. Initial soil samples were further processed using pestle and mortar for analysis of total C (TC) and N (TN) by dry combustion (VarioMax CNS macro elemental analyzer, Elementar, Hanau, Germany). Routine soil tests were also conducted by the Virginia Tech soil testing laboratory in the fall of study years (Table 4.3) (Maguire and Heckendorn, 2011). Oven dried soil was analyzed with the Solvita® 1-day CO_2 burst test (Haney et al., 2008b), and 28-day aerobic incubation (Haney et al., 2008b) at cover crop termination and V4 sampling periods. Air dried soil, and oven dried soil used for 28-day aerobic incubation, was extracted with 2 *M* KCL (Bremner and Keeney, 1966) prior to analysis for NH_3-N and NO_3-N. Ammonia and NO_3-N concentrations were determined using automated injection flow analysis (Lachat Instruments, Milwaukee, WI) with QuickChem sodium salicylate method 12-107-06-2-A (Hofer, 2001) and QuickChem 12-107-04-1-B using Cd reduction (Knepel, 2003), respectively. Solvita® 1-day CO_2 burst test methodology was followed according packaged instructions and patented gel paddles were read with Solvita® digital color reader (Solvita®, Mt. Vernon, ME). Soil subsamples were brought to 50% water-filled pore space as indicated by Franzluebbers (1999) and incubated for 28-days at 25°C ± 1°C. Post-incubated soil was oven dried at 40°C, extracted with 2 *M* KCL, and analyzed for NH_3-N and NO_3-N as mentioned previously. Differences between pre- and post-incubation inorganic N are considered PMN.

Cover crop aboveground DM was hand clipped from a 0.1 m^2 area immediately before WCC termination. Dry matter samples were dried at 60°C for 48 hr in a forced air oven, ground to pass a 2 mm screen using a Wiley sample mill (Thomas Scientific, Swedesboro, NJ) and TC and TN determined via dry combustion (VarioMax CNS macro elemental analyzer, Elementar, Hanau, Germany). Corn was harvested from the center two rows of each plot with a small plot combine, and grain yield, moisture, and test weight determined using a Graingage™ system (Juniper Systems, Logan, UT). Grain yields from all trials are reported 155 g kg^{-1} moisture content. Relative corn yield was calculated for each replication by [100(check-plot yield)/(plateau yield)].

4.3.3 Statistical Analysis

Statistical analyses were performed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, 2012). All variables were analyzed by location, and starter FN rate due to significant interaction between location and treatments. Mean comparisons using Tukey's Honestly Significant Difference (HSD) (α=0.05) were made to separate treatment effects when *F* tests indicated that significant differences existed (p<0.05). Correlation analysis was performed using the CORR procedure in SAS 9.4. Pearson's correlation coefficients were determined for all soil, WCC, and corn parameter combinations. Soil N tests and relative corn yield data were analyzed using the Cate-Nelson separation method (Cate and Nelson, 1965) and performed using the NLIN procedure in SAS 9.4.

4.4 Results and Discussion

Winter cover crop DM, N content, and C:N ratio are reported in table 4.4 and were discussed at length in chapters 2 and 3. Average monthly temperatures and daily precipitation is reported in figures 4.1 and 4.2. At WCC termination, mean DM for cereal rye, RV mix, and hairy vetch was 2356, 2000, and 1864 kg ha^{-1} in 2013; and 2055, 2701, and 692 kg ha^{-1} in 2014, respectively (Table 4.6). Average N content for cereal rye, RV mix, and hairy vetch was 35, 51, and 60 kg N ha^{-1} in 2013; and 40, 69, and 24 kg N ha^{-1} in 2014, respectively (Table 4.6). Significant differences for residual soil nitrogen were most apparent for soil nitrate (NO_3-N) during WCC termination and corn growth stage (GS) V4 of both years (data presented in chapter 2). In general, hairy vetch treatments had higher residual soil NO_3-N in the subsoil at WCC termination and un the surface 30 cm during V4 (data presented in chapter 2).

Winter cover crop effects on soil N tests are reported in table 4.5. Solvita® was responsive ($P<0.01$) to WCC main effects at only CCM2 during WCC termination sampling period (Table 4.5). Mean Solvita® values for CCM2 were at WCC termination were 33, 34, and 40 mg kg^{-1} for cereal rye, RV mix, and hairy vetch, respectively (Table 4.6). Location CCM2 also had highest TC and soil organic matter (SOM) (Table 4.3). Residual soil NO_3-N at V4 from 0-15 and 0-30 cm were responsive to WCC main effects at 50, and 25% of the locations, respectively (Table 4.5). Hairy vetch had highest NO_3-N values where significant differences were observed (Table 4.6). Average NO_3-N concentrations at 0-15 cm for cereal rye, RV mix, and hairy vetch were 7.0, 7.8, and 10.5 mg kg^{-1} in 2013; and 11.6, 13.6, and 18.7 mg kg^{-1} in 2014 (Table 4.6). Average NO_3-N concentrations at 0-30 cm for cereal rye, RV mix, and hairy vetch were 6.1, 7.7, and 8.1 mg kg^{-1} in 2013; and 11.9, 12.2, and 17.5 mg kg^{-1} in 2014 (Table 4.6).

4.4.1 Residual soil NO_3-N at 0-15 and 0-30 cm

Pearson's correlation matrix for soil N test's relationship with soil, WCC, and corn parameters are reported in table 4.7. Nitrate concentrations at both depths responded to WCC main effects (Table 4.6). Nitrate concentrations at 0-15 cm better correlated to WCC main effects than at 0-30 cm (Table 4.6). Similar results were reported by Vaughan and Evanylo (1999), who suggested sampling to 15 cm in no-till fields with WCC. Nitrate concentrations at both depths, which were sampled at corn GS V4, were sensitive to preplant soil N parameters, but were not sensitive to V4 PMN (Table 4.7). Interestingly, neither aboveground WCC DM nor N content (data not presented) was correlated with NO_3-N at either sampling depth (Table 4.7). Instead, NO_3-N concentrations at both depths were positively correlated with WCC TN and negatively correlated with WCC C:N (Table 4.7). Neither of these parameters are measures of residue mass, but only concentration. Nitrate concentrations at both depths were well correlated with corn check yield and relative yield (Table 4.7). These results indicated residual soil NO_3-N at both depths were sensitive to the soils inherent PAN supplying capacity to corn (check yield parameter) and the soils productivity (relative corn yield parameter). Conversely, Spargo et al. (2009) reported no quantitative relationship between residual soil NO_3-N at 0-30 cm and either corn check yields or relative yield.

Relative corn yields never reached 100% during the two year study (Table 4.6). Highest relative yields were in hairy vetch treatments, but never reached 80% (Table 4.6). Residual soil NO_3-N concentrations exceeded the critical concentration of 22 mg kg^{-1} defined by Vaughan and Evanylo (1999) at six out of 89 observations, but never reached 100% relative yield (Figure 4.3). Similarly, 10 out of 89 observations exceeded the critical concentration of 18 mg kg^{-1} defined by Evanylo and Alley (1997) for the standard PSNT method (NO_3-N at 0-30 cm), but never reached

100% relative yield (Figure 4.4). Hairy vetch treatments consisted of 67 and 60% of the observations in quadrant B of figures 4.3 and 4.4, respectively. The majority of the observations above the critical concentration originated from location BRM2, which only had 36 kg N ha^{-1} in the aboveground WCC DM, but 18.2 mg NO_3-N kg^{-1} in the upper 15 cm at WCC termination (Tables 4.4 and 4.6). These high NO_3-N concentrations were surprising since there was very little hairy vetch DM and no history of organic amendments at BRM2. Magdoff (1991) reported that some soils will respond to FN even when PSNT values are above defined critical concentrations especially when conditions are favorable for leaching as they are in the coarse coastal plain soils found in eastern Virginia.

Fertilizer N recommendation adjustments for PSNT are defined in The Virginia Nutrient Management Standards and Criteria (Virginia Department of Conservation and Recreation, 2014). The critical concentration reported is slightly more conservative (20 mg kg^{-1}) than published by Evanylo and Alley (1997), which was 18 mg kg^{-1}. Hairy vetch treatment at BRM2 had NO_3-N concentrations at 0-30 cm higher than 20 mg kg^{-1}, and recommendations would have suggested zero sidedress FN (Virginia Department of Conservation and Recreation, 2005). Had the grain producer accepted the VADCR recommendation and forgone sidedress FN, maximum yields would not have been achieved (Table 4.6) and lost profits would have been approximately US\$780 ha^{-1} (Assuming 5-year corn and FN prices of US\$207 Mg $corn^{-1}$ and US\$1.11 kg FN^{-1}). Fertilizer N reductions for NO_3-N concentrations at 0-30 cm between 11 and 20 mg kg^{-1} are 50 to 70% from sidedress FN specified in the field’s nutrient management plan (Virginia Department of Conservation and Recreation, 2005). Six out of 24 location-by-WCC combinations had NO_3-N concentrations within the abovementioned range at 0-30 cm (Table 4.6). With the exception of RV mix treatment at BRM2, AONR for the other five location-by-

WCC combinations were on average 51% lower than sidedress FN recommendations in their respective nutrient management plans (data not presented). The average NO_3-N concentration at 0-30 cm for these location-by-WCC combinations were 15.3 mg kg^{-1} (Table 4.6), which suggests that nutrient management planners should recommend conservative FN reductions with 50% as the median.

4.4.2 Solvita® 1-Day Burst Test

Solvita® measured at WCC termination (preplant Solvita®) had best correlation with to residual soil inorganic N at WCC termination (preplant inorganic N) with r=0.63 and $p<0.001$ (Table 4.7). Preplant inorganic N and preplant PMN were both significantly correlated to preplant and V4 Solvita® (Table 4.7); however, V4 Solvita® was not correlated to V4 PMN (Table 4.7). These results indicated different responses for PMN and/or Solvita® due to changes in sampling date. Haney et al. (2008b) reported higher correlation between PMN and Solvita®; however their results were from soils mixed with various rates of dairy manures. In our study Solvita® had better correlation with inorganic N and NO_3-N at 0-15 cm than PMN, regardless of sampling date (Table 4.7). Nitrate concentrations at both depths were similarly correlated to preplant PMN as both Solvita® methods were. However, due to sampling period and a potentially faster turnaround time, these results make preplant Solvita® the most attractive method for measuring PMN.

Solvita® had an interesting response to corn parameters (Table 4.7). Unlike the results from NO_3-N concentrations at either depth, Solvita® was not correlated to corn check yield (Table 4.7); however, Solvita® was positively correlated to relative corn yield (Table 4.7). These results suggest Solvita® was capable of predicting responsiveness of corn grain yield to FN, however it was unable to predict the soils inherent PAN supplying capacity to corn. Preplant

Solvita® had slightly better correlation (r=0.33) to relative corn yield than when sampled at V4 (Table 4.7).

The Cate-Nelson analysis of relationship between relative yield and Solvita® was unable to determine a critical concentration within the independent variables range for either sampling period (Figures 4.5 and 4.6). These results may be attributed to the relatively low SOM of the soils tested, and further indicates the limited use of Solvita® as a tool to predict FN rate adjustments to cropland characteristic of eastern Virginia.

4.5 Conclusion

Results of this study indicated that residual soil NO_3-N and Solvita® methods have limited value in predicting sidedress FN reductions associated with WCC. Both PSNT methods were more highly correlated to WCC effects than both Solvita® test methods. Critical NO_3-N values were reached at six and 10 of the 89 observations for residual soil NO_3-N concentrations at both depths, respectively; however all location-by-WCC combinations were responsive to sidedress FN. Results indicated that critical NO_3-N concentrations should be reevaluated for fields where legume WCC supplies substantial PAN. Critical Solvita® CO_2 concentrations were not determined in this study. Both residual soil NO_3-N and Solvita® test methods may be better suited for producers that apply high quantities of organic amendments, or are interested in monitoring long-term changes in SOM.

4.6 References

Babcock, B.A. and A.M. Blackmer. 1992. The value of reducing temporal input nonuniformities. J. Agric. Res. Econ. 17: 335-347.

Brann, D.E., A.O. Abaye and P.R. Peterson. 2000. Crop description. In: D. E. Brann, D. L. Holshouser and G. L. Mullins, editors, Agronomy Handbook. Publ. no. 424-100, Virginia Coop. Ext., Blacksburg, VA. p. 1-30.

Bremner, J.M. and D.R. Keeney. 1966. Determination and isotope-ratio analysis of different forms of nitrogen in soils: 3. Exchangeable ammonium, nitrate, and nitrite by extraction-distillation methods. Soil Sci. Soc. Am. Proc. 30: 577-582.

Bundy, L.G. and J.J. Meisinger. 1994. Nitrogen availability indices. In: P. J. Bottomley, J. S. Angle and R. W. Weaver, editors, Methods of Soil Analysis. Part 2: Microbiological and Biochemical Properties. SSSA book series 5.2. SSSA, Madison, WI. p. 951-984.

Cate, R.B. and L.A. Nelson. 1965. A rapid method for correlation of soil test analyses with plant response data. NC State University Agricultural Experiment Station.

Evanylo, G.K. and M.M. Alley. 1997. Presidedress soil nitrogen test for corn in Virginia. Commun. Soil Sci. Plant Anal. 28: 1285-1301.

Franzluebbers, A.J. 1999. Potential C and N mineralization and microbial biomass from intact and increasingly disturbed soils of varying texture. Soil Biol. Biochem. 31: 1083-1090.

Haney, R.L., W.F. Brinton and E. Evans. 2008a. Soil CO2 respiration: comparison of chemical titration, CO2 IRGA analysis and the Solvita gel system. Renew. Agric. Food Syst. 23: 171-176.

Haney, R.L., W.H. Brinton and E. Evans. 2008b. Estimating soil carbon, nitrogen, and phosphorus mineralization from short-term carbon dioxide respiration. Commun. Soil Sci. Plant Anal. 39: 2706-2720.

Hofer, S. 2001. QuikChem Method 12-107-06-2-A: Determination of ammonia (salicylate) in 2 *M* KCl soil extracts by flow injection analysis. Lachat Instrum., Milwaukee, WI.

Knepel, K. 2003. QuikChem Method 12-107-04-1-B: Determination of nitrate in 2*M* KCl soil extracts by flow injection analysis. Lachat Instrum., Milwaukee, WI.

