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NITROGEN MANAGEMENT USING MULTI-SPECIES COVER CROP MIXTURES

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ABSTRACT

Nitrogen management is an important part of any farm system; nitrogen is typically the most limiting nutrient for plant growth, the most expensive nutrient applied to crops as fertilizer, and is easily lost from soil through processes such as leaching, denitrification, and volatilization. Nitrogen deficiency can lead to poor yields and nitrogen overabundance can cause nitrate leaching. Losses of nitrogen to the environment cause issues such as ground water pollution, eutrophication of water bodies, and can act as greenhouse gases. Nitrogen fertilizer is extremely energy intensive to manufacture and accounts for a large portion of agriculture's carbon footprint. Cover crops provide a potential tool in farm system nitrogen management, lessening the need for expensive chemical fertilizer inputs and reducing nitrate leaching. Cover crops can be used for nitrogen management in three scenarios: to retain nitrogen against leaching, to fix nitrogen from the atmosphere to supply to the following crop, or to do both. This thesis examines the third scenario, utilizing mixed-species cover crop plantings composed of various combinations of a winter hardy legume, a winter killed legume, and a winter hardy grass. The main goal of the research is to determine the optimal species composition and seeding rates of a cover crop to balance the nitrogen retention and nitrogen supply functions. We used a response surface design to study how different plant densities of fava bean (winter killed legume), red clover (winter hardy legume), and triticale (winter hardy grass) interacted to influence nitrogen retention and supply. Using the response surface design, we created 20 unique cover crop treatments, each replicated three times. Fava bean was grown at four different densities (0, 56, 112, and 168 kg/ha) in monocultures and in bicultures with red clover planted at 13 kg/ha. Four different densities of triticale (0, 22, 45, 67 kg/ha) were crossed with the fava bean/red clover bicultures to form tricultures with different rates of fava bean and triticale plant densities. We measured cover crop biomass in October 2012 and soil nitrate concentrations in November 2012 and March 2013 as indicators of potential nitrogen retention and supply. There was a positive relationship between fava bean plant density and nitrogen content, with a hyperbolic yield-density model showing the best fit to the data. Increasing fava bean plant density reduced red clover biomass nitrogen in the biculture plantings, however. No negative relationship was observed between triticale and red clover; the relationship requires future research as neither species had reached full maturity at the October sampling date. Increased fall N uptake by triticale in the tricultures was correlated with lower soil nitrate concentrations in early spring, suggesting that including triticale as a component of a mixture may be effective at reducing nitrate leaching.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter 1

Introduction

Modern agriculture has become highly mechanized, focused on monocultures, and dependent on inorganic fertilizers in the form of expensive off-farm chemical inputs. Though the modernization of agriculture has arguably increased yields, there have also been negative consequences. These include heavy soil erosion and the upset of balanced biogeochemical cycles. Nitrogen and phosphorus, two of the most important nutrients limiting biological production, are applied extensively in modern agricultural systems. Their overabundance has led to nutrient leaching and runoff, resulting in global eutrophication. The adoption of cover cropping in modern agricultural systems provides a potential aid in lessening the negative effects of soil loss and nutrient pollution. (Gardner and Drinkwater, 2009; Drinkwater and Snapp, 2007)

A cover crop is a crop planted after the harvest of a main crop and terminated before the planting of the next cash crop. Typically, in the Mid-Atlantic Region of North America, a cash crop grows from late spring to mid-to-late summer and a cover crop is grown from fall to early spring. Cover crops provide a number of beneficial functions; they retain soil and build soil structure, they fix and retain nutrients, and use deep roots to harvest them from soil depths, and they aid in weed and pest suppression (Snapp et. al., 2005).

Nitrogen management is an important part of any farm system; nitrogen is typically the most limiting nutrient for plant growth, the most expensive nutrient applied to crops as fertilizer, and is easily lost from soil through processes such as leaching, denitrification, and volatilization. Nitrogen deficiency can lead to poor yields and nitrogen overabundance can cause nitrate leaching. Losses of nitrogen to the environment cause issues such as ground water pollution, eutrophication of water bodies, and can act as greenhouse gases. Nitrogen fertilizer is extremely energy intensive to manufacture and accounts for a large portion of agriculture's carbon footprint. Cover crops provide a potential tool in farm system nitrogen management, lessening the need for expensive chemical fertilizer inputs and reducing nitrate leaching. (Gardner and Drinkwater, 2009; Drinkwater and Snapp, 2007)

Typically, cover crops have been used for nitrogen management in three scenarios: to retain nitrogen against nitrate leaching, to fix nitrogen from the atmosphere for the subsequent crop, or to do both. When the goal is to retain nitrogen, a winter hardy grass is often planted in the fall to absorb remaining nitrogen from the previous crop and prevent it from leaching over the winter and early spring. In the spring, the grass is terminated, leaving abundant dead plant residues. These residues contain high carbon to nitrogen ratios, which increase biological activity and, in turn, cause a greater demand for N by the microbial biomass. The result is that N is immobilized; microorganisms in the soil temporarily convert N to organic N, which is not immediately available to plants. For these reasons, grasses are used only for nitrogen retention. Legumes, on the other hand, provide a means to increase available N supply for the subsequent crop. As legume residues decompose, nitrogen is mineralized and is available for the following crop. Winter hardy legumes are planted in the fall as cover crops. Upon establishment, they fix nitrogen during the fall, winter, and early spring. After termination in the spring, fixed nitrogen is quickly released for absorption by the following summer cash crop. Due to the immediate availability of N decomposed from legume residues, the N is susceptible to leaching before the subsequent crop can take advantage of it. (Johnson et. al., 2005)

Though an overview of the current literature on nitrogen management using cover crops shows that grasses and legumes are beneficial for their prescribed functions (Tonnito et. al., 2006), an effective nitrogen management plan should aim to manage both supply and retention of nitrogen. Legumes do not perform well at retaining nitrogen from leaching, and grasses do not supply the nitrogen they retain to the cash crop quickly enough (Gardner and Drinkwater, 2009). Recent research investigates the potential to plant cover crop mixtures of both a grass and a legume in order to balance both functions (Ranells and Wagger, 1997; 1996; Schipanski and Drinkwater, 2011).

