EVALUATING THE EFFECTS OF COVER CROPS ON NITROGEN CYCLING IN THE CENTRAL SANDS

by

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Chapter 1: Introduction

The Central Sands of Wisconsin is one of the leading vegetable production centers in the U.S. The state is the highest producer of snap beans and third highest producer of potatoes, and also ranked third for processing sweet corn in the U.S. (WI 2016 Agricultural Statistics). The region's sandy soils, low organic matter, and clay content require pivot irrigation and nutrient inputs for productive yields. This combination of porous sandy soil and high inputs can result in nutrient leaching into local and national waters. Recommended N rates for optimal yield production in sandy soils in Wisconsin is 67 kg N ha^{-1} for snap beans, 280 kg N ha^{-1} for potatoes, and 168 kg N ha^{-1} for sweet corn. Recommendations are not uniform across states, however, for example for optimal sweet corn production in Michigan the state recommendation is 134 kg N ha^{-1} and in Minnesota the recommendation is 146 kg N ha^{-1}, both are lower than Wisconsin's recommendation (Warncke et al., 2005; Rosen and Eliason, 2005).

Agricultural production contributes at least 90% of nitrate contamination to Wisconsin's groundwater (Shaw, 1994) and nitrate contamination has become the top groundwater contaminant in the state (WI groundwater Coordinating Council, 2015). Nitrate-N is a water-soluble form of nitrogen that is regulated in drinking water at 10 mg L^{-1} nitrate-N by the U.S. Environmental Protection Agency at (USEPA, 1992). Nitrate contamination is most dangerous for infants, wherein exposure over 10 mg L^{-1} can cause Methemoglobinemia or “blue baby syndrome”, leading to a reduction in the child’s blood oxygen levels. Travelling beyond regional boundaries, nitrate contamination is a risk for national waterways as well.

Central Sands’ drainage feeds into the surface waters of the Mississippi River Basin, impacting ecosystems hundreds of miles away. Nitrogen loading from agricultural production is estimated to provide at least 65% of the total N contributing to oxygen depletion and hypoxic conditions in the Gulf of Mexico (Justic et al. 1995; Burkart and James 1999; Goolsby et al. 1999). In 2105 the hypoxic zone in the Gulf of Mexico was the size of Connecticut and Rhode Island combined (16,760 square kilometers), three times larger than the 2001 approved EPA taskforce goal (5,000 square kilometers) (Louisiana Marine Consortium, 2015). As nitrate contamination grows in the Gulf, researchers work to reduce impact and optimize nutrient management practices in agricultural systems.

Biological control of nutrient cycling with cover crops has the potential to reduce N rate and leaching while maintaining optimal yields in agricultural systems. Leguminous cover crops contain high amounts of N, have low C:N, and release fixed N quickly. Typical release of 50% of legume N occurs within four weeks of termination and releases of the rest by approximately 10 weeks (Stute and Posner 1995; Lupwayi and Soon 2015). This relatively quick release of N can be taken up by the crop and reduce N rate. Additionally, legume cover crops can impact soil microclimates, reducing soil heat and moisture stress (Thiessen Martens et al. 2001). In fine-textured soils, clay particles and organic matter bind to soil nitrate mineralized from legume cover crops, reducing leaching potential (Kraft and Stites 2003). On course-textured sandy soils, legume cover crops are not bound in the soil profile and have greater potential for N loss beyond the root zone before cash crop uptake (Cherr et al., 2006; Parr et al., 2011). In the Central Sands, West et al. (2016) measured no N credit from spring planted field pea. Also on a sandy soil, Cherr et al. (2006) documented no reduction in optimal N rate after three different legume cover crops. Speedy decomposition of leguminous cover crops depends greatly on climatic conditions and cover crop nutrient composition; species selection is specific to each environment.

Grass cover crops have higher C:N and lower N content than legumes, requiring soil N for decomposition, potentially competing with cash crop N uptake and mineralizing more slowly than legumes (Snapp et al., 2005; Kaspar et al., 2012). However, in the Central Sands Bundy and Andraski (2005) measured sweet corn yield benefit and reduction in economic optimum N rate from fall planted rye cover crop. Similarly, Gentile et al. (2009) measured a change in N transformation with the combined use of N fertilizer and high C:N organic residues. Grass cover crops are also used for reduction of residual soil N leaching following cash crop harvest. A meta-analysis of non-leguminous cover crop studies reported a 70% reduction in leaching potential with grass cover crops compared to fallow (Tonitto et al., 2006). However, leaching reduction potential is closely related to soil type and biomass production (Kaspar et al., 2012). In the Central Sands grass cover crops are most commonly used to combat wind erosion, however, cover crop variety and climatic conditions have potential to alter soil N transformations.

Understanding the rate at which cover crop organic N mineralizes into plant available nitrogen is critical for optimizing N efficiency and minimizing losses. N transformations vary according to environmental conditions, microbial community, moisture content and flow, soil microclimate, and management practices that are not represented in the laboratory setting (Binkley and Hart, 1989). Therefore, in-situ N mineralization measurement techniques are arguably more reliable than laboratory. Various in-situ methods have been used to quantify N transformations, advancing with time. Eno (1960) used buried resin bags, for a more precise technique that combined buried resin bags and PVC columns, DiStefano and Gholz (1986) and Brye et al. (2002) quantified soil volume and with mineralization measurements. Gentile et al. (2009) used the ^{15}N tracer method to document N immobilization in combined, high carbon to nitrogen ratio organic residues and mineral N fertilizer treatments. In this study we used a modified version of the buried resin bag in PVC column procedure of Brye et al. (2002). This method is more cost effective than the ^{15}N tracer method and soil column volume allows for field-scale quantification of mineralization.

Through quantification of N mineralization after oat cover crop in sandy soils and sweet corn yield impact following oat and legume cover crops, we learn of the potential for biological N control through cover cropping in the Central Sands region.

To further understand cover crop impact on sweet corn production this study quantified mineralization of spring planted oat in sandy soil and evaluated spring planted oat and legume cover crop potential for sweet corn nitrogen credit. Specific study objectives were to: (i) quantify spring-planted cover crop growth and N uptake, (ii) determine the effect of oat cover crop and N fertilizer on in-situ N-mineralization and seasonal PAN, (iii) determine the effect of spring planted cover crops on sweet corn yield.

Chapter 2: Evaluating the Effect of Cover Crops on Sweet Corn Yield

Abstract

Spring-planted cover crops in the upper Midwestern United States (U.S.) may provide a nitrogen benefit to subsequent sweet corn crops in fields where late fall-harvested crops limit the use of fall-planted cover crops. The objectives of this study were to measure spring-planted cover crop growth and nitrogen (N) uptake and subsequent effect on sweet corn (*Zea mays L.*) yield. Conducted across two growing seasons at the University of Wisconsin Hancock Agricultural Research Station in the Central Sands region of Wisconsin, the experimental design was a randomized complete block, split-plot design with five cover crop whole-plot treatments (chickling vetch (*Vicia villosa*), berseem clover (*Trifolium alexandrinum*), oat (*Avena sativa*) + berseem clover, oat, and no cover) and six split–plot N-rate treatments (0, 56, 112, 168, 224 and 280 kg-N ha^{-1}). Cover crop biomass and N uptake varied greatly between seasons, most likely due to differences in accumulation of growing degree days in the spring. In both study years, cover crops did not affect the agronomic optimal N rate (AONR) for sweet corn. These findings suggest that regardless of cover crop biomass production, N from spring-planted cover crops is not available for sweet corn crop uptake in this region on its irrigated sandy soils.

Introduction

Wisconsin is the third largest sweet corn producing state in the U.S. (Wisconsin 2014 Agricultural Statistics), with the majority of the state's sweet corn production produced under pivot irrigation in the sandy soils of the Central Sand region. In this region, the recommended nitrogen application rate for sweet corn production is 168 kg N ha^{-1} for irrigated sands with less than 2% soil organic matter (Laboski and Peters, 2012). This management system, with significant quantities of readily-mineralizable N on highly leaching soils, contributes, at least partially, to elevated nitrate concentrations in the region's ground water (Kraft et al., 2003). On sandy soils, cover crops can be used to both reduce N leaching (Snapp et al., 2005) and supply N to the cash crop, allowing for the potential mitigation of N leaching from these systems while retaining N for the cash crop, lowering economically optimal N rates in these systems (Bundy and Andraski, 2005).

With cash crops occupying fields for the majority of the growing season, cover crops tend to be limited to grasses (typically cereal rye (Secale cereale) or oat) planted in late fall to minimize wind erosion. In fields where cash crops are not harvested until late October, such as field corn (Zea mays) or soybeans (Glycine max), farmers are limited to planting spring-seeded cover crops. Sweet corn is a 90-day crop and can be planted from early May through early July. For the sweet corn planted later in the growing season (June and July), there is an opportunity for a spring (March or April) planting of a cover crop, which allows adequate time for cover crops to establish and serve as a supplemental N source due to either sequestration of existing N soil resources or fixation of atmospheric N by legumes.

Past research on nitrogen uptake of cash crops following spring-planted legume and grass cover crops in the Central Sands has reported varying N benefits for sweet corn produced following cover crop integration (West et al., 2016; Andraski and Bundy, 2005). Investigating the potential benefits of field pea (*Pisum sativum*) as a spring-seeded cover crop preceding sweet corn in the Central Sands, West et al. (2016) and Johnson et al. (2012) determined no to minimal N benefit from field pea in this system. In contrast, Andraski and Bundy (2005) determined an N credit in two out of three field seasons from fall-planted oat for field corn in the Central Sands. Therefore, based on these three regionally-based studies, fall-planted grass cover crops are more likely to provide an N credit compared to spring-planted legumes.

Although the aforementioned studies provide a basis to begin to derive cover crop recommendations for this region, several management variables require further investigation. Beyond field pea, other legume cover crops have not been tested for potential biomass production or N contribution to the cash crop production season. Additionally, cover crop termination methods and subsequent effects on N uptake by the cash crop have not been studied. West et al. (2016) and Johnson et al. (2012) both terminated the field pea cover crop through mechanical tillage and/or cultivation. These aggressive termination techniques, incorporating residue into the soil, may have hastened the mineralization of N present in the cover crop biomass. Thus, optimal cover crop management practices for cropping systems of the Central Sands remain to be determined, particularly as related to selection of spring-planted species (grasses and legumes) and termination method (chemical versus mechanical). The goal of the study was to determine the nitrogen credit of spring-planted grass and legume cover crops for sweet corn on irrigated sand. Specific study objectives were to: (i) measure spring-planted cover crop growth and N uptake and (ii) determine the impact of spring planted cover crops on sweet corn yield.

Materials and Methods

Site Description and Experimental Design

A two-year study was conducted in 2014 and 2015 at the University of Wisconsin, Hancock Agricultural Research Station (HARS) (latitude: 44°8’23” N; longitude: 89°31’23” W; elevation: 328 m) on and overhead-irrigated Plainfield loamy sand soil (mixed, mesic Typic Udipsamments). The 2012 fall soil test for the 2014 field indicated 6.5 pH, 0.9% organic matter (OM), 89 mg phosphorus (P) kg^{-1}, and 66 mg potassium (K) kg^{-1}. The 2013 fall soil test for the 2015 field indicated 6.5 pH, 0.9% OM, 121 mg P kg^{-1}, and 85 mg K kg^{-1}. The experimental design was a randomized complete block split-plot, replicated four times. Whole plot treatments (7.3 m x 27.4 m) were spring-planted oat (OAT), chickling vetch (CV), berseem clover (BC), oat + berseem (O+B) clover and no cover crop (NONE). Split plot treatments (4.6 m x 7.3 m, six corn rows wide) consisted of urea-N fertilizer applications: 0, 56, 112, 168, 224, and 280 kg-N ha^{-1}.

The experiment in 2014 followed two years of field corn and in fall 2013, the field received a single tillage pass with a Turbo-Till®, (Great Plains Manufacturing, Inc.; Salina, Kansas) field cultivator at 20 cm depth. In spring 2014, the field received seedbed preparation with three passes of the Turbo-Till®, followed by one pass with a 20 cm Brillion™ (Landoll Corporation; Marysville, Kansas) soil finisher. In study year 2015, the experiment followed a soybean-potato rotation, with no tillage in fall 2014. Cover crop seedbed preparation in 2015 consisted of one pass with the Turbo-Till® field cultivator at 20 cm depth and 112 kg ha^{-1} potash (0-0-60).

Cover crop was drill seeded with the Oliver-Superior No. 64® Grain Drill on 21 April 2014 and on 16 April 2015. Seeding rates were 134 kg ha^{-1} for oat (variety not stated in 2014, 'Saber' in 2015), 67 kg ha^{-1} for chickling vetch ('AC Greenfix'), 13 kg ha^{-1} for berseem clover (variety not stated in 2014; 'Balady 1' in 2015), and the combined treatment was 67 kg ha^{-1} for oat and 11 kg ha^{-1} berseem clover. Chickling vetch was inoculated with 'N-Dure™' (Verdesian; Cary, North Carolina) and berseem with Nitragin® Gold (Novozymes; River Falls, Wisconsin). Cover crop seeds were obtained from Albert Lea Seed (Albert Lea, Minnesota) both years of the study.

Cover crop was terminated on 10 June 2014 with Credit Extra® (Nufarm Americas Inc.; Alsip, Illinois; active ingredient (a.i.) 2.3% glyphosate, mixed with nonionic 80/20 surfactant, and ammonium sulfate (AMS, 21-0-0-24S, 1.2 L ha^{-1})). Chickling vetch plots were also treated with 2,4 D Amine 4, (Loveland Products Inc.; Greenley, Colorado, a.i. 46.5% dimethylamine salt of 2,4-Dichloro-phenoxyacetic acid) and Parallel® Plus Herbicide (Makhteshim Agan of North America, Inc.; Raleigh, North Carolina, a.i. atrazine 2-chloro-4-ethylamino-6-isopropylamino-s-triazine and metolachlor 2-chloro-N-acetamide) on 16 June 2014. Chickling vetch plots received their last herbicide treatment on 31 July 2014 of Laudis® (Bayer CropScience LP; Research Triangle Park, North Carolina, a.i. 34.5% tembotrione 2-cyclohexanedione mixed with AMS and methylated seed oil) on 31 July 2014. In the 2015 season, all cover crops were terminated 12 June 2015 with an application of Mad Dog Plus® (Loveland Products Inc.; Greenley, Colorado, a.i. 41% glyphosate mixed with, nonionic 80/20 surfactant, and AMS). The oat cover crop stand required surface cultivation with an M&W® 10' Dyna-Drive® (Alamo Group Inc.; Seguin, TX) on 16 June 2015 and a second herbicide application [Parallel® (Atrazine) (1.6 L ha^{-1})] on 19 June 2015 for complete cover crop termination.