Magdoff, F. 1991. Understanding the Magdoff pre-sidedress nitrate test for corn. J. Prod. Agric. 4: 297-305.

Maguire, R.O., and S.E. Heckendorn. 2011. Soil test recommendations for Virginia. Virginia Coop. Ext., Blacksburg, VA. Available at http://www.soiltest.vt.edu/PDF/lab-procedures.pdf. (verified Dec. 12, 2014).

Musser, W.N., J.S. Shortle, K. Kreahling, B. Roach, W.-C. Huang, D.B. Beegle and R.H. Fox. 1995. An economic analysis of the pre-sidedress nitrogen test for Pennsylvania corn production. Rev. Agric. Econ. 17: 25-35.

Ranells, N.N. and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crop monocultures and bicultures. Agron. J. 88: 777-882.

Spargo, J.T., M.M. Alley, W.E. Thomason and S.M. Nagle. 2009. Illinois soil nitrogen test for prediction of fertilizer nitrogen needs of corn in Virginia. Soil Science Society of America journal 73: 434-442.

USDA-NRCS. 2001. Soil quality test kit guide. USDA-NRCS, Soil Quality Institute, Ames, IA.

USDA-NRCS. 2008. Web soil survey. Available at http://websoilsurvey.nrcs.usda.gov/app/. (verified 10/07/2014).

Vaughan, J.D. and G.K. Evanylo. 1999. Soil nitrogen dynamics in winter cover crop-corn systems. Commun. Soil Sci. Plant Anal. 30: 31-52.

Virginia Department of Conservation and Recreation. 2005. Virginia nutrient management standards and criteria. Richmond, VA.

Woods End Laboratory. 2014. Potential mineralizable nitrogen calculator. Available at http://solvita.com/soil/potential-min-n-calc. (verified October 2014). Solvita and Woods End Laboratories, Inc. Mt. Vernon, ME.

4.7 Tables

Table 4.1. Experimental location, soil series, and select soil characteristics for study years 2012-2013 and 2013-2014.

Year	Location	Latitude	Longitude	Soil Series†	Surface Texture†	Drainage Class†	Hydrologic Group†	Land Capability†	Corn Productivity Group‡	Nitrogen Loss Risk‡
2012-2013	BRM1	37.66	-76.68	Bethera/Daleville	L	Poorly	C/D	4w	V	L
	CCM1	37.63	-76.68	Suffolk	LS	Well	B	1	IIIb	M
	JBE1	37.82	-76.88	Kempsville	FSL	Well	B	1	IIIa	M
	PDE1	37.81	-76.80	Kempsville	FSL	Well	B	1	IIIa	M
2013-2014	BRM2	37.67	-76.70	Bama	FSL	Well	B	2e	IIIa	M
	CCM2	37.69	-76.72	Kempsville	FSL	Well	B	1	IIIa	M
	JBE2	37.78	-76.87	Kempsville	FSL	Well	B	1	IIIa	M
	JHE2	37.79	-76.78	Atlee	SiL	Moderately well	C	2w	IIIa	L

† Published in USDA-NRCS (2008)

‡ Published in Virginia Department of Conservation and Recreation (2014)

Table 4.2. Experimental locations, sampling dates, winter annual cover crops (WCC) seeding rates, WCC varieties, and corn hybrid varieties.

Year	Location	Preplant Sampling Date	V4 Sampling Date	Cereal Rye Seeding Rate	RV[†] Mix (Rye Component) Seeding Rate	RV Mix (Vetch Component) Seeding Rate	Hairy Vetch Seeding Rate	Cereal Rye cultivar	Hairy Vetch cultivar	Corn Hybrid
				------------------------	kg ha^{-1}	------------------------				
2012-2013	BRM1	14-May	13-Jun	101	67	22	28	Abruzzi	VNS	Syngenta N68B-3111
	CCM1	22-Apr	28-May	101	67	22	28	Abruzzi	VNS	Pioneer 35F50AM
	JBE1	17-Apr	28-May	101	67	17	34	Abruzzi	VNS	Pioneer 0912HR
	PDE1	17-Apr	28-May	101	67	17	22	Abruzzi	VNS	Pioneer 1184HR
2013-2014	BRM2	6-May	1-Jun	101	67	22	28	VNS[‡]	VNS	Syngenta N68B-3111
	CCM2	14-Apr	1-Jun	101	67	22	28	VNS	VNS	Doeblers 747AM
	JBE2	25-Apr	1-Jun	101	67	17	22	VNS	VNS	Pioneer 0210HR
	JHE2	5-May	1-Jun	101	67	17	22	VNS	VNS	Pioneer 1105AM

[†] RV mix: cereal rye + hairy vetch mixture.
[‡] VNS: Variety not stated.

Table 4.3. Initial soil analysis of pH, primary Mehlich-I extractible macronutrients, KCL extractable NO_3-N and NH_4-N, total N, total C, and soil organic matter for experimental locations in study years 2012-2013 and 2013-2014.

Year	Location	pH†	P‡	K‡	NO_3-N§	NH_4-N§	Total N¶	Total C¶	Soil Organic Matter#
				-------------mg kg^{-1}-------------				----------g kg-1----------	
2012-2013	BRM1	6.7	48.5	169	5.4	3.9	0.92	9.3	17.8
	CCM1	6.3	17.3	107	3.4	5.2	0.91	11	17.5
	JBE1	6.0	11.8	116	4.2	4.6	0.94	9.1	15.8
	PDE1	6.1	15.0	135	2.9	3.4	1.1	9.9	18.5
2013-2014	BRM2	6.7	13.8	174	3.0	4.3	0.93	8.8	17.8
	CCM2	6.0	10.5	70.3	5.4	3.0	1.0	12	22.3
	JBE2	6.3	7.75	73.8	4.3	2.1	0.93	8.7	16.8
	JHE2	5.8	16.5	62.5	5.3	3.9	1.1	11	21.3

† pH: 1:1 soil:water.
‡ P and K: Mehlich I.
§ NH_4-N and NO_3-N: 2 M KCL; automated flow injection analysis.
¶ Total C and total N: dry combustion.
# Soil Organic Matter: Walkley-Black method.

Table 4.4. Least square means for winter annual cover crops (WCC) aboveground DM yield, N content, and C:N ratio at two sampling periods and eight locations.

Sample period			WCC Termination					
Variable			DM yield		N Content		C:N ratio	
Year	Site	WCC	---------- kg ha-1 ----------					
2012-2013	BRM1	R	6254	a[†]	91	a	29	a
		RV	5000	a	150	a	16	ab
		V	5088	a	146	a	14	b
	CCM1	R	779	a	14	a	22	a
		RV	922	a	19	a	19	a
		V	635	a	23	a	11	b
	JBE1	R	1532	a	21	b	27	a
		RV	1338	a	18	b	29	a
		V	1102	a	48	a	10	b
	PDE1	R	858	a	13	b	25	a
		RV	743	a	18	b	17	b
		V	633	a	24	a	11	c
2013-2014	BRM2	R	2608	ab	58	b	19	a
		RV	4591	a	153	a	13	b
		V	950	b	36	b	11	b
	CCM2	R	692	a	16	a	18	a
		RV	1179	a	37	a	13	b
		V	619	a	20	a	13	b
	JBE2	R	2887	b	40	ab	30	a
		RV	3512	a	53	a	27	a
		V	778	c	25	b	13	b
	JHE2	R	2034	a	46	a	18	b
		RV	1523	b	32	b	19	a
		V	422	c	14	c	12	c
2012-2013	Mean	R	2356		35		26	
		RV	2000		51		20	
		V	1864		60		12	
2013-2014	Mean	R	2055		40		21	
		RV	2701		69		18	
		V	692		24		12	

[†]Means within each column and location followed by the same lowercase letter are not significantly different (P > 0.05)

Table 4.5. Analysis of variance for winter annual cover crops (WCC) effects on soil N tests by location.

Sample period		WCC Termination		----------Corn GS V4----------		
		NO_3-N	Solvita CO_2 burst	NO_3-N	Solvita CO_2 burst	NO_3-N
Year	Location	--------------------0-15 cm--------------------				0-30 cm
2012-2013	BRM1	ns	ns	**	ns	ns
	CCM1	ns	ns	ns	ns	**
	JBE1	ns	ns	ns	ns	ns
	PDE1	ns	ns	***	ns	ns
2013-2014	BRM2	**	ns	***	ns	ns
	CCM2	ns	**	**	ns	**
	JBE2	**	ns	ns	ns	ns
	JHE2	*	ns	ns	ns	ns

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
ns Nonsignificant at the 0.05 probability level.

Table 4.6. Least square means for soil N tests by location.

Sample period			------WCC Termination------				--------------------Corn GS V4--------------------						----------Corn Harvest----------			
			NO_3-N		Solvita CO_2 burst		NO_3-N		NO_3-N		Solvita CO_2 burst		Yield Plateau‡	AONR‡	Yield at FN=0§	Relative Yield
			-------------------0-15 cm-------------------						---0-30 cm---		---0-15 cm---					
Year	Site	WCC	--mg kg^{-1}--										Mg ha^{-1}	kg N ha^{-1}	Mg ha^{-1}	%
2012-2013	BRM1	R	2.0	a†	14	a	4.1	b	4.5	a	13	a	10.1	125	3.9	39
		RV	4.1	a	17	a	8.1	a	10.5	a	15	a	12.3	179	6.7	54
		V	4.2	a	17	a	10.7	a	9.0	a	14	a	13.8	147	10.2	74
	CCM1	R	1.2	a	18	a	6.8	a	4.3	b	15	a	11.6	135	5.4	47
		RV	1.5	a	23	a	6.4	a	4.8	b	16	a	10.9	57	6.5	60
		V	2.1	a	14	a	8.7	a	6.2	a	17	a	12.2	179	5.6	46
	JBE1	R	3.4	a	13	a	8.2	a	7.3	a	12	a	13.3	172	5.0	38
		RV	3.0	a	12	a	9.4	a	6.1	a	11	a	13.3	169	5.9	44
		V	3.4	a	16	a	12.2	a	8.6	a	12	a	10.4	23	7.9	76
	PDE1	R	2.7	a	25	a	9.1	b	8.2	a	20	a	10.9	113	6.1	56
		RV	3.6	a	23	a	7.3	c	8.7	a	15	a	10.3	63	7.6	74
		V	3.0	a	18	a	10.4	a	8.6	a	17	a	10.8	130	7.0	65
2013-2012	BRM2	R	1.9	b	25	a	13.4	c	18.7	a	20	a	12.2	67	6.2	51
		RV	5.7	b	21	a	18.4	b	19.2	a	25	a	14.1	174	7.1	50
		V	18.2	a	22	a	29.6	a	25.8	a	24	a	15.0	160	9.8	65
	CCM2	R	2.1	a	33	b	12.2	b	7.7	c	31	a	9.2	54	6.1	66
		RV	2.4	a	34	b	12.3	b	10.9	b	32	a	9.0	179	6.6	73
		V	3.6	a	40	a	18.8	a	16.4	a	34	a	9.9	75	7.2	73
	JBE2	R	2.8	b	25	a	11.6	a	12.8	a	21	a	10.6	135	6.4	60
		RV	1.9	b	23	a	14.5	a	9.4	a	22	a	11.8	142	5.8	49
		V	4.0	a	23	a	16.9	a	18.1	a	22	a	9.6	4	6.4	67
	JHE2	R	0.7	b	26	a	9.5	a	8.3	a	23	a	9.8	135	4.6	47
		RV	0.8	b	31	a	9.2	a	9.2	a	25	a	10.6	168	5.6	53
		V	1.4	a	25	a	9.5	a	11.9	a	21	a	10.9	140	5.4	50
2012-2013	Mean	R	2.4		17		7.0		6.1		15		11.5	136	5.1	45
		RV	3.1		19		7.8		7.7		14		11.7	117	6.7	58
		V	3.2		16		10.5		8.1		15		11.8	120	7.7	65
2013-2014	Mean	R	1.9		27		11.6		11.9		24		10.5	98	5.8	56
		RV	2.7		27		13.6		12.2		26		11.4	166	6.3	56
		V	6.8		28		18.7		17.5		25		11.3	95	8.0	64
	CV		34		20		25		38		23		NA	NA	17	NA

†Means within each column and location followed by the same uppercase letter are not significantly different ($P > 0.05$)

‡Starter FN rate=45 kg ha^{-1}

§Starter FN rate=0 kg ha^{-1}

Table 4.7. Correlation coefficients for the relationship between soil N tests and soil, WCC, and corn parameters.

	Soil parameters										WCC parameters						Corn parameters			
Soil N test	Preplant inorganic N		Preplant PMN		V4 inorganic N		V4 NO_3-N at 0-15 cm		V4 PMN		WCC DM		WCC TN		WCC CN		Check yield		Relative yield	
Preplant Solvita	0.63	***	0.30	**	0.33	**	0.30	**	0.05	ns	-0.31	**	0.03	ns	-0.13	ns	0.03	ns	0.33	**
V4 Solvita	0.63	***	0.34	**	0.52	***	0.51	***	-0.02	ns	-0.18	ns	0.17	ns	-0.24	*	0.06	ns	0.25	*
V4 NO_3-N at 0-15 cm	0.54	***	0.30	**	0.94	***	1.00		-0.17	ns	-0.08	ns	0.40	**	-0.36	**	0.45	***	0.28	**
V4 NO_3-N at 0-30 cm	0.32	**	0.33	**	0.66	***	0.71	***	-0.09	ns	0.06	ns	0.33	**	-0.32	**	0.45	***	0.27	**

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
ns Nonsignificant at the 0.05 probability level.

4.8 Figures

Figure 4.1. 2012-2013 and 2013-2012 and 30 year monthly mean temperature for Tappahannock, VA.

