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THE EFFECT OF COVER CROP TREATMENTS AND DROUGHT ON SOIL NITRIFICATION POTENTIAL

JENA MARIE TROLIO
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Reviewed and approved* by the following:

Jason Kaye
Associate Professor of Soil Biogeochemistry
Thesis Supervisor

Robert Shannon
Associate Professor and Program Coordinator of Environmental Resource Management
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

Humans have a significant impact on the global nitrogen (N) cycle, and have doubled the amount of relative nitrogen in the biosphere. The majority of this impact is due to agricultural systems. Shifts in modern agricultural production, especially increased synthetic fertilizer, have led to increased nitrification potential, or the rate at which ammonium (NH_4^+) is converted biologically to oxidized N, in soil. Increased soil nitrification rate can create an economic loss for farmers and have adverse effects on the environment when oxidized N is leached through the soil profile. Managing an agricultural system to suppress nitrification rates is favorable. Elements of agricultural systems such as the dynamics of soil nitrifiers, the environmental effects of climate change, and the expansion of cover crops as a tool for nutrient management have a large influence over the soil nitrification potential. Despite their vast importance, the interactions between these elements and the impact they have on nitrification potential are generally unknown. This project was completed in two portions, a field study and a laboratory study, to achieve a better grasp on the effects of cover crops and drought on soil nitrification potential and the dynamics of soil nitrifier microbial communities. Soil samples that underwent different cover crop and drought treatments were analyzed for their inorganic N contents and their nitrification potentials to determine if the treatments created any significant differences.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter 1

Introduction

1.1 N in the Biosphere

N (N) is an element essential for all life forms, and it is often one of the most influential elements in determining the ecosystem dynamics of many terrestrial and marine ecosystems (Vitousek et. al 1997). When N becomes readily available in ecosystems, it often fosters increased productivity and biomass accumulation (Vitousek et. al 1997). N is a necessity to an ecosystem, but too much can be damaging. Humans have approximately doubled the amount of N inputs to the global N cycle within the last 100 years (Vitousek et. al 1997). The majority of this anthropogenic impact has come from agricultural systems (Liu et al. 2010). Several shifts in agricultural production and management practices occurred in the 20th century that aimed to meet the food production needs of a growing global population, most importantly increased N fertilizer inputs. Additional shifts have included decreased crop diversity, simplified crop rotations, separation of crop and livestock production, increased irrigation and drainage through the soil profile, and increased soil tillage (Subbaraeo et al. 2012). These changes in agricultural production have allowed for food production to keep pace with the rising population, but with many environmental costs.

To some degree, the addition of N is beneficial for plant growth, but plants are unable to take up all of the N currently added to most agricultural systems. As more N is

added to the system, more is lost through nitrate leaching and denitrification. Nitrate (NO_3^-) leached from agriculture has led to groundwater contamination and water quality degradation of areas such as the Chesapeake Bay. Denitrification, the process by which NO_3^- is reduced to gaseous forms, contributes to acid rain and increased concentrations of nitrous oxide (N_2O), a potent greenhouse gas. Managing agricultural systems to suppress N losses could limit these environmental impacts while still providing plants with enough N to grow.

1.2 Nitrification within the N Cycle

Nitrification is the process within the global N cycle in which reduced N in the form of ammonia (NH_3) or ammonium (NH_4^+) is converted biologically to oxidized N in the form of either nitrate (NO_3^-) or nitrite (NO_2^-) (Norton and Stark 2011). The process occurs sequentially, NH_4^+ is first oxidized to nitrite, and then nitrite continues to be oxidized to NO_3^-. It is in this way that nitrification

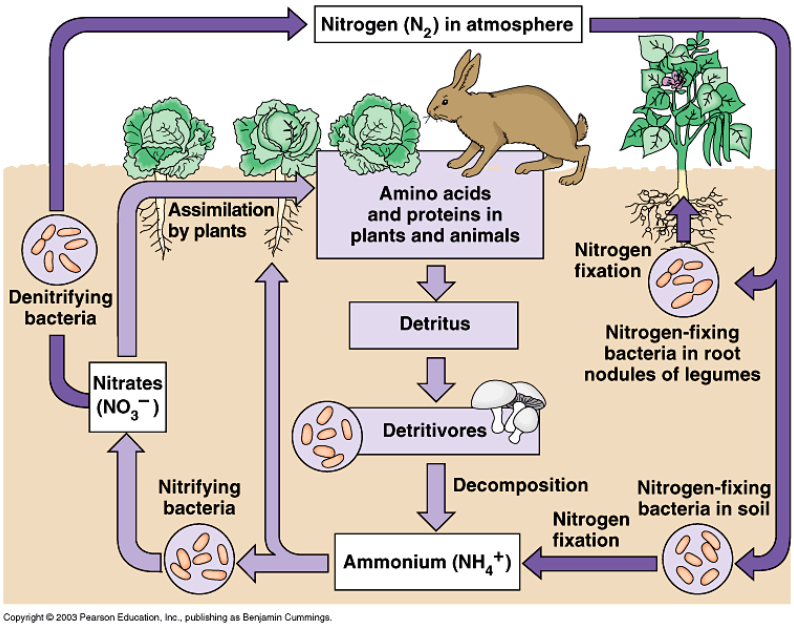


Figure 1. Diagram of the soil nitrogen cycle from Pearson Education Inc., 2003.

links the most reduced and the most oxidized forms of N in the cycle. Nitrification plays a large role in determining the ecosystem services that the soil provides. The nitrification process reduces NH_4^+ accumulation, increases the NO_3^- available in a soil ecosystem, and determines the availability of different inorganic N sources available for plant uptake.

Due to its positive charge, NH_4^+ becomes attracted and bound electrostatically to negatively charged soil particles. This relationship prevents the leaching of NH_4^+ through the soil profile. Conversely, NO_3^-, being negatively charged, is not bound to soil particles, and leaches much more easily through the soil profile (Subbaraeo et al. 2012). The nitrification process produces the nitrogen oxide trace gases NO and NO_2, which contribute to acid rain and formation of Tropospheric ozone. Also produced as a trace gas is the greenhouse gas N_2O, which has a high global warming potential up to 300 times that of CO_2 (Gödde and Conrad 2000, Subbaraeo et al. 2012). These same gases are formed as NO_3^- is reduced through denitrification. Therefore, though high nitrifying soils have more N available for plant growth, they can also lose large amounts of N. These losses not only affect the environment, but also have negative effects on the US economy. It is estimated that up to 70% of N-fertilizer inputs are lost due to rapid nitrification, resulting in the loss of US $81 billion per year (Subbaraeo et. al 2012).

NO_3^- has three fates in soil ecosystems – plant or microbial uptake, which are advantageous, and loss from the system, which is environmentally and economically harmful. The strong influence that nitrification potential has on the fate of soil N leads to several critical questions: Is it possible to manage agricultural systems in a way that will suppress soil nitrification potential while still providing plants with the N they need to

grow? How might global climate change, which is predicted to involve longer and more frequent periods of drought, impact these potential management practices?

1.3 Soil Nitrifier Populations

Fertilizer, often applied in the form of NH_4^+ is rapidly converted to NO_3^- by soil nitrifier populations. Chemolithotrophic microbes currently carry out the primary mechanism of nitrification in aerobic soil environments (Norton and Stark 2011). It was long believed that the only soil microbes that carried out nitrification were ammonia-oxidizing bacteria (AOB). In 2005, it was found that ammonia-oxidizing archaea (AOA) are not only nitrifying populations present in soil, but that they are often more widely distributed and numerous than AOB in many soil environments (Taylor et. al 2010).

Several factors in natural systems influence soil nitrification potential, one of which is substrate availability. In order for nitrifier communities to live and expand successfully, they must have access to NH_4^+/NH_3, CO_2, and O_2 (Norton and Stark 2011). The limiting factor controlling nitrification potential in soils is often NH_4^+/NH_3. In agricultural systems, availability of these substrates may be increased by any one of the following occurrences: mineralization, additions of NH_4^+ fertilizers and animal wastes, and atmospheric deposition of NH_4^+. Availability of these substrates may be decreased by immobilization, plant assimilation, and ammonia volatilization (Norton and Stark 2011). Other environmental factors that can affect microbial condition and mediate substrate diffusion include oxygen, water potential, temperature, and acidity and alkalinity of the soil all have an effect on soil nitrification potential (Norton and Stark 2011).

1.4 Cover Crops

Cover crops are grasses, legumes, or forbs planted to provide seasonal soil cover on cropland when the soil would otherwise be bare. Cover crops can be planted in different combinations and during different times of the year to provide different functions within agricultural systems. Cover crops provide numerous environmental and economic benefits that make them favorable for use in agricultural systems, such as soil cover, stablization by root systems, conservation of soil moisture, and protection from runoff, erosion, weeds, and pests (Schipanski et. al 2014). Economically, cover crops can save money by reducing the need to purchase inputs such as fertilizers, pesticides, and herbicides (Snapp et. al 2005).

When cover crop biomass is mixed into soil via tilling or another agricultural technology, the residues of the cover crops add organic matter and nutrients to the soil. For this reason, cover crops can be manipulated to provide soils with appropriate nutrients at different times of the year (Cook et. al 2010). This organic matter may also provide NH_4^+ substrate for nitrifier populations and encourage increased soil nitrification potential by creating favorable environments for microbial activity. On the other hand, cover crops may also suppress nitrifier communities because the added organic matter may support populations of heterotrophic microbes that out-compete the nitrifiers for resources (Paul 2007). Few studies to data have examined the effects of cover crops on soil nitrifier populations and soil nitrification potential, therefore whether the organic matter causes an increase or decrease in soil nitrification potential is generally unknown.

1.5 Nitrification and Drought

Moisture is one of the most important factors influencing nitrification potential in many environments, including soils. There are two mechanisms by which drought can affect soil nitrifier populations – cytoplasmic dehydration and substrate limitation (Stark and Firestone, 1995). In the case of cytoplasmic dehydration, lower water availability in the soil can inhibit microbial activity through physiological effects of the drought on the soil microbes (Stark and Firestone, 1995). When soil environments become dry, the soil solution becomes more concentrated. Soil microbes aim to have intracellular solute concentrations that are slightly higher than the extracellular solute concentrations. In response to this need, soil microorganisms increase their intracellular solute concentrations by either producing their own organic solutes or taking up ions from the extracellular solution (Stark and Firestone, 1995). High solute concentrations within the cells of soil microorganisms inhibit enzyme activity, reduce the degree of hydration of the enzymes, and thus cytoplasmic dehydration ensues (Stark and Firestone, 1995).

The second way that drought can influence soil nitrifier populations is through limiting substrate availability (Stark and Firestone, 1995). When soils experience drought conditions, the pores within soil matrices drain and the water films coating the surface of soil matrices become thinner. This complicates the path that substrate molecules follow, and the rate of substrate diffusion to the soil microorganisms declines (Stark and Firestone, 1995).

Drought can also create differential effects on the two different types of soil nitrifiers, AOA and AOB. AOB is more sensitive to drought than other types of bacteria

are, and AOA is typically more tolerant to drought conditions than AOB (Stark and Firestone 1995).

Chapter 2

Research Questions and Hypotheses

In soil ecosystems, there is vast importance in the dynamics of soil nitrifiers, the environmental effects of climate change, and the expansion of cover crops as a tool for nutrient management. Despite the importance of these subjects, there is a lack of information that links their effects. Therefore, we set out to learn about the effects these subjects and their various interactions would have on soil nitrification potential. This study was completed in two separate phases: a field study phase and a laboratory study phase. Unexpected results in the field study phase presented the opportunity to create the second laboratory phase. The first three objectives and hypotheses align with the field portion of the study, while the second three objectives and hypotheses align with laboratory portion of the study.