Sweet corn ('DMC 21-84', Del Monte Foods Hybrid Yellow Sweet Corn Seed) was planted on 13 June 2014 and 19 June 2015 with a John Deere Max Emerge™ (Deere & Company; Olathe, Kansas) 2 four-row planter at a seeding density of 24,500 plants ha^{-1}. Six rows were planted per plot at 28.5 cm row spacing and starter fertilizer (10-20-20-4S-2Ca+micronutrients) was applied at planting (224 kg ha^{-1}). Urea-N fertilizer was hand applied at 56 kg-N ha^{-1} during the V4 sweet corn growth stage and 56 kg-N ha^{-1}, 112 kg ha^{-1}, 168 kg-N ha^{-1}, and 224 kg-N ha^{-1} at the V8 growth stage. Fertilizer was irrigated within 24 hours of application in 2014 and on the same day of application in 2015. Irrigation, insecticide, and herbicide were applied to the sweet corn as needed.

Sample Collection and Analysis

Precipitation and daily air temperatures (maximum and minimum) measurements were recorded at HARS (Hancock Research Station-UW Extension AG Weather) and were used to calculate growing degree day accumulation for both the cover crop and sweet corn growing seasons and were calculated as:

Growing Degree Days °C (GDD) = $[(T°C_{(Daily\ MAX)} + T°C_{(Daily\ MIN)})/2]/T_{BASE}$

Where if the daily maximum temperature >30° was set equal to 30° and if the daily minimum temperature <10° was set equal to 10°. T_{BASE} is the base temperature for the organism, where sweet corn T_{BASE} = 10° and oat T_{BASE} = 5.5°.

Cover crop stand counts and above ground biomass (AGB) were collected on 10 June 2014 and 19 June 2015, with three samples collected per whole plot from a 0.37 m^2 area in 2014 and a 0.14 m^2 area in 2015. Cover crop biomass samples were dried in a 60°C forced-air dryer for one week, mechanically ground using a 0.5 mm sieve, and stored in plastic vials until analysis. Nitrogen content of cover crop biomass was determined by re-drying samples for at least 24 hours prior to analysis, with total carbon (C) and total nitrogen determined using flash combustion (Thermo Fisher Scientific Flash EA 1112 NC Analyzer, Thermo Fisher Scientific Inc., Waltham, MA). Sweet corn was harvested at maturity (90 DAP in 2014 and 89 DAP in 2015) on 11 September 2014 and 11 September 2015. Yield was determined as both fresh weight yield (Mg ha^{-1}) and ear yield (as thousand ears per hectare) by harvesting marketable ears in rows three and four of each six-row plot. Ears were counted and immediately weighed (unhusked) in the field for fresh weight yield calculation.

Statistical Analysis

Statistical analysis was completed using SAS (Statistical Analysis System, version 9.2, SAS Institute, Cary, NC). Cover crop biomass, C yield, N yield, and C:N ratio were analyzed by year using Proc MIXED, with blocks as a random effect. For sweet corn yields, each study year was evaluated separately and analysis of variance (ANOVA) was conducted to determine significant effects of cover crop and N-rate (Proc MIXED) with blocks (cover crop treatment) as random effects. To determine agronomic optimal N rate (AONR) by cover crop treatment by year N response data were fit to linear, linear-plateau, quadratic, and quadratic-plateau using Proc REG and Proc NLIN. The N rate response data were visually inspected and the model with the largest coefficient of determination (R^2) value was reported. The AONR is the minimum recommended N rate necessary to achieve the maximum yield.

Results and Discussion

Cover crops

The monthly air temperatures during the 2014 cover crop growing season were 1 to 3˚C above 30-year normal temperatures (citation for 30-yr average?) averaging 5˚C (1˚C above the 30-year normal) in April, 14˚C (3˚C above the 30-year normal) in May, and 20˚C (2˚C above the 30-year normal) in June. Cover crops were not irrigated and total precipitation was 196 mm from cover crop seeding to termination in 2014.

In 2015, the monthly temperatures during the oat growing season were at or 4˚C above 30-year normal temperatures, averaging 8˚C in April (at the 30-year normal), 15˚C (4 ˚C above the 30-year normal) in May, and 18˚C (4˚C above the 30-year normal) in June. Cover crop GDD were higher in 2015 compared to 2014; however, the difference between yearly GDD narrowed by cover crop termination. Total precipitation throughout the 2015 oat growing season was 191 mm.

Cover crop growth, biomass production, and N uptake varied greatly between seasons, with more biomass and N uptake measured in 2015. Compared to 2014, legume cover crop (berseem clover and chickling vetch) AGB was 12-14 times greater in 2015. The 2014 chickling vetch production (258 kg ha^{-1}, 12 kg N ha^{-1}) was below the expected AGB and within expected N-uptake range (339 to 4000 kg ha^{-1} and 6 to 161 kg N ha^{-1}) (Thiessen Marten et al., 2001; Bouman et al., 1993; Buechi et al., 2015; Rinnofner et al., 2008), while production in 2015 (3717 kg ha^{-1}, 134 kg N ha^{-1}) was close to the greatest values previously reported. The C:N ratios of chickling vetch were similar both years of this study (9 in 2014 and 12 in 2015) and to previously reported values (Buechi et al., 2015; Rinnofner et al., 2008). Berseem clover AGB production and N uptake in 2014 (71 kg ha^{-1} and 3 kg N ha^{-1}) was lower than measured berseem and other clover species in the literature (500 to 200 kg ha^{-1}) (Fakhari et al. 2015; Parr et al. 2011; Read et al. 2011). Berseem clover AGB production in 2015 (891 kg ha^{-1}) and C:N (17) were within the range of values reported in other published studies; however N uptake was lower than expected (20 kg N ha^{-1}) (Fakhari et al. 2015; Marstorp and Kirchmann,1991; Parr et al. 2011; Read et al. 2011; Snapp et al. 2005). Berseem clover's poor biomass production and N-uptake in both growing seasons suggests that April through May planting dates couple with a June termination date may not allow for the adequate growth in the Central Sands region of Wisconsin.

Oat and combined oat/berseem clover production, also varied greatly between seasons. Oat AGB in 2014 (272 kg ha^{-1}) was 21 times lower compared to 2015 (5824 kg ha^{-1}) (Table 1) and combined treatment (oat + berseem clover)

AGB was 17 times greater than 2015. Oat biomass in both 2014 and 2015 was within range of other studies in the region, from 7 to 91 kg N ha^{-1} and C:N between 15 and 33 (Andraski and Bundy, 2005; Contrera-Govea and Albrecht, 2005). To varying magnitudes, oat AGB variability has been documented in other upper Midwestern cropping studies. In a Wisconsin-based study, Andraski and Bundy (2005) noted 5-fold differences in oat biomass (590 kg ha^{-1} to 3010 kg ha^{-1}) between years for their fall planted and winter killed cover crop. Also in Wisconsin, Contreras-Govea and Albrecht (2005) measured spring-planted oat biomass with a mean weight of 7700 kg ha^{-1} following 77 days of growth (mid-April to late October). Pro-rated, this values corresponds with the biomass accumulation during the 2015 field season of this study (100 kg AGB ha^{-1} day^{-1}).

Combined oat and berseem clover treatment in both 2014 and 2015 had the greatest AGB (333 kg ha^{-1} in 2014 and 5864 kg ha^{-1} in 2015) and N uptake (9 kg N ha^{-1} in 2014 and 140 kg N ha^{-1} in 2015) of all cover crops, falling within the range of reported values for combined grass and legume AGB measurements in published literature (177 to 6175 kg ha^{-1} and 60 kg N ha^{-1} to 115 kg N ha^{-1}) (T. Rinnofner et al. 2008; Parr et al. 2011).

Sweet corn

Mean monthly air temperatures during the 2014 sweet corn growing season deviated from -5 to 2°C around the 30-year normal temperatures, averaging 20°C in June (2°C above the 30-year normal), 19°C in July (1°C below the 30-year normal), 20°C in August (2°C below the 30-year normal), and 15°C in August (5°C below the 30-year normal). GDD were higher than those in 2015, accumulating 891 GDD in 2014. Total accumulated water (precipitation 272 mm + irrigation 276 mm) throughout the sweet corn growing season was 548 mm.

In the 2015 sweet corn growing season mean monthly air temperatures deviated -3 to 1°C around the 30-year normal temperatures, averaging 18°C in June (at the 30-year normal), 21°C in July (1°C above the 30-year normal), 19°C in August (3°C below the 30-year normal), and 18°C in August (2°C below the 30-year normal). Total accumulated GDD were 845 in 2015 and total accumulated water (precipitation 264 mm + irrigation 256 mm) throughout the 2015 sweet corn growing season was 519 mm.

Sweet corn yields were evaluated separately between ear yield (1000 ear ha^{-1}) and fresh weight yield (Mg ha^{-1}) in both 2014 and 2015 and were standardized to the same plant density (9,720 plants ha^{-1})). Analysis of variance shows that applied nitrogen rate significantly impacted sweet corn yield in both 2014 and 2015 ($p< 0.05$). There was an interaction effect between cover crop treatment and N rate in study year 2014 ($p< 0.05$) (Table 2).

In 2014, sweet corn ear yield responses to increasing N applications on BC, CV, and NONE treatments were quadratic (Figure 1), with AONRs at or near the highest N rate used in this study (280 kg N ha^{-1}). Sweet corn ear yield responses in 2014 to OAT and O+B were linear (Figure 2). In the same year, sweet corn fresh weight yield responses to all treatments were linear, but with CV and NONE plateauing at N rates of 171 and 148 kg N ha^{-1} (Figures 1 & 2). In 2015, sweet corn ear yield responses to all cover crop treatments were quadratic, with AONRs of 215, 216, 221,259, and 269 kg N ha^{-1} for NONE, OAT, OAT+B, CV, and BC, respectively (Figures 3 & 4). Sweet corn fresh weight yield responses to N in 2015 were linear to 121, 136, 138, and 138 kg N ha^{-1} for NONE, OAT, OAT+B, and BC, respectively. Sweet corn fresh weight yield response to N following CV in 2015 was quadratic (AONR = 280 kg N ha^{-1}) (Figure 3). In both 2014 and 2015, regardless of biomass accumulation differences, neither year saw an N credit from the cover crop and N-rate treatments. In both study years, each treatment combination had a higher AONR as compared to the control; therefore, mineralized N from the cover crops did not affect sweet corn yield regardless of N rate. In spite of cover crop seasonal production differences, cover crops did not provide a nitrogen benefit for sweet corn yield.

Yield response to cover crops in both years had a coefficient of determination (R^2) above 0.5 except for the 2014 chickling vetch treatment (ear yield R^2 = 0.39 and fresh weight yield R^2 = 0.66), which was caused by higher sweet corn yield in 0 kg N ha^{-1} treatments across all blocks, compared to 56 kg N ha^{-1}. In 2014, chickling vetch required two additional herbicide applications after sweet corn planting; this extra biomass accumulation was not measured though it is possible that it competed with sweet corn growth or contributed to an unmeasured interaction that reduced yields. In order to determine a more realistic agronomic optimal N rate and a stronger relationship between chickling vetch treatment and yield response, regression analysis was completed a second time, removing 0 kg N ha^{-1} data points from the analysis. Quadratic (R^2 = 0.92) and linear-plateau (R^2 = 0.93) models were fit to the fresh weight yield data and adjusted agronomic optimal N rates of 217 kg N ha^{-1} (fresh weight yield = 13 Mg ha^{-1}) and 77 kg N ha^{-1} (fresh weight yield = 11 Mg ha^{-1}) were determined. Sweet corn ear yield data with 0 kg N ha^{-1} data points removed was also fit to quadratic (R^2 = 0.83) and linear-plateau (R^2 = 0.82) models, determining adjusted agronomic optimal N rates of 226 kg N ha^{-1} (ear yield = 49,000 ears ha^{-1}) and 126 kg N ha^{-1} (ear yield = 45,000 ears ha^{-1}). Upon removal of the 0-N data points, the newly adjusted 2014 chickling vetch agronomic optimal N rates fluctuated above and below the no cover treatments' (AONR = 148 kg N ha^{-1} at 10 Mg ha^{-1} fresh weight yield and AONR = 279 kg N ha^{-1} at 44,000 ears ha^{-1}). Agronomic optimum N rate for fresh weight yield determined by linear-plateau regression was lower than the control, however with similar R^2 values quadratic regression of the same data determined a greater agronomic optimal N rate. Regarding regression of the ear yield data, both regression models determined lower agronomic optimum N rate values than the control. This inconsistency in agronomic optimum N rate across regression analysis could be attributed to the variable mean values for N-rates 168 kg N ha^{-1} (12 Mg ha^{-1} & 48,000 ears ha^{-1}), 224 kg N ha^{-1} (11 Mg ha^{-1} &

38,000 ears ha^{-1}), and 280 kg N ha^{-1} (12 Mg ha^{-1} & 50,000 ears ha^{-1}) in the 2014 chickling vetch treatment. Variability in the 2014 chickling vetch dataset is responsible for low R^2 values (quadratic regression) and is potentially better described by higher order polynomial regression (fourth order $R^2 = 0.99$ & AONR = 151 kg N ha^{-1}), accounting for the dataset's abnormal peaks and valleys.

These findings are consistent with previous work comparing sweet corn yield benefit of leguminous cover crops in sandy soils. Johnson et al. (2012) measured minimal N benefit from spring-planted field pea cover crop in the Central Sands and West et al. (2016) reported no nitrogen credit from spring-planted field pea also in the Central Sands. In the warm-temperate environment of Florida, Cherr et al. (2007) documented no sweet corn yield benefit from fall-planted white vetch in sandy soil. Parr et al. (2011) also determined no N credit from legumes (berseem clover, red clover, or crimson clover) on sandy soils of North Carolina. Thus, our findings agree with other studies on leguminous cover crops, suggesting rapid mineralization in sandy soil and subsequent leaching of plant available N beyond the root zone prevent N benefit to sweet corn crop.

We did not determine an N credit with oat cover crop, but higher yields were obtained at higher N rates compared to no cover crop The N benefits of grass cover crops and combined grass + legume cover crop treatments are not clearly defined in the literature. Andraski and Bundy (2005) measured a reduction in economic optimum N rate in two out of three study years following fall-planted oat cover crop in sandy soil. Also in sandy soils, Parr et al. (2011) measured no N benefit of combined grass and legume biculture cover crop treatments; however Sainju et al. (2005) did measure an N benefit from biculture a cover crop treatment to the subsequent crop. On a silt loam, Stute et al. (1995) documented an N benefit from an oat/legume-corn rotation. Thus, prior studies do not clearly corroborate our findings: that spring-planted oat cover crop provided zero N-credit to the subsequent sweet corn crop, but did provide a yield benefit at higher N-rates.