Competition between species is a key concern in planting grass-legume bi-cultures and other cover crop mixtures. Schipanski and Drinkwater (2011) observed that red clover biomass production was reduced when interseeded with orchardgrass, possibly due to competition for light. Studies involving cover crop bi-cultures and multi-species mixtures are beginning to investigate competition among cover crops in order to decide the optimal seeding rates for proper establishment and function of both the grass and legume involved in the treatment. From the weed science literature, Cousens (1991) provides three types of experimental designs for determining mixture densities, each with benefits and flaws based upon experiment objective. The additive design involves one species planted at a constant density compared to another planted at varying densities, in order to see how the varying densities affect the constant. Though this method is praised for its simplicity and ease of interpretation, it is criticized for not taking into account intra-specific competition; the competition modeled is only one species' effect on the other. In the second type of design, the replacement series, the density of both species are varied so that their total plant density is constant, but the seeding ratios are varied. Cousens asserts that this design has been the most commonly used by ecologists. Though it does a much better job of discovering how two species interact with each other by varying densities, replacement series often involve densities that are too low or not biologically feasible and therefore uninteresting. The response surface design aims to solve the problems of the aforementioned designs by varying the densities of both species. This allows for a more complete and complex model of potential plantings. Often response surfaces include an additional set of plantings of monoculture of each species in the experiment to examine intra-species competition as well. Species in a cover crop mixture compete with themselves and with each other, resulting in multiple complex relationships. The response surface design, paired with monoculture plantings of the same individual densities chosen for mixtures, provides a method to investigate these complex relationships. Neumann et al., (2009) suggest that a response surface design be used to evaluate optimal intercrop compositions. We chose to use this design, a response surface, in order to create mixtures of red clover, fava bean, and triticale.

In addition to the constraints mentioned for researching cover crop mixtures, the practice of real, farm scale cover crop planting involves constraints as well. Typical commodity grain farms in the Mid-Atlantic region operate on corn monocultures, or corn-soy rotations. The late-fall harvesting dates of corn and soy leave little time for the planting and establishment of a cover crop before winter. Indeed, farmers surveyed about the use of cover crops said that that the opportunity cost of giving up a season of cash crops was a primary deterrent to growing cover crops (Snapp et. al., 2005).

Different strategies to increase opportunities for cover crop use have been discussed. One such way was not to get rid of a cash crop growing season, but rather to add a season of small grain, such as winter wheat, into the rotation. The mid-summer harvest of wheat allows for several months of warm weather necessary for the establishment of a cover crop (Snapp et. al., 2005). In fact, in much of Pennsylvania and latitudes northward, a planting date after small grain harvest may be the only feasible crop rotation entry point for winter-killed cover crop species which must produce their biomass before killing frosts occur.

Roth (2013) has developed a new farm implement to deal with the cover crop planting date constraint associated with corn production. The interseeder is a farm implement that plants cover crops in between rows of an already established corn crop, at the V6-V8 stage. Cover crops thus have a much longer period to establish while corn grows, as well as after the corn harvest. So far research has shown that cover crops planted in this way do not compete with corn yields. Roth suggests that not only are the cover crops useful for typical cover crop functions, but also they can provide additional forage for grazing. This study involves planting of cover crops in late July, assuming that the short window for establishment will be addressed by incorporating a winter wheat crop into the crop rotation.

The constraints of seed cost were also considered. Fava bean is an expensive cover crop due to the high seeding rate usually recommended for maximum biomass production. Therefore, in order to determine a seeding rate that provides an optimum level of N at a reasonable cost, fava bean was planted separately as a monoculture, in addition to being involved in the response surface treatments.

This thesis explores how cover crop mixtures balance the functions of nitrogen retention and supply utilizing data from a field experiment planted at the Russell E. Larson Agricultural Research Center in Centre County, Pennsylvania. The main goal of the experiment is to determine the optimal species composition and seeding rates of a cover crop to balance the nitrogen retention and nitrogen supply functions. We used a response surface design to study how different plant densities of fava bean (winter killed legume), red clover (winter hardy legume), and triticale (winter hardy grass) interacted to influence nitrogen retention and supply.

Utilizing data on cover crop plant density, cover crop biomass nitrogen content, and soil nitrate concentration collected from the field experiment, I hypothesized that 1) there will be a positive relationship between fava bean plant density and fava bean biomass nitrogen content, with biomass nitrogen content reaching a plateau at high plant densities; 2) competition between fava bean and red clover will result in a negative relationship between fava bean plant density and red clover nitrogen content; 3) there will be an optimal level of fava bean plant density in a fava bean – red clover bi-culture that will maximize total cover crop biomass N content; 4) competition between triticale and red clover will result in a negative relationship between triticale plant density and red clover biomass N content; and 5) increased N uptake by triticale in a mixture will lead to lower soil nitrate concentrations in early spring.

Chapter 2

Methods and Materials

Study Area

The experiment site is located in a 2 ha field at Penn State University's Russell E. Larson Research and Education Center at Rock Springs, in Centre County, Pennsylvania. The field is situated within the Nittany Valley of the Ridge and Valley Province of the Appalachian Mountains of North America. Average temperatures range from -7 to 28º C with > 1000 mm of precipitation regularly occurring throughout the year (NOAA). The soil in the field is a Hagerstown series, derived from limestone parent material, with a particle size analysis of 16% sand, 35% silt and 49% clay. Previous crops in the rotation were barley in 2010, oats in 2011, and wheat in 2012. The field has been under no-till soil management practices typical of the region since 2009.