Field Study:

Objective 1. To determine if the presence of a cover crop species or mixture of species has an effect on the soil nitrification rate as compared to the nitrification rate of soil left fallow.

Hypothesis 1. I hypothesized that plots with cover crop treatments will support higher soil nitrification potentials. This is hypothesized because plots of soil with cover crop treatments will contain residue from the cover crop treatments, and the

decomposition of the cover crop residue will mineralize N, producing ammonium, a key substrate for nitrification. The increased substrate will lead to an increased nitrification potential in the experimental plots with cover crop treatments as opposed to the fallow plots.

Objective 2. To assess the soil nitrification rate in drought-induced soils as compared to control soils and examine the rates for any present trends.

Hypothesis 2. I hypothesized that the drought subplots with rain exclusion shelters installed will have soils with suppressed nitrification potential as compared to soils in the control plots. Drought conditions often affect soil nitrifier bacteria by causing cytoplasmic dehydration within the cells and also by limiting substrate (Stark and Firestone 1995). These two impacts will likely cause suppressed soil nitrification potential in the drought plots as compared to the control plots.

Objective 3. To understand if cover crop treatments will buffer the effects of drought on soil nitrification potential.

Hypothesis 3. I hypothesized that cover crop treatments would act as a buffer against some of the suppression of nitrification brought about by drought. Although drought conditions reduce substrate availability to microbial populations (Stark and Firestone 1995), I hypothesized that the additional substrate in the plots with cover crop treatments would help make up for some of the drought-limited substrate availability.

Laboratory Study:

Objective 4. To further explore the impact of drought and cover crop treatments on soil nitrification rate by using a more controlled environment to isolate the effects I was interested in.

Hypothesis 4. For the same rationale as above, I hypothesized that the soils that experience a longer induced drought period will exhibit suppressed nitrification potential as compared to soils that experience a shorter induced drought period. Based on field study data, it is hypothesized that non-legume cover crop treatments will exhibit suppressed nitrification potential as compared to legume cover crop treatments and the no cover crop control.

Objective 5. To further explore the interaction between cover crop treatments and drought to better understand if the cover crop treatments act as a buffer to the drought conditions.

Hypothesis 5. Based on the results of the drought study, I hypothesized that some of the cover crop treatments would act as a buffer against drought. I hypothesized that relative to the controls, the decline in nitrification in the drought treatment would be less in the field pea monoculture than in rye and canola monocultures.

Objective 6. To understand how drought and cover crops affect the two different kinds of nitrifier populations, ammonia-oxidizing Archaea (AOA) and ammonia-oxidizing bacteria (AOB), and their ability to function.

Hypothesis 6. The soils in the laboratory portion of the study will most likely have high amounts of NO_3^-, since they will have cover crop organic residue mixed in and decomposing within the soil. It has been shown that in soils with high N loads, the

nitrification potential is determined much more by populations of AOB rather than AOA (Jie Di et. al 2010). For this reason, I hypothesized that the ratio of AOA to AOB would see larger variations in soils with cover crop treatments, which add N to the system.

Chapter 3

Methods

3.1 Field Study Soil Sampling and Experimental Design

This study is nested in a long-term cover crop diversity experiment established at the Russell E. Larson Research and Education Center at Rock Springs, PA in 2012. In July, 2013 researchers installed rain exclusion shelters to induce drought conditions in a corn crop grown after several cover crop treatments. The rain exclusion shelters were added to sub-plots within the larger cover crop treatment plots and each paired with a designated control sub-plot. Researchers from the long-term cover crop diversity experiment sampled soil from both control and rain exclusion sub-plots eight weeks after the rain shelters were installed. Four cores to a 20 cm depth were collected from each sub-plot, homogenized, and stored at 4^{o}C until further processing. Aseptic procedures were followed in the field and lab to avoid contamination between samples.

The larger cover crop diversity experiment is a randomized complete block design with four replications in which twelve cover crop diversity treatments are embedded in a rotation of corn (*Zea mays*), soybean (*Glycine max*), and wheat (*Triticum aestivum*). The following five cover crop treatments preceding corn were used in this experiment: 1) No cover crop control, 2) Red clover monoculture (*Trifolium pretense*), 3) Cereal rye monoculture (*Secale cereale*), 4) Canola monoculture, and 5) N management 3-sprecies

Figure 2. Diagram of the experimental design of the field study.

mixture: red clover, Austrian winter pea, and cereal rye.

3.2 Analysis of Field Study Samples

The field study soil samples were initially analyzed for gravimetric water content (GWC) and concentrations of inorganic N. Subsamples of approximately 10 grams of soil were weighed into tins and then dried in an oven at a temperature of 105^{oC} for at least 24 hours to obtain the dry weight of the soil. From the wet and dry soil weights, the gravimetric water content (water wt/oven dry soil wt) for each soil sample was calculated. Additionally, subsamples of approximately 20 grams of soil were weighed into specimen cups, extracted in 100ml of 2M KCl, and shaken for an hour to be analyzed for inorganic N. Then, the samples were filtered through Whatman 1 filter paper and extracts were stored in vials and frozen until they were analyzed for NH_4^+ and NO_3^- (Sims et. al 1995, Doane and Horwáth 2003). The table with this soil sampling information as well as concentrations of inorganic N can be found in Appendix A.

The soil samples were analyzed for nitrification potential using the Shaken Soil-Slurry Method (Hart et. al 1994). Using this method, nitrification potential can be measured when nitrifier populations are exposed to non-limiting conditions of substrate and O_2 (Hart et. al 1994). Subsamples of about 15 grams of soil were weighed into specimen cups and 100 ml of a solution containing KH_2PO_4 (potassium monobasic phosphate) K_2HPO_4 (potassium dibasic phosphate) and $(NH_4)_2SO_4$ (ammonium sulfate) added to the soil subsamples (Hart et. al 1994). This created a soil-slurry solution that was then shaken for 24 hours. During the 24-hour time period, the soil-slurry solution

was sampled from at four different time periods (Hart et. al 1994). The ideal times are 2, 4, 22, and 24 hours into the shaking procedure. Since these are optimal, they were the sampling times used in this study. Samples were centrifuged at 7,500 rpm for 8 minutes (Hart et. al 1994) and then pipetted into scintillation vials, in which they were frozen until they were analyzed for NO_3^- concentrations. Soil samples were analyzed for NO_3^- concentrations at the four different sampling time periods using the vanadium (III) chloride method (Doane and Horwáth 2003) and the microplate reader. Nitrification potential was determined by taking a linear regression of the NO_3^- concentrations from the four different sampling times. The slope of the linear regression was taken to be the rate (see Appendix B for regression equations).

3.3 Laboratory/Greenhouse Study Experimental Design

Soils for the laboratory portion of the experiment were also taken from the Russell Larson Research and Education Center at Rock Springs, PA. Soil was added to twelve 6-inch pots that would contain six different cover crop treatments, and the pots of soil were placed in a greenhouse in the Agricultural Sciences and Industries Building on the Penn State campus. The soils were watered in the pots for one week before planting to restimulate any microbial communities that may have been hindered while the soil was left to partially dry. Cover crops were planted a week after the pots of soil were first watered. The following six cover crop treatments were used in this experiment: 1) no cover crop control, 2) cowpea monoculture, 3) field pea monoculture, 4) barley monoculture, 5) cereal rye monoculture, 6) canola monoculture. Two of each of the

grasses and legumes were planted with the intention of using whichever grew most successfully in the experiment. The cover crops were then left to grow for about six weeks and watered regularly. There were no fertilizer or nutrient treatments added to the soil, but the legumes were inoculated.

Immediately following the six-week growth period, the cover crop aboveground biomass was cut and the wet weights were taken. Samples of each cover crop treatment were taken and dried to obtain the dry weight. The amount of sample taken to determine the dry weight was based upon how much aboveground biomass of the cover crop was present. Tables with the recorded wet and dry weights of the different cover crop treatments can be found in Appendix C. The remaining cover crop aboveground biomass was cut into small pieces (around ½ inch) and mixed into the soil it had been grown in. The roots were mixed into the soil as well. The mixture of soil, cover crop clippings, and roots were incubated in plastic bags for two weeks. The incubation process allowed the cover crop clippings to simulate the effect of cover crop residue that was seen in the field as much as possible given the allotted time and scope of the experiment.

Following the incubation period, soil samples were separated into specimen cups (15 grams for samples that would be analyzed for nitrificaiton potential and 20 grams for samples that would be analyzed for inorganic N) based upon cover crop treatment, what type of analysis they would receive, and how long they would undergo an induced drought. The cover crop treatments used were 1) no cover crop control, 2) field pea monoculture, 3) cereal rye monoculture, and 4) canola monoculture. The cowpea monoculture was not used in the final portion of the experiment because it did not produce as much aboveground biomass as the field pea treatment. The cereal rye

monoculture was used as opposed to the barley in order to replicate the field study as accurately as possible. Subsamples of about 10 grams of soil were weighed into tins and dried in an oven to determine initial GWC for each cover crop treatment (Appendix D). Analyses were completed to determine 1) inorganic N, 2) nitrification potential with contributions from both AOA and AOB, and 3) nitrification potential with a knockout chemical (C_8) to suppress nitrification contributions of AOB (Taylor et. al 2013). Half of the soil samples underwent a one-week drought period, while the other half of the soil samples underwent a two-week drought period prior to being analyzed. These three analyses were done twice, the first after one week of drought and the second after two weeks of drought, with four replicates for each cover crop treatment.

In addition to the soils that were sampled for inorganic N during week one and week two of the drought, soil samples were also distributed into specimen cups to be analyzed for inorganic N throughout the two-week drought process. This was done to gain a better understanding of soil inorganic N concentrations as soils dried. Soils were destructively sampled periodically for inorganic N at the following times after beginning the drought process: 0 days, 3 days, 6 days, and 9 days.

3.4 Analysis of Laboratory Samples

Inorganic N analysis in this portion of the study was completed identically to the inorganic N analysis of the field samples. When analyzing inorganic N and nitrification potential simultaneously, the hour-long inorganic N shake began at the same time as the 24-hour shake. When analyzing the periodic inorganic N samples, there was no time

constraint to beginning the shaking process. Inorganic N samples were analyzed for NH_4^+ and NO_3^- concentrations using the microplate reader.

The main difference between the analysis of the samples from the two study phases was in the addition of the knockout chemical, C_8 (1-octyne), to inhibit nitrification by AOB. One day prior to the conclusion of the one-week and two-week drought periods, all of the soil samples for the three different analyses (inorganic N, nitrification potential with C_8, nitrification potential without C_8) received aliquots of water to bring them back to 60% of their water holding capacity (WHC). This step was necessary so that the C_8 would be able to diffuse through the soil samples that were receiving the knockout chemical. 40 µl of C_8 was then added to the appropriate samples and the specimen cups were capped immediately. All of the cups of soil were then capped overnight and analyzed the following morning.

Soil samples were analyzed for nitrification potential once again using the 24-hour Shaken Soil-Slurry Method. The soil-slurries both with and without the C_8 addition were analyzed and sampled identically over the 24-hour shake. Samples were taken at the ideal times as referenced in the protocol (Hart et. al 1994): 2, 4, 22, and 24 hours into the shaking process. Soil samples were analyzed for NO_3^- concentrations at the four different sampling time periods using the vanadium (III) chloride method and the microplate reader. Nitrification potential was determined by taking a linear regression of the NO_3^- concentrations from the four different sampling times.