Conclusion

Legume and grass spring-planted cover crop treatments did not reduce optimal N rate for sweet corn production in sandy soil, regardless of biomass produced during the cover crop growing season. However, slight gains in sweet corn yield were obtained following a cover crop at higher rates of applied N. Berseem clover, as a single species or part of a cover crop mix, is not recommended as a cover crop in this system because of low productivity. Chickling vetch may also be problematic when grown as a spring-sown cover crop in the Central Sands, as termination required additional chemical applications or mechanical tillage as compared to the other cover crops trialed. The existing, underlying concern of farmers regarding the integration of spring-seeded cover crops into the cropping systems of the Central Sands was realized in in 2014, where cover crop growth was slow and little biomass was produced. It is not clear that growers will be able to obtain a consistent cover crop when spring seeding in this region.

While this study focused on the role of spring-seeded cover crops on nitrogen availability to the subsequent cash crop, it also provides greater understanding of the broader impacts of cover crops planted in this region for other ecosystem services, specifically mitigation of the impacts of wind erosion. If possible within the season constraints of the typical crop rotations in Central Wisconsin, farmers will establish fall planted cover crops, often cereal rye, in field corn and soybean, allowing for adequate cover to reliably control wind erosion in the spring. Concerns exist that higher amounts of biomass from a grass cover crop may lead to a reduction in available N to the subsequent cash crops. However, this study demonstrated that large amounts of biomass from a grass cover crop in the spring displayed no negative effects on yield or optimum N rate. Thus, the use of cover crops integrating the multifunctional strategy of a conservation management practice will not affect production of sweet corn in this region. The future of N management research in these systems should focus on improved nitrogen use efficiency through in-season N application, working towards optimal N rate reductions.

Tables and Figures

TABLE 1 Cover crop dry matter biomass and nitrogen uptake at Hancock Agricultural Research Station in 2014 and 2015. Cover crops abbreviations are: BC=berseem clover, CV=chickling vetch, O+B=oat and berseem clover, and OAT=oat.

	2014					2015				
Cover Crop	Plant Pop.[a]	Biomass	Total C	Total N	C:N	Plant Pop.	Biomass	Total C	Total N	C:N
	1000 plants ha^{-1}	kg ha^{-1}	kg C ha^{-1}	kg N ha^{-1}	%	1000 plants ha^{-1}	kg ha^{-1}	kg C ha^{-1}	kg N ha^{-1}	%
BC	1,050	71 (17)[b]	31 (8)	3 (0.8)	11 (0.6)	3,250	891 (678)	353 (273)	20 (16)	17 (1.4)
CV	260	258 (82)	108 (96)	12 (3)	9 (0.3)	2,090	3717 (850)	1567 (369)	134 (24)	12 (0.6)
O+B	1,920 (O) 970 (B)	333 (85)	137 (36)	9(3)	15 (1.2)	8,820 (O) 3,070 (B)	5864 (1842)	2430 (774)	140 (59)	18 (3)
OAT	4,690	272 (40)	112 (14)	6 (0.6)	18 (0.7)	13,310	5824 (845)	2419 (331)	119 (30)	20 (4)

[a]Target plant population was 4,409,000 plants ha^{-1} for BC, 3,274,000 plants ha^{-1} for CV, 2,015,000 + 3,674,000 plants ha^{-1} for O+B respectively, and 4,030,000 plants ha^{-1} for OAT.

[b]Number in parenthesis indicates standard deviation.

TABLE 2 Sweet corn fresh yield ANOVA results as affected by cover crop and N rate at Hancock Agricultural Research Station in 2014 and 2015. Analysis conducted by year.

	Mean Yield			
	2014		2015	
Treatment	Mg ha^{-1}	1000 Ears ha^{-1}	Mg ha^{-1}	1000 Ears ha^{-1}
Cover Crop				
Berseem Clover	7.45a	30.9a	14.7a	46.0a
Chickling Vetch	8.47a	35.3a	15.7a	47.1a
Oat + Berseem Clover	6.77a	30.0a	14.3a	44.4a
Oat	5.48a	25.6a	14.1a	47.0a
No Cover	6.36a	26.5a	13.2a	43.0a
N rate, kg ha^{-1}				
0	1.85a	11.2a	1.67a	7.09a
56	1.44a	8.02a	6.76b	26.0b
112	6.30a	27.5b	18.0c	55.8c
168	10.1b	40.6c	19.3c	58.3c
224	10.8b	41.6c	19.2c	60.8c
280	11.5b	48.5c	22.0c	64.1c
Source of variation			*P* value	
Cover Crop	0.0005	0.0785	0.3022	0.3459
N rate	<.0001	<.0001	<.0001	<.0001
Cover Crop*N rate	0.0235	0.0039	0.6263	0.4413

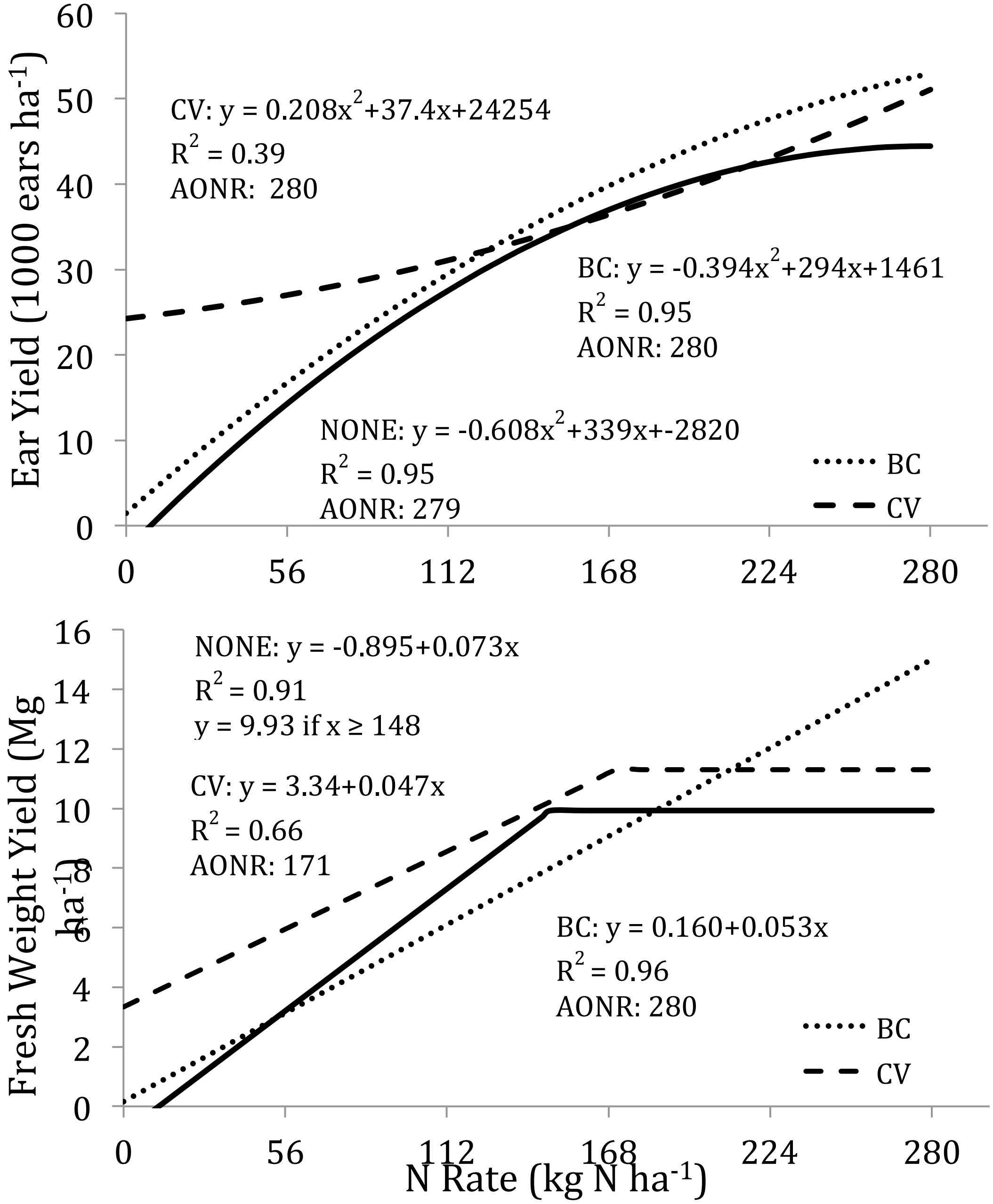

FIGURE 1 Sweet corn agronomic optimal N rate (AONR) as determined by regression modeling following each cover crop treatment (berseem clover (BC), chickling vetch (CV), no cover crop (NONE)) and nitrogen (N) rate reported as ear yield (1000 ears ha^{-1}) (top) and fresh weight yield (Mg ha^{-1}) (bottom), Hancock, WI, 2014.

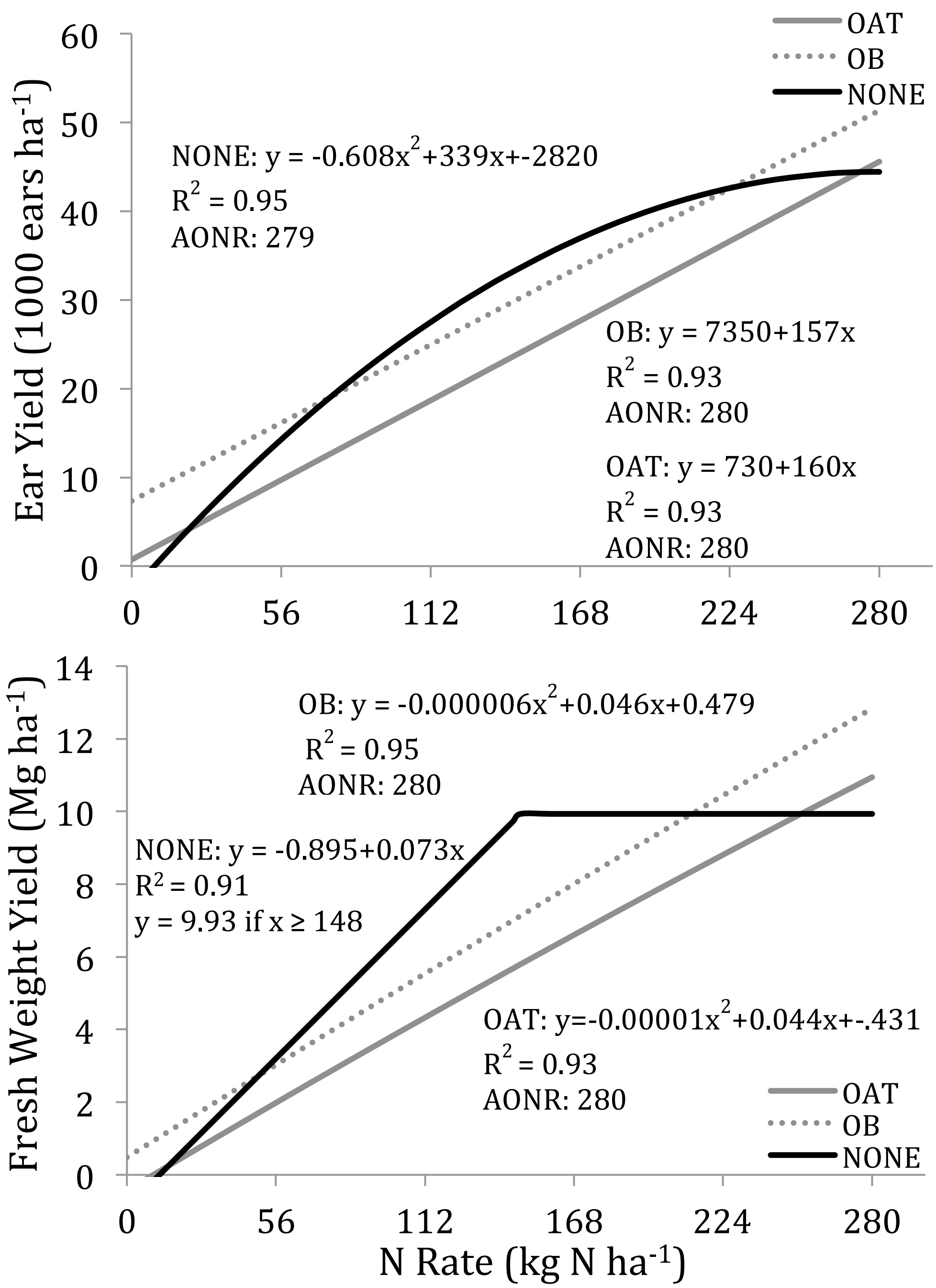

FIGURE 2 Sweet corn agronomic optimal N rate (AONR) as determined by regression modeling following each cover crop treatment (berseem clover (BC), chickling vetch (CV), no cover crop (NONE)) and nitrogen (N) rate reported as ear yield (1000 ears ha^{-1}) (top) and fresh weight yield (Mg ha^{-1}) (bottom), Hancock, WI, 2014.