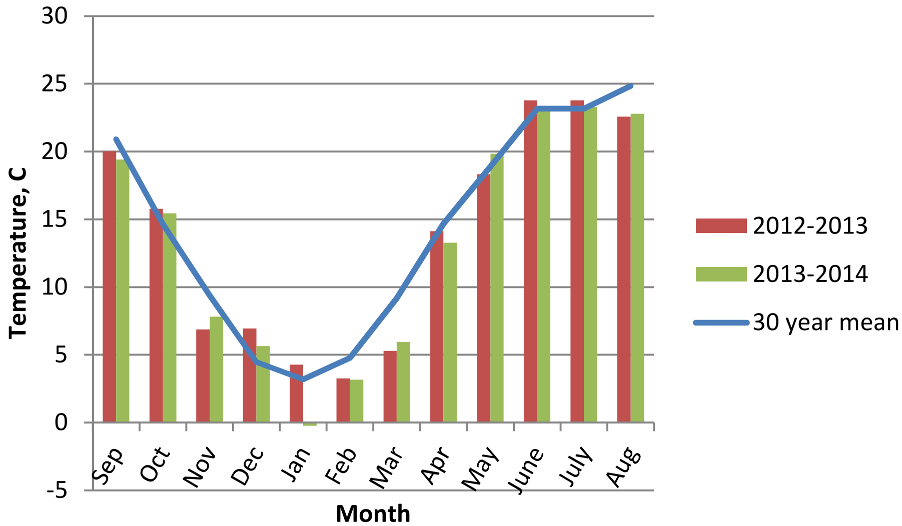


Figure 4.2. Daily precipitation for Tappahannock, VA.

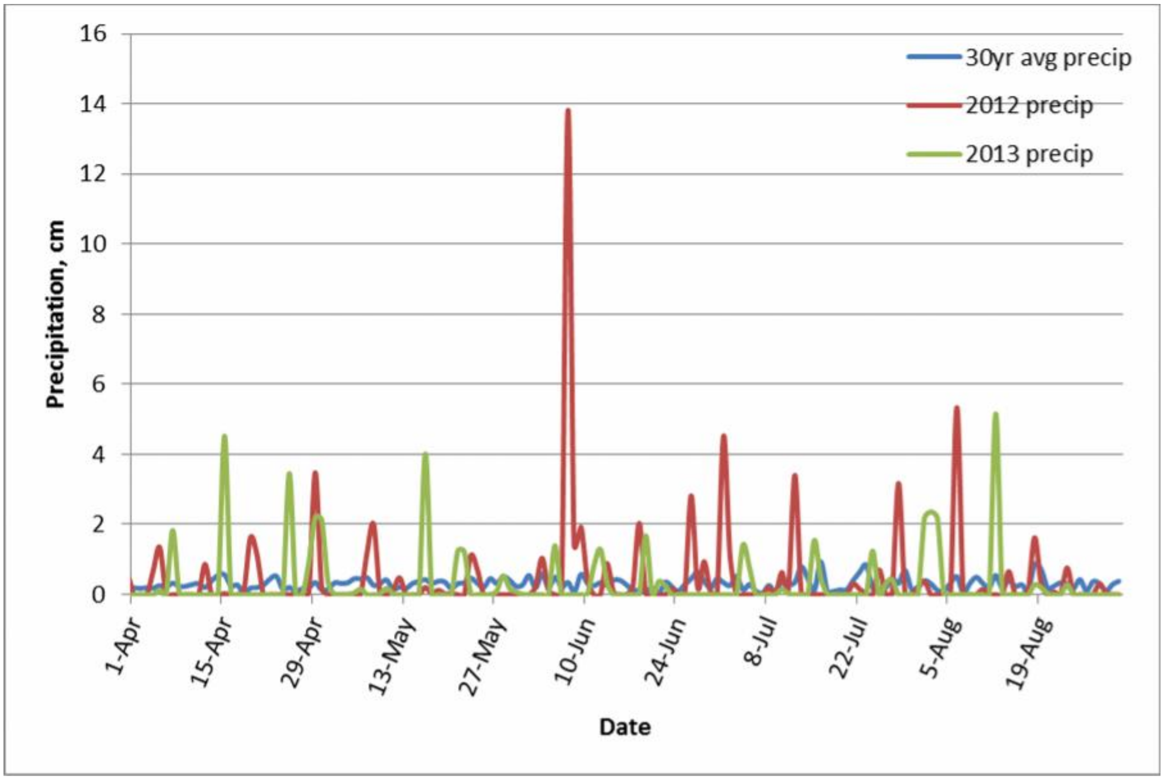


Figure 4.3. Corn grain relative yield versus V4 NO_3-N at 0-15 cm and relative corn yield with established critical NO_3-N concentration of 22 mg kg^{-1} (Vaughan and Evanylo, 1999).

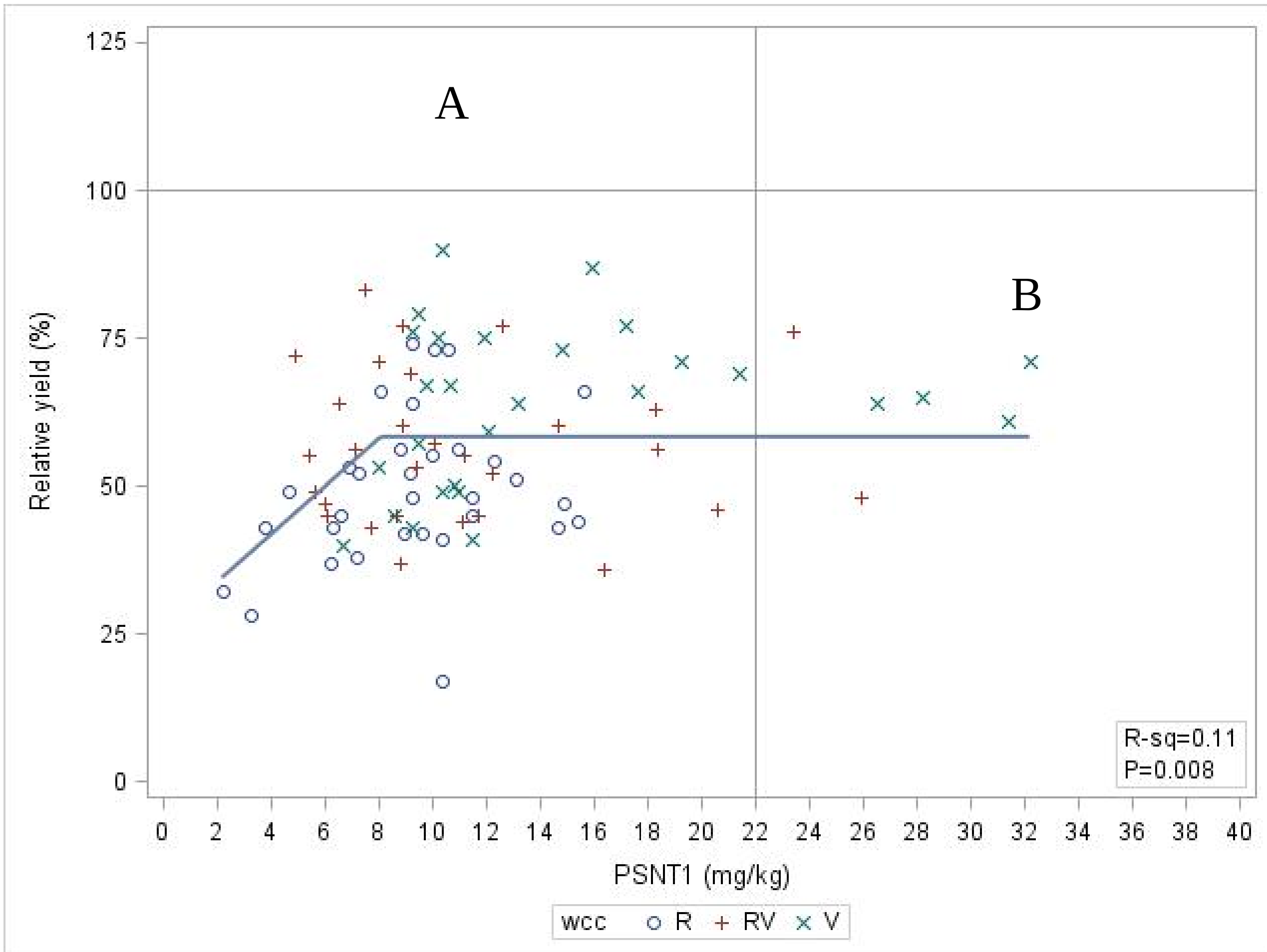


Figure 4.4. Corn grain relative yield versus V4 NO_3-N at 0-30 cm and relative yield with established critical NO_3-N concentration of 22 mg kg^{-1} (Evanylo and Alley, 1997).

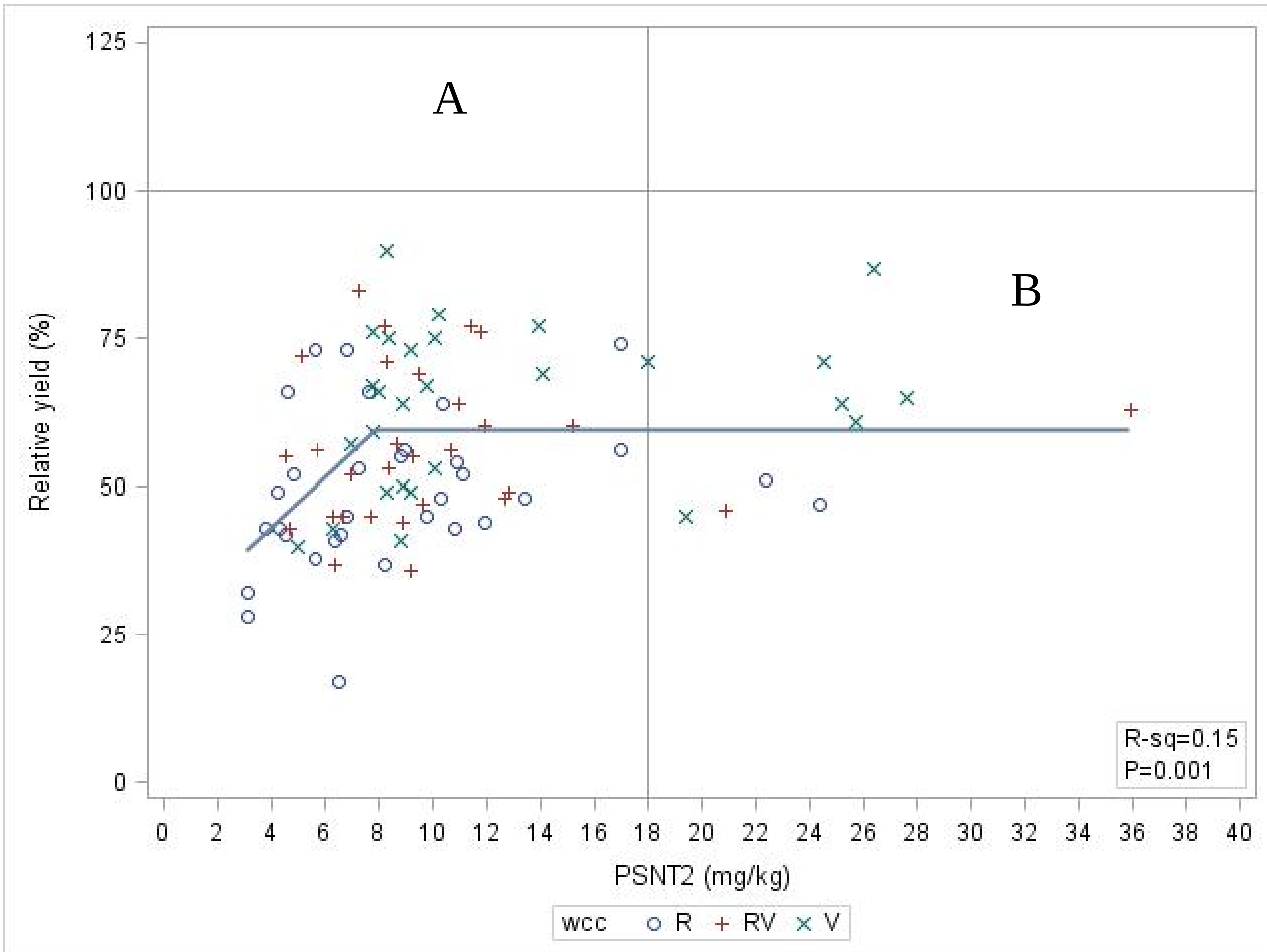


Figure 4.5. Corn grain relative yield versus preplant Solvita® 1-day CO_2 burst test and relative yield.