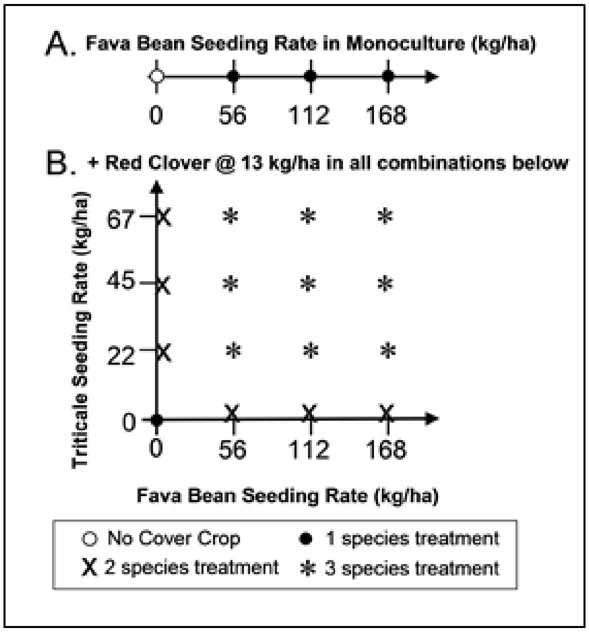
Experimental Design

The experiment utilized a response surface design including 20 different treatments of cover crop monocultures, mixtures, and a no cover crop control (See Figure 3-1).

Fava bean was planted at seeding rates of 0, 56, 112, and 168 kg/ha and triticale was planted at seeding rates of 0, 22, 45, and 67 kg/ha. The four seeding rate levels for each species were crossed with each other to form the response surface. Red clover was planted at a consistent seeding rate of 13 kg/ha in all treatments in the response surface. Thus when the seeding rate of one species was 0, the result was a biculture with red clover and the other species. In order to address intra-specific fava bean competition, additional treatments of fava bean monoculture were planted at the same seeding rates as in the response surface.

Treatments were replicated three times in a randomized complete block design. Plots were 12.192 meters long by 3.048 meters wide, with two ranks of 12 plots in each block. Cover crops were planted with a cone seeder attachment on a no-till drill with the seeds for each plot pre-weighed to the target seeding rates and mixed together prior to planting. The actual plant densities resulting from the target seeding rates are used in the data analysis, however. For reference, the 56 kg/ha seeding rate of fava bean is equivalent to 15 seeds / m^2 and the 22 kg/ha seeding rate of triticale is equivalent to 50 seeds/m^2. The plots were planted July 31, 2012 following winter wheat grain and straw harvest. On August 1, 2012 glyphosate was sprayed to suppress weeds prior to cover crop germination.

Figure 2-1. Response Surface Design



Biomass Samples

Two biomass samples per plot were taken using a 0.25 m^2 quadrat on October 26, 2012. Fava bean biomass was collected from every plot in the experiment, red clover biomass was collected from the 0 kg/ha triticale seeding rate level of the response surface and red clover and triticale biomass were collected from the 56 kg/ha fava bean seeding rate level of the response surface. Samples were separated by species and individual plants of fava bean and triticale were counted within each quadrat to determine plant density. Red clover was planted at a consistent seeding rate across all treatments, so red clover plant density was not measured. Cover crop biomass samples were dried in a forced draft oven at 65 deg C for a minimum of two weeks prior to weighing. After drying and weighing, the two biomass sample quadrats were composited and ground through a 1mm screen. Carbon and nitrogen concentrations were measured with a flash combustion analyzer (Carlo Erba Instruments) in the Penn State Soil Research Cluster Laboratory.

Soil Samples

Six soil cores were taken per sampled plot using a 1.8 cm diameter closed tip soil probe (JMC, Inc.) on November 21, 2012 and March 29, 2013. Soil samples were homogenized and approximately 20g of field moist soil was extracted with 100 mL of 2M potassium chloride on a reciprocal shaker for 1 hr. Extracts were filtered through Whatman 1 filter paper and frozen for subsequent analysis. Nitrate concentration was measured in the extract using the vanadium chloride method, with absorbances measured on a microplate reader.

Statistical Analysis

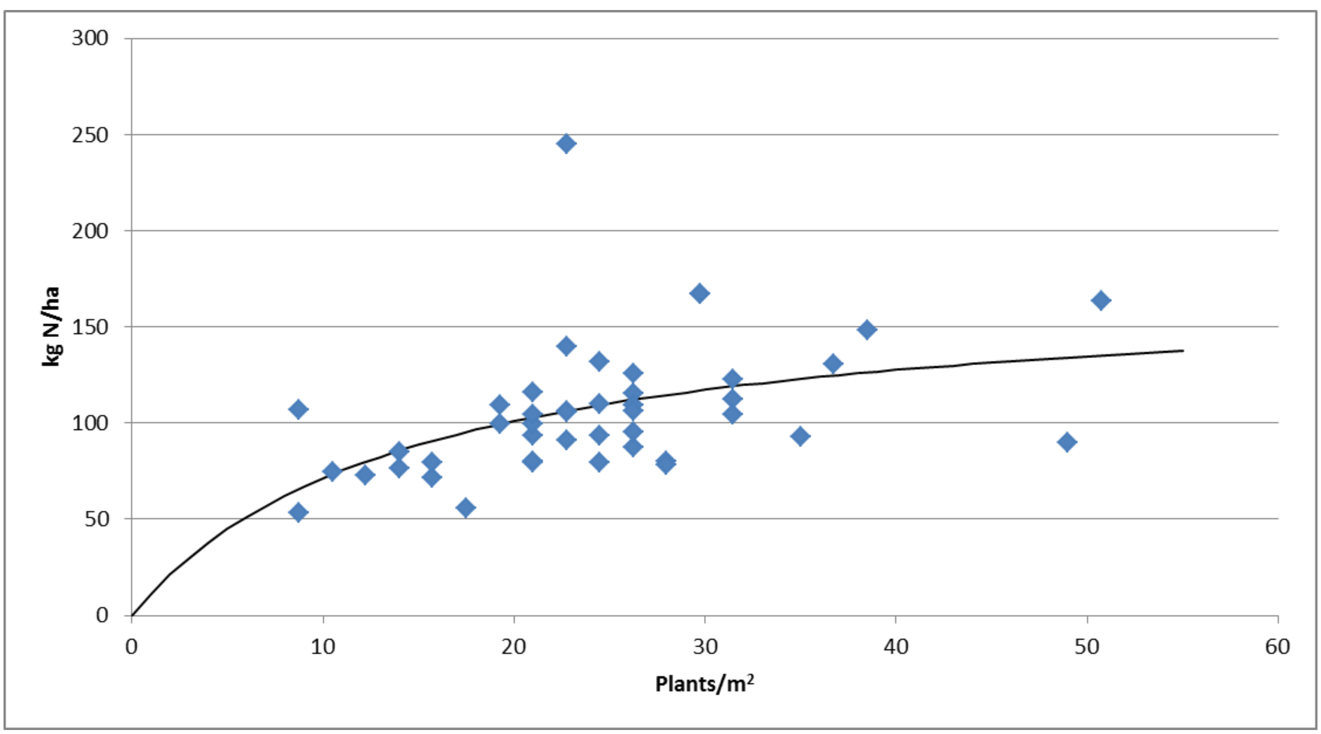
Relationships between fava bean and triticale plant density and the response variables of interested were determined with linear and non-linear regression models using Proc NL MIXED in SAS 9.2 (SAS Institute, Cary, NC). We used the Akaike information criterion to compare the goodness of fit of different models when appropriate. A cover crop treatment effect on soil nitrate concentrations was tested for through analysis of variance and mean comparison tests using Fisher's Least Significant Difference at $P<0.05$ with Proc MIXED in SAS.