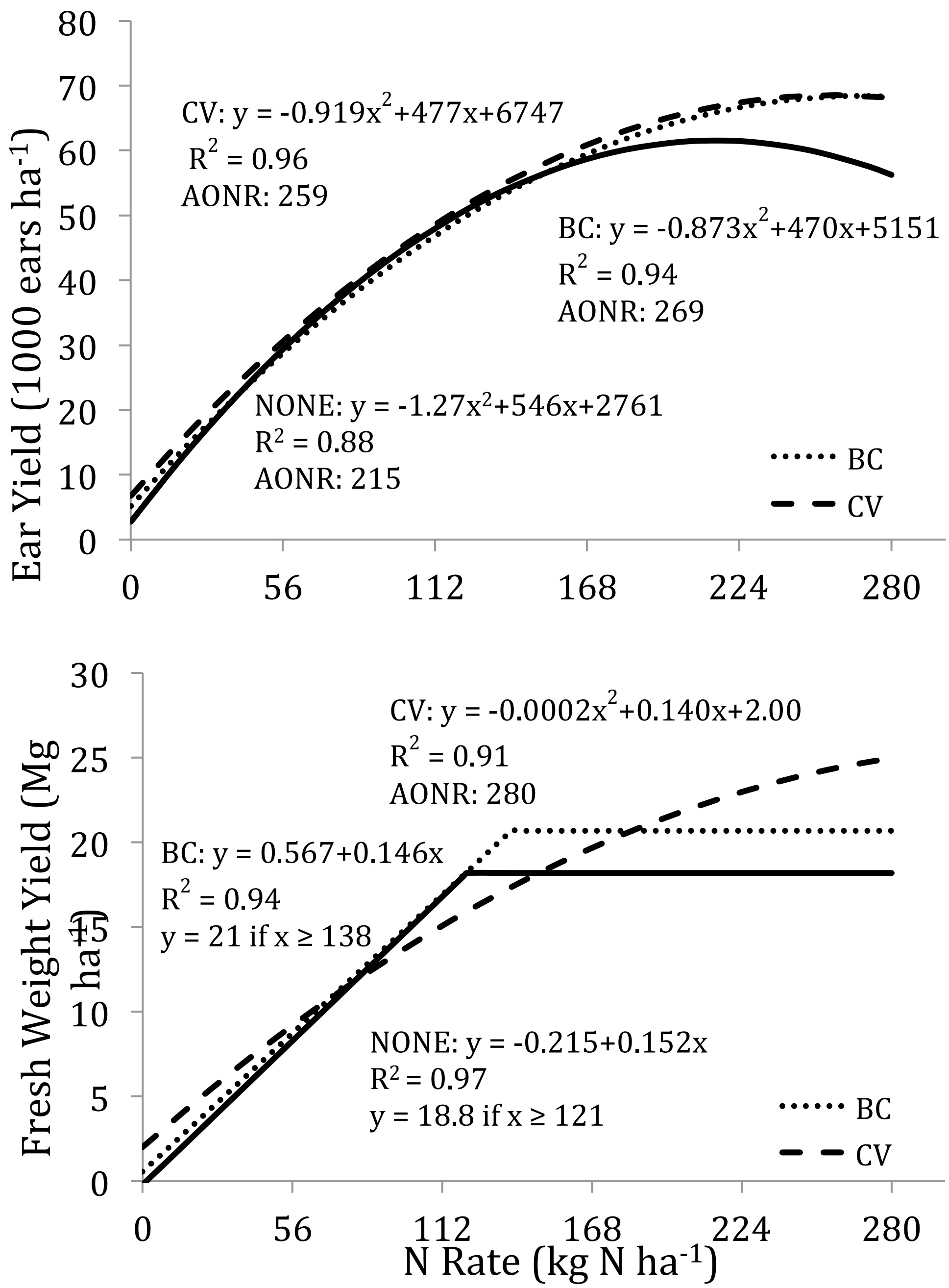

FIGURE 3 Sweet corn agronomic optimal N rate (AONR) as determined by regression modeling following each cover crop treatment (berseem clover (BC), chickling vetch (CV), no cover crop (NONE)) and nitrogen (N) rate reported as ear yield (1000 ears ha^{-1}) (top) and fresh weight yield (Mg ha^{-1}) (bottom), Hancock, WI, 2015.

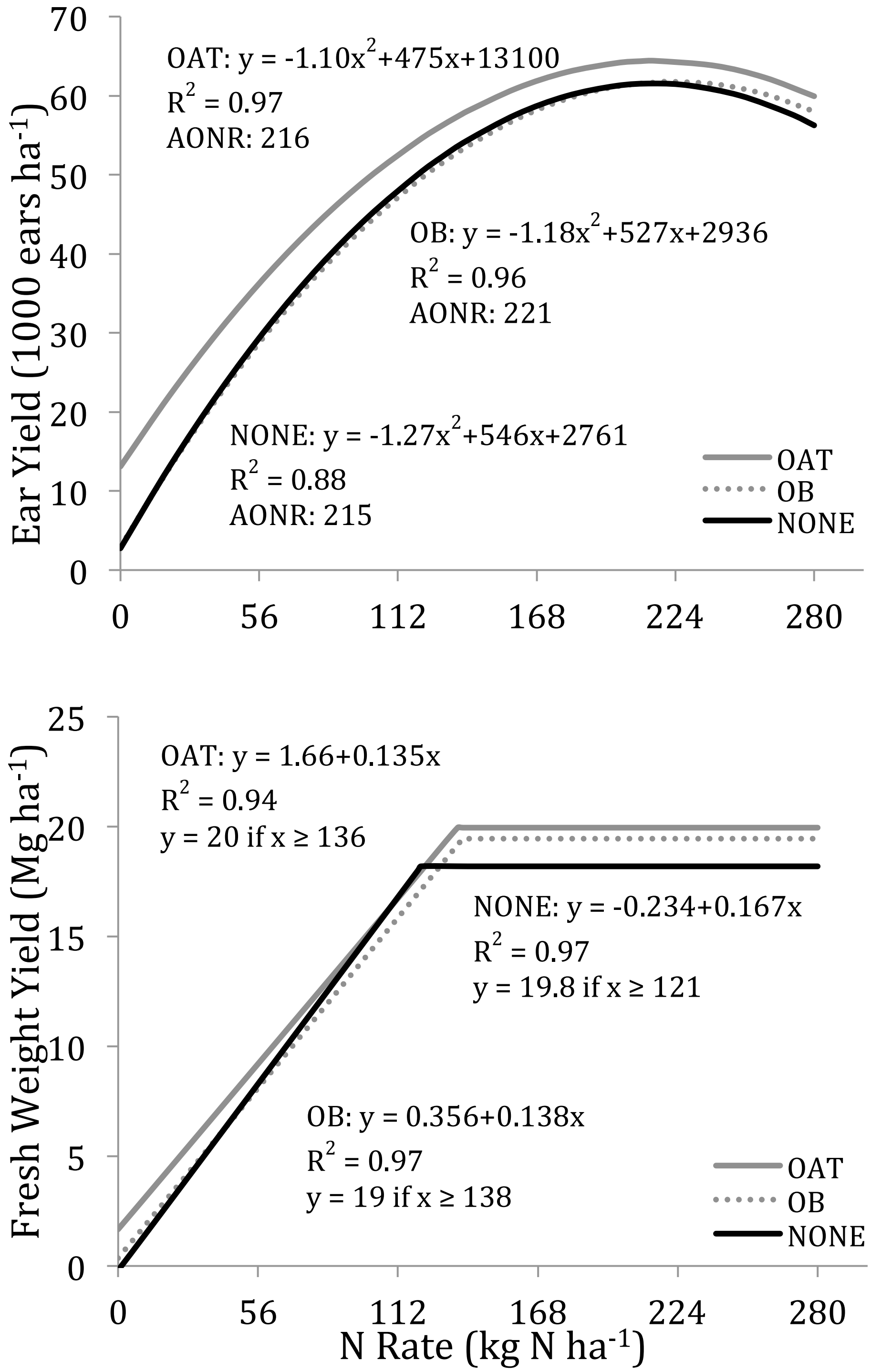

FIGURE 4 Sweet corn agronomic optimal N rate (AONR) as determined by regression modeling following each cover crop treatment (berseem clover (BC), chickling vetch (CV), no cover crop (NONE)) and nitrogen (N) rate reported as ear yield (1000 ears ha^{-1}) (top) and fresh weight yield (Mg ha^{-1}) (bottom), Hancock, WI, 2015.

SAS Code

Yield

```
data CC2014;
input cc $ nrt blk yield;
datalines;
proc glimmix data=CC2014 plots=studentpanel;
    class blk cc nrt;
    model yield = cc nrt cc*nrt;
    random blk;
lsmeans cc/diff;
lsmeans cc*nrt/diff;
run;
proc sort; by blk cc nrt;
proc print;
run;
```

Yield Regression

```
proc print data=yield;
data b; set yield;
N = NRate;
N2 = N*N;
proc print data=b;
DATA REG; SET b;
PROC REG;
MODEL Yield=N;
PROC REG;
MODEL Yield=N N2;
OUTPUT OUT=X RESIDUAL=R;
PROC NLIN;
PARMS B0=8 B1=0.44 KNOT=100;
AGEPLUS=MAX (N - KNOT, 0);
MODEL Yield = B0 + B1*N - B1*AGEPLUS;
OUTPUT OUT=B PREDICTED=YP RESIDUAL=RR;
Proc Plot;
plot yield*n yp*n='*' /overlay;
plot rr*n;
run;
PROC NLIN;
PARMS A=8 B=0.44 C=-.0015;
N0=-145*B/C;
DB=-.5/C;
DC=.5*B/C**2;
IF N<N0 THEN DO;
MODEL Yield=A+B*N+C*N*N;
DER.A=1;
DER.B=N;
DER.C=N*N;
END;
ELSE DO;
MODEL Yield=A+B*N0+C*N0*N0;
```

```
DER.A=1;
DER.B=N0+B*DB+      2*C*N0*DB;
DER.C=   B*DC+N0*N0+2*C*N0*DC;
END;
IF _OBS_=1 & _ITER_>0 THEN DO;
PLATEAU=A+B*N0+C*N0*N0;
PUT N0=PLATEAU=;
end;
OUTPUT OUT=b predicted=grainyldp residual=gyresid;
proc plot;
plot Yield*N grainyldp*N='*' / overlay vpos=35;
plot gyresid*n;
run;
```

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Chapter 3: Oat Cover Crop Growth and Influence on Net Nitrogen Mineralization in Sandy Soil

Abstract

Cover crops are widely used in the Central Sands region of Wisconsin, but their effect on seasonal N cycling is not well quantified. The objectives of this study were to quantify spring-planted oat (*Avena sativa*) cover crop growth and N-uptake, determine the effect of oat cover crop and N fertilizer on in-situ mineralization and seasonal plant available nitrogen (PAN), and determine the effect of spring planted oat cover crops on sweet corn (*Zea mays L.*) N uptake. The study was conducted across two growing seasons at the Hancock Agricultural Research Station in the Central Sands of Wisconsin and the experimental design was a randomized complete block, split-plot design with two whole-plot treatments (oat and no cover) and two split–plot N-rate treatments (0 and 168 kg-N ha^{-1}). In-situ mineralization columns with anion and cation resins were used to measure seasonal mineralization rates every 30 days during the growing season. Oat biomass and N uptake varied greatly between years (272 kg ha^{-1} and 6 kg N ha^{-1} in 2014 and 5824 kg ha^{-1} and 119 kg N ha^{-1} in 2015, respectively), but there was no effect of the oat cover crop on N mineralization or sweet corn N uptake in either year. However, oat cover crop did impact soil nitrate and ammonium when measured at approximately 10-day intervals. The in-situ mineralization method provided values within range of other studies, but was not

quantitative based on N budgets. These findings suggest that oat cover crops do not appear to meaningfully effect the N cycle in this region.

Introduction

The Wisconsin Central Sands region is characterized by sandy soils and production of vegetable crops for the local vegetable processing economy. The region's soil is comprised of 90% course-textured sand, glacial outwash from the Wisconsin glaciation that altered the North American landscape most recently 25,000 years ago (Wisconsin Geological & Natural History Survey » Ice Age Geology). Given the region's sandy soil and low soil organic matter, agricultural productivity requires high inputs of irrigated water and nutrients. In the Central Sands, the combination of nitrogen application and frequent irrigation on sandy soil can result in nitrate-N groundwater loading of 77% of total fertilizer N applied (Kraft and Stites, 2003). This nitrate-N can leach into local, regional, and eventually national waters, which can cause hypoxia in aquatic ecosystems (Justic et al., 1995; Burkart and James, 1999).

The Central Sands landscape is comprised of expansive plains and producers in the region use grass cover crops to reduce wind erosion after crop harvest. However, farmers may be unable to establish cover crops in the fall following corn or soybean (*Glycine max*) harvest. Spring-planted cover crops are an option preceding late-summer planted crops such as sweet corn, which can be planted as late as mid-July, but the effects on the N cycle of spring-planted grass cover crops are not well quantified. On sandy soil, grass covers appear to be more likely to provide an N benefit compared to legumes as previous work on field pea (*Pisum sativum*), chickling vetch (*Vicia villosa*), and berseem clover (*Trifolium alexandrinum*) in this region have shown no N credit (Johnson et al., 2012, West et al., 2016, Ivancic et al., Chapter 2). Spring-seeded legume covers result in low biomass production and their low C:N ratio biomass appears to decompose and mineralize too quickly and leach out of the root zone prior to uptake by sweet corn (West et al., 2016). In contrast, grass cover crops have been shown to provide N benefits in this region in the form of economic optimum nitrogen rates (EONR). Andraski and Bundy (2005) documented a reduction in EONR of sweet corn following fall-planted oat cover crop in two of three years. The authors also compared the growth and N-uptake across three fall-planted grass cover crops, oat, rye and triticale, before sweet corn planting and determined that oat resulted in the greatest aboveground biomass and N-uptake. Depending on the growth and C:N ratio of an oat cover crop when terminated, an N credit may be provided or immobilization of applied N may occur. In the sandy soils of Machanga, Kenya, Chivenge et al. (2009) quantified N cycling of combined treatments of high C:N ratio (60 to 208) plant residues and N fertilizer, measuring N immobilization and reduced leaching with a combined application.

Mineralization and other nitrogen transformations vary according to moisture content, microbial community, soil microclimate, and management practices that are not easily represented in a laboratory setting (Binkley and Hart, 1989). It is argued that due to these environmental variances, in-situ field experiments provide more accurate mineralization measurements than laboratory. Various in-situ methods have been used to quantify N transformations, advancing with time. Eno (1960) used buried resin bags, DiStefano and Gholz (1986) and Brye et al. (2002) combined resin bags with PVC columns for a more precise technique that quantified soil volume with mineralization measurements. For this study, we used the combined soil column and ionic resin technique to measure in-situ mineralization. This method uses a known soil volume as a useful tool for quantifying field-scale mineralization.

This study quantified mineralization of spring-planted oat in a sweet corn cropping system in the Central Sands to better understand oat cover crop effect on N cycling. Specific study objectives were to: (i) quantify spring-planted oat cover crop growth and N uptake, (ii) determine the effect of oat cover crop and N fertilizer on in-situ N-mineralization and seasonal PAN, and (iii) determine the effect of spring planted oat cover crops on sweet corn N uptake.