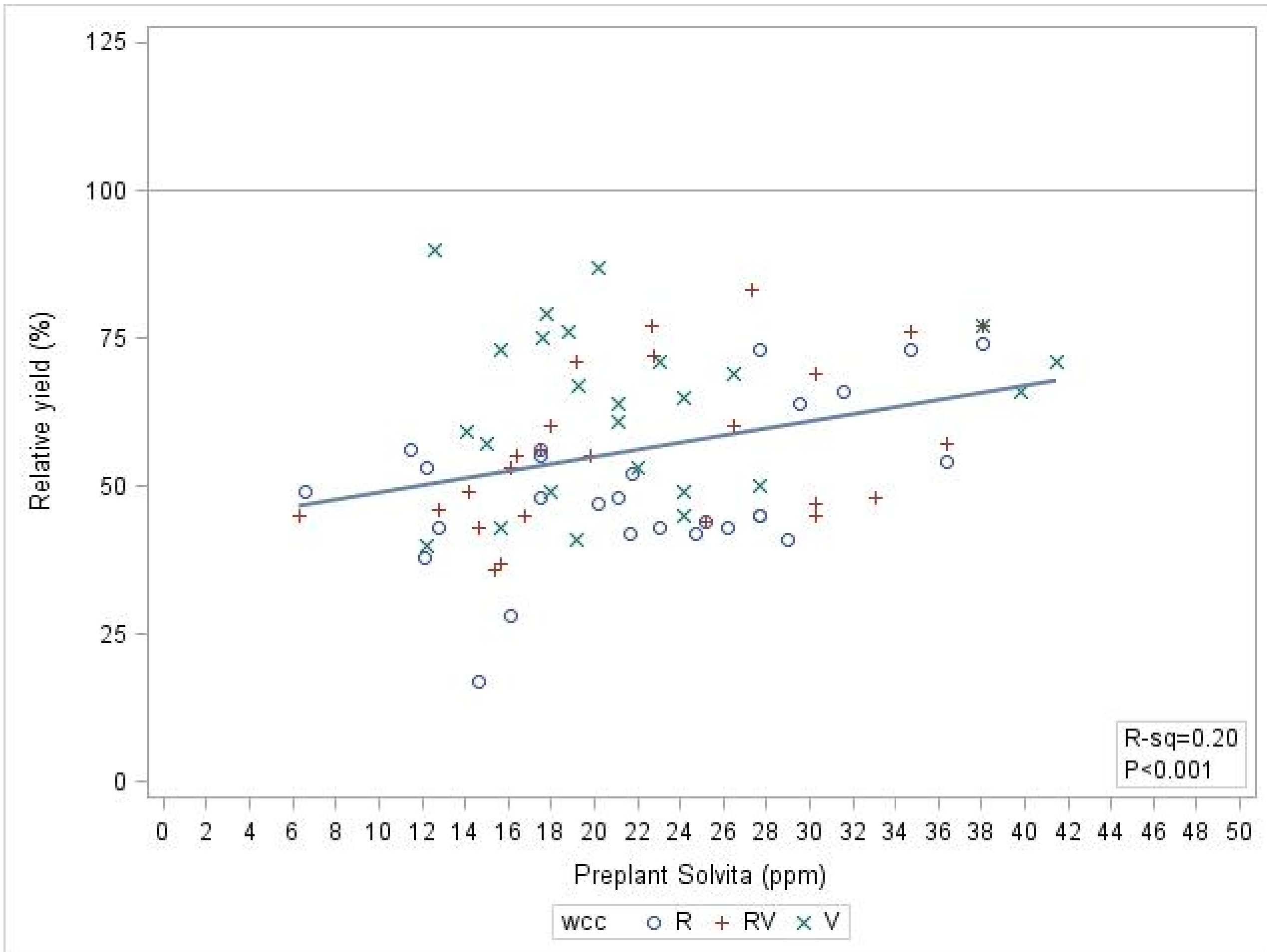
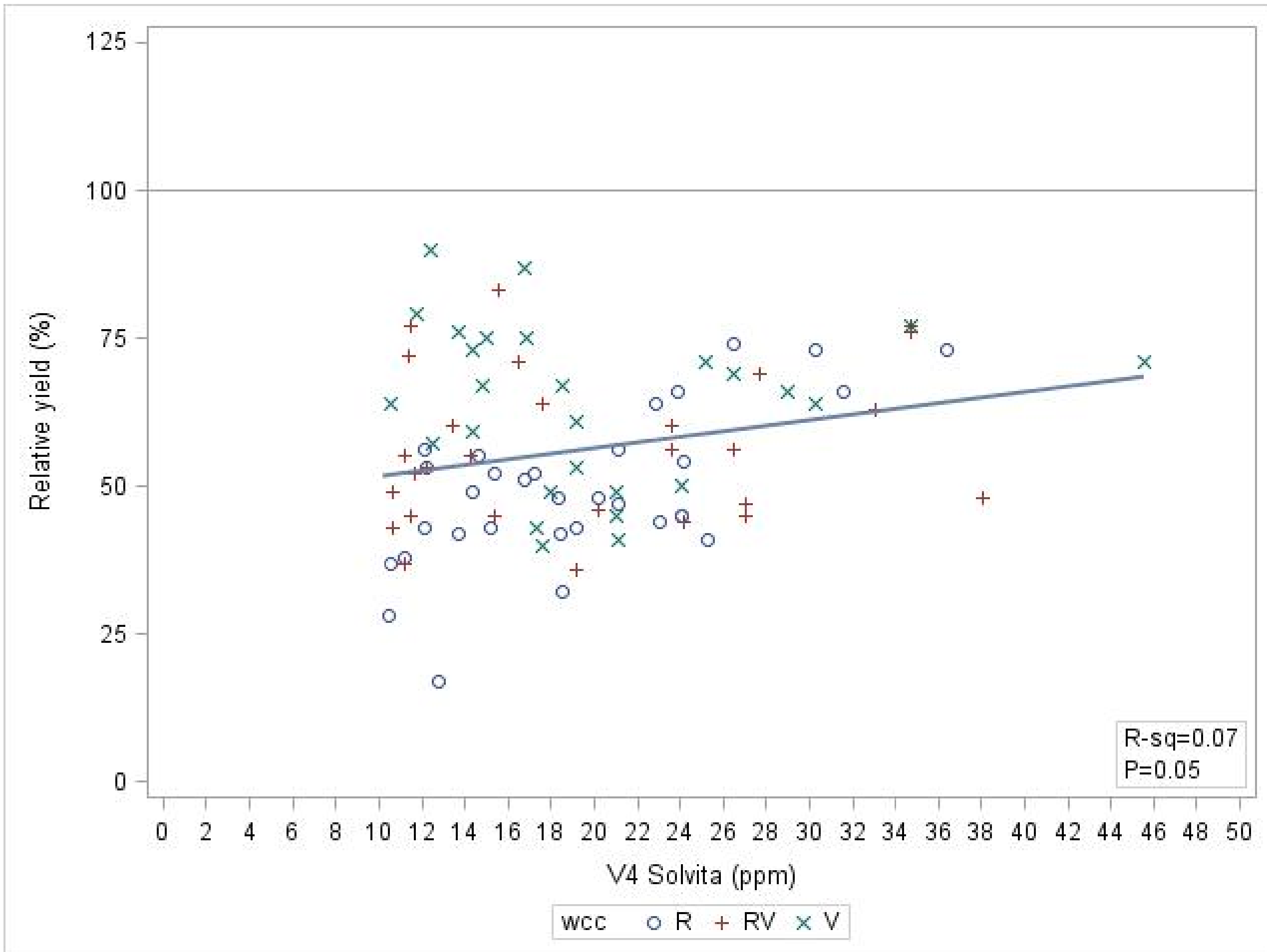


Figure 4.6. Corn grain relative yield versus V4 Solvita® 1-day CO_2 burst test and relative yield.



5. Summary and Conclusion

Understanding the effects of interseeded winter annual cover crops (WCC) on residual soil nitrogen (N) and subsequent corn yield in the mid-Atlantic region is essential due the region's commitment to WCC as a best management practice (BMP) to meet water quality goals in the Chesapeake Bay watershed. Adoption of Interseeded WCC into soybean will dramatically increase the percentage of land in WCC since the majority of land following soybean lays fallow. Historically producers have not seeded WCC after soybean due to the short period of time for establishment. Interseeding WCC into standing soybean has potential as a successful seeding method for fall establishment. Our objectives in this study were to determine (1) the success of interseeded WCC on soil N scavenging; (2) their ability to provide subsequent corn with plant available N (PAN); and (3) their influence on in-season soil N tests for corn.

Complementary to past research, our study suggests that residual soil N following soybean is similar to that after corn. This finding illustrates the importance of establishing successful WCC stands during the winter fallow niche following soybean. Compared to other studies WCC biomass accumulation performed poorly in the fall, but normal in the spring. Best results for cereal rye N scavenging was 18 and 91 kg N ha^{-1} in the fall and spring, respectively. These results indicate that there is potential for cereal rye to conserve residual soil N that would otherwise leach into shallow groundwater and eventually discharge into surface waters; however most of these benefits occur during the spring before corn establishes.

More promising is the ability of hairy vetch supplying PAN to subsequent corn. Hairy vetch and RV mix aboveground biomass N content was on average 42 and 84 kg N ha^{-1} at WCC termination. However, when hairy vetch termination was delayed until mid-May, aboveground biomass N content was 146 and 150 kg N ha^{-1} for hairy vetch and RV mix, respectively.

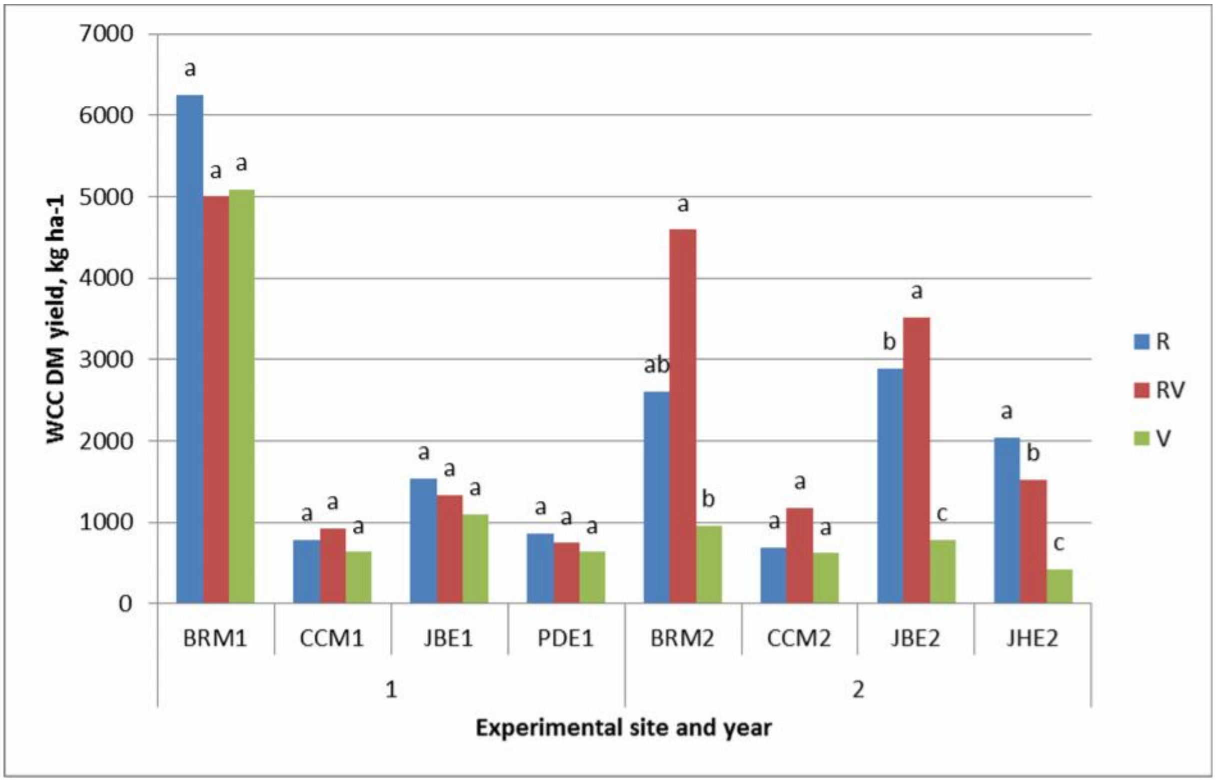
Delayed hairy vetch termination and corn planting in normal climatic years can increase hairy vetch N contribution to corn without reducing corn yields. Corn grain yield plateaus were generally in the order of hairy vetch > RV mix > cereal rye. Corn grain yield increased with increasing sidedress fertilizer nitrogen (FN) rates in hairy vetch treatments at most locations. Therefore, instead of decreasing sidedress FN requirement, hairy vetch increased maximum corn yields (non-N rotation effect). Hairy vetch N credits were calculated using two different methods: FN replacement and AONR difference. The FN replacement method generally reduced FN rates in hairy vetch treatments to be comparable with optimum yields in cereal rye treatments. Of the two methods, the AONR difference method resulted in highest net returns.

Hairy vetch increased presidedress nitrate test values, but did not improve sidedress FN recommendations. Conversely, Solvita® CO_2 burst test did not respond to WCC treatments. Occasionally the presidedress nitrate test (PSNT) concentrations were greater than critical values previously established for Virginia. However in those instances, corn was still responsive to FN, and maximum profits would not have been achieved had the producers forgone sidedress FN. These results indicate that the PSNT may be a viable in-season soil N test, but that current critical values should be revised for legume WCC.

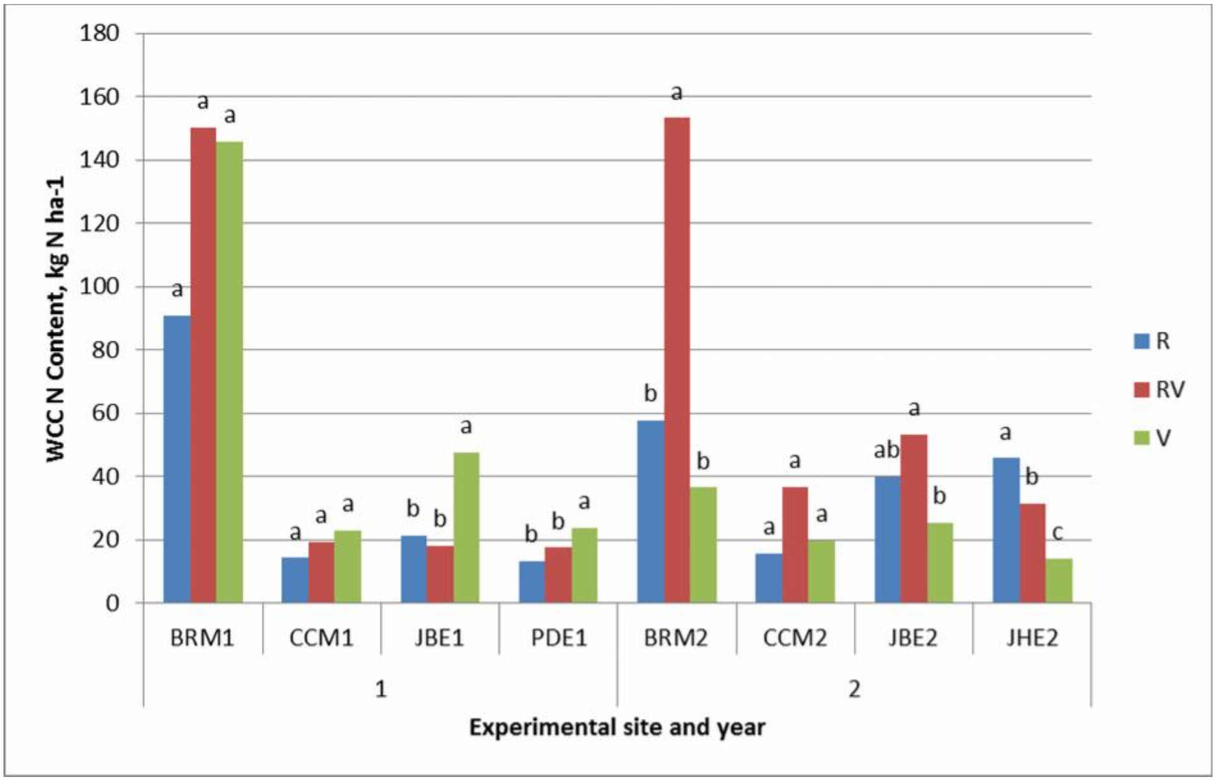
Interseeded WCC into standing soybean has potential to meet producer's goals for residual soil N conservation and supplying PAN to subsequent cash crops; and also environmentalist's goals in reducing N leaching. Year-long vegetative cover is necessary to help the Commonwealth of Virginia reach agreed upon surface water nutrient goals established in the most recent Chesapeake Bay Watershed Agreement of 2014. Interseeding WCC into soybean is one promising method to achieve year-long vegetative cover. Based on our research, interseeded WCC provides little fall N scavenging potential. However, spring N scavenging was similar with most published data. On average, corn following hairy vetch had higher yield plateaus and lower AONR than when following cereal rye. Improved WCC performance (N scavenging and N accumulation) may be achieved when interseeded into earlier maturing soybean varieties and delaying WCC termination. Future research is needed to improve management practices that would optimize interseeded WCC performance.