Chapter 3

Results

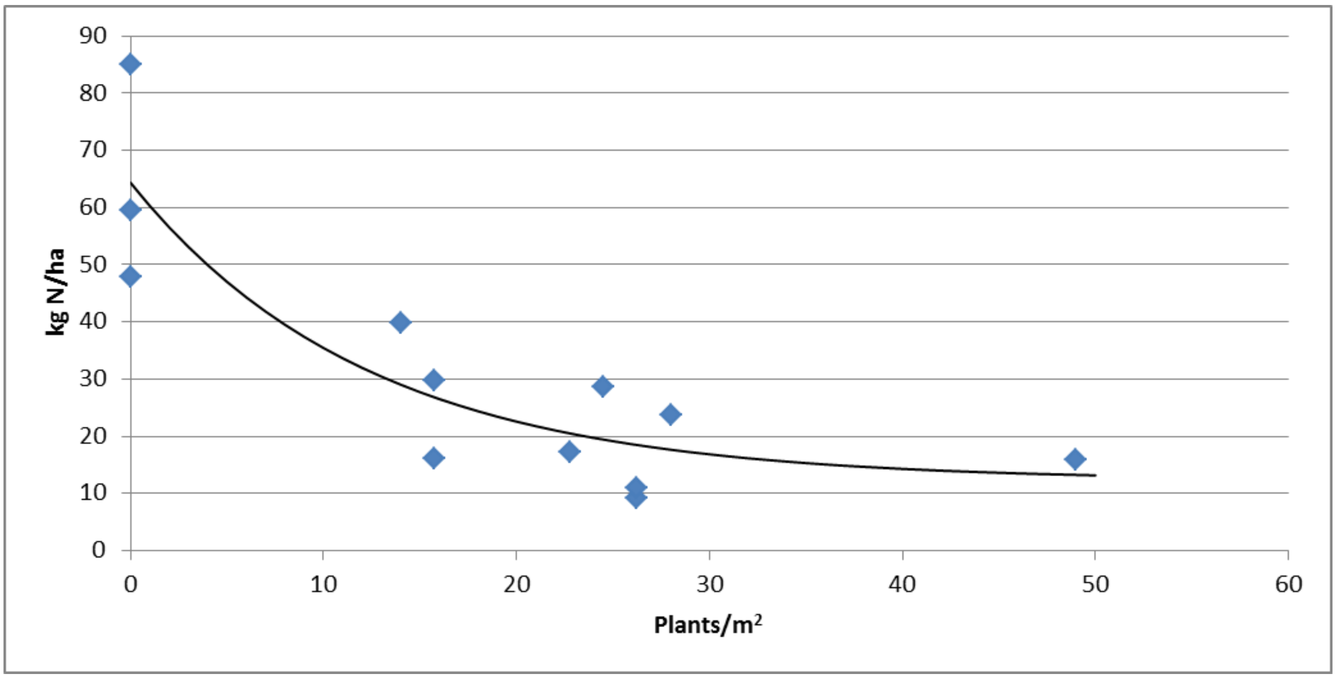
There was a positive relationship between fava bean plant density and fava bean biomass nitrogen per hectare (Figure 3-1). The hyperbolic crop yield density response model (Cousens, 1991) showed the best fit to the data with an akaike criterion model (aic) of 431.6. Before using the hyperbolic crop yield density model, we performed a simple straight line regression, which had an aic of 432.7. We also adjusted the model to a straight line with a plateau, because we hypothesized that the effect of fava bean plant density on biomass N content would plateau, but the fit was worse than the simple straight line model (aic=433.6).

Figure 3-1. The relationship between fava bean plant density and fava bean biomass N per hectare in October 2012. The relationship was best fit by the hyperbolic yield density model kgN/ha = $N_{fb}/(bco + bccN_{fb})$ where N_{fb} is fava bean density and bco and bcc are fitted parameters. bco = 0.08249 and bcc = 0.005776