3.5 Statistical Analysis

To test for differences in nitrification potential rates in both the field and laboratory study, we used SAS Statistical Analysis Software. Prior to beginning each analysis, we used proc univariate to assess the normality of the data. The data were normally distributed with non-significant Shapiro-Wilk Test p-values ($p= 0.17$ and $p=0.53$ for nitrification potential in the field and laboratory study, respectively). We used proc mixed on the field study data to determine the significance of the cover crop treatments, drought conditions, and the their interaction and included a random block effect. The Fisher's LSD value of $p<0.05$ was used to determine the significance of the treatments and interactions. A repeated measures analysis was done on the laboratory samples to determine the significance of the cover crop treatments and the length of drought period, and their the interaction in proc mixed. In the statistical analysis of the treatments in the laboratory study, only the samples that did not receive the C_8 knockout chemical were included. The reasoning behind this decision is further discussed in the following results section (Chapter 4.6).

Chapter 4

Results

4.1 Field Study: Inorganic N

NO_3^- concentrations following the eight-week drought differed across cover crop treatments and between drought and non-drought subplots (Figure 3). The non-drought plots for all cover crop treatments had smaller average NO_3^- concentrations than the drought plots. The red clover monoculture, the 3-species N-management mixture, and the fallow plots saw the highest average NO_3^- concentrations in their respective drought plots (0.90-0.98 mg kg^{-1}). While the average NO_3^- concentrations for the non-drought plots were consistently low, the lowest average NO_3^- concentration was seen in the fallow plots (0.10 $\pm$ 1 SE mg kg-1), which is interesting because the fallow plots exhibited the highest average NO_3^- concentration in the drought samples.

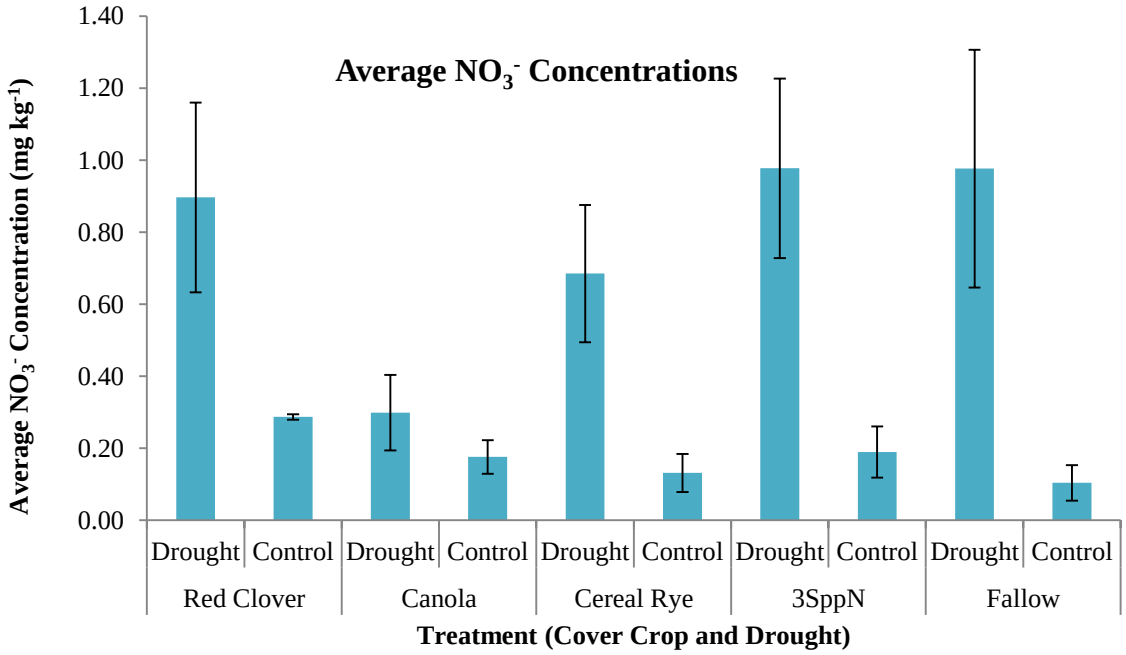


Figure 3. Average inorganic NO_3^- concentrations separated by cover crop treatment and drought and control subplots. Error bars represent plus/minus one standard error of the mean.

NH_4^+ concentrations were higher than the NO_3^- concentrations in the soil samples (Figure 4). All of the average NH_4^+ samples for cover crops in the drought and control plots were above 0.9 mg kg^{-1}. The average concentrations of NH_4^+ in the drought subplots tended to be higher than those in the control plots.

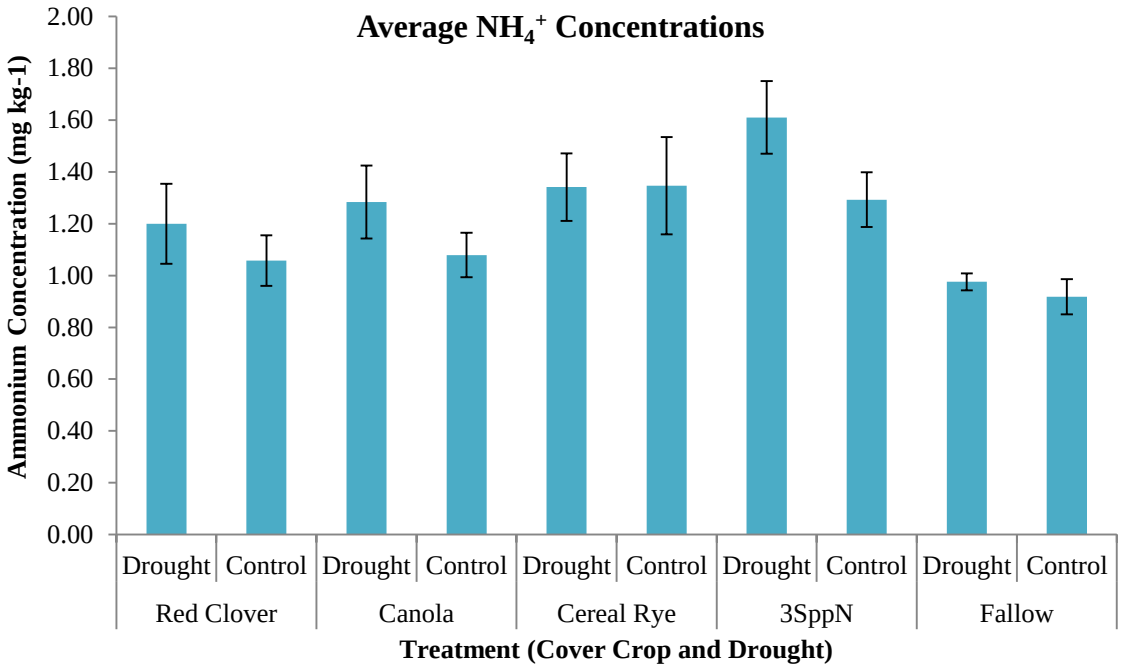


Figure 4. Average inorganic NH4+ concentrations separated by cover crop treatment and drought and control subplots. Error bars represent plus/minus one standard error of the mean.

4.2 Field Study: Cover Crop Effects on Nitrification Potential

Cover crop treatments did not have a significant effect on nitrification potential ($p=0.32$). There were, however, trends present. Non-legume cover crop monocultures (cereal rye, canola) tended to have lower nitrification potentials (12.2 $\pm$ 1 SE and 13.3 $\pm$ 1 SE mg kg^{-1} d^{-1}, respectively) than the red clover monoculture (14.2 $\pm$ 1 SE mg kg^{-1} d^{-1}), the cover crop mixture (15.1 $\pm$ 1 SE mg kg^{-1} d-1), and the fallow plots (15.1 $\pm$ 1 SE mg kg^{-1} d^{-1}) (Figure 5). A plot of average NO_3^- concentration for each cover crop treatment over the 24-hour shaken soil-slurry, with samples taken at hours 2,4,22, and 24, can be found in Appendix B. This plot also has a linear regression for each cover crop treatment, the slope of which is the nitrification potential.

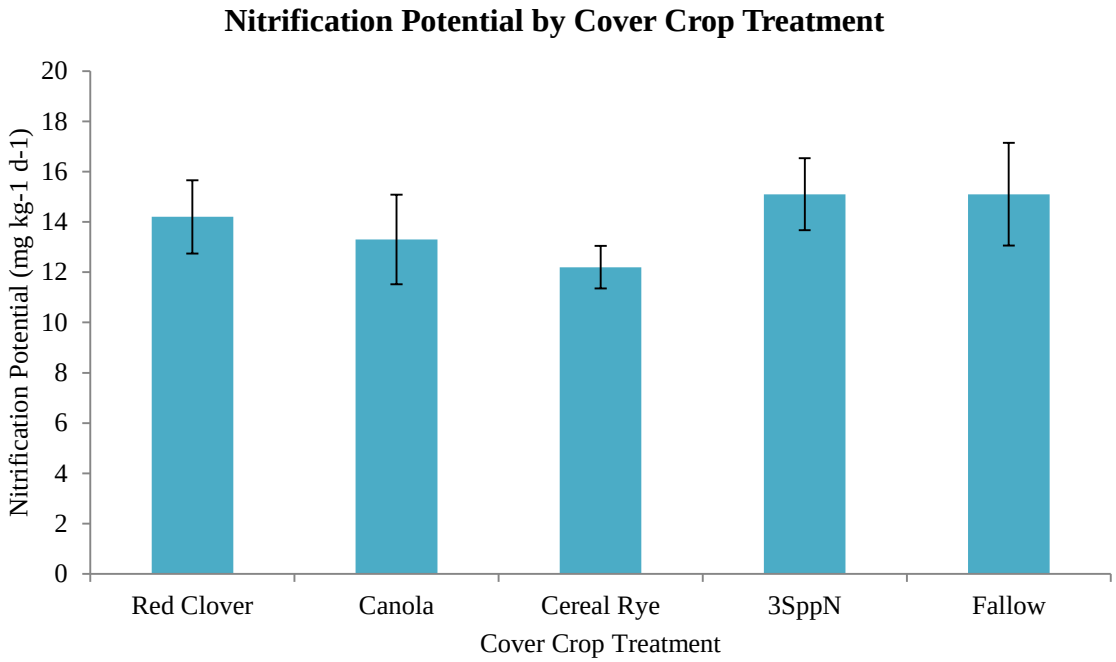


Figure 5. Plot of nitrification potential in mg kg^{-1} d^{-1} by cover crop treatment. Error bars represent plus/minus one standard error of the mean.

4.3 Field Study: Drought Treatment Effects on Nitrification Potential

Nitrification potential was not different in drought and non-drought sub-plots ($p=0.90$). The average nitrification potential for the drought treatment and the control were 14.1 $\pm$ 1 SE mg kg^{-1} d^{-1} and 13.8 $\pm$ 1 SE mg kg^{-1} d^{-1}, respectively (Figure 6). A plot of average NO_3^- concentrations in the drought and non-drought soils throughout the 24-hour shaken soil-slurry can also be seen in Appendix B.