Appendix

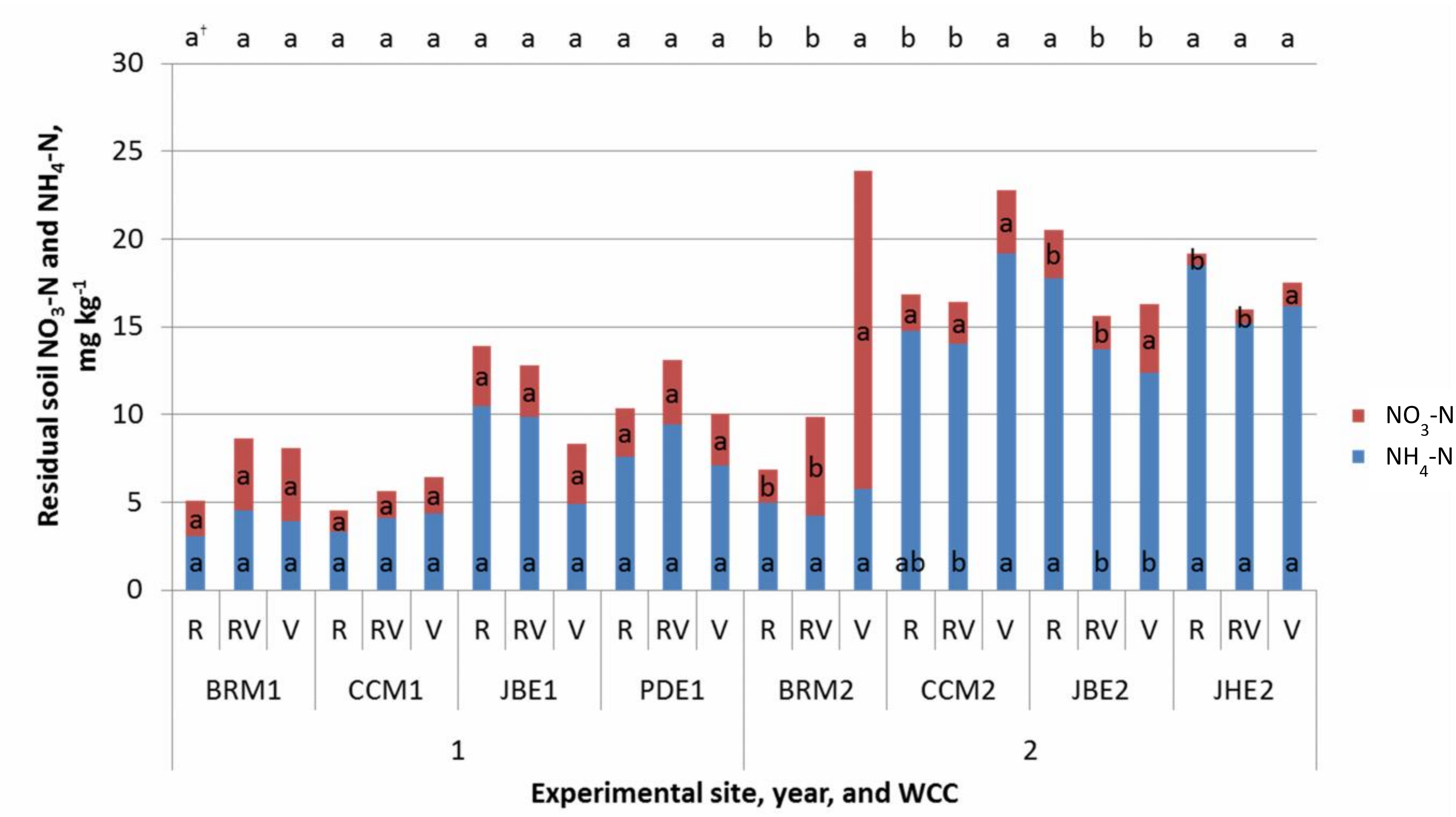
Appendix A. Winter annual cover crops (WCC) dry matter (DM) yield at eight locations during WCC termination 2013-2014.



Appendix B. Winter annual cover crops (WCC) N content at eight locations during WCC termination 2013-2014.

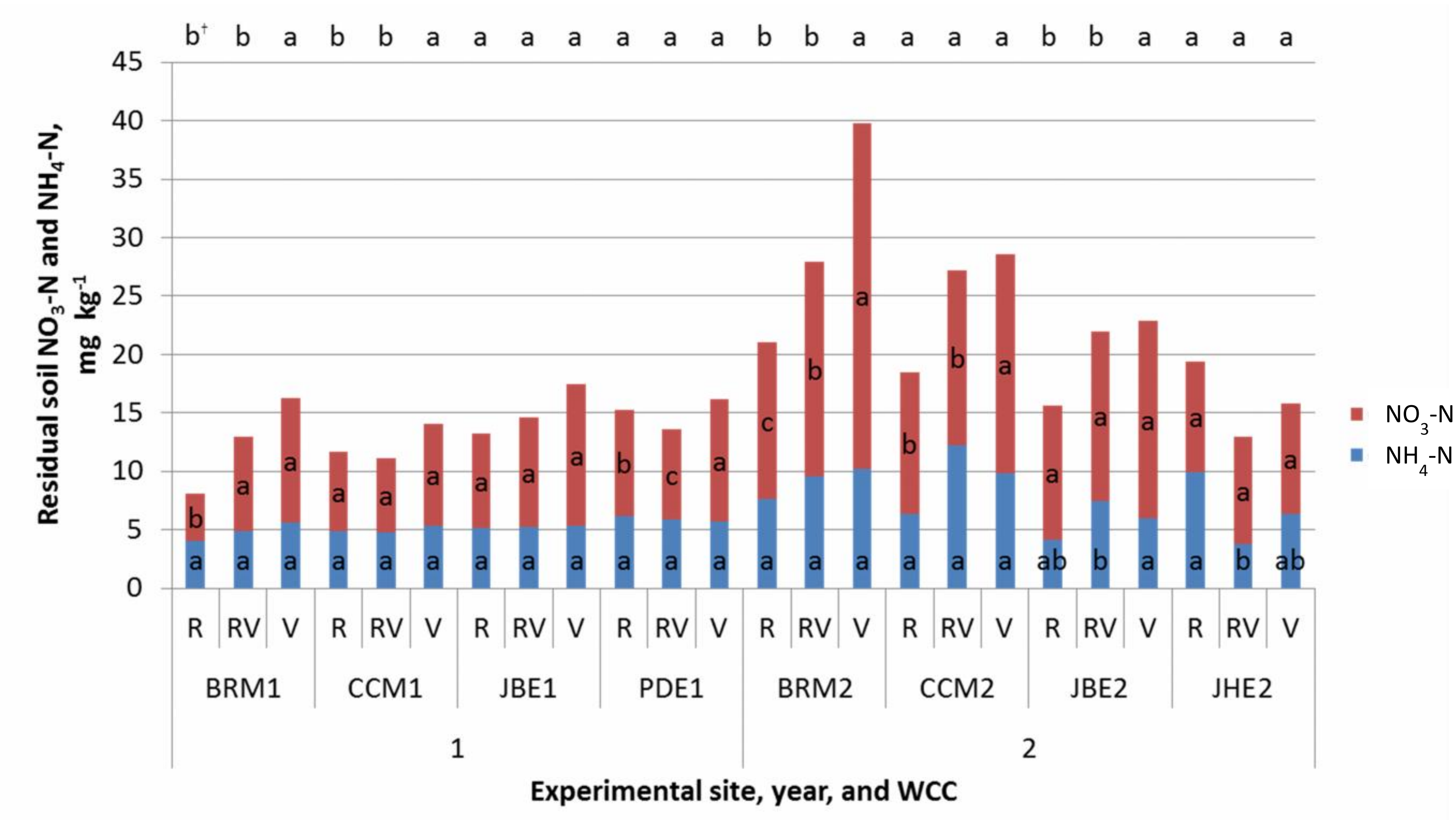


Appendix C. Residual soil N, NO3-N, and NH4-N at winter cover crop termination and depth 0-15 cm.



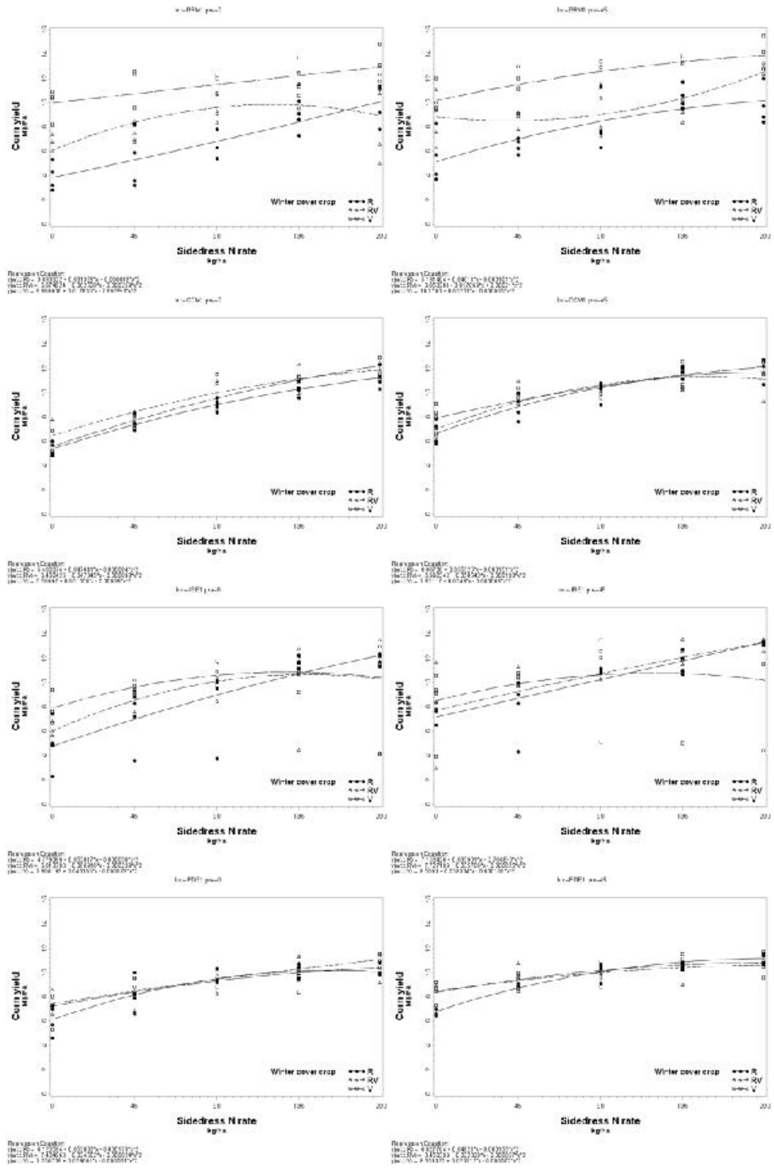
† Means within each location and residual soil N variable followed by the same lowercase letter are not significantly different at 0.05 level. Lowercase letters above the chart are representative of residual soil N (NO_3-N + NH_4-N).

Appendix D. Residual soil N, NO3-N, and NH4-N at corn GS V4 and depth 0-15 cm.

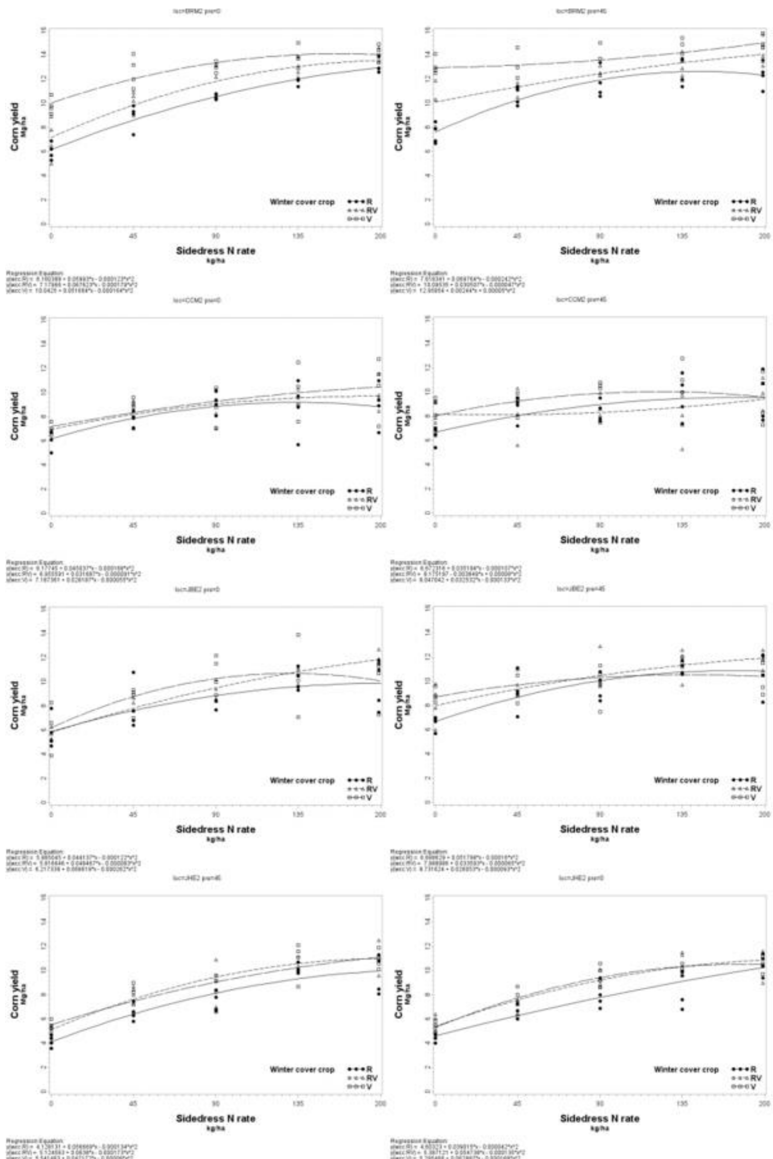


† Means within each location and residual soil N variable followed by the same lowercase letter are not significantly different at 0.05 level. Lowercase letters above the chart are representative of residual soil N (NO_3-N + NH_4-N).