Materials and Methods

Site Description and Experimental Design

A two-year study was conducted in 2014 and 2015 at the University of Wisconsin, Hancock Agricultural Research Station (HARS) (latitude: 44°8’23” N; longitude: 89°31’23” W; elevation: 328 m) on an overhead-irrigated Plainfield loamy sand soil (mixed, mesic Typic Udipsamments). The experimental design was a randomized complete block, split-plot design with two whole-plot treatments (oat and no cover) and two split–plot N-rate treatments (0 and 168 kg-N ha^{-1}), replicated four times. This study was conducted within select treatments of a larger study (described in Chapter 2) and include the oat (OAT) and no cover crop (NONE) without N and with 168 kg N ha^{-1} (OAT+N and NONE+N) treatments. Oat cover crop was drill seeded on 21 April 2014 and on 16 April 2015 at 134 kg ha^{-1} and terminated on 10 June 2014 with an application of Credit Extra®, (Nufarm Americas Inc.; Alsip, Illinois) [active ingredient (a.i.) 2.3% glyphosate, mixed with nonionic 80/20 surfactant and ammonium sulfate (AMS, 21-0-0-24S)].Cover crop termination began on 12 June 2015 with an application of Mad Dog Plus® (Loveland Products Inc.; Greenley, Colorado) [a.i. 41% glyphosate, mixed with N-(phosphonomethyl) glycine, nonionic 80/20 surfactant, and AMS] and required surface cultivation with an M&W®10' Dyna-Drive® (Alamo Group Inc.; Seguin, TX). On 16 June 2015, a second herbicide application of Parallel® (Adama USA; Raleigh, NC) [ai. 84% metolachlor: 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide] was applied on 19 June 2015 for complete cover crop termination. The oat variety was not stated in 2014 and was Saber in 2015. Sweet corn (Del Monte Foods Hybrid Yellow Sweet Corn Seed, variety DMC 21-84) was planted on 13 June 2014 and 19 June 2015 with a John Deere Max Emerge™ (Deere &

Company; Olathe, Kansas) four-row planter at a seeding density of 24,500 plants ha^{-1} and harvested by hand 11 September 2014 and 11 September 2015. Fertilizer application to corn was split between two, 56 kg-N ha^{-1} during V-4 (between 0-30 days) and 112 kg-N ha^{-1} during V-8 (between 30-60 days) growing stages. Equivalent quantities of urea-N fertilizer (six urea prills for the 56 kg N ha^{-1} application rate and 12 prills for the 112 kg N ha^{-1} application rate) were applied to each aboveground soil core area in order to ensure uniform application.

Plant Collection and Analysis

Precipitation and daily air temperatures (maximum and minimum) measurements were recorded at HARS and were used to calculate growing degree day accumulation for both the cover crop and sweet corn growing seasons and were calculated as:

Growing Degree Days °C (GDD) = $[(T°C_{(Daily\ MAX)} + T°C_{(Daily\ MIN)})/2]/T_{BASE}$

Where if the daily maximum temperature >30° was set equal to 30° and if the daily minimum temperature <10° was set equal to 10°. The base temperature (T_{BASE}) for each plant was sweet corn T_{BASE} = 10° and oat T_{BASE} = 5.5°. Data collected from HARS daily temperature collection station (Hancock Agricultural Research Station, 2016; Table 1).

Above ground biomass (AGB) was collected on 10 June 2014 and 19 June 2015; three samples were collected per whole plot from a 0.37 m^2 area in 2014 and a 0.14 m^2 area in 2015. Sweet corn was harvested and subsampled on 11 September 2014 and 11 September 2015. Randomly selected subsamples of six ears and six stalks were collected from outside of the harvest rows (3 and 4) from rows 1, 2, 5, and 6 across all treatments. Cover crops, ears, and stalks were weighed separately in the field. Stalks were chopped and one subsample was collected per plot. Ears were cut into 2.5 cm medallions and one subsample was collected per ear, totaling six medallion subsamples per plot. Cover crop biomass samples, ear subsamples, and stalk subsamples were dried in a 60°C forced-air dryer for one week, re-weighed for dry weight, and mechanically ground using a 0.5 mm sieve and stored in plastic vials until analysis. Nitrogen content of cover crop and sweet corn biomass was determined by re-drying samples for at least 24 hours prior to analysis and total carbon and total nitrogen analysis using a flash combustion procedure (Thermo Fisher Scientific Flash EA 1112 NC Analyzer, Thermo Fisher Scientific Inc., Waltman, MA).

In-situ Mineralization Columns and Soil Sample Collection and Analysis

Nitrogen mineralization rates were measured using in-situ incubation cores and ion-exchange resin sachets similar to those described by Brye et al. (2002). Cores were constructed of polyvinyl chloride pipes (30.5 cm in depth and 20 cm in diameter). On the day of planting, two cores were inserted in each plot by hand (physically forced in using a mallet), one between rows two and three and the second core between rows four and five in each plot. Cores were placed approximately 0.6 m in from the south end of each plot and moved approximately 0.6 m further north with each new installation. After insertion, cores were carefully excavated with shovels; attention was paid to removing the core without disturbing the soil within. Once removed, cores were inverted, 5 cm of the soil were removed from the base and a resin sachet was curled in its place covering the core's entire surface area. Resin sachets were made of L'eggs Ultra Sheer Pantyhose (Hanesbrands Inc., Winston Salem, North Carolina), size large, cut at the thigh, filled with 30 g of Rexyn 300 (H-OH) ion-exchange resin beads and secured with a knot. After sachet insertion, the remaining space between the sachet and the base of the core was filled with soil, covered with a 23 cm x 23 cm square mesh and zip tied around the base in order to secure the soil and resin sachet within the core. The core was then inserted back into the hole from which it came. Soil cores were incubated in-situ for three 30-day intervals (0-30, 30-60, and 60-90 days) throughout the sweet corn growing season.

Soil was sampled from the area outside of the core on the first day of incubation to determine initial NO_3-N and NH_4-N concentrations. Soil was extracted by combining 1.5g (± 0.05) of soil with 15 ml of 2M KCL and mechanically oscillating the samples for 15 minutes. Samples were then filtered and the extractant was analyzed for NO_3-N using a vanadium chloride reaction as described by Doane and Horwath (2003) and for NH_4-N using a colormetric Berthelot method as described in Hood-Nowonty et al. (2010). After 30-days of incubation, cores were excavated and the soil within each core was extracted. The soil core samples were weighed in the field and subsampled for soil moisture determination for bulk density calculations. Soil moisture subsamples were placed in aluminum tins and dried in a 105°C oven for 24 hours.

Resin sachets were immediately stored on ice after incubation and extracted within a week. Once in the laboratory, resin was removed from the nylon sachet and weighed. Resin was placed in scintillation vials with 40 mL 2M KCL and mechanically oscillated for 60 minutes (Wolf, 2010). Extractant was filtered and sent to the University of Wisconsin, Madison Soil and Plant Analysis Laboratory for NO_3-N and NH_4-N analysis by flow injection on a Lachat QuickChem 8000. On the same day of soil column removal new soil columns with fresh resin sachets were inserted.

Soil samples were collected outside of the incubated cores every ten days throughout the sweet corn growing season and analyzed for NH_4-N and NO_3-N concentrations. In 2014 the ten sampling time points (TP1 to TP10) were: 13 June, 23 June, 2 July, 10 July, 21 July, 31 July, 8 August, 18 August, 29 August, and 14 September. In 2015 the 9 sampling points (TP1 to TP9) were: 19 June, 30 June, 9 July, 17 July, 29 July, 6 August, 17 August, 26 August, and 11 September. Samples were taken to a 30cm depth at approximately 30 cm on the north, south and either east or west sides of each soil core, depending upon soil column placement within the plot. Samples were not taken between harvest rows three and four. Samples were dried in a forced air drier for at least one week and ground to pass through a 2 mm sieve. Soil samples were analyzed for NO_3-N and NH_4-N using the Doane and Horwath (2003) and Hood-Nowonty et al. (2010) procedures, as described above.

Calculations and Statistical Analysis

The total amount of N taken up by plants throughout the growing season was calculated as Total N uptake (TNU) using the summation of plant-available N concentration in the sweet corn ears and sweet corn stalks.

$$TNU = N_{EAR} + N_{STALK}$$

Partial nutrient balance (PNB) is the amount of N that is presumably lost to the environment, and is calculated here as a ratio of N removed (ear) over the amount of N applied.

$$PNB = N_{EAR} / N_{APPLIED}$$

The N uptake efficiency (NUE) of urea-N for sweet corn production was calculated per unit N applied as the difference between $TNU_{(Applied\text{-}N)}$ and $TNU_{(Control)}$ over the over total N applied.

$$NUE = (TNU_{(Applied\text{-}N)} - TNU_{(Control)})/\text{Applied-N}$$

Net mineralization calculations were conducted for each year and 30-day time period. Similar to Noe (2011), we summed the differences between starting and ending NO_3-N and NH_4-N concentrations of incubated soils and added ending resin NO_3-N and NH_4-N concentrations.

Analysis of variance (ANOVA) was conducted to determine the effect of cover crop and N rate on N mineralization, sweet corn N uptake, PNB, and NUE. For simplicity, statistical analysis was conducted with four main plot treatments (NONE, NONE+N, OAT, and OAT+N). Proc Mixed was used with block as a random effect and time periods and study years were analyzed separately. Soil N data were log transformed in order to satisfy the homogeneity of variance statistical assumption and analyzed with Proc MIXED with block as a random effect and REPEATED = sampling time and SUBJECT = block × treatment. Model type (compound symmetry = CS, heterogeneous CS = CSH, ante dependence = ANTE(1), or spatial covariance power = SP(POW)) was determined by the lowest akaike and bayesian information criterion scores. The 2014 data were evaluated using SP(POW) model type and the 2015 datasets were evaluated using type CSH for NH_4-N data, type CS for NO_3-N, and type ANTE(1) for PAN. Mean comparisons were conducted using LSMEANS for all analyses, except for nitrate, ammonium, and PAN where LSMEANS was used with SLICE to identify significant treatment effects at each sampling time. All statistics were conducted in SAS (Statistical Analysis System, version 9.2, SAS Institute, Cary, NC) and N mineralization treatment significance is reported at the alpha=0.10 significance level and soil N and sweet corn N-uptake, PNB, and NUE treatment significance is reported at alpha=0.05 significance level.

Results

Oat Temperature, Precipitation, and Seasonal Growth

The monthly air temperatures during the 2014 oat growing season were 1 to 3˚C above 30-year normal temperatures, averaging 5˚C (1˚C above the 30-year normal) in April, 14˚C (3˚C above the 30-year normal) in May, and 20˚C (2˚C above the 30-year normal) in June (Table 1 and Fig. 2). Cover crops were not irrigated and total precipitation was 196 mm from cover crop seeding to termination in 2014 (Fig. 1).

Oat GDD were higher in 2015 compared to 2014 (Fig. 3). In 2015, the monthly temperatures during the oat growing season were at or 4˚C above 30-year normal temperatures, averaging 8˚C in April (at the 30-year normal), 15˚C (4 ˚C above the 30-year normal) in May, and 18˚C (4˚C above the 30-year normal) in June (Table 1). Total precipitation throughout the 2015 oat growing season was 191 mm (Fig. 1 & Fig. 2).

Oat total AGB (5824 kg ha^{-1}) was 183% greater in 2015 than 2014. Accordingly, 2015 total C was 2,419 kg-C ha^{-1}, 182% greater than 2014, and total N was 119 kg-N ha^{-1}, 180% greater than 2014 (Table 2). Cover crop biomass varied greatly (272 kg ha^{-1} in 2014 and 5,824 kg ha^{-1} in 2015) between study years.

Mineralization

Mean monthly air temperatures during the 2014 sweet corn growing season and mineralization core incubation deviated from -5 to 2°C around the 30-year normal temperatures, averaging 20°C in June (2°C above the 30-year normal), 19°C in July (1°C below the 30-year normal), 20°C in August (2°C below the 30-year normal), and 15°C in September (5°C below the 30-year normal) (Table 1). Total accumulated water (precipitation 271 mm, irrigation 314 mm) throughout the sweet corn growing season was 585 mm (Fig.1, Fig.2). The 2014 growing season accumulated 891 GDD in 2014 (Fig. 3). Net N mineralization during the first 30 days of the 2014 sweet corn growing season were 13 and 16 kg ha^{-1} in the OAT and NONE and 25 and 27 kg ha^{-1} in the N-applied treatments (OAT+N and NONE+N), respectively. Mineralization within the 0-30 day interval was significantly greater in the NONE+N and OAT+N treatments compared to the NONE and OAT treatments (Fig. 4). Mineralization in the 30-60 day time period was 38 and 49 kg ha^{-1} in OAT and NONE and 81 and 101 kg ha^{-1} in OAT+N and NONE+N, respectively. There was no significant treatment difference between cover crop treatments and their controls (e.g. OAT vs. NONE and OAT+N vs. NONE+N). During the 60-90 day time period, mineralization was 4 and 6 kg ha^{-1} in NONE and OAT, respectively, and was 31 kg ha^{-1} in both NONE+N and OAT+N. Mineralization pattern remained the same during this time period, there was no significant treatment difference between the cover crop treatments (OAT+N and OAT) and their controls (NONE+N and NONE) (Fig. 4).

In the 2015 sweet corn growing season and mineralization core incubation, mean monthly air temperatures deviated -3 to 1°C around the 30-year normal temperatures, averaging 18°C in June (at the 30-year normal), 21°C in July (1°C above the 30-year normal), 19°C in August (3°C below the 30-year normal), and 18°C in September (2°C below the 30-year normal) (Table 1). Total accumulated GDDs were 845 in 2015 and total accumulated water (precipitation 263 mm, irrigation 312 mm) throughout the 2015 sweet corn growing season was 575 mm (Fig.1, Fig.3). Mineralization values in 2015 during the 0-30 day time period were 3 and 12 kg ha^{-1} in NONE and OAT and 31 and 40 kg ha^{-1} in NONE+N and OAT+N, respectively. There was no significant difference between cover crop treatments compared to their controls (NONE and NONE+N) (Fig. 5). During the 30-60 day growing period mineralization was 12 and 17 kg ha^{-1} in NONE and OAT and 35 and 40 kg ha^{-1} in NONE+N and OAT+N, respectively. There was no significant treatment difference between cover crop treatments (OAT+N and OAT) and their no cover controls (NONE+N and NONE). During the 60-90 day time period net mineralization was 3 and 25 kg ha^{-1} in OAT and NONE and -7 and 7 kg ha^{-1} in the OAT+N and NONE+N treatments, respectively. The OAT+N treatment during 60-90 days displayed negative net nitrogen mineralization; however the standard error is 8.6 and overlaps zero, suggesting that the mean is not different than zero. In 2015, throughout the entire 90-day growing season mineralization patterns remained the same amongst treatments.