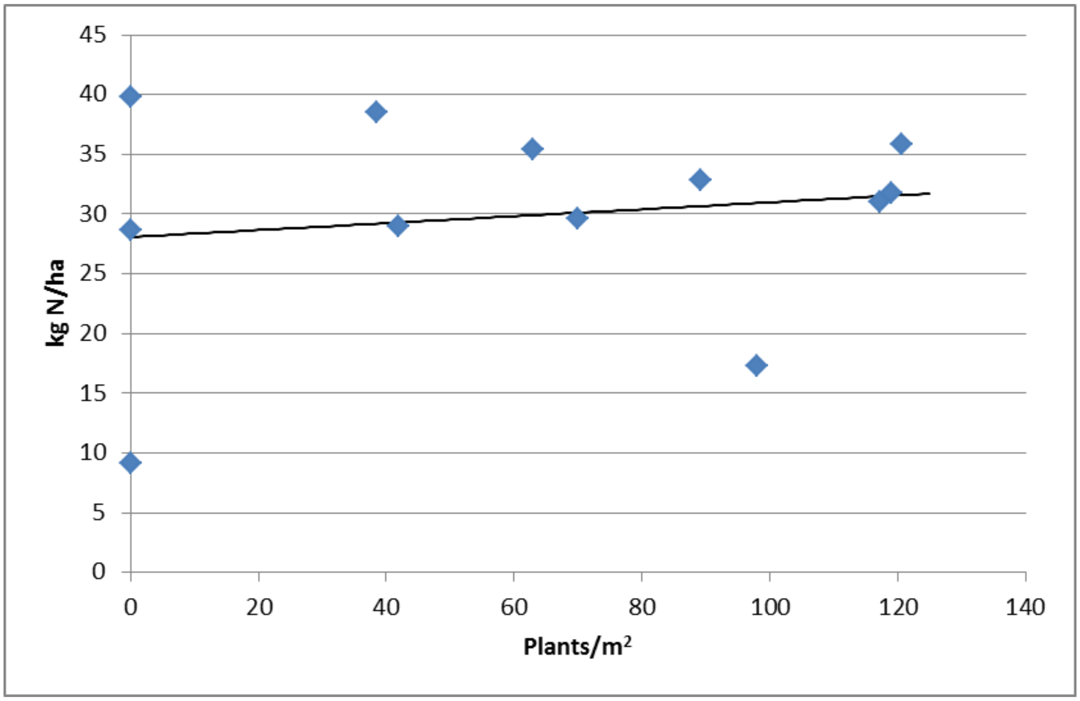
Results show a negative relationship between fava bean plant density and red clover nitrogen per hectare. A negative exponential model was fit to the data (Figure 3-2).

Figure 3-2. The relationship between fava bean plant density and red clover nitrogen per hectare in October 2012. The relationship was best fit by a negative exponential model $y = a * (1-b*e^{-c*d})$ where y is the biomass N content of red clover and d is fava bean plant density and a, b, and c are fitted parameters. a = 12.2675, b = -4.2449, and c = 0.08093



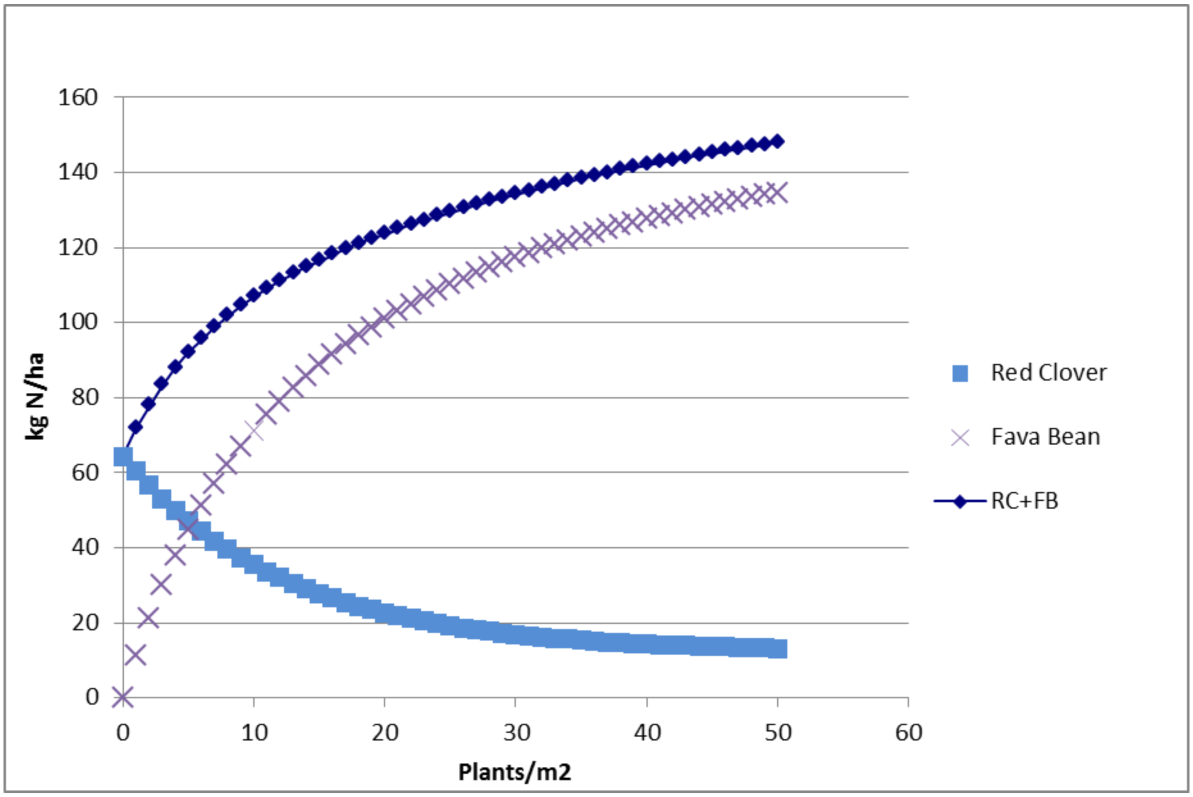
Though fava bean plant density significantly affected red clover nitrogen per hectare, triticale plant density had no effect on red clover nitrogen content. Using linear regression a value of p = 0.5943 was obtained, meaning that the change in slope was not significantly different from zero. (Figure 3-3).

Figure 3-3. The relationship between triticale plant density and red clover biomass nitrogen per hectare in October 2012. The relationship was fit to the line y = 0.02907x + 28.0769. p = 0.5943, therefore the slope was not significantly different than 0.