Appendix E. Quadratic regression curves of corn grain yield as a function of sidedress fertilizer nitrogen (FN) rates at four locations and two starter FN rates in 2013.

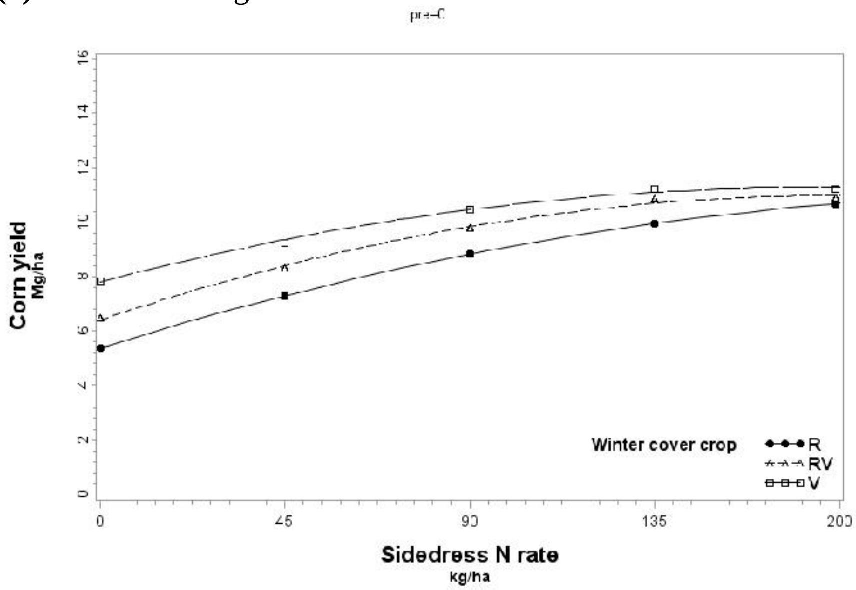


Appendix F. Quadratic regression curves of corn grain yield as a function of sidedress fertilizer nitrogen (FN) rates at four locations and two starter FN rates in 2014.



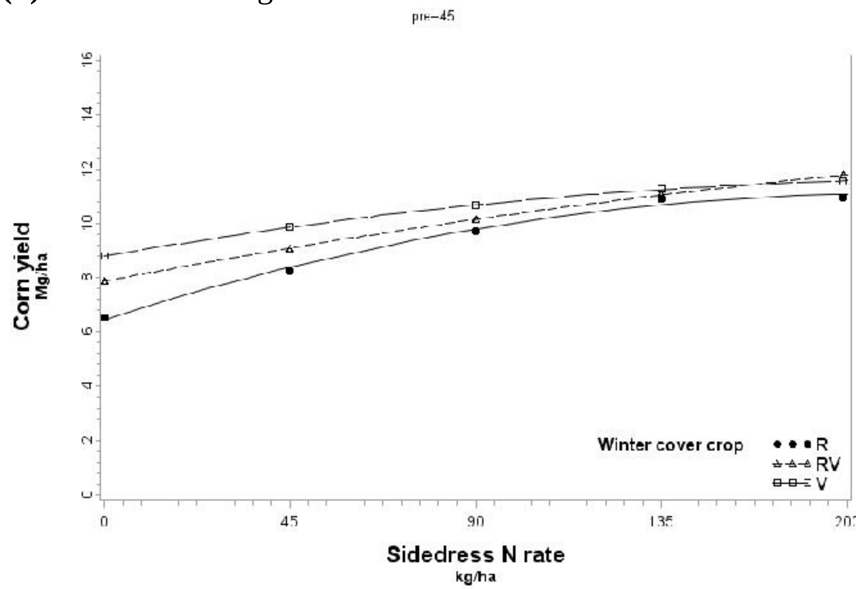
Appendix G. Quadratic regression curves of corn grain yield as a function of sidedress fertilizer nitrogen (FN) rates averaged over all eight locations 2013-2014.

(a) Starter FN=0 kg FN ha^{-1}



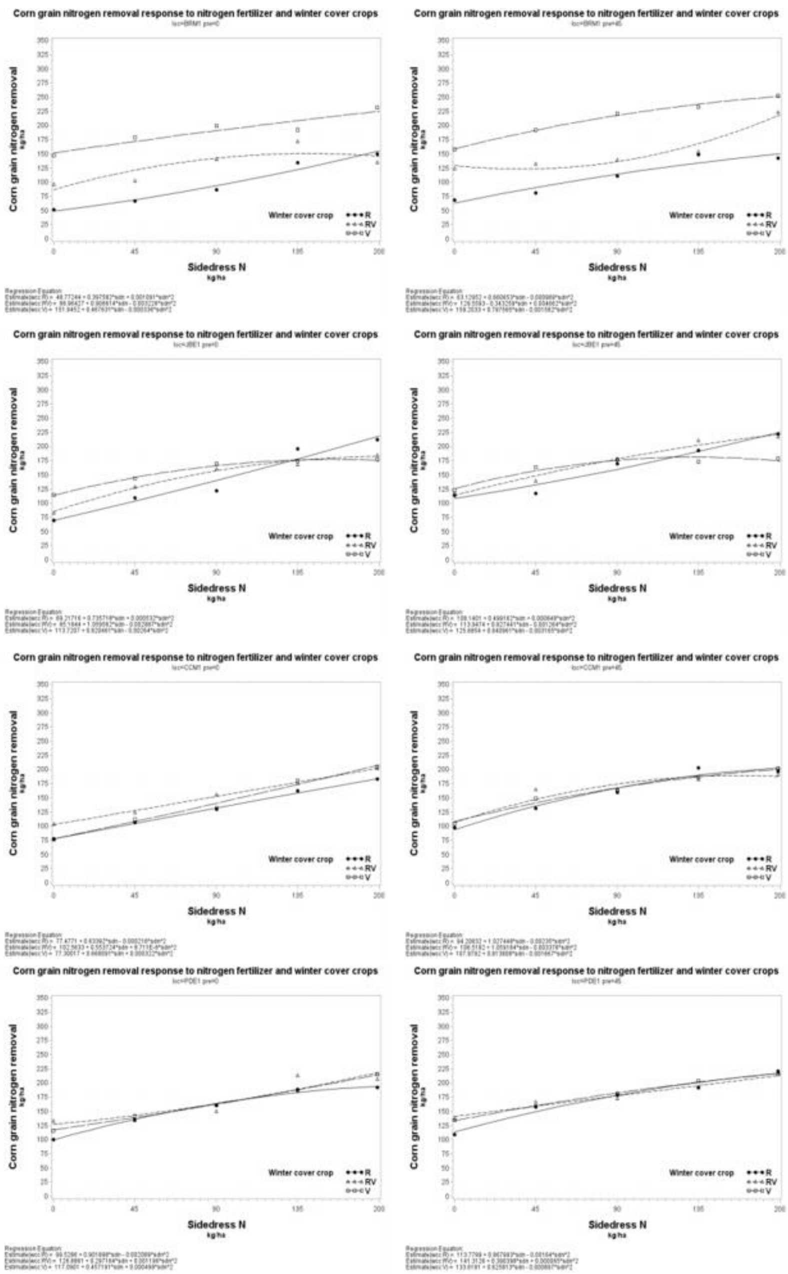
Regression Equation:
PRY(wcc:R) = 5.373073 + 0.077172*x - 0.000098*x^2
PRY(wcc:RV) = 6.407347 + 0.050781*x - 0.000141*x^2
PRY(wcc:V) = 7.795121 + 0.040126*x - 0.000115*x^2

(b) Starter FN=45 kg FN ha^{-1}

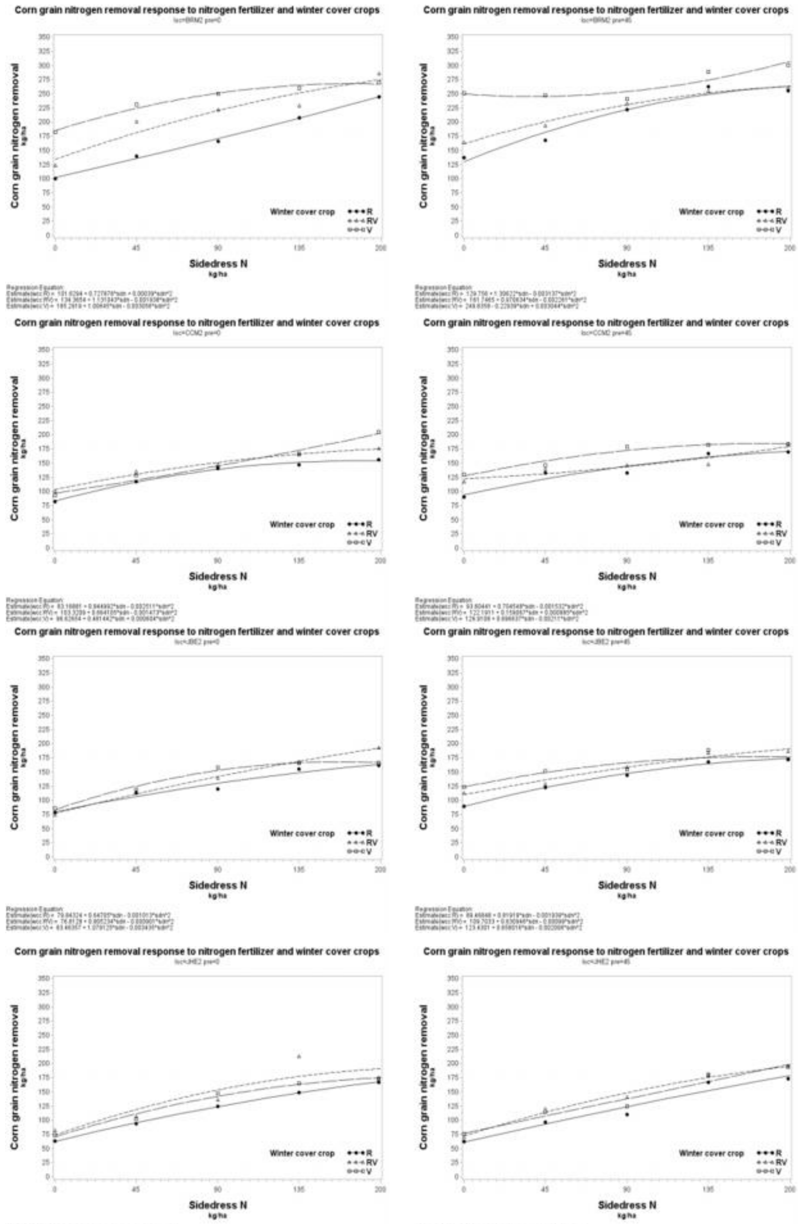


Regression Equation
PRY(wcc:R) = 6.456663 + 0.048053*x - 0.000125*x^2
PRY(wcc:RV) = 7.878486 + 0.026768*x - 0.000039*x^2
PRY(wcc:V) = 8.789927 + 0.025526*x - 0.000062*x^2

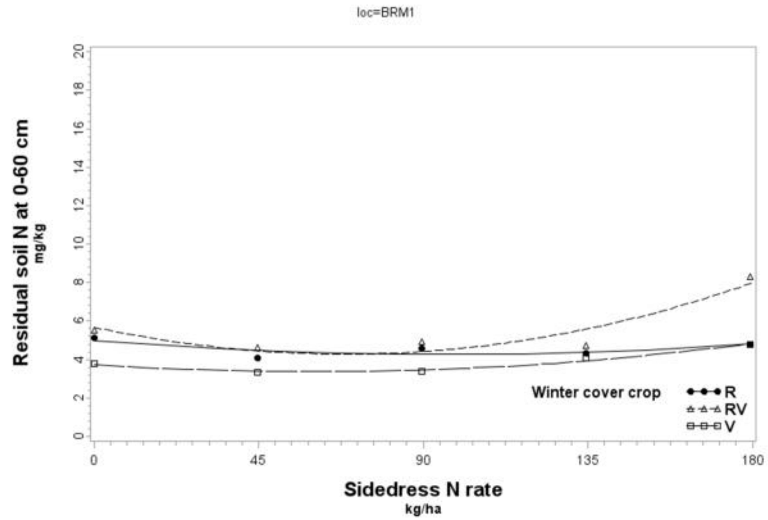
Appendix H. Quadratic regression curves of corn grain N content as a function of sidedress fertilizer nitrogen (FN) rates at four locations and two starter FN rates in 2013.



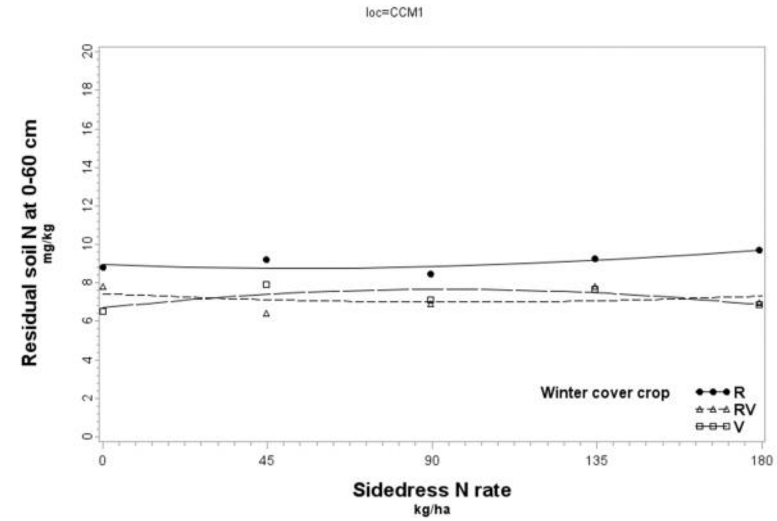
Appendix I. Quadratic regression curves of corn grain N content as a function of sidedress fertilizer nitrogen (FN) rates at four locations and two starter FN rates in 2014.