Sweet Corn N-Uptake

The 2014 sweet corn stalk N uptake was significantly greater in NONE+N compared to NONE and OAT, while ear N was greater in NONE+N and OAT+N compared to NONE and OAT. The TNU in NONE+N was greater than in NONE. There were no treatment differences for PNB but the NUE of NONE+N was significantly greater N than OAT+N (Table 3). In 2015, stalk N uptake was significantly greater in the NONE+N treatment compared to NONE, while ear N uptake was significantly greater in the N-applied treatments compared to all others. The TNU was significantly lower in the NONE treatment compared to NONE+N and OAT+N and OAT had significantly less TNU compared to NONE+N. In 2015, there was no significant treatment difference in PNB, and NUE was significantly greater in NONE+N compared to OAT+N (Table 3).

Soil NH_4-N and NO_3-N

Analysis of soil NH_4-N and NO_3-N in both 2014 and 2015 was conducted on log-transformed data. In 2014 OAT NH_4-N was significantly greater than NONE in time point 3, but the relative difference between the highest and lowest value was only 0.4 mg kg^{-1} and N had not been applied at that time point. In 2014, NONE had significantly greater NO_3-N content than OAT at TP7 and TP10 and OAT+N had significantly greater NO_3-N content than NONE+N at TP7 and TP8. This suggests that there may be different mineralization patterns of oat biomass late in the growing season depending on the presence or absence of N fertilizer.

Treatment significance was also determined for NO_3-N at TP3 and TP4 and for PAN at TP2, TP5, TP7, and TP10, however these treatments differences were only between N-applied treatments and no-N treatments.

In 2015 the only significant difference between an oat treatment and a no cover crop treatment was measured at TP 1, where NONE had significantly greater NH_4-N than OAT. Also in 2015, there were significant treatment differences for NO_3-N at TP7 and for PAN at TP4, TP7, and TP9, but only represent differences between N-applied treatments and no-N treatments (Fig. 7).

Discussion

Oat Biomass

Oat cover crop growth, biomass production, and N uptake are substantially different between seasons. Cooler temperatures during the 2014 oat growing season reduced germination and led to lower biomass in 2014 (272 kg ha^{-1}) a difference of 21 times lower production compared to 2015 (5824 kg ha^{-1}) (Table 2). Oat AGB variability has been documented in other northern Midwest cropping studies, however at differing magnitudes. In a six-year study near Ames, Iowa, fall-planted and winter-killed oat biomass production increased 22 times from the lowest production (70 kg ha^{-1}) to the highest (1540 kg ha^{-1}) (Kaspar et al. 2012). Similar to our study, greater biomass was associated with warmer temperatures during the oat growing season (Kaspar et al. 2012). In a Central

Sands-based study, Andraski and Bundy (2005) also noted oat biomass variability in their fall planted and winter killed cover crop, however the difference was 5-fold between years, 590 kg ha^{-1} to 3010 kg ha^{-1}. Also in Wisconsin, Contreras-Govea and Albrecht (2005) measured spring-planted oat biomass with a mean weight of 7700 kg ha^{-1} following 77 days of growth (mid-April to late October). Pro-rated, Contrera-Govea and Albrecht (2005) reported the same biomass accumulation as we did in our 2015 field season (100 kg AGB ha^{-1} day^{-1}).

Oat C:N did not display large differences between years, though these values were lower compared to other oat studies. Our study's C:N values are most similar to those cited in Andraski and Bundy (2005). Also in the Central Sands, this study measured C:N between 15 and 33 (1570 kg ha^{-1} AGB) after approximately 12 weeks of growth (August – November). Higher C:N ratios have been reported with greater biomass production. Radicetti et al. (2016) documented C:N of 47 (5680 kg AGB ha^{-1}) and Baggs et al. (2000) measured C:N of 38 (140 kg N ha^{-1} in AGB). A similar C:N (24.8) was measured by Kumar et al. (2009), however they produced greater AGB (9700 kg AGB ha-1) on a silt loam compared to our study and Andraski and Bundy's (2005). Spatially, the three studies were completed in similar climates and latitudes, N44° in the Central Sands of Wisconsin and N42° at the Kumar et al. (2009) study site, in New York. However, planting dates differed between the studies, Andraski and Bundy

(2005) and Kumar et al. (2009) both planted oat in the fall after cash crop harvest and our study was spring planted. Additionally, Kumar et al. (2009) moldboard plowed, disked, and fertilized their fields with 51 kg ha^{-1} of N just before cover crop planting, this field management was potentially responsible for improving oat yield. In our study in 2015 residual soil N concentrations were likely higher prior to oat planting due to the previous season's potato crop. Additionally, our 2015 oat cover crop was terminated at the start of reproductive growth, potentially contributing to low C:N.

Mineralization and Soil NH_4-N and NO_3-N

As compared to other mineralization studies utilizing a similar in-situ soil column and ion-exchange resin procedure, our seasonal mineralization rates fall within the range of reported values. Wu et al. (2007) measured mineralization in a corn cropping system in sandy soil between 51 to 75 kg N ha^{-1} 30 days^{-1}. The authors completed this study in Ontario, Canada and also documented a mineralization peak during the 30-60 day time period. In another sandy soil cover cropping study, O'Conell et al. (2015) documented mineralization in grass and legume cover cropping systems on a sandy loam between -70 and 155 kg N ha^{-1} 30 days^{-1}. Brye et al. (2002) documented mineralization from -20 to 59 kg N ha^{-1} 30 days^{-1} in a silt loam no-till corn cropping system. With similar course-textured soils, forest ecosystems have lower mineralization compared to our measurements or the other referenced cropping systems', measuring 0.6 to 4.6 kg

N ha^{-1} 30 $days^{-1}$ (Wilhelm et al.,2013) and 4.2 kg N ha^{-1} 30 $days^{-1}$ (Raison et al.,1987). Our study's net mineralization was greater than those measured in forest ecosystems and, while on the low end of the range, compared to other similar cropping system's studies.

Soil NO_3-N and NH_4-N findings were in congruence with 2014 and 2015 net mineralization findings between N-applied treatments and no-N treatments; however significant difference between treatments at approximately 10-day intervals in 2014 would suggest that oat cover crop did impact mineralization on a narrower timescale than was detectable with the in-situ method. Specifically in 2014 at TP7 (56 days after planting) there was greater NO_3-N in OAT+N compared to NONE+N while at the same time the NONE treatment had greater NO_3-N than OAT. This may suggest a priming effect of the N fertilizer on decomposition and mineralization of oat biomass later in the growing season. This effect can also be seen at TP8, where OAT+N had greater NO_3-N compared to NONE+N, and at TP10, where NONE had greater NO_3-N compared to OAT. Results from the in-situ mineralization columns during 60-90 days in 2014 did not result in treatment differences between any oat and no cover crop treatments (Figure 4).

Sweet Corn N Uptake

Oat cover crop did not significantly increase sweet corn N uptake. The only significant treatment difference in total N uptake between cover crop treatment and their controls was in the 2014 OAT treatment compared to the NONE treatment. This difference was not seen in the 2014 mineralization data however it was present in the soil N data. In 2014 and 2015 there was no statistical significance between partial nutrient balance (PNB) treatments and their controls, therefore, while the amount of N that was unaccounted for in the 2015 PNB was lower in the OAT+N treatments compared to the control, the reduction was not significant enough to impact season-long N-loss patterns. The N uptake efficiency (NUE) of 2015 NONE+N was significantly greater than the control, meaning that the oat negatively impacted fertilizer N uptake in corn compared to the NONE+N treatment. The oat treatment did not have a significant enough impact on mineralization to synchronize plant available N with plant growth needs and did not provide an N credit (see Chapter 2). In a fall planted grass cover crop study on sandy soil Olesen et al. (2009) measured lower NUE in winter cereals on course sandy soil as compared to a loamy sand or sandy loam soil. These findings are also similar to West et al. (2016), wherein no sweet corn N credit was measured from spring planted field pea in the Central Sands.

Assessing the Quantitative Precision of the In-situ Method

The in-situ soil core and resin bead mineralization method may lack quantitative precision. We summed the relative difference between treatments in soil column N and the relative difference between treatments in resin N (leached N) and subtracted it from total N applied, calculating over 101 kg N ha^{-1} as unaccounted for in the no cover treatments and 91 kg N ha^{-1} in the oat treatments in 2014. In 2015, 143 kg ha^{-1} was unaccounted for in the no cover treatments and 142 kg N ha^{-1} in the oat treatments. In both field seasons a fraction of the fertilizer-N is accounted for, this discrepancy has also been presented in other mineralization and mass balance studies. In 1991 Errebhi et al. (1998) documented a mass balance discrepancy ranging from -36 to 85 kg N ha^{-1} in a sandy loam potato cropping system. In this study they calculated the difference between total N_{in} (initial soil N, fertilizer N, irrigation N, mineralized N) minus total N_{out} (plant N, leached N, final soil N). Saffinga et al. (1977) in a Central Sands-based potato study calculated a mass balance difference between -20 to 95 kg N ha^{-1} of N applied (fertilizer N and irrigation N) minus N out of the soil profile (leachate and plant uptake).

The major differences in N mineralization between years can be attributed to large differences in the amount of N captured on the resins. We analyzed the amount of applied N that was leached out of the soil column by calculating the relative difference between N-applied treatments (NONE+N and OAT+N) and their controls (NONE and OAT) on the resin. In 2014, the year with low biomass, the NONE+N treatment had 33% of total N applied captured on the resin, 56 kg N ha^{-1}. The OAT+N treatment in 2014 had 30% of total N applied captured on the resin, 50 kg N ha^{-1}. In 2015, the year with greater biomass, NONE+N treatment only had 1% of the total N applied captured in the resins, 2 kg N ha^{-1}. The OAT+N treatment only had 3% of the total N applied captured on the resin N, leaching 5 kg ha^{-1}. Similar leaching studies conducted in irrigated sandy soil cropping systems found a range of values higher than our leaching values, however within range. The following studies calculated leaching on sandy soils in irrigated potato cropping systems; Veneterea et al. (2011) documented 21.1 kg N ha^{-1}, Zvomuya et al. (2003) 80 kg- N ha^{-1}, and Delgado et al. (2001) 94 kg N ha^{-1}.

Denitrification, immobilization, and volatilization are three potential causes of imprecise quantification of soil N. High rates of denitrification are unlikely in these sandy soils (Strong and Fillery, 2002). Nitrogen immobilization was measured in our study and was only present in 2015 at 5 kg N ha^{-1}. Groundwater NO_3-N (18 mg L^{-1} NO_3-N, approximately 52 kg N ha^{-1}) (Bundy and Andraski, 2005) applied through irrigation was not accounted for in these post-evaluations, including them would lower N uptake. The other potential cause of nitrogen loss could be attributed to ammonia volatilization. This may be responsible for a portion of lost N, however volatilization was minimized through post fertilizer irrigation and average urea volatilization ranges between 3 – 40% of total N applied. Holcomb et al. (2011) measured 15 – 40% loss on sandy soil, Rawluk et al. (2001) measured 20 – 26% loss on a clay loam, and Thapa et al. (2015) measured 3 – 4% loss on a silt loam. In 2014 the fertilizer was irrigated within 4 hours of application, however, in 2015, the year with greater column N unaccounted for, urea was irrigated within 24 hours of fertilization and could be responsible for some N loss through ammonia gas. Given that the leached values in both years are similar to those in the literature, it is unlikely that the remaining fertilizer N balance was leached through the soil profile and uncaptured by the in-situ resin and soil column method. Plant uptake was not a factor here either; method design excluded roots from the soil column.

The unaccounted for N in the soil column and resin could be the result of lack of precision in the in-situ column method. Soil column procedures were the same between both study years and resin sachet insertion was completed by the lead scientists on this project, Kate Ivancic and Matthew Ruark, and the laboratory's senior technician, Mack Naber. Perhaps additional design changes can be further refined in the future in order to improve consistency in resin N captured. These imperfect soil N budgets indicate that the in-situ soil column and resin bead procedure is not the right tool for precise quantification of nutrients; however it is a valuable tool useful for capturing mineralization treatment differences and trends over time.

Conclusion

Spring-planted oats were ineffective at altering nitrogen cycling on a seasonal (30 day) scale in the Central Sands. Over a 10-day timescale, soil NH_4 and NO_3 displayed small changes in N cycling patterns, suggesting that oat does impact mineralization in these systems, however the transformation is too rapid to impact seasonal-scale (30 day) net mineralization using an in-situ mineralization column. The in-situ method provided mineralization trends consistent with the soil N measurements and other mineralization studies, however is was not a useful tool for quantitative N budget calculation. While there was no apparent N credit of the oat, it is important to note that the oat did not slow down mineralization in any meaningful way regardless of biomass amount. Thus, the use of grass cover crops for wind erosion control in the Central Sands of Wisconsin will have little effect on the nitrogen cycle. Future efforts to improve N use efficiency in this region will need to come through in-season management of N.

Tables and Figures

Table 1. Mean monthly air temperature at Hancock, WI 2014 and 2015. Means for air temperature for 2014 and 2015 are presented as deviations from mean 30-year normal temperatures (1985-2015).

	Air Temperature		
		Deviation from mean	
Month	30-yr normal	2014	2015
	°C		
Jan.	-8	-6	-1
Feb.	-6	-7	-7
Mar.	-3	-1	3
Apr.	4	1	4
May.	11	3	4
Jun.	18	2	0
Jul.	20	-1	1
Aug.	22	-2	-3
Sep.	20	-5	-2
Oct.	12	-4	-1
Nov.	4	-7	-4
Dec.	-3	-1	3

Table 2. Oat cover crop biomass and nitrogen uptake. All data are presented on a dry-matter basis.

Year	Biomass	Total C	Total N	C:N
	kg ha^{-1}	kg C ha^{-1}	kg N ha^{-1}	%
2014	272 (40)+	112 (14)	6 (0.6)	18 (0.7)
2015	5824 (845)	2419 (331)	119 (30)	20 (4)

+ Number in parenthesis indicates standard deviation.

Table 3. Nitrogen uptake in sweet corn stalk and ear in 2014 and 2015. Concentrations determined under four treatments (NONE, NONE+N, OAT, OAT+N). Nitrogen treatments were 0 kg N ha^{-1} and 168 kg N ha^{-1}. Fertilizer applied during V4 and V8 growth stages 56 kg ha^{-1} (between 0-30 days) and 112 kg ha^{-1} (between 30-60 days), respectively. Partial nutrient balance (PNB) and N uptake efficiency (NUE) were calculated for each cover crop treatment separately. Within each column for each statistically significant treatment factor, means followed by the same letter are not significantly different (α = 0.05).