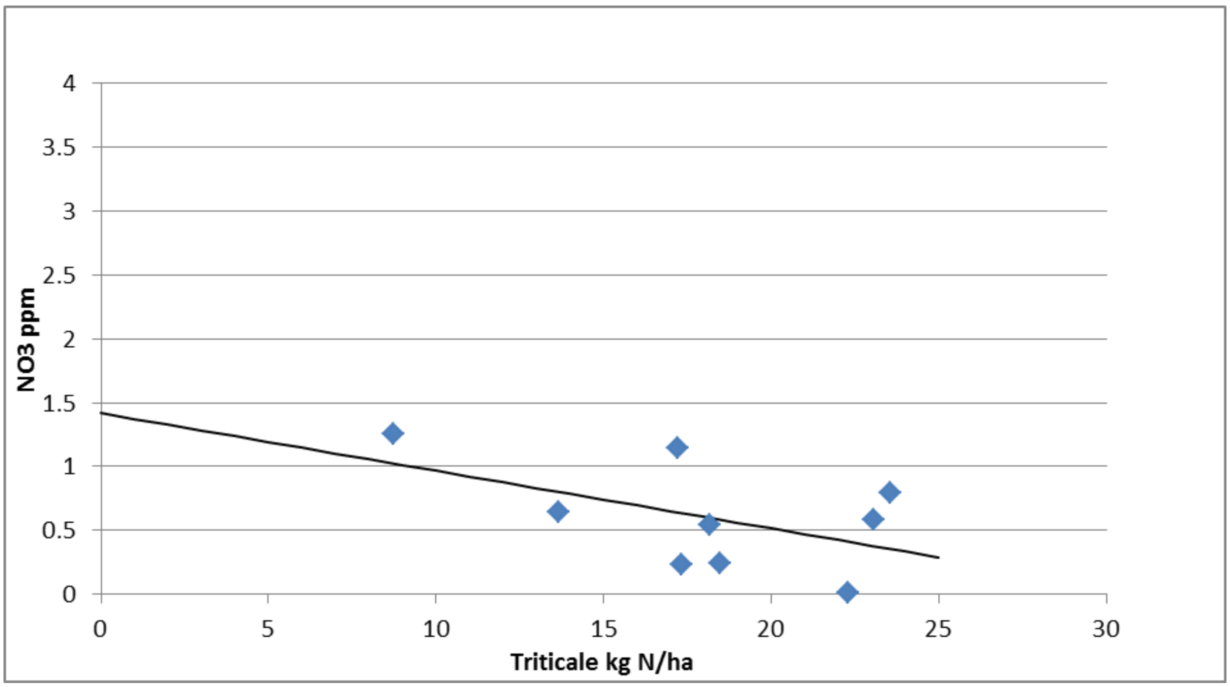
Results for fava bean biomass N content and red clover N content were plotted on the same chart against fava bean plant density. Using a theoretical approach based on those two curves, fava bean plant density was plotted against combined fava bean and red clover biomass N content (Figure 3-4). The combined curve resembles that of just fava bean N content, yet appears to plateau sooner than just fava bean N content.

Figure 3-4. The relationship between fava bean plant density and biomass N per hectare for fava bean, red clover, and fava bean and red clover. Fava bean biomass N is modeled using a hyperbolic crop yield density model and red clover biomass is modeled using a negative exponential model.



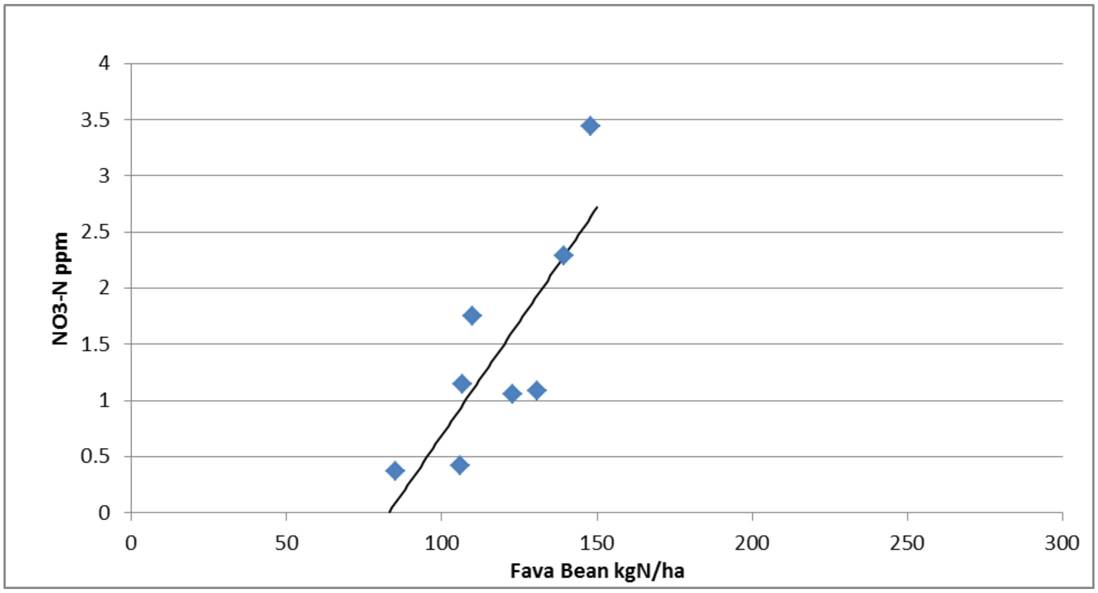
Triticale nitrogen per hectare shows a negative relationship with soil nitrate; as nitrogen content in a plot increases, soil nitrate decreases (Figure 3-5). This relationship was modeled using linear regression, with $p = 0.1026$, making the relationship very close to being statistically significant.

Figure 3-5. The relationship between triticale biomass N content in October 2012 and soil nitrate in March 2013. The relationship was fit to the line $y = -0.04526x+1.4194$. $p = 0.1026$, showing that the relationship was very close to being significant.