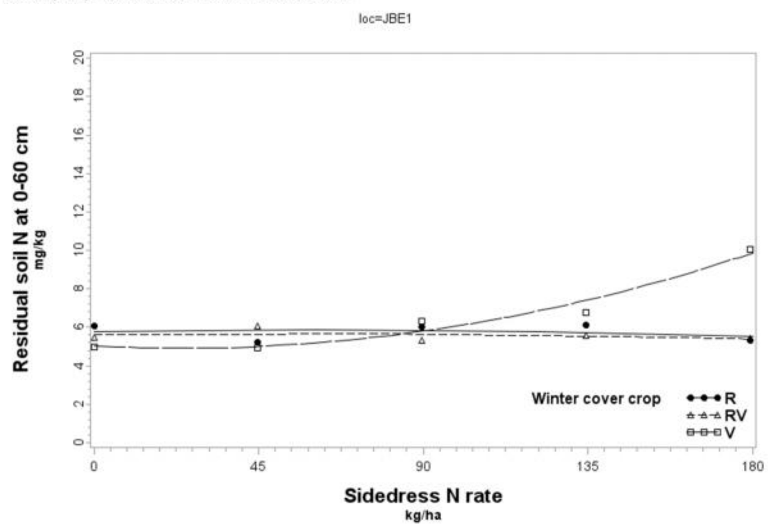
Appendix J. Quadratic regression curves of residual soil N (NO_3-N + NH_4-N) at 0-60 cm as a function of sidedress fertilizer nitrogen (FN) rates averaged over preplant FN rates at four locations during 2013 corn harvest.



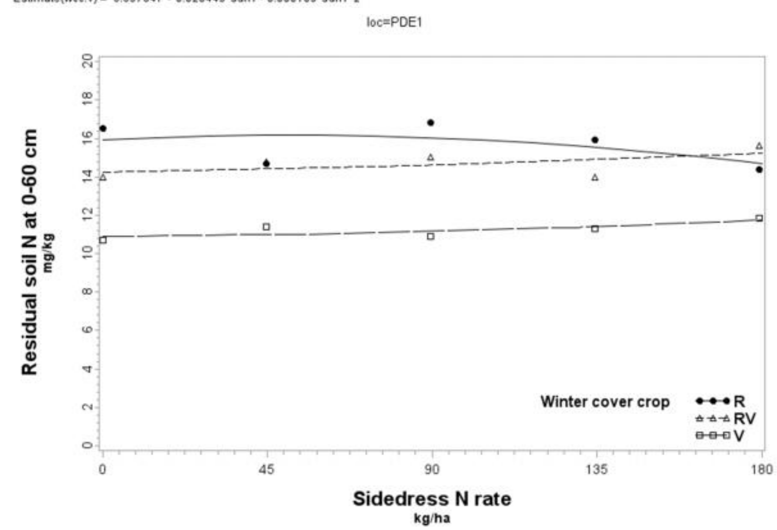
Regression Equation:
Estimate(wcc:R) = 4.98525 - 0.015219*sdn1 + 0.00008*sdn1^2
Estimate(wcc:RV) = 5.675933 - 0.04082*sdn1 + 0.000298*sdn1^2
Estimate(wcc:V) = 3.740874 - 0.012506*sdn1 + 0.000103*sdn1^2



Regression Equation:
Estimate(wcc:R) = 8.946499 - 0.006622*sdn1 + 0.000061*sdn1^2
Estimate(wcc:RV) = 7.438978 - 0.009237*sdn1 + 0.000048*sdn1^2
Estimate(wcc:V) = 6.697847 + 0.020449*sdn1 - 0.000109*sdn1^2



Regression Equation:
Estimate(wcc:R) = 5.79472 + 0.002636*sdn1 - 0.000023*sdn1^2
Estimate(wcc:RV) = 5.621667 + 0.001886*sdn1 - 0.000018*sdn1^2
Estimate(wcc:V) = 5.02236 - 0.009649*sdn1 + 0.000203*sdn1^2



Regression Equation:
Estimate(wcc:R) = 15.9303 + 0.009084*sdn1 - 0.000089*sdn1^2
Estimate(wcc:RV) = 14.24633 + 0.00252*sdn1 + 0.000017*sdn1^2
Estimate(wcc:V) = 10.89071 + 0.000916*sdn1 + 0.000021*sdn1^2

Appendix K. Literature review of hairy vetch N contribution to no-till corn of peer-reviewed studies.

Study	State	Region	USDA hardiness zone	Annual precip. (cm)	HV DM	HV N content	TN	Chk. y-int†	HV y-int†	Chk. AONR‡	HV AONR‡	Chk Plat. yld§	HV Plat. yld§	RR¶	FN Credit#	Reference
				cm	kg ha^{-1}	kg N ha^{-1}	%									
1a	KY	KY	6b	127	3350	103	3.1	1.04	3.28	100	100	4.6	5.2	72.1	78	(Blevins et al., 1990)
1b	KY	KY	6b	127	3350	103	3.1	1.06	3.53	170	170	6.3	7.4	56.2	79	(Blevins et al., 1990)
3a	MD	CP	7b	112	2921	124	4.2	3.5	4.7	247	41	6.6	6.2	71.7	79	(Clark et al., 1997a; 1997b)
3b	MD	CP	7b	112	3331	130	3.9	5.3	8.3	117	30	9.2	10.3	90.1	73	(Clark et al., 1997a; 1997b)
3c	MD	CP	7b	112	3161	131	4.1	4.6	8.9	231	0	9.5	8.9	94.0	90	(Clark et al., 1997a; 1997b)
3d	MD	CP	7b	112	3362	123	3.7	5.3	9.8	113	111	10.1	11.5	96.8	89	(Clark et al., 1997a; 1997b)
3e	MD	CP	7b	112	3895	144	3.7	4.5	8.4	229	33	9.6	9.7	87.2	136	(Clark et al., 1997a; 1997b)
3f	MD	CP	7b	112	5023	193	3.8	6.2	9.9	190	118	11.3	10.7	87.6	93	(Clark et al., 1997a; 1997b)
3g	MD	P	7a	107	3053	108	3.5	2.6	6.7	133	166	8.0	9.3	83.8	79	(Clark et al., 1997a; 1997b)
3h	MD	P	7a	107	2056	69	3.4	5.4	4.4	200	168	6.3	6.5	69.8	-40	(Clark et al., 1997a; 1997b)
3i	MD	P	7a	107	3180	118	3.7	4.4	8.2	343	133	12.1	11.8	67.8	136	(Clark et al., 1997a; 1997b)
3j	MD	P	7a	107	3677	139	3.8	6.1	6.3	102	120	7.0	6.7	90.0	15	(Clark et al., 1997a; 1997b)
3k	MD	P	7a	107	4756	185	3.9	3.4	10.1	172	287	9.4	13.9	107.4	106	(Clark et al., 1997a; 1997b)
3l	MD	P	7a	107	4318	133	3.1	4.4	5.2	113	97	6.9	6.6	75.4	32	(Clark et al., 1997a; 1997b)
4a	PA	P	6a	107	1600	61	3.8	2.9	7.1	208	.	6.8	.	104.4	168	(Cook et al., 2010)
4b	PA	P	6a	107	4800	211	4.4	3.7	8.3	238	.	6.0	.	138.3	168	(Cook et al., 2010)
4c	PA	P	6a	107	7400	305	4.1	2.8	8.8	136	.	6.5	.	135.4	168	(Cook et al., 2010)
4d	PA	P	6a	107	3600	90	2.5	6.3	5.8	107	.	12.0	.	48.3	0	(Cook et al., 2010)
4e	PA	P	6a	107	4500	131	2.9	6.7	7.6	168	.	11.2	.	67.9	34	(Cook et al., 2010)
4f	PA	P	6a	107	4900	221	4.5	5.1	4.4	114	.	11.6	.	37.9	-6	(Cook et al., 2010)
5a	KY	KY	6a	112	3200	91	2.8	4.4	6.0	255	255	7.3	6.5	82.2	140	(Corak et al., 1991)
6a	MD	CP	7b	112	5133	206	4.0	4.4	7.2	156	148	7.2	9.9	100.0	86	(Decker et al., 1994)
6b	MD	P	7a	107	3233	112	3.5	6.2	6.7	108	85	7.2	7.7	93.1	57	(Decker et al., 1994)
8a	KY	KY	6a	112	5100	209	4.1	3.2	7.2	100	100	6.5	10.1	110.8	117	(Frye et al., 1985)
9a	MD	CP	7b	112	9010	351	3.9	4.2	10.6	90	0	8.0	10.6	132.5	152	(Holderbaum et al., 1990)

9b	MD	CP	7b	112	7440	288	3.9	1.8	5.4	90	0	5.5	5.4	98.2	88	(Holderbaum et al., 1990)
9c	MD	P	7a	107	3350	161	4.8	10.4	11.5	0	0	10.4	11.5	110.6	124	(Holderbaum et al., 1990)
9d	MD	P	7a	107	5140	190	3.7	4.9	10.3	90	0	10.5	10.3	98.1	87	(Holderbaum et al., 1990)
10a	KY	KY	6a	112	3250	125	3.8	0.4	4.1	100	100	6.6	9.1	62.7	54	(Huntington et al., 1985)
11a	GA	P	7b	137	2144	123	5.7	.	8.3	.	132	.	10.0	.	.	(McVay et al., 1989)
12a	TN	KY	7b	132	.	.	.	1.9	4.7	224	202	7.2	8.0	65.3	.	(Roberts et al., 1998)
13a	KY	KY	6a	112	3133	123	3.9	3.1	6.0	203	170	7.2	7.6	83.3	112	(Utomo et al., 1990)
13b	KY	KY	6a	112	3500	135	3.9	2.4	6.8	259	170	9.1	8.4	74.7	131	(Utomo et al., 1990)
14a	VA	P	6b	102	310	14	4.5	.	6.8	.	.	.	.	.	.	(Vaughan and Evanylo, 1998)
14b	VA	P	6b	102	2180	86	3.9	.	7.1	.	.	.	.	.	.	(Vaughanand Evanylo, 1998)
14c	VA	P	6b	102	2270	84	3.7	.	8.0	.	.	.	.	.	.	(Vaughanand Evanylo, 1998)
15a	NC	P	6b	122	5630	234	4.2	6.5	8.3	207	94	10.1	12.5	.	100	(Vaughan et al., 2000)
15b	NC	P	6b	122	.		.	6.6	11.0	234	151	12.9	13.7	.	.	(Vaughan et al., 2000)
16a	NC	P	7b	112	2350	114	4.9	7.5	9.6	169	118	9.8	10.4	97.8	132	(Wagger, 1989a)
16b	NC	P	7b	112	3410	146	4.3	8.5	11.3	187	200	11.7	11.6	96.8	129	(Wagger, 1989)
16c	NC	P	7b	112	4180	154	3.7	3.5	6.8	162	0	5.1	6.8	132.7	194	(Wagger, 1989)
16d	NC	P	7b	112	7120	229	3.2	3.3	5.8	164	102	4.9	6.2	118.8	157	(Wagger, 1989)
17a	MD	CP	7b	112	2980	104	3.5	4.0	9.0	161	32	9.1	9.7	.	158	(Clark et al., 2007a; 2007b)
17b	MD	CP	7b	112	5690	179	3.1	4.0	9.5	162	170	10.1	11.1	.	146	(Clark et al., 2007a; 2007b)
18a	NC	P	7b	112	5600	180	3.2	5.7	7.3	86	.	7.3	.	99.32	112	(Parr et al., 2011)
18b	NC	P	7b	112	5200	179	3.4	5.1	8.2	82	.	6.2	.	131.45	112	(Parr et al., 2011)
18g	NC	P	7b	112	6250	203	3.2	2.7	3.6	203	.	6.8	.	52.94	32	(Parr et al., 2011)
18h	NC	P	7b	112	4900	138.5	2.8	4.4	3.3	232	.	9.2	.	35.33	0	(Parr et al., 2011)
20a	ROK	ROK	7a		5500	205	3.7	5.4	10.7	155	163	10.4	11.2	.	149	(Seo et al., 2000)
20b	ROK	ROK	7a		4330	195	4.5	1.8	8.6	181	125	8.5	8.8	.	161	(Seo et al., 2000)
50 Observations					4226	154	3.7	4	7	163	111	8	9	89	98	

† Y-intercept of quadratic-plus-plateau curve (equivalent to yield with zero FN).