	2014					2015				
Treatment	Stalk N	Ear N	TNU	PNB	NUE	Stalk N	Ear N	TNU	PNB	NUE
	kg N ha^{-1}					kg N ha^{-1}				
NONE	29b	0.4b	29c			42b	2c	45c		
NONE+N	51a	30a	82a	0.2	0.3a	119a	50a	169a	0.7	0.7a
OAT	39ab	11b	50b			76ab	9b	85bc		
OAT+N	51a	26a	78a	0.2	0.2a	90a	59a	149ab	0.4	0.4b

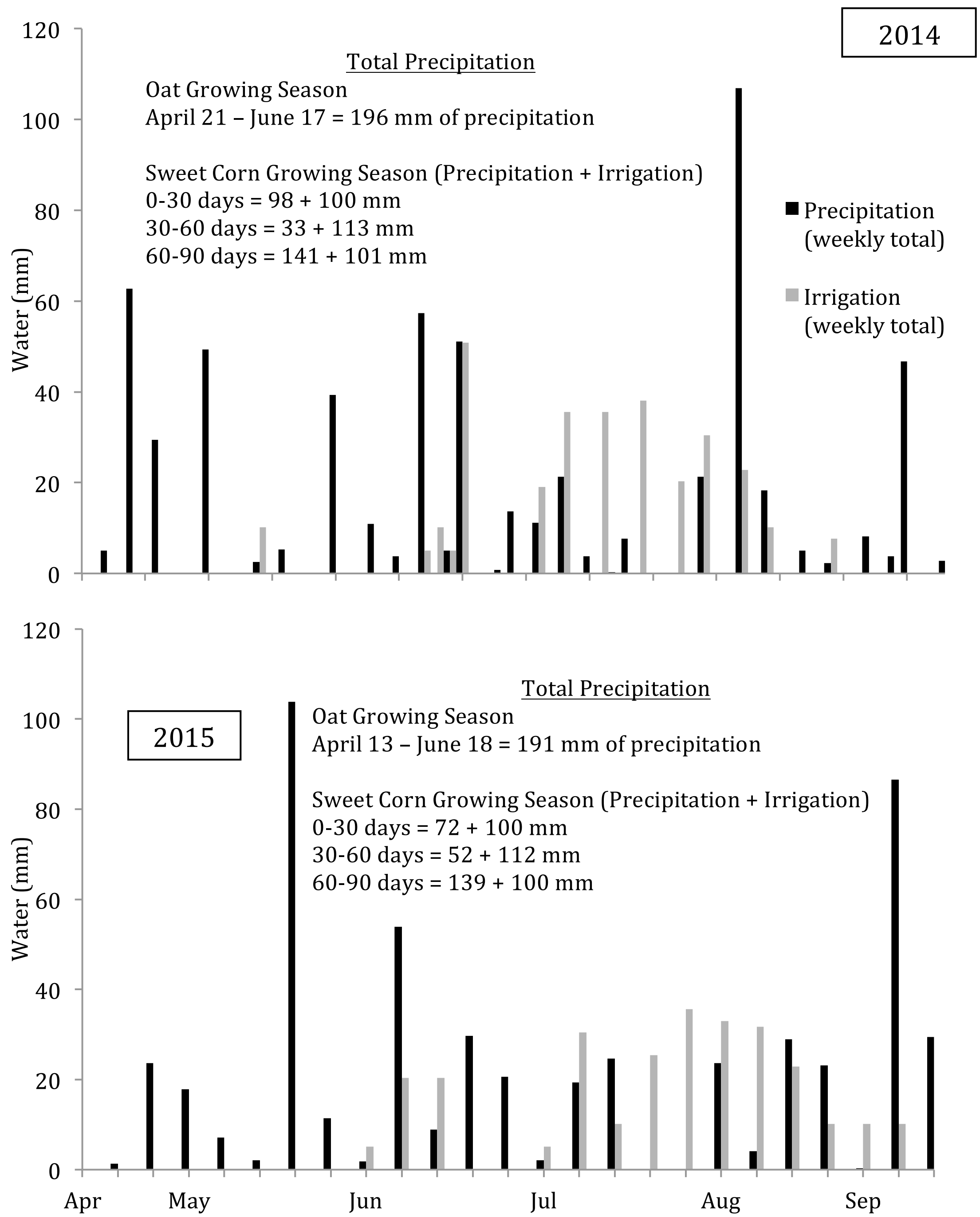

Fig. 1. Weekly accumulated rate of precipitation and irrigation for sweet corn growing season at Hancock WI, 2014 and 2015. Planting 24 April 2014 and 17 April 2015 for cover crop and 13 June 2014 and 19 June 2015 for sweet corn. Termination 10 June 2014 and 16 June 2015 for cover crop and 11 September 2014 and 11 September 2015 for sweet corn harvest.

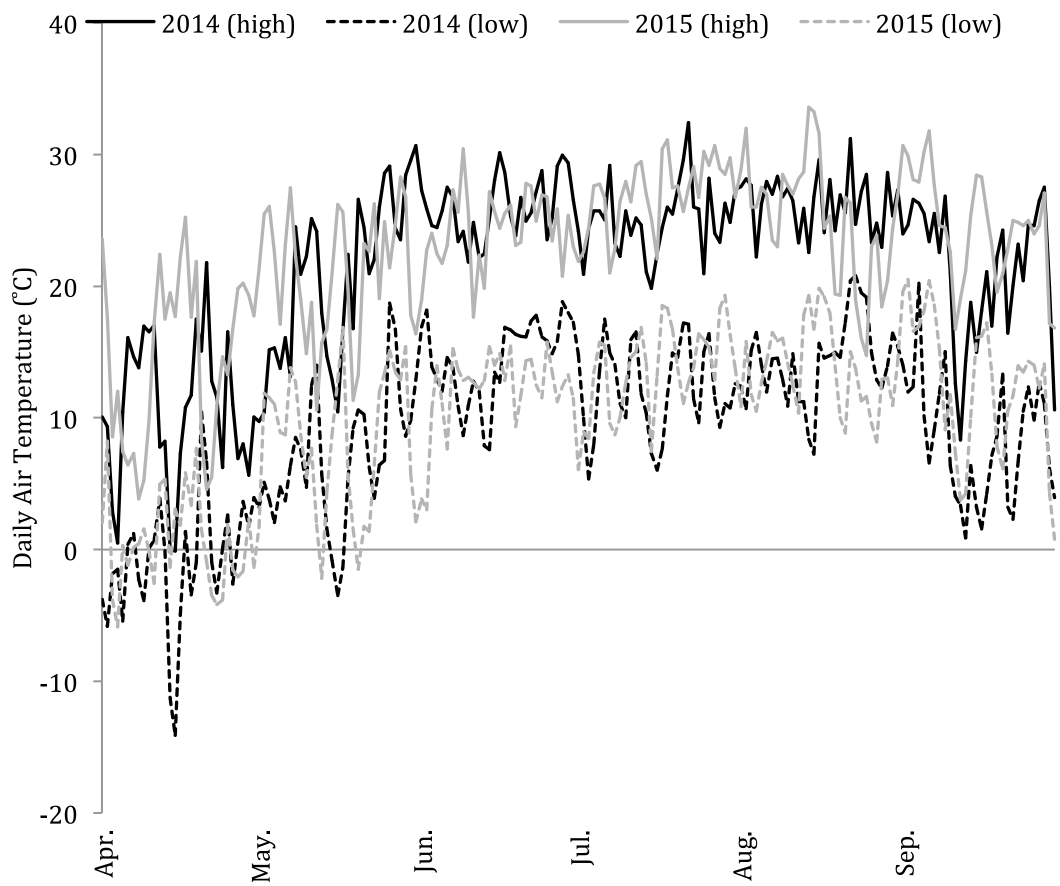

Fig. 2. Maximum and minimum daily air temperatures at Hancock, WI in 2014 and 2015.

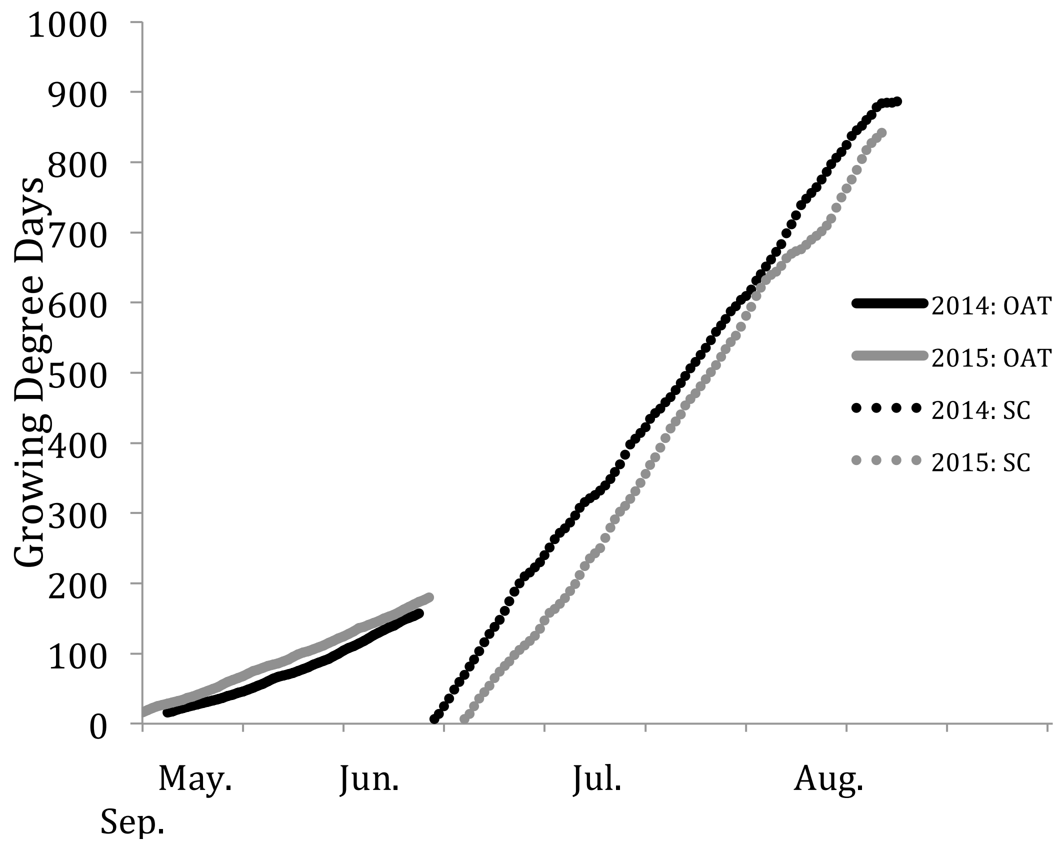

Fig. 3. Accumulated growing degree days during the cover crop and sweet corn growing seasons 2014 & 2015, calculated using modified method. Cover crop planting (OAT) 24 April 2014 and 17 April 2015 and termination 10 June 2014 and 16 June 2015. Sweet corn planting (SC) 13 June 2014 and 19 June 2015 and harvest 14 September 2014 and 11 September 2015.

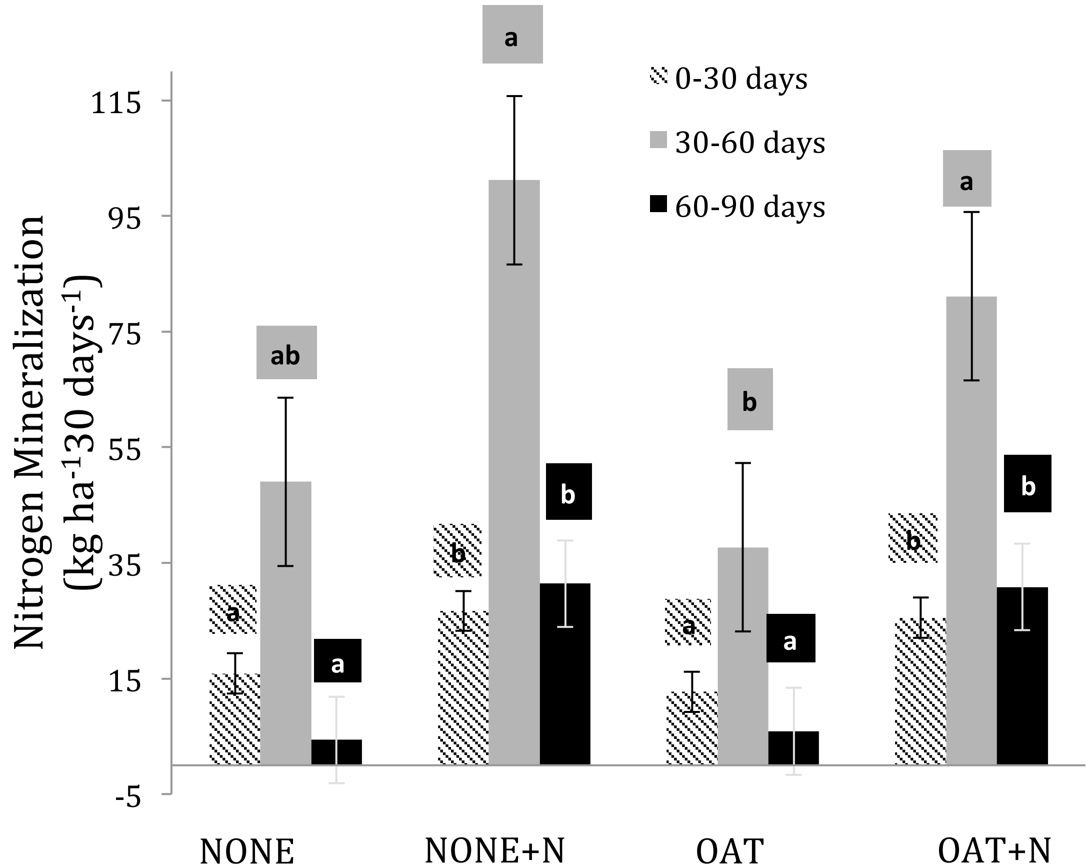

Fig. 4. Nitrogen mineralization in 30 day increments (0-30, 30-60, and 60-90) under four treatments (NONE, NONE+N, OAT, OAT+N) at the Hancock Agricultural Experiment Station in 2014. Nitrogen treatments were 0 kg N ha^{-1} and 168 kg N ha^{-1}. Fertilizer applied during V4 and V8 growth stages 56 kg ha^{-1} (between 0-30 days) and 112 kg ha^{-1} (between 30-60 days), respectively. ANOVA completed across treatments within time periods, columns with the same letter are not significantly different *(P* < 0.1).