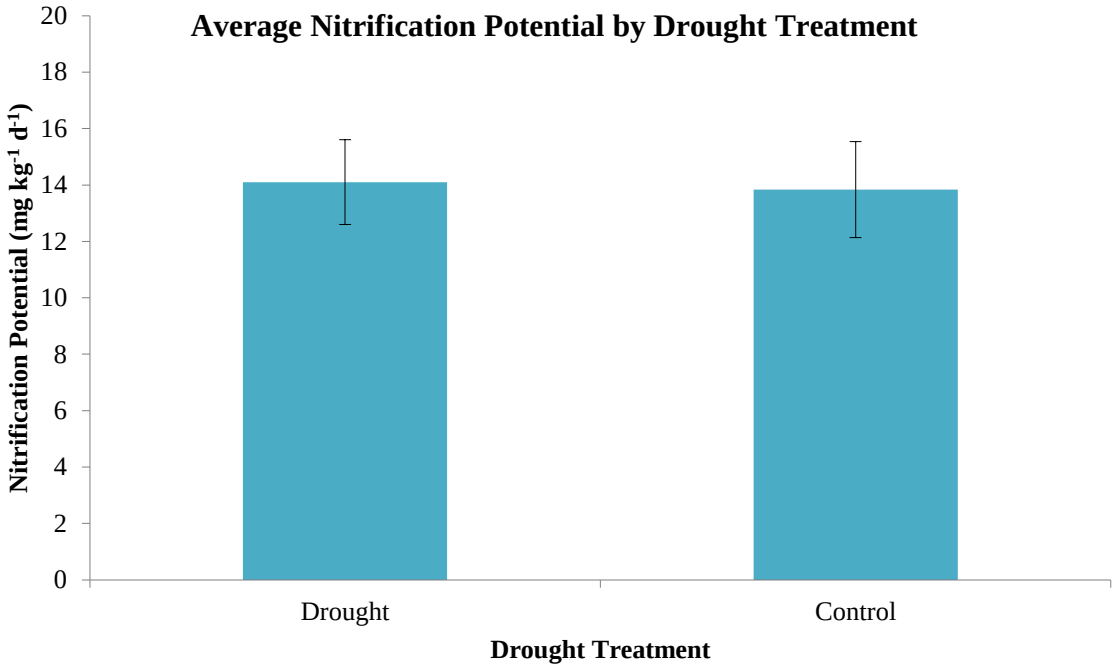


Figure 6. Plot of nitrification potential in mg kg^{-1} d^{-1} by drought treatment. Error bars represent plus/minus one standard error of the mean.

The full table of NO_3^- concentrations and nitrification potentials collected for each soil sample during the 24-hour shaken soil-slurry can be seen in Appendix B.

4.4 Field Study: Interaction between Cover Crops and Drought

One of the main objectives of the field study was to gain an understanding of how the interaction between cover crop treatments and drought affected soil nitrification potential, but the results indicated that there was no interaction ($p=0.92$). The average nitrification potential for drought and non-drought samples was similar for each of the cover crop treatments, and there was no consistent trend of all the drought samples being higher, or all the non-drought samples being higher within each cover crop treatment (Figure 7). The non-drought fallow plots exhibited the highest average nitrification potential (15.5 ± 1 SE mg kg^{-1} d^{-1}) followed closely by the non-drought 3SppN plots (15.4 ± 1 SE mg kg^{-1} d^{-1}). The non-drought cereal rye monoculture plots exhibited the lowest average nitrification potential (11.9 ± 1 SE mg kg^{-1} d^{-1}) followed by the drought-induced cereal rye monoculture plots (12.5 ± 1 SE mg kg^{-1} d^{-1}).

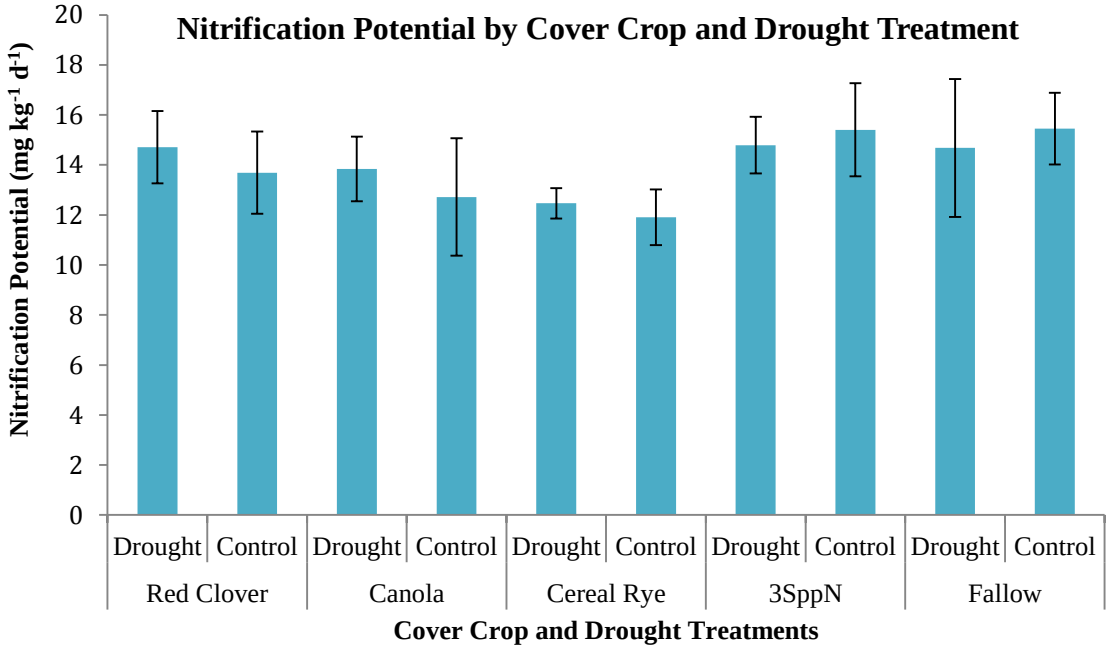


Figure 7. Plot of nitrification potential in mg kg^{-1} d^{-1} by cover crop and drought treatments. Error bars represent plus/minus one standard error of the mean.

4.5 Laboratory Study: Inorganic N

There were several trends in the average NO_3^- and NH_4^+ concentrations in each cover crop treatment over the one week and two week drought periods (Figure 8, Figure 9). The average NO_3^- concentrations for each cover crop treatment appeared to slightly decease between one week and two weeks of drought, with the exception of the control plots (Figure 8). The field pea soils exhibited the highest average NO_3^- concentration after the first week of drought (102.5 $\pm$ 1 SE mg kg^{-1}), while after the second week of drought, the control soils exhibited the highest average NO_3^- concentration (99.1 $\pm$ 1 SE mg kg^{-1}). The cereal rye exhibited the lowest average NO_3^- concentration after both the first and second weeks of drought (69.7 and 66.3 $\pm$ 1 SE mg kg^{-1}, respectively).

Throughout both the one and two week drought periods, cereal rye and canola treatments tended to have lower average NO_3^- concentrations than the field pea treatment and the no cover crop control.

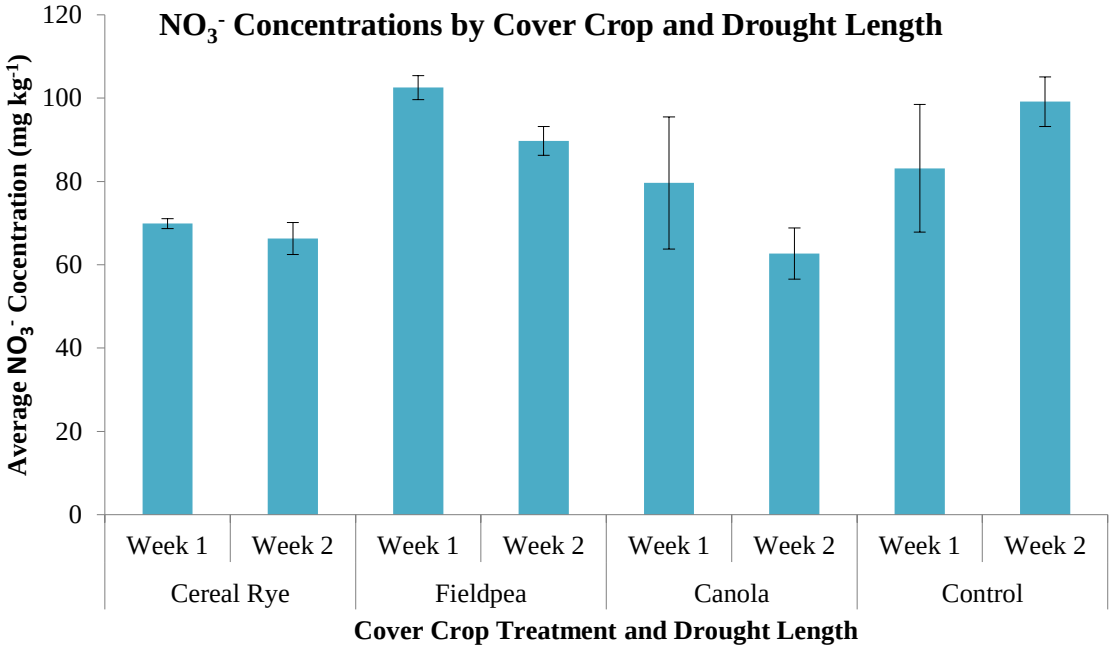


Figure 8. Average inorganic NO_3^- concentrations by cover crop treatment and length of drought. Error bars represent plus/minus one standard error of the mean.

In contrast to the average NO_3^- concentrations, the average concentrations of NH_4^+ increased slightly for all of the cover crop treatments between the first week of drought and the second week of drought (Figure 9). The canola and no cover crop control plots had lower ranges of average NH_4^+ concentration after the first week of drought than the cereal rye and field pea (0.90-0.91 mg kg^{-1} and 1.2-1.3 mg kg^{-1}, respectively). After the second week of drought, the average NH_4^+ concentrations were fairly consistent across all cover crop treatments, ranging from 1.3-1.4 mg kg^{-1}).

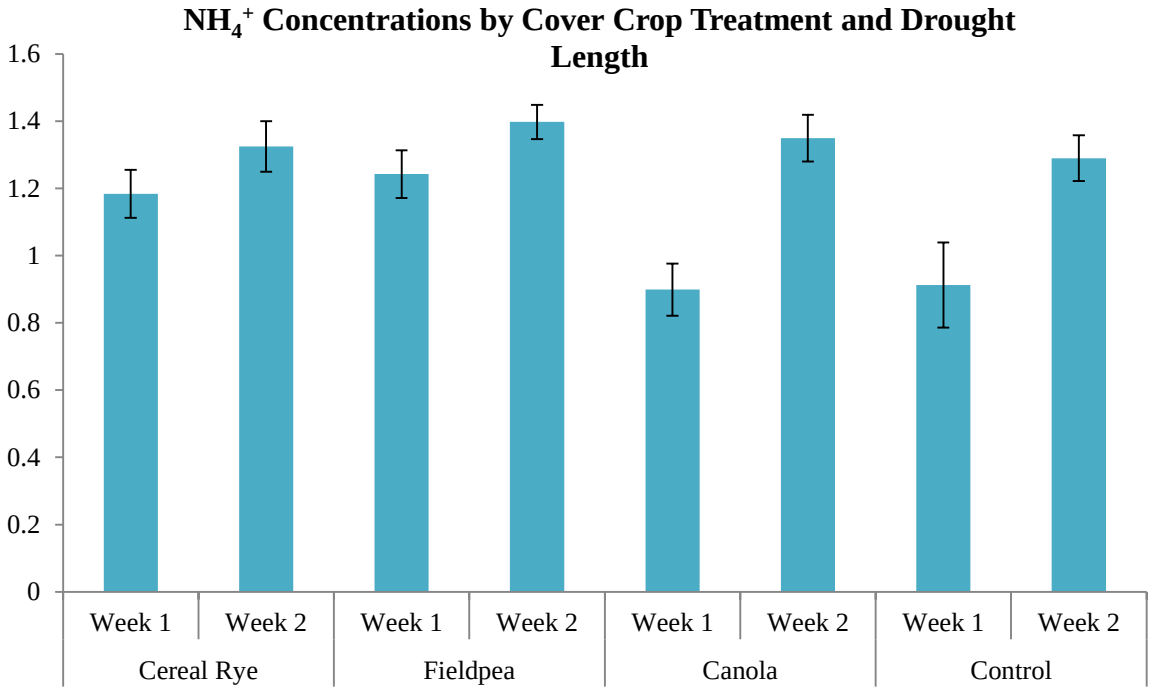


Figure 9. Average inorganic NH4+ concentrations by cover crop treatment and length of drought. Error bars represent plus/minus one standard error of the mean.