Conversely to triticale results, fava bean biomass N per hectare shows a positive relationship with soil nitrate; as fava bean biomass N increases, so does nitrate. This relationship was modeled using linear regression, with p= 0.0042, making the fit statistically significant.

Figure 3-6. The relationship between fava bean biomass N content in October 2012 and soil nitrate in March 2013. The relationship fit to the line y = 0.04050x-3.3581. p = 0.0042, therefore the fit is statistically significant.



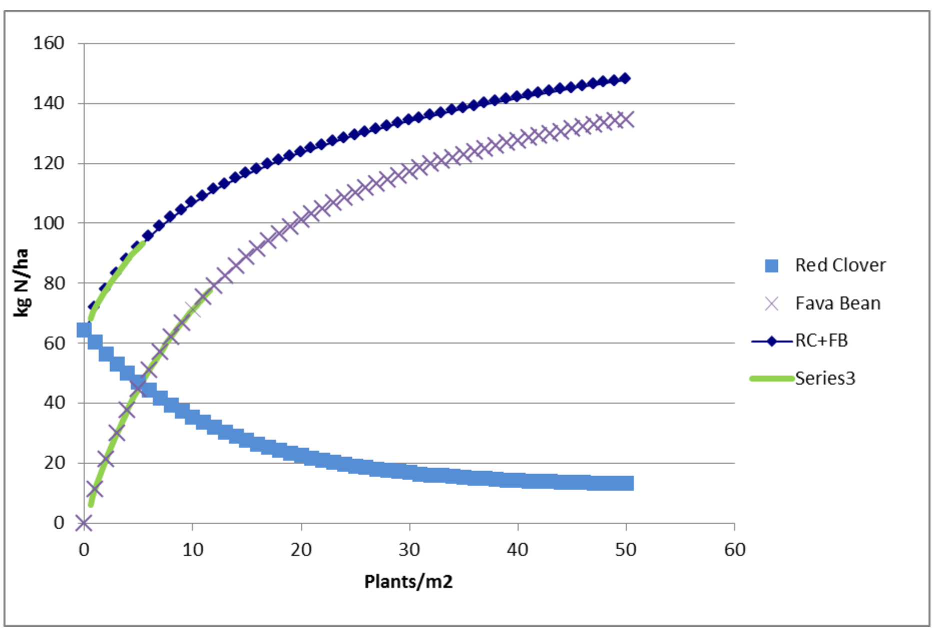
Soil nitrate values were only significant for a few of the treatments. In November 2012, the no cover treatment was significant at 2.83 ppm and the 56 kg/ha of fava bean treatment was significant. Yet, in March 2013 the only two significant treatments were the 168 kg/ha of fava bean at 1.49 ppm and the biculture of 13 kg red clover and 45 at $1.85E^{-15}$ ppm.

Table 3-1. Soil NO3-N ppm from November 2012 and March 2013 sampling along with mean comparisons. Distinct letters denote significant differences (P<0.05, LSD).

	Nov-12	Mar-13
Treatment	Estimate	Estimate
No Cover 0N	2.83 A	0.53 CD
FB56	0.68 B	0.86 BC
FB112	0.46 BC	1.49 AB
RC13+TR22	0.37 BC	0.16 CD
FB56+RC13	0.30 C	0.58 CD
FB168	0.26 C	1.86 A
RC13	0.26 C	0.41 CD
FB56+RC13+TR22	0.22 C	0.83 BC
RC13+TR67	0.20 C	0.05 CD
FB56+RC13+TR67	0.16 C	0.26 CD
RC13+TR45	0.11 C	1.18E-15 D
FB56+RC13+TR45	0.10 C	0.72 BCD

Finally, a simple economic analysis was performed to determine optimal fava bean seeding rates based on the ability of the fava bean to accumulate nitrogen in its biomass. We assumed that 1 kg of N fertilizer costs $1.30 and 1 kg of fava bean seed costs $1.30 and that 1 kg of fava bean seed is equivalent to 0.27 plants/m^2. Because the per kilogram cost of fava bean seed and N fertilizer are the same, the point at which it will no longer make economic sense to buy fava bean seed over fertilizer for the N fertilizer benefits will be when the addition of 1 kg of fava bean seed (0.27 plants/m^2) no longer produces 1 kg of N. This point occurs above 11.6 plants/m^2 or 43 kg/ha of seed. Therefore, after planting 43 kg/ha of fava bean seed, it is more economical to purchase nitrogen fertilizer as a source of N than it is to plant higher seeding rates of fava bean. The same analysis was performed on the theoretical curve of red clover and fava bean biomass N content compared to fava bean density. This shows when planting fava bean with red clover, when it will no longer be financially viable to add fava bean seed above 5 plants/m^2 or 18 kg/ha of seed

Figure 3-7. Economic Analysis. The green line on each shows the portion of the line where it is economically viable to plant fava bean seed. For fava bean monocultures, the point of diminishing returns occurs at 11 plants/m^2. For fava bean and red clover bicultures, it occurs at a lower plant density 5 plants/m^2.



Chapter 4

Discussion

My hypothesis that there will be a positive relationship between fava bean plant density and fava bean biomass nitrogen content was proven to be statistically significant in the results. Because the data matches the hyperbolic crop yield density response model, results further confirm the hypothesis that biomass nitrogen content reaches a plateau at high plant densities. This information is important for consideration of fava bean as a cover crop. Fava bean seed is expensive for farmers; identifying the point at which fava bean N content plateaus is useful in determining optimal seeding rates. Results showed that it may not be financially effective to plant fava bean solely for nitrogen addition above seeding rates of 43 kg/ha. This is significant because this seeding rate is much lower than seeding rates usually recommended for fava beans, which range from 100 to 200 kg/ha. Also, calculation only takes into account the price for fava bean seed, not the additional costs such as spraying glyphosphate to kill weeds prior to cover crop germination. On the other hand, this analysis only takes into account one beneficial aspect of the cover crop, ability to add nitrogen. A fava bean cover crop would also hold soil, prevent erosion, add biodiversity, and break up disease cycles. Growing corn after all of the treatments will give greater insight into how fava bean N affects yields.