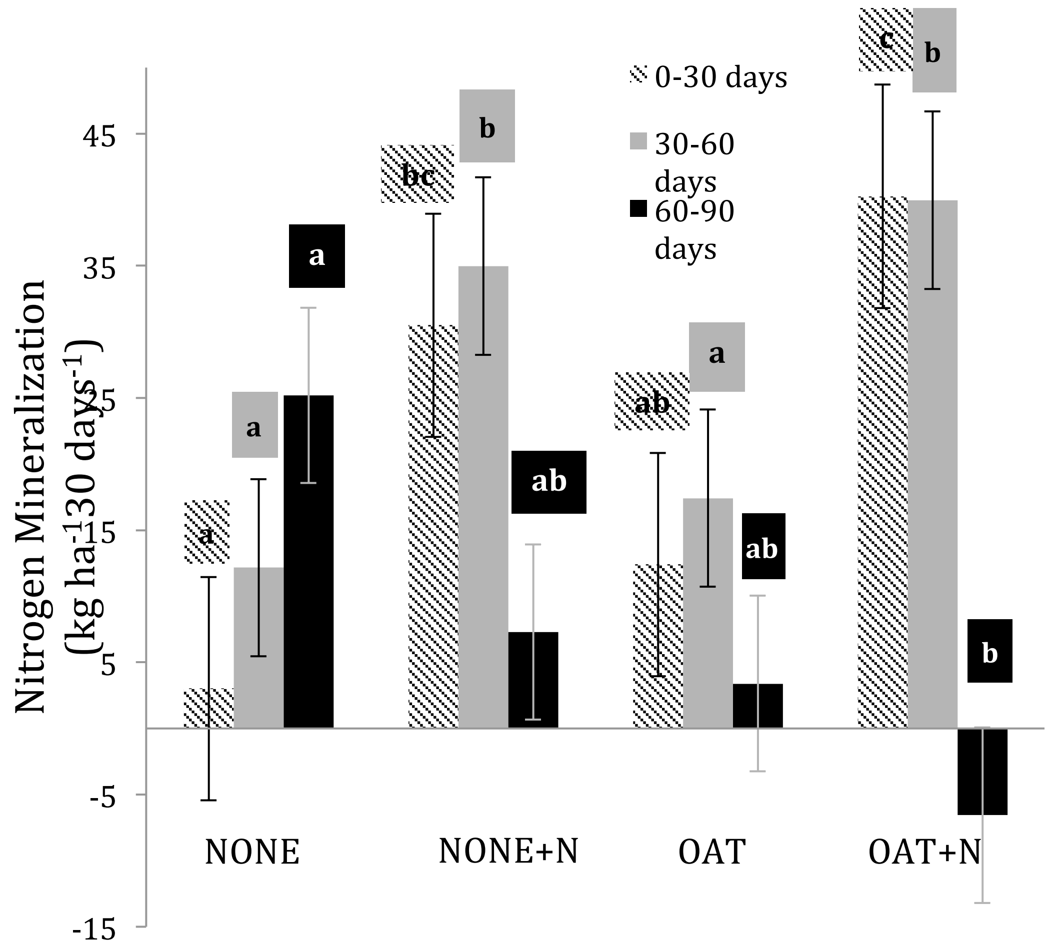

Fig. 5. Nitrogen mineralization in 30 day increments (0-30, 30-60, 60-90) under four treatments (NONE, NONE+N, OAT, OAT+N) at the Hancock Agricultural Experiment Station in 2015. Nitrogen treatments were 0 kg N ha^{-1} and 168 kg N ha^{-1}. Fertilizer applied during V4 and V8 growth stages 56 kg ha^{-1}(between 0-30 days) and 112 kg ha^{-1} (between 30-60 days), respectively. ANOVA completed across treatments within time periods, columns with the same letter are not significantly different ($P < 0.1$).

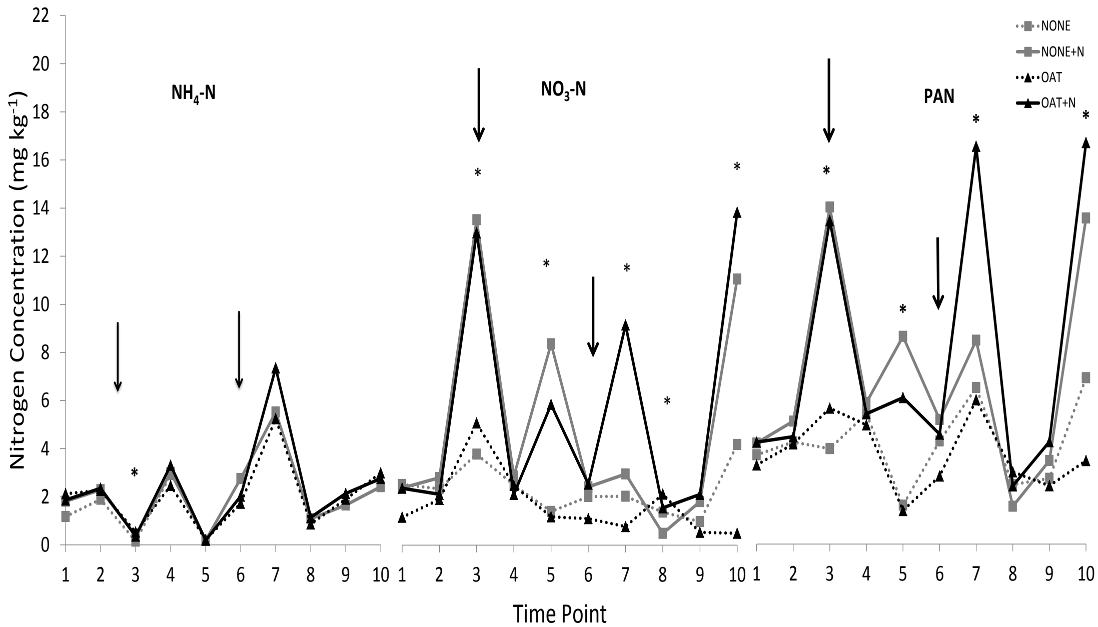

Fig. 6. Soil ammonium-N, nitrate-N, and plant available nitrogen (PAN) concentrations collected approximately every 10 days throughout the sweet corn growing season at the Hancock Agricultural Research Station in 2014. Treatment include no cover crop (NONE), no cover crop with 168 kg ha^{-1} of N (NONE+N), oat cover crop (OAT), and oat cover crop with 168 kg ha^{-1} of N (OAT+N). Arrows indicate timing of fertilizer applications at the V4 (56 kg-N ha^{-1}) and V8 (112 kg-N ha^{-1}) growth stages. Time points are every 9 – 13 days starting on 13 June and the last time point was at sweet corn harvest (11 September).

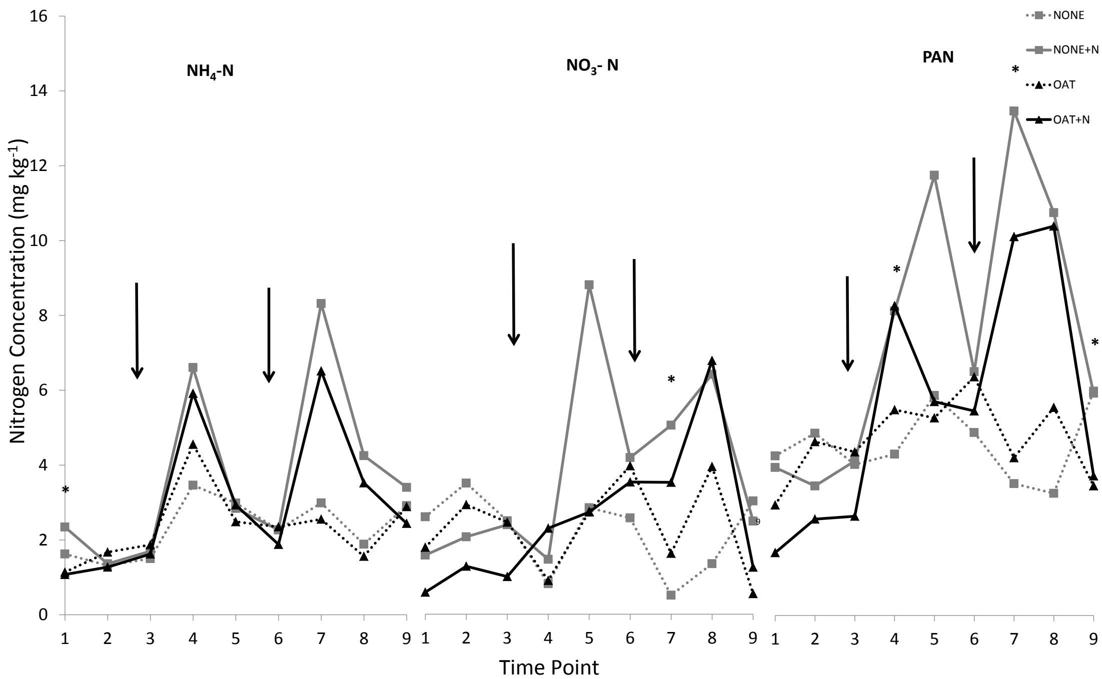

Fig. 7. Soil ammonium-N, nitrate-N, and plant available nitrogen (PAN) concentrations collected approximately every 10 days throughout the sweet corn growing season at the Hancock Agricultural Research Station in 2015. Treatment include no cover crop (NONE), no cover crop with 168 kg ha^{-1} of N (NONE+N), oat cover crop (OAT), and oat cover crop with 168 kg ha^{-1} of N (OAT+N). Arrows indicate timing of fertilizer applications at the V4 (56 kg-N ha^{-1}) and V8 (112 kg-N ha^{-1}) growth stages. Time points are every 9 – 13 days starting on 19 June and the last time point was at sweet corn harvest (11 September 2015).

SAS Code

N Mineralization

```
data min1;
input int blk trt $ nmin;
datalines;
proc glimmix data=min1 plots=studentpanel;
   class blk trt;
   model nmin = trt;
   random blk;
run;
proc sort; by blk trt int;
proc print;
run;
proc mixed;
by int;
class blk trt;
model nmin = trt;
random blk;
lsmeans trt / diff;
run;
proc sort; by blk trt int;
proc print;
run;
proc glimmix data=min2 plots=studentpanel;
   class blk trt;
   model nmin = trt;
   random blk;
run;
proc sort; by blk trt int;
proc print;
run;
data min22; set min2;
 lognmin=log(nmin);
run;
proc glimmix data=min22 plots=studentpanel;
   class blk trt;
   model lognmin = trt;
   random blk;
run;
proc mixed;
by int;
class blk trt;
model lognmin = trt;
random blk;
lsmeans trt / diff;
```

```
run;
proc sort; by blk trt int;
proc print;
run;
```

Sweet Corn Biomass

```
proc glimmix data=ear15 plots=studentpanel;
        class trt blk;
        model ear = trt;
        random blk;
proc print;
run;
data ear151; set ear15;
 logear=log(ear);
run;
proc glimmix data=ear151 plots=studentpanel;
        class trt blk;
        model logear = trt;
        random blk;
run;
proc glm data=ear151;
   class trt blk;
   model ear = trt;
         random blk;
   means trt/ LSD LINES alpha=0.1;
   lsmeans trt/ PDIFF adjust=Tukey alpha=0.1;
run;
proc mixed data=ear151;
   class trt blk;
   model ear = trt;
         random blk;
   lsmeans trt/ PDIFF adjust=Tukey alpha=0.1;
 ods output diffs=ppp lsmeans=mmm;
 ods listing exclude diffs lsmeans;
run;

%include 'z:Kate\pdmix800.sas';

%pdmix800(ppp,mmm,alpha=.1,sort=yes);
run;
```

Soil NO_3 and NO_4

```
proc glimmix data=b plots=studentpanel;
        class block trt time;
        model ammonium = trt|time;
```

```
            random block block*trt;
run;
proc sort; by block trt time;
proc print;
run;

data bb; set b;
 logammonium=log(ammonium);
run;
proc glimmix data=bb plots=studentpanel;
            class block trt time;
            model logammonium = trt|time;
            random block block*trt;
run;
proc sort; by block trt time;
proc print;
run;
proc mixed;
class block trt time;
model logammonium = trt|time;
random block block*trt;
repeated / subject=block*trt type=sp(pow)(t);
lsmeans trt*time / diff slice=time;
run;
proc sort; by block trt time;
proc print;
run;
proc mixed;
class block trt time;
model logammonium = trt|time;
random block block*trt;
repeated / subject=block*trt type=ante(1);
lsmeans trt*time / diff slice=time;
run;
proc sort; by block trt time;
proc print;
run;
proc mixed;
class block trt time;
model logammonium = trt|time;
random block block*trt;
repeated / subject=block*trt type=cs;
lsmeans trt*time / diff slice=time;
run;
proc sort; by block trt time;
proc print;
run;
proc mixed;
```

```
class block trt time;
model logammonium = trt|time;
random block block*trt;
repeated / subject=block*trt type=csh;
lsmeans trt*time / diff slice=time;
run;
proc sort; by block trt time;
proc print;
run;
```

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Chapter 4: Overall Conclusions and Future Work

The findings of this study demonstrate no N benefit from spring planted cover crops on irrigated sandy soil. Our results also show the rapid mineralization and N loss potential in these systems, framing future N management focus around in-season application. Mineralization of oat cover crops was not significantly different from no cover crop treatments on a 30-day scale and our findings suggest that environmental conditions and variable biomass accumulation between years can speed mineralization to fewer than 10-day cycles. Additionally, legume and oat cover crop combinations gave zero N credit to the subsequent sweet corn crop. These findings reiterate the narrow timeframe in irrigated sandy soil systems wherein both cover crop N is mineralized and sweet corn plant uptake is greatest.

As evident from our findings, mineralization in field conditions is challenging to predict. Fluctuations in soil microbial populations in response to soil moisture, temperature, organic matter composition, pH, and residual soil nutrients are just a portion of the factors impacting mineralization. Measuring the entire biological processing picture is nearly impossible in these environments, and the natural processes are just one part of the solution. The social aspect of N management also needs to be considered for truly comprehensive nutrient management recommendations.

Optimizing yields while minimizing nutrient loss is a goal for all producers. However, with changes in production recommendations come questions of economic viability, social responsibility, human health, policy implications and a host of other considerations impacted in this complex system. The broader, agroecological implications of this study have not been fully explored and warrant further investigation. Application of these findings and consideration of their social and landscape impacts is critical.

Reduction of nitrate leaching and its impact on groundwater is a multifaceted issue. Wisconsin is a top vegetable producer in the U.S. and nutrient management recommendations play a crucial role in national water quality. Recommendation determination should be made by a team of multidisciplinary experts rather than a few environmental scientists. Understanding the biological processing behind N management is just one of many factors. In order to ensure the health of our nation's waters and the livelihoods that depend on them, policy and management recommendations should consider environmental and social impacts, alike.