NH_4^+ and NO_3^- samples were also collected at several different sampling dates throughout the drought period to get a better picture of how these concentrations were changing. Changes in average inorganic NO_3^-, inorganic NH_4^+, and total inorganic N over four sampling dates throughout the drought period were separated by cover crop (Figures 10-13). The NH_4^+ concentrations stayed relatively consistent and were similar across all cover crop treatments. The control samples contained higher values of NO_3^- than the samples treated with cover crops.

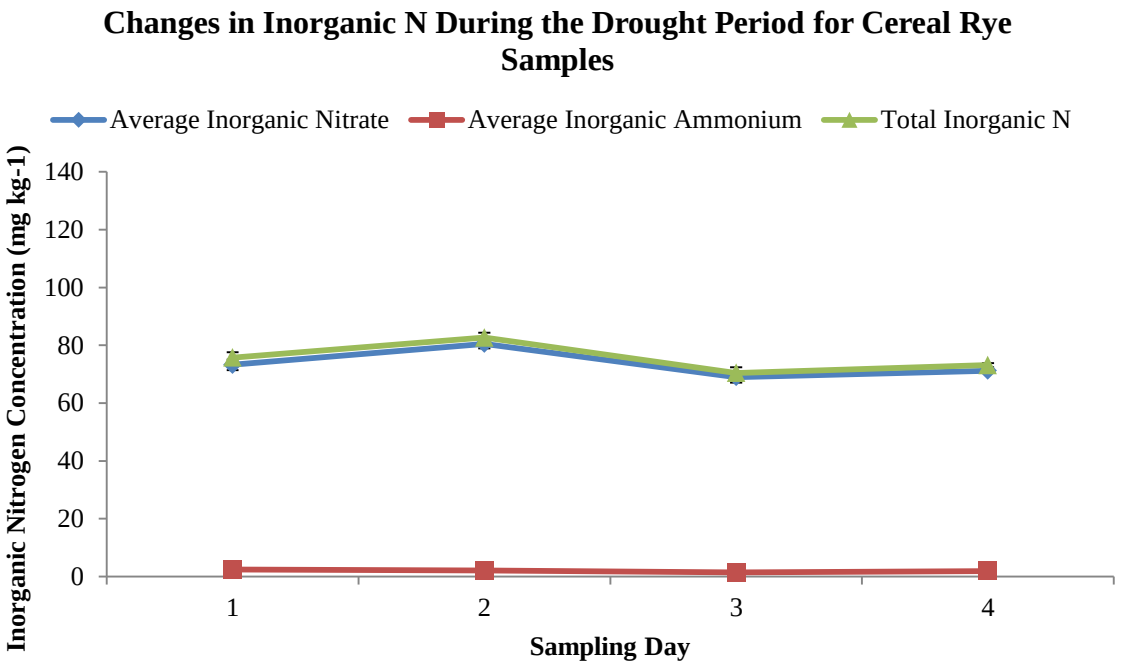


Figure 10. Changes in inorganic N concentrations in cereal rye samples during four sampling days throughout the two week drought period. Error bars represent plus/minus one standard error of the mean.

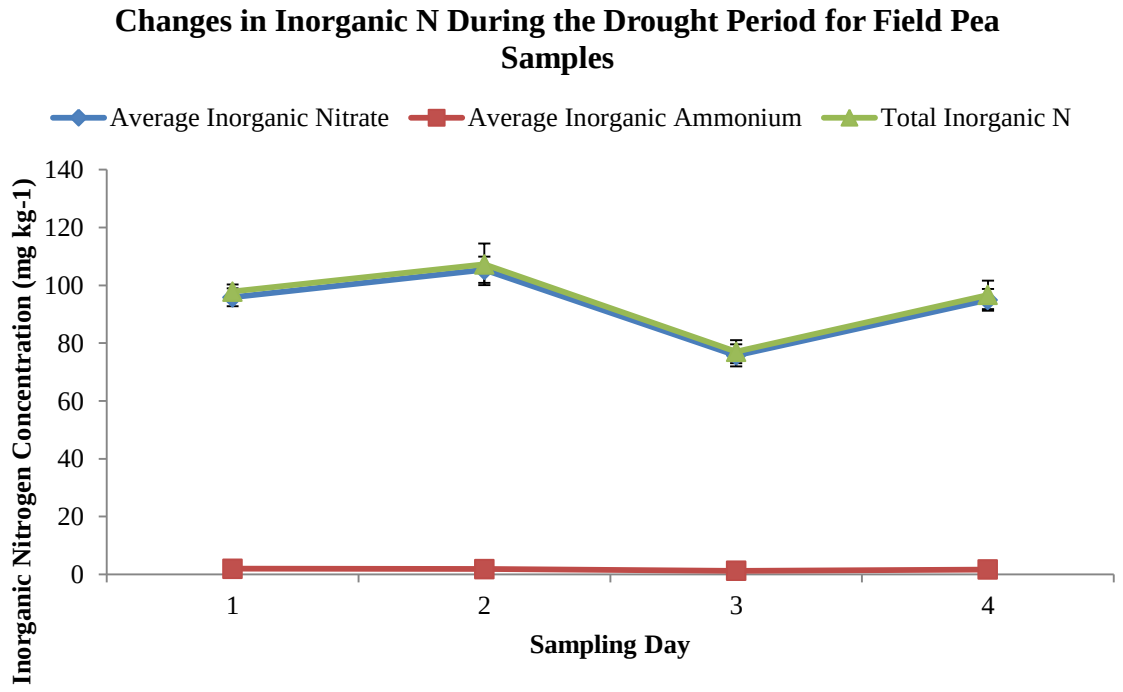


Figure 11. Changes in inorganic N concentrations in field pea samples during four sampling days throughout the two week drought period. Error bars represent plus/minus one standard error of the mean.

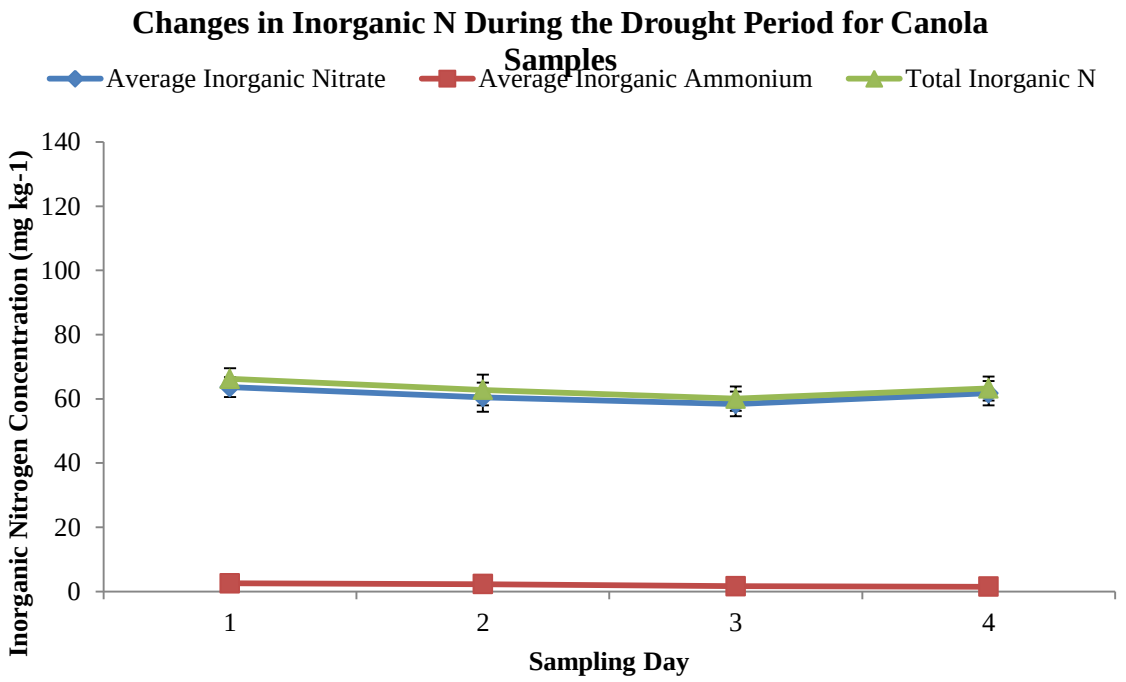


Figure 12. Changes in inorganic N concentrations in canola samples during four sampling days throughout the two week drought period. Error bars represent plus/minus one standard error of the mean.

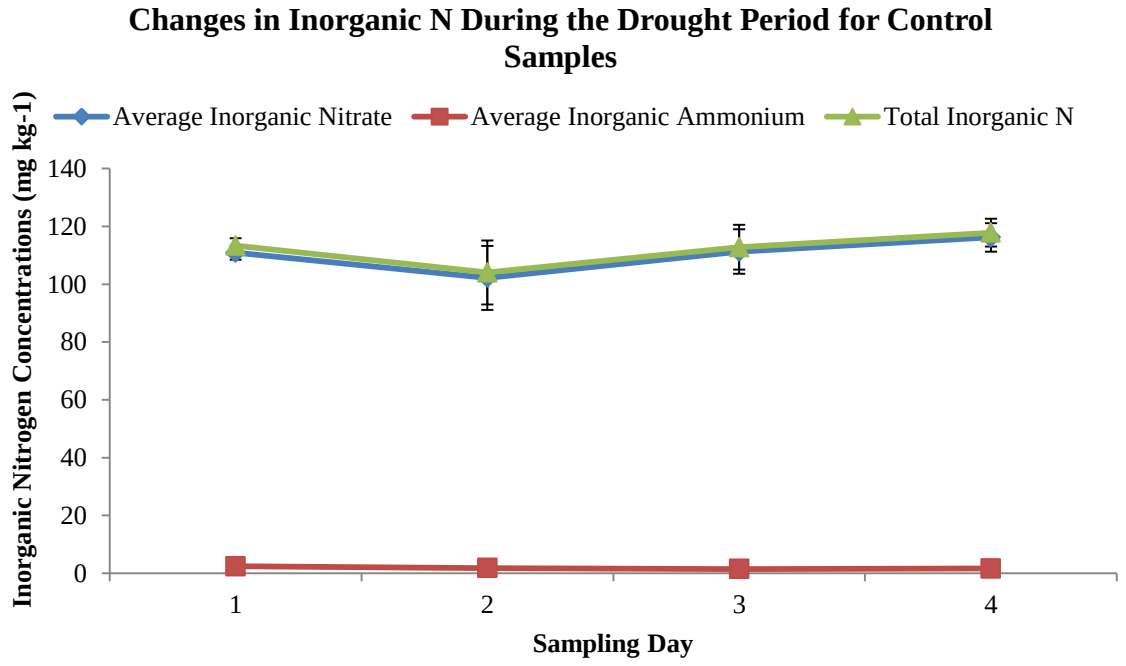


Figure 13. Changes in inorganic N concentrations in control samples during four sampling days throughout the two week drought period. Error bars represent plus/minus one standard error of the mean.