Results proved my hypothesis that competition between fava bean and red clover will result in a negative relationship between fava bean plant density and red clover nitrogen content. The negative relationship could be the result of a competition for light and/or space. Research has shown clover to be affected negatively by competition; Schipanksi and Drinkwater (2011) found that clover production was lower when planted in bi-culture with orchardgrass than in monoculture. This conclusion, considered with that from data from fava bean biomass N and density may provide the most pertinent finding for planting cover crop mixtures from this report. Figure 4-4 shows that when red clover and fava bean N content are combined and plotted against fava bean density, a plateauing effect occurs. The curve plateaus before that of just fava bean N content, strongly suggesting that there is a point at which adding fava bean begins to diminish N content due to competition with red clover. After examining the seeding rates and performing an economic analysis, results showed that when planted with red clover, it was no longer financially sound to plant fava bean for N additions over seeding rates of 18 kg/ha. This again is much lower than the seeding rates that are typically recommended. Though the rates are low, it is important to remember that any reduction in the use of fossil-fuel based fertilizers has environmental benefits, along with being cheaper than N fertilizers even if at low rates. There are limitations to our analysis of competitiveness; spring biomass samples of red clover will tell us more about whether competition that occurred before the winter months will persist into spring. We expect that red clover will continue to fix nitrogen in the spring, without competition from fava bean, which has winter killed.

Contrary to my hypothesis, triticale plant density did not have a negative relationship with red clover nitrogen content; results show no relation. This is contrary to the aforementioned study in which red clover was negatively affected by orchardgrass (Schipanski and Drinkwater, 2011). However, these results may be misleading. Both triticale and red clover are winter hardy species that are slow to establish in the fall. It is possible that neither triticale nor red clover is mature enough to affect the other. Another important consideration is how each species procures and utilizes nitrogen. Triticale uses nitrogen from the soil; red clover can use soil nitrogen, or it can fix nitrogen from the atmosphere. In nitrogen limited soils, such as those sampled with red clover and triticale, there may have been less competition between triticale and red clover because triticale was limited by lack of soil nitrogen and red clover was given a boost because it can fix its own nitrogen. Future research should continue to study this relationship as the two species mature and interact.

In plots where triticale biomass nitrogen content was higher, soil nitrate was lower. This makes sense. Triticale is planted to retain nitrogen, so higher triticale nitrogen content suggests higher triticale nitrogen retention. Soils with high nitrate suggest low retention by triticale and susceptibility to leaching, and low soil nitrate could suggest higher retention by triticale. Soil nitrate results for fava bean showed the opposite; where fava bean N content was higher, soil nitrate was higher in March following fava bean winterkill and residue decomposition. This suggests that fava bean were also doing their job fixing nitrogen. It is important to consider that soil nitrate is very mobile, and testing for it shows only a snapshot of the nitrate concentration on each sampling date. Resin capsules were placed in plots to measure accumulated soil leaching. Results from these capsules will provide insights to whether the negative relationship between triticale nitrogen content and soil nitrate is meaningful for reducing nitrate leaching.

Chapter 5

Conclusion

This study provides preliminary insight into optimum cover crop seeding rates in the discussed monocultures and mixtures. Though results show that fava bean in monoculture is not an economic choice to completely replace N fertilizer, it does have potential to supplement fertilizer. In a red clover-fava bean bi-culture, fava bean proves to be even less feasible as of the most recent sampling. However, red clover is expected to continue to fix nitrogen into the spring. Once adjusted for other costs involving cover crop adoption (herbicides, equipment, extra time) even a small replacement of fertilizer provides the benefit of all cover crops, including erosion protection, increased biodiversity, as well as lessening the use of fossil fuels to provide nutrients. Though fava bean alone was the most economically viable to add nitrogen at the most recent sampling dates, potential for nitrogen loss must be considered as well. Planted in monoculture, fava bean poses the risk of losing much of the nitrogen it fixes. Red clover, on the other hand, will continue to grow and fix nitrogen until termination in early spring. Triticale has potential to be a very useful part of the N supply-demand puzzle as early results suggest that it retains N that would be lost and that it can be planted at high seeding rates without interspecific competition. Even though fava bean and red clover compete, the mixture that will best balance N supply and demand will contain triticale along with red clover and fava bean. Fava bean alone cannot supply a steady enough supply of N because it winter kills. Red clover alone, though it does not winter kill, poses a risk of leaching N after termination and before the next crop can take advantage of it. The response surface model provides an excellent format to further research these intricate relationships

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ACADEMIC VITA

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Current Address Until May 2013:
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EDUCATION:

The Pennsylvania State University, University Park, PA
Schreyer Honors College
College of Earth and Mineral Sciences
Expected Graduation May 2013
Geography, B.A.

St. Joseph's Preparatory High School, Philadelphia, PA
Graduated May 2009
National Honor Society

EXPERIENCE:

Pennypack Farm and Education Center - Intern
Summer 2011

-Aid farm manager on basic daily farm chores and maintenance such as seeding, weeding, and harvesting
-Educate farm visitors and campers about sustainable agriculture, gardening, and the environment
-Interact with CSA members and organize the pickup room

Sustainable Agriculture Club – President
2013
-Take meeting minutes
-Send club emails
-Organize volunteers at Shaver's Creek Maple Harvest Festival
-Volunteer at the Center for Sustainability Community Gardens

Spring Creek Homesteading Fund Food System Mapping Team
Fall 2011
-Collaborate with community members

-Consolidate information from multiple databases
-Create a map of producers, distributors, and venders in Centre County and the surrounding area

American Indian Housing Initiative
Summer 2011-Fall 2011
-Learn and perform residential energy audits
-Participated in sustainability education projects with Northern Cheyenne youth
-Learn about the Northern Cheyenne culture through readings as well as a two-week trip to the reservation in Montana

OTHER WORK:

Penn State Snowboard Club - President – THON Chair **-** Treasurer
2010-2013
-Organize financials for a two hundred plus member club, and for three club trips each with at least forty club members
-Dance in THON and helped organize canning weekends