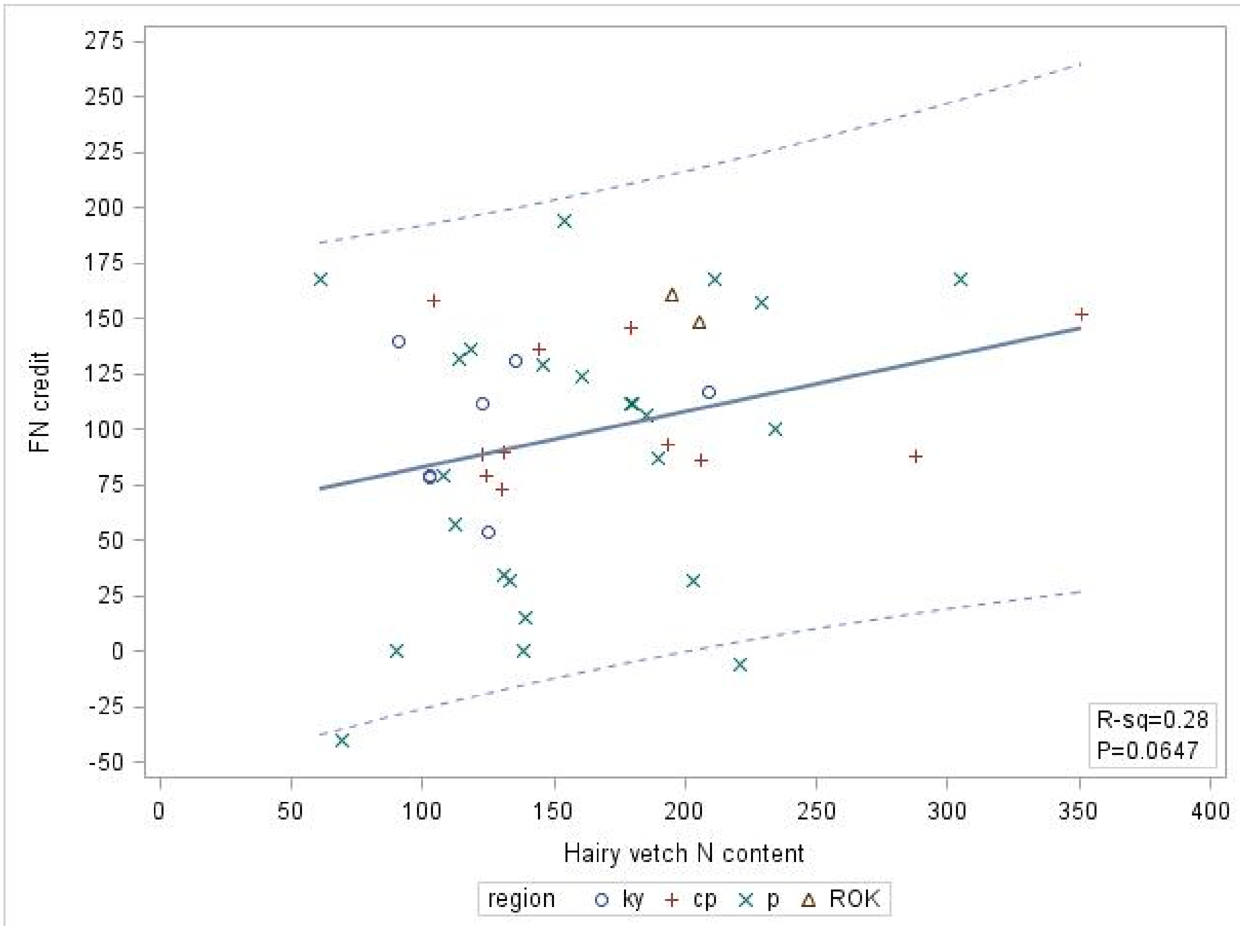
‡ Agronomic optimum N rate determined from solving the first derivative of the quadratic equation.

§ Plateau yield determined by solving the quadratic formula as a function of AONR.

¶ Response ratio=100*((hairy vetch y-intercept)/(check plot plateau yield).

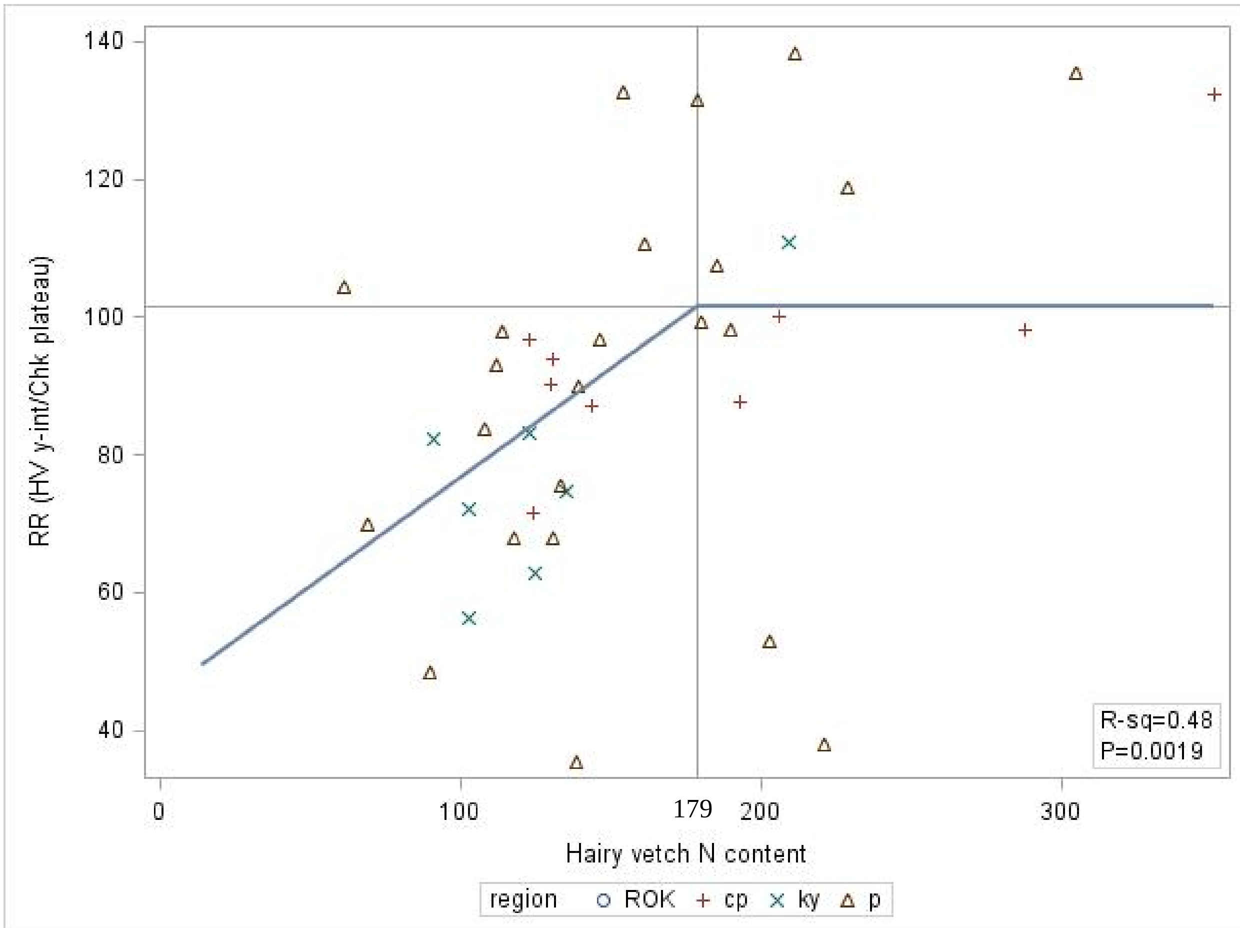
Fertilizer nitrogen credit (FN difference method) determined by subtracting hairy vetch y-intercept from the check plot using the quadratic formula.

Appendix L. Regression analysis of fertilizer nitrogen (FN) credit† relative to hairy vetch aboveground N content (kg N ha^{-1}) of peer-reviewed studies.

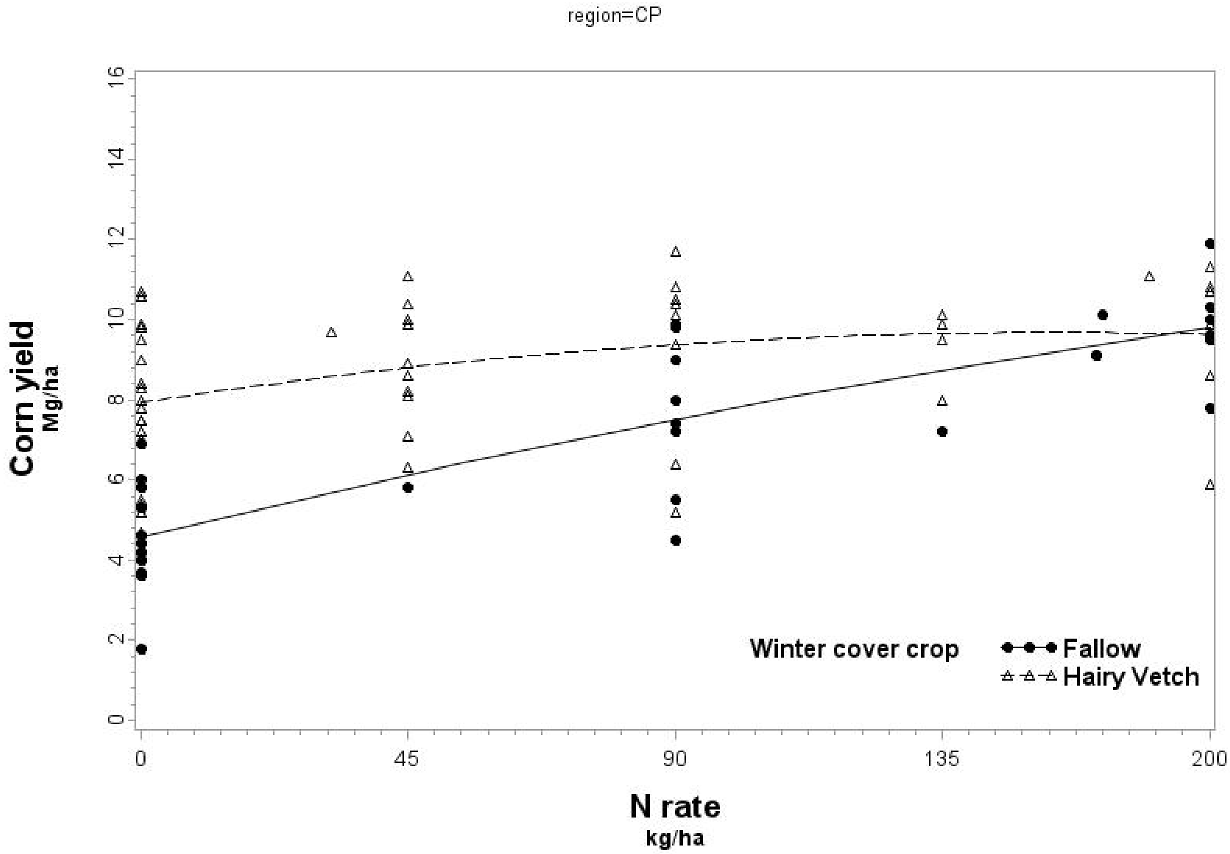


† FN credit (FN equivalence) is the FN rate required to achieve similar corn grain yield in fallow treatments relative to corn grain yields in hairy vetch treatments without FN.

Appendix M. Cate-Nelson analysis of response ratio (RR) relative to hairy vetch N content of peer-reviewed studies.

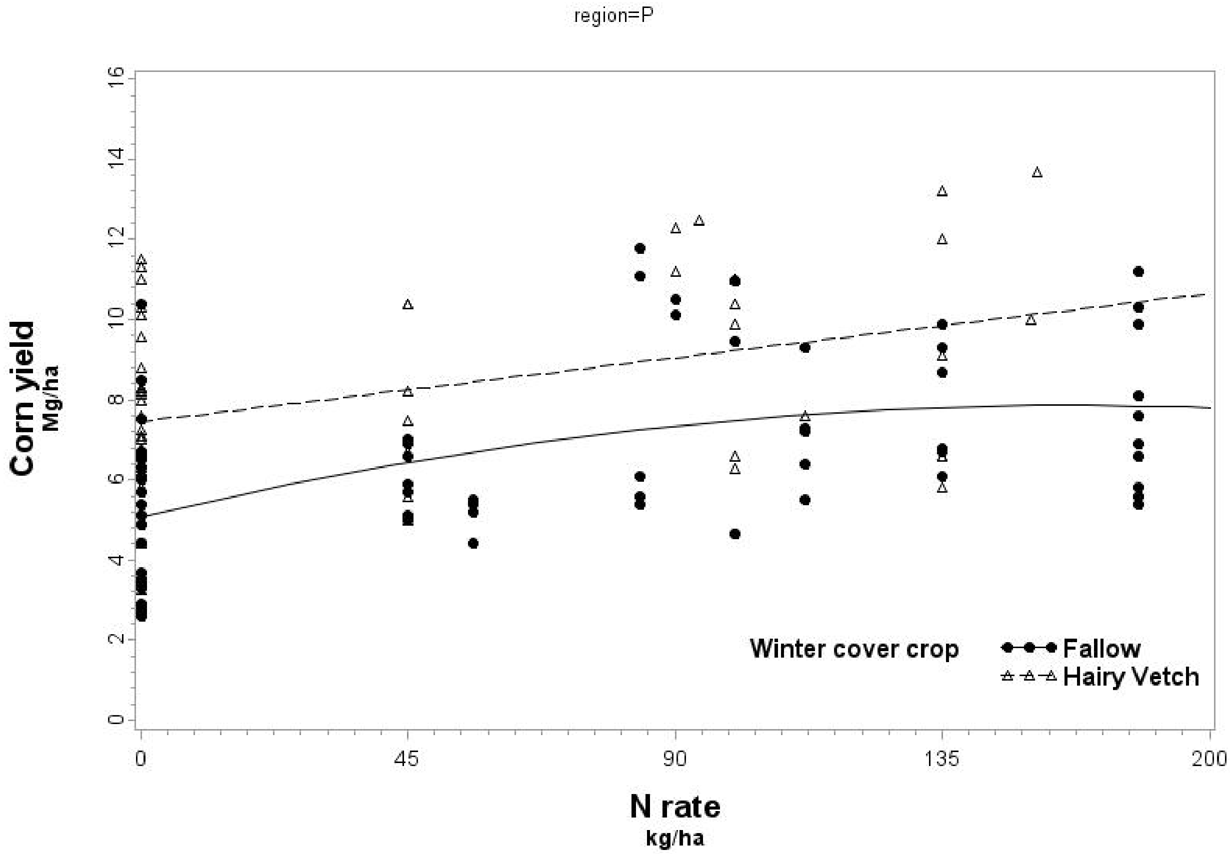


Appendix N. Regression analysis of corn grain yield relative to fertilizer N rate for corn following fallow and corn following hairy vetch WCC in coastal plain region of peer-reviewed studies.



Regression Equation:
y(wcc:chk) = 4.562776 + 0.036267*x - 0.000039*x^2
y(wcc:hv) = 7.93679 + 0.022609*x - 0.000073*x^2

Appendix O. Regression analysis of corn grain yield relative to fertilizer N rate for corn following fallow and corn following hairy vetch WCC in piedmont region of peer-reviewed studies.



Regression Equation:
y(wcc:chk) = 5.062611 + 0.035407*x - 0.000112*x^2
y(wcc:hv) = 7.447881 + 0.017304*x + 2.752E-6*x^2