4.6 Laboratory Study: Soil Nitrifier Communities

After the first week of drought, average nitrification potential appeared as negative values for all soils that were treated with the knockout chemical, C_8, to suppress nitrification by soil ammonia-oxidizing bacteria (AOB) (Figure 14). These values were simplified to assume that there was no contribution to nitrification potential by soil ammonia-oxidizing archaea (AOA). All of the soils treated with the knockout chemical exhibited negative nitrification potentials, regardless of cover crop treatments or drought length. There was a trend present across all cover crop treatments in which the nitrification potential became more negative after two weeks of drought than after one week of drought (Figure 15). After both the first and second weeks of drought, the field pea treatment exhibited the most negative nitrification potential (-6.6 ± 1 SE mg kg^{-1} d^{-1} and -8.6 ± 1 SE mg kg^{-1} d^{-1}, respectively), while the control plots exhibited the least negative values for nitrification potential after both one and two weeks of drought treatment ($-3.5 \pm$ SE mg kg^{-1} d^{-1} and -5 ± 1 SE mg kg^{-1} d^{-1}, respectively).

Statistical analysis on the significance of average nitrification potential of the different soil nitrifier communities were not run due to the fact that archaea appeared to have no contribution to soil nitrification potential. Only soil samples that were not treated with C_8 were included in the statistical analysis for the laboratory study.

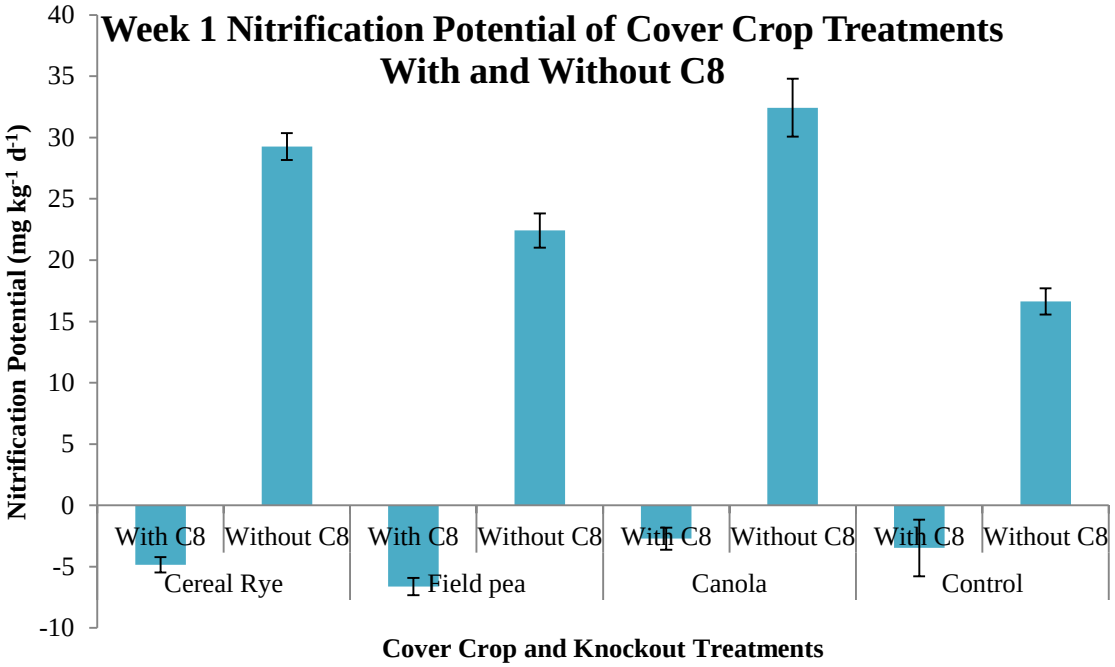


Figure 14. Average nitrification potential in mg kg^{-1} d^{-1} by cover crop and knockout treatments after one week of drought. Error bars represent plus/minus one standard error of the mean.

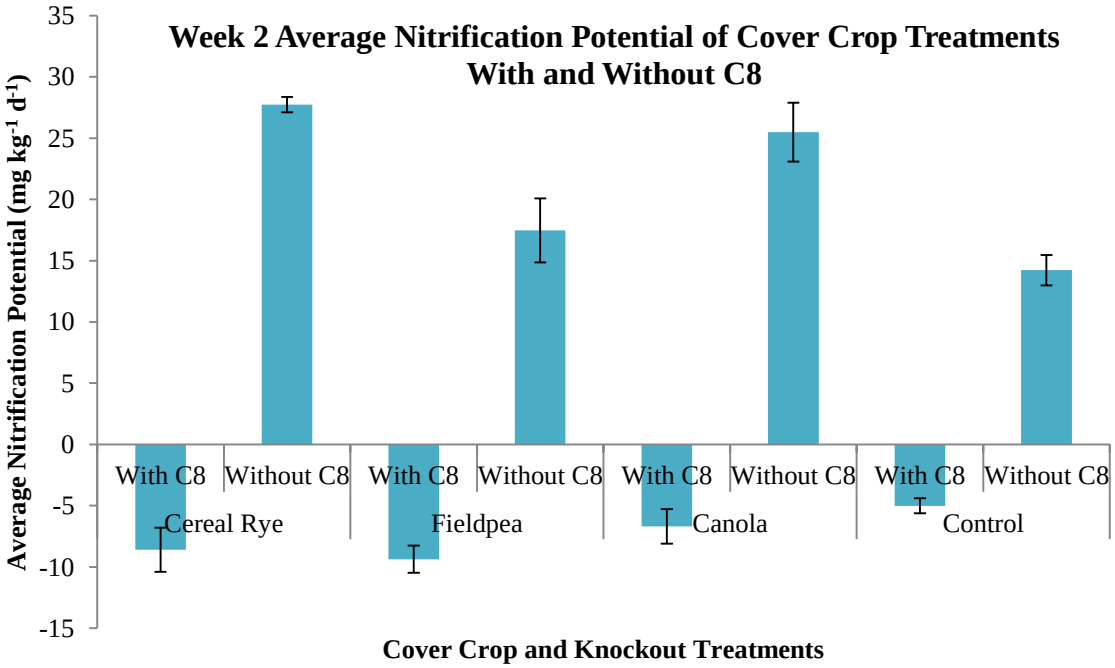


Figure 15. Average nitrification potential in mg kg-1 d-1 by cover crop and knockout treatments after two weeks of drought. Error bars represent plus/minus one standard error of the mean.

4.7 Laboratory Study: Cover Crop Treatments and Drought Length

Both the period of drought length and the cover crop treatments created a significant difference in the nitrification potentials of the soils in this study ($p = 0.008$ and $p = 0.03$, respectively), but their interaction was not significant ($p = 0.5$).

A decrease in average nitrification potential from week one to week two was seen across the board in all of the cover crop treatments, as well (Figure 16). After the first week of drought, the canola cover crop treatment exhibited the highest nitrification potential ($32.4 \pm$ SE mg kg^{-1} d^{-1}) while the no cover crop control exhibited the lowest nitrification potential ($16.6 \pm$ SE mg kg^{-1} d^{-1}). After the second week of drought, the cereal rye exhibited the highest rate of nitrification potential ($29.3 \pm$ SE mg kg^{-1} d^{-1}), and the no cover crop control samples continued to exhibit the lowest average nitrification potential ($14.2 \pm$ SE mg kg^{-1} d^{-1}). There wasn't a significant difference in the average nitrification potential between the cereal rye and cover crop treatments, but the rest of the treatments were significantly different in average nitrification potential.

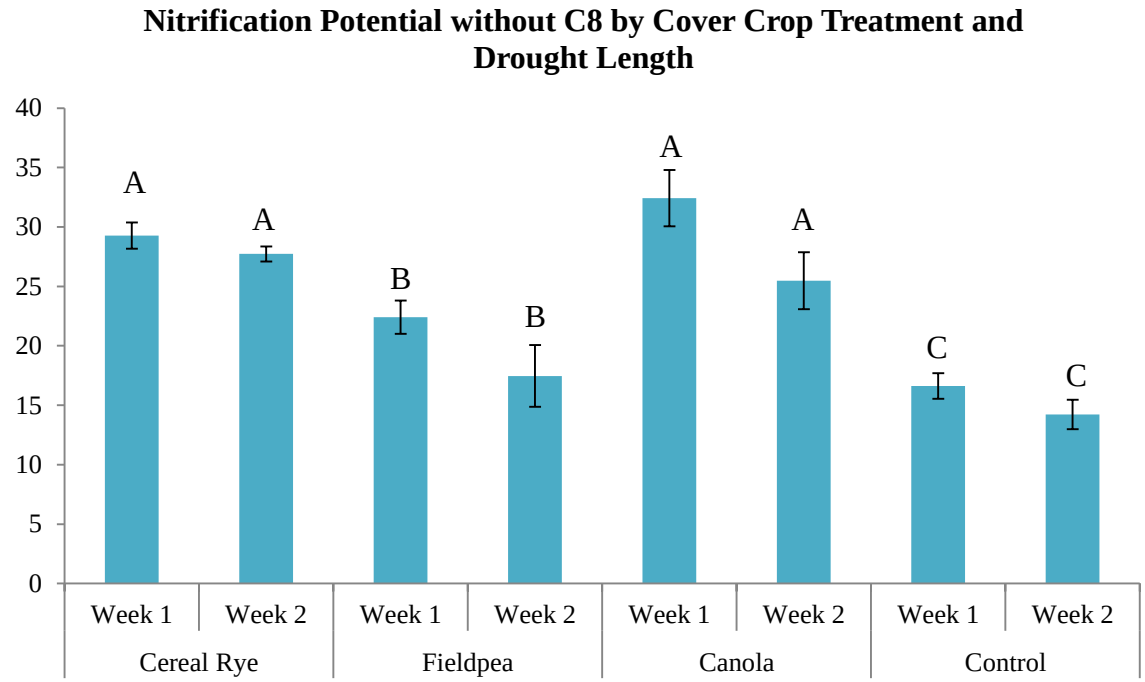


Figure 16. Average nitrification potential by cover crop treatment and drought length of samples without C8. Error bars represent plus/minus one standard error of the mean. The letters differentiate significant differences by cover crop treatment within each drought period.

While all of the samples exhibited a depressed nitrification potential after two weeks of drought as compared to after the first week of drought, the amounts by which the nitrification potential decreased varied by cover crop treatment (Figure 17). The slopes of the lines for each cover crop treatment exhibit the degree to which the average nitrification potential changed from week one of drought to week two of drought. The canola treatment experienced the largest change in nitrification potential, while the cereal rye experienced the smallest change, but there was not a significant interaction between cover crop and drought length ($p=0.5$).

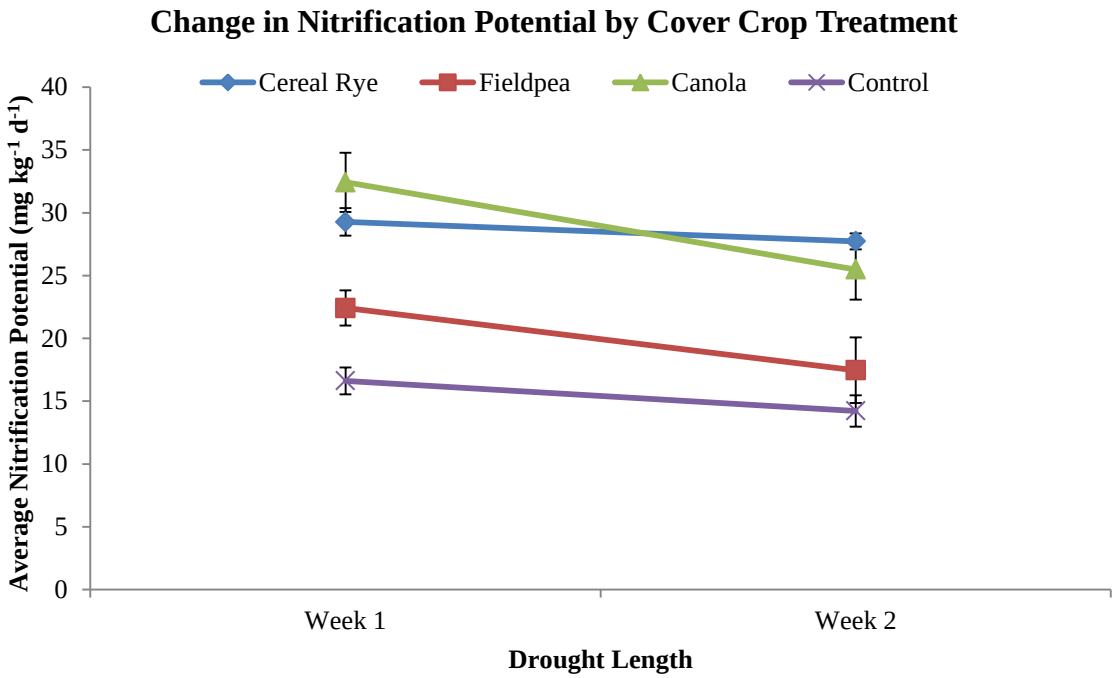


Figure 17. Change in average nitrification potential between one week and two weeks of drought for each cover crop treatment.

Chapter 5

Discussion

5.1 Field Study: Cover Crop Treatments

I hypothesized that cover crop treatments would exhibit higher nitrification potential than the fallow control because I believed the cover crop organic matter would support soil nitrifier communities. My results, however, showed the opposite trend; fallow plots and the N-management three species mixture had the highest average nitrification potential (15.1 $\pm$ SE mg kg^{-1} d^{-1} for both treatments). The treatments that tended to have the lowest nitrification potential were the two non-legume monoculture cover crop treatments, cereal rye (12.2 $\pm$ SE mg kg^{-1} d^{-1}) and canola (13.3 $\pm$ SE mg kg^{-1} d^{-1}). These results indicate that cover crops may be a potential tool to suppress nitrification rates and mitigate N losses from agricultural systems. These results also support the theory that some organic matter from cover crop treatments may support soil heterotrophic bacteria rather than soil nitfiers, thus suppressing the soil nitrification potential. From the trends seen in the field experiment data, it is now a question as to why some cover crops had no impact on nitrification potential relative to the control while others suppressed nitrification potential.

5.2 Field Study: Drought Treatment

Based on previous research, I hypothesized that drought conditions in the field study would suppress nitrification rates (Stark and Firestone 1995). We found no significant differences in nitrification potential in drought and non-drought soils. In fact, there was actually a slightly higher average nitrification potential seen in the drought samples in comparison to the non-drought samples. This probably occurred because at the time the soils were sampled, both the drought and non-drought plots of soil were very dry, and had relatively the same average gravimetric water content (0.08 and 0.10 for the drought and non-drought soils, respectively). The lack of difference between drought and non-drought soils in this study presented the opportunity to further explore the effects of drought on soil nitrification potential in a setting where environmental variables could be more efficiently isolated and managed.

5.3 Field Study: Interaction between Cover Crops and Drought

I hypothesized that there would be an interaction between the cover crop treatments and the drought and non-drought soils, assuming that the organic residue from some of the cover crop treatments would buffer the suppression of nitrification potential from the drought conditions. This interaction was not seen in the data, and I believe this occurred for the same reason that there was no significance between the drought and non-drought samples. Both the drought and non-drought samples contained relatively the same gravimetric water content at the time of sampling, so although there wasn't an interaction between drought and cover crop treatment present in this data, this probably

occurred because the soils that received the drought treatment and the non-drought soils both underwent a similar natural drought due to climactic conditions. The lack of significance in the data also presented an opportunity to further explore this interaction in a more controlled environment so that the drought could be isolated.

5.3 Laboratory Study: Soil Nitrifier Communities

I hypothesized that AOB would have a demonstrate a larger contribution to soil nitrification potential than AOA in the laboratory study. This was found to be true. The soil samples that were treated with the knockout chemical, C_8, to suppress all nitrification contributions of AOB, actually exhibited negative values for nitrification potential.

Negative nitrification values could occur for a variety of reasons. For purposes of analysis, I assumed the negative nitrification potentials to mean that there is no contribution to nitrification potential by AOA, NH_4^+-oxidizing archaea. This was unexpected, because although soils that are high in N tend to have the nitrification potential dynamics dominated by AOB (Jie Di et. al 2010), I expected that there would be some archaea signature. It was expected that there would be a larger influence on nitrification potential from AOB. For statistical analysis purposes, the nitrification potentials in soils that received the knockout chemical were approximated to be zero, but the results call to question why the samples actually exhibited negative nitrification potentials. The negative potentials could be an indicator that immobilization is occurring at a faster rate than mineralization due to a high microbial growth rate (Rathbone et. al 1998). The negative potentials could also indicate that denitrification is occurring more

rapidly than nitrification. This trend was interesting because it did not occur randomly; the average nitrification potentials were consistently negative for all the treatments that received the knockout chemical, and they became increasingly negative after two weeks of drought as compared to one week. This phenomenon would be an interesting topic for a future study.

5.4 Laboratory Study: Cover Crop Treatments, Drought Length, and Interactions between Cover Crops and Drought

In the laboratory phase of the study, the induced drought had the expected effects on the average nitrification potentials. For purposes of simplification, only the samples that did not receive the knockout chemical will be discussed in this section. All treatments experienced a reduction in nitrification potential between one week of drought and two weeks of drought. This was the behavior that I hypothesized, because drought conditions have been shown to suppress soil nitrification potential (Stark and Firestone 1995).

On the other hand, the average nitrification potentials of the cover crop treatments were not as I had hypothesized, and the cover crop treatment trends from the laboratory portion of the study were the opposite from what was seen in the field study. In the field study, the canola and cereal rye monocultures exhibited the smallest nitrification potential, while the fallow plots and the 3-species N-management mixture exhibited the largest nitrification potential. Based upon these results, I hypothesized that the canola and cereal rye would exhibit the smallest nitrification potential in the laboratory study, and the field pea, the legume, as well as the control would exhibit larger nitrification

potentials. The exact opposite was seen in the laboratory study, as the cereal rye and the canola exhibited similarly high nitrification potential (32.4 $\pm$ SE mg kg^{-1} d^{-1} for the canola treatment after week 1 of drought and 29.3 $\pm$ SE mg kg^{-1} d^{-1} for the cereal rye treatment after week 2 of drought). The average nitrification potential of the control samples was the smallest. The reason for these unexpected results may be due to the fact that this was done as a pot study, and because the different cover crop treatments produced varying amounts of biomass that were used in the incubation. Cereal rye and canola samples had more biomass mixed in than did the field pea samples, and for that reason may have supported more nitrifier activity, and thus higher nitrification potentials. Mass biomass for each cover crop treatment can be seen in Appendix C. Also, the field pea and the control soil samples had much higher starting concentrations of NO_3^- than the canola and the cereal rye samples. This could be an indicator that by the time the 24-hour shaken soil-slurry was completed, there was less substrate available for nitrification in the field pea and control plots because the starting NO_3^- concentrations were already high. Also, the field pea samples dried faster than the rest of the samples (see Appendix D for gravimetric water content). Since drought suppresses nitrification potential, the faster drying of the field pea samples could be a potential reason for the decreased nitrification potential.

5.5 Summary of Key Findings

There are many things that can be taken from this study and applied towards future research. The soil N cycle and the nitrification reaction are very influential over

many soil processes, and managing agricultural systems to suppress soil nitrification potential could prove to be very valuable. Given how influential nitrification is within soil ecosystems, very little is known as to how nitrification potential could be managed, and the dynamics of the AOA and AOB communities within soil.

In both the field and laboratory study, there were trends in which average nitrification potential varied between cover crop treatments. Although different cover crops exhibited different trends in the field and laboratory study, the presence of trends indicates that this is a research topic that should be further explored. Cover crops are already used in agricultural practices to decrease soil erosion and control NO_3^- leaching, so it is worth additional research to determine if there is a direct relationship between cover crop treatments and nitrification potential suppression.

Additionally, the laboratory study proved that nitrification potential is suppressed by drought. Increased drought length and intensity in some agriculturally productive parts of the world is one of the potential impending effects of climate change. If drought has been proven to suppress nitrification potential, these elongated and intensified drought conditions could drastically change the soil N cycle. In some areas, the suppression in nitrification potential could reduce environmental degradation in the system by preventing NO_3^- leaching and denitrification. Adversely, if the periods of drought became too long or too intense, nitrification potential could be too severely suppressed, limiting N available for plant uptake.

The dynamics of AOA and AOB are also worth further investigation. The assay used in this laboratory study was only developed within the last year (Taylor et. al 2013), and it is much more feasible and cost-efficient for short-term assays of microbial nitrifier

communities than previous methodologies. It would be interesting to further explore nitrifier contributions and dynamics in different types of soil conditions using this assay to gain a better understanding of how the populations interact.

Appendix A

Field Study Soil Sampling Data Sheet and Inorganic N Concentrations

Table 1. Field study data: gravimetric water content, NO_3^- concentrations, and NH4+ concentrations.

Plot	Trt	Cover crop	KCl soil (g)	GWC tin (g)	tin + soil wet (g)	tin + soil dry (g)	GWC fw	GWC dw	GWC	NO_3^- mg/kg od	NH_4^+ mg/kg od
301	C	Red Clover	20.88	1.35	11.45	10.23	10.10	8.88	0.14	-0.2680	1.3154
301	D	Red Clover	20.33	1.34	11.29	10.70	9.95	9.36	0.06	-0.2759	1.6466
303	C	Canola	20.70	1.34	11.20	10.66	9.86	9.32	0.06	-0.4414	1.2956
303	D	Canola	20.35	1.34	11.43	10.63	10.09	9.29	0.09	-0.3955	1.5439
305	C	Cereal Rye	20.64	1.34	11.03	10.06	9.69	8.72	0.11	-0.5150	1.5852
305	D	Cereal Rye	20.41	1.31	11.28	10.43	9.97	9.12	0.09	-0.1935	1.5720
306	C	3SppN	20.41	1.35	11.15	10.19	9.80	8.84	0.11	-0.6344	1.1374
306	D	3SppN	20.13	1.31	11.38	10.64	10.07	9.33	0.08	0.4856	1.5901
307	C	Fallow	19.88	1.31	11.56	10.37	10.25	9.06	0.13	-0.4730	1.0412
307	D	Fallow	20.24	1.32	11.09	10.10	9.77	8.78	0.11	-0.2459	0.9821
501	C	Fallow	20.51	1.30	11.30	10.38	10.00	9.08	0.10	-0.3080	0.9990
501	D	Fallow	19.89	1.32	11.45	10.64	10.13	9.32	0.09	0.0568	1.0557
504	C	Cereal Rye	20.23	1.31	11.08	10.10	9.77	8.79	0.11	-0.3855	1.1084
504	D	Cereal Rye	20.51	1.30	11.12	10.26	9.82	8.96	0.10	0.1688	1.4663
506	C	3SppN	20.45	1.29	11.27	10.61	9.98	9.32	0.07	-0.1884	1.4908
506	D	3SppN	20.15	1.27	11.24	10.63	9.97	9.36	0.07	0.1438	1.9686
508	C	Canola	20.35	1.34	11.28	10.59	9.94	9.25	0.07	-0.2347	0.8767
508	D	Canola	20.01	1.26	11.40	10.65	10.14	9.39	0.08	-0.4449	1.4142
512	C	Red Clover	20.08	1.27	11.16	10.48	9.89	9.21	0.07	-0.2376	0.8875
512	D	Red Clover	20.10	1.28	11.23	10.75	9.95	9.47	0.05	0.9977	1.0237
803	C	Cereal Rye	20.41	1.31	11.23	10.40	9.92	9.09	0.09	-0.2835	0.9519
803	D	Cereal Rye	20.18	1.30	11.61	10.99	10.31	9.69	0.06	0.6759	0.9745
805	C	Canola	20.07	1.31	11.13	10.27	9.82	8.96	0.10	-0.3821	1.0567
805	D	Canola	20.59	1.31	11.47	10.70	10.16	9.39	0.08	0.0102	0.8939
807	C	Fallow	20.64	1.30	11.28	10.46	9.98	9.16	0.09	-0.5254	0.7367
807	D	Fallow	20.33	1.31	11.60	10.80	10.29	9.49	0.08	1.2720	0.9688
808	C	Red Clover	20.23	1.30	11.37	10.29	10.07	8.99	0.12	-0.2950	1.0972
808	D	Red Clover	20.50	1.29	11.36	10.56	10.07	9.27	0.09	0.2567	0.9630

812	C	3SppN	20.62	1.31	11.60	10.75	10.29	9.44	0.09	-0.3474	1.0834
812	D	3SppN	20.34	1.30	11.26	10.57	9.96	9.27	0.07	1.1240	1.2820
1001	C	Fallow	20.00	1.28	11.35	10.64	10.07	9.36	0.08	-0.4886	0.8930
1001	D	Fallow	20.16	1.29	11.25	10.65	9.96	9.36	0.06	0.6323	0.8948
1002	C	Cereal Rye	20.65	1.29	11.45	10.58	10.16	9.29	0.09	-0.4827	1.7382
1002	D	Cereal Rye	20.14	1.31	11.37	10.58	10.06	9.27	0.09	-0.0805	1.3513
1003	C	Red Clover	20.18	1.29	11.26	10.54	9.97	9.25	0.08	-0.2600	0.9281
1003	D	Red Clover	20.12	1.30	11.12	10.36	9.82	9.06	0.08	0.4655	1.1645
1007	C	Canola	20.03	1.28	11.29	10.22	10.01	8.94	0.12	-0.4164	1.0858
1007	D	Canola	20.11	1.30	11.40	10.54	10.10	9.24	0.09	-0.1503	1.2813
1009	C	3SppN	20.47	1.30	11.15	9.91	9.85	8.61	0.14	-0.3466	1.4586
1009	D	3SppN	20.26	1.29	11.24	10.32	9.95	9.03	0.10	-0.0124	1.5983

Appendix B

Field Study 24-Hour Shaken Soil-Slurry NO_3^- Concentrations and Nitrification Potential

Table 2. Field study data: NO_3^- concentrations during the 24-hour shaken soil-slurry and nitrification potential.

Cover Crop	Plot	Treatment	NO_3^- Concentration per Hour (mg kg^{-1})				Nitrification Potential (mg kg^{-1} d^{-1})
			2	4	22	24	
Red Clover	301	Drought	0.2343	0.2343	7.0455	14.6859	13.1
Red Clover	301	Control	0.1023	0.3124	8.7167	12.8558	12.8
Red Clover	512	Drought	0.9965	1.2463	9.0658	13.5040	12.4
Red Clover	512	Control	-0.0619	0.5906	7.4324	12.7121	12.0
Red Clover	808	Drought	0.3773	1.4171	11.5351	20.8932	18.8
Red Clover	808	Control	0.5577	1.4504	13.1997	19.3234	18.5
Red Clover	1003	Drought	0.5366	1.3754	10.4825	15.4355	14.6
Red Clover	1003	Control	-0.0820	1.2079	8.5109	11.3487	11.4
Canola	303	Control	0.8596	0.3501	5.7978	10.4028	9.1
Canola	303	Drought	0.0377	0.1385	6.1675	11.8134	10.9
Canola	508	Control	0.9386	1.0388	7.1270	12.0537	10.5
Canola	508	Drought	0.0374	1.8804	9.1121	17.5457	15.3
Canola	805	Control	0.4997	1.2231	7.8740	12.7969	11.6
Canola	805	Drought	0.5614	1.3268	8.0146	14.2793	12.5
Canola	1007	Control	0.6604	1.8001	10.9592	23.1644	19.6
Canola	1007	Drought	0.8957	2.2434	11.6564	18.5783	16.6
Cereal Rye	305	Control	0.1204	0.2025	8.2045	12.4313	12.3
Cereal Rye	305	Drought	0.0174	0.0775	6.8451	13.4725	12.4
Cereal Rye	504	Control	0.8009	1.1099	9.5988	16.3364	14.7
Cereal Rye	504	Drought	1.3471	2.1127	10.5941	16.1343	14.2
Cereal Rye	803	Control	0.6730	1.5330	6.3245	13.9623	11.2
Cereal Rye	803	Drought	1.1871	2.2777	8.5832	13.6593	11.5
Cereal Rye	1002	Control	-0.2048	0.7453	6.5271	9.3978	9.4
Cereal Rye	1002	Drought	0.9069	1.6345	10.5682	11.5384	11.7
3SppN	306	Control	-0.0441	0.1007	7.8140	14.2658	13.5
3SppN	306	Drought	0.5131	0.7314	9.8563	15.7677	14.8

3SppN	506	Control	0.5328	1.2862	10.5856	16.3358	15.3
3SppN	506	Drought	1.2515	2.0876	10.2495	12.8374	11.9
3SppN	812	Control	0.0583	0.8714	7.5591	13.2508	12.2
3SppN	812	Drought	1.5220	2.0764	9.4220	18.3517	14.9
3SppN	1009	Control	0.8884	2.3312	15.2954	21.8942	20.7
3SppN	1009	Drought	1.5794	3.0803	13.9719	19.3874	17.5
Fallow	307	Control	0.5187	0.8316	10.4260	15.7446	15.1
Fallow	307	Drought	0.6562	0.9650	12.4338	24.5202	21.7
Fallow	501	Control	0.5091	1.0413	11.8706	20.5299	18.9
Fallow	501	Drought	1.2130	1.7398	13.0657	16.8546	16.3
Fallow	807	Control	0.3393	1.1641	9.9750	17.5588	16.0
Fallow	807	Drought	1.0070	1.9156	7.6907	13.4859	11.2
Fallow	1001	Control	0.4354	1.0525	8.3986	12.6390	11.9
Fallow	1001	Drought	1.4233	2.0373	7.9193	11.1079	9.5

Table 3. Nitrification potential in mg kg^{-1} d^{-1} for each cover crop treatment and replicate.

Treatment	Replicate	Nitrification Potential (mg kg^{-1} d^{-1})
Red Clover	1	13.0
Red Clover	2	12.2
Red Clover	3	18.7
Red Clover	4	13.0
Canola	1	10.0
Canola	2	12.9
Canola	3	12.1
Canola	4	18.1
Cereal Rye	1	12.4
Cereal Rye	2	14.4
Cereal Rye	3	11.4
Cereal Rye	4	10.5
3SppN	1	14.2
3SppN	2	13.6
3SppN	3	13.6
3SppN	4	19.1
Fallow	1	18.4
Fallow	2	17.6
Fallow	3	13.6
Fallow	4	10.7

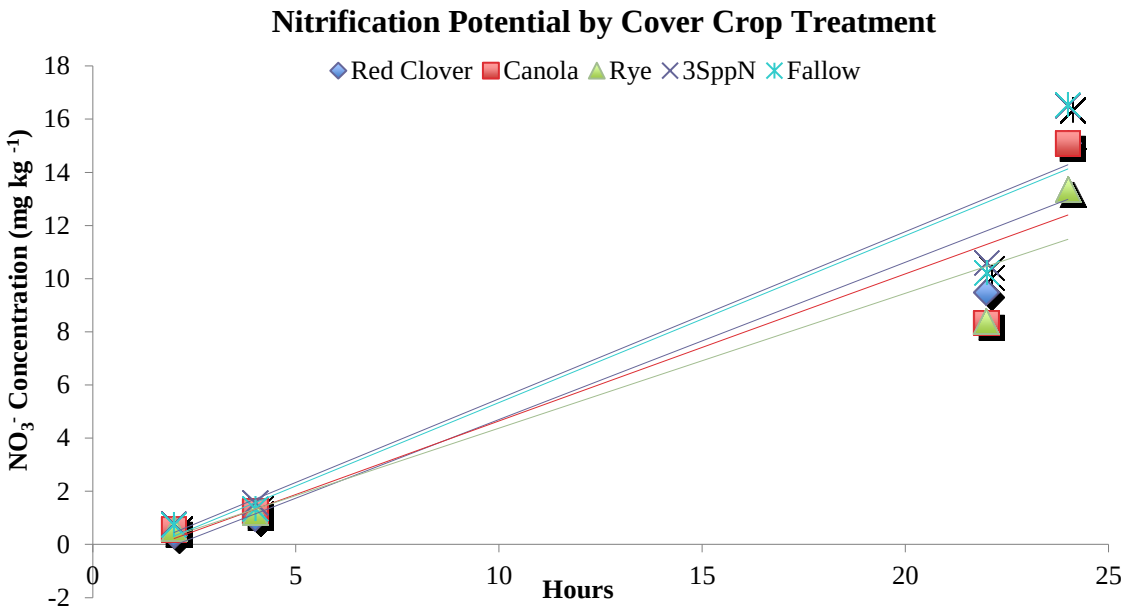


Figure 18. Plot of average NO_3^- concentration in mg kg^{-1} at hours 2, 4, 22, and 24 of the shaken soil-slurry by cover crop treatment.

Table 4. Average nitrification potential in mg kg^{-1} d^{-1} and linear regression equations for each cover crop treatment.

Cover Crop Treatment	Linear Regression Equation	Nitrification Potential (mg kg^{-1} d^{-1})
Red Clover	y = 0.5917x - 1.2161	14.2
Canola	y = 0.5532x - 0.9404	13.3
Cereal Rye	y = 0.5077x - 0.7027	12.2
3SppN	y = 0.6278x - 0.9404	15.1
Fallow	y = 0.6291x - 0.8129	15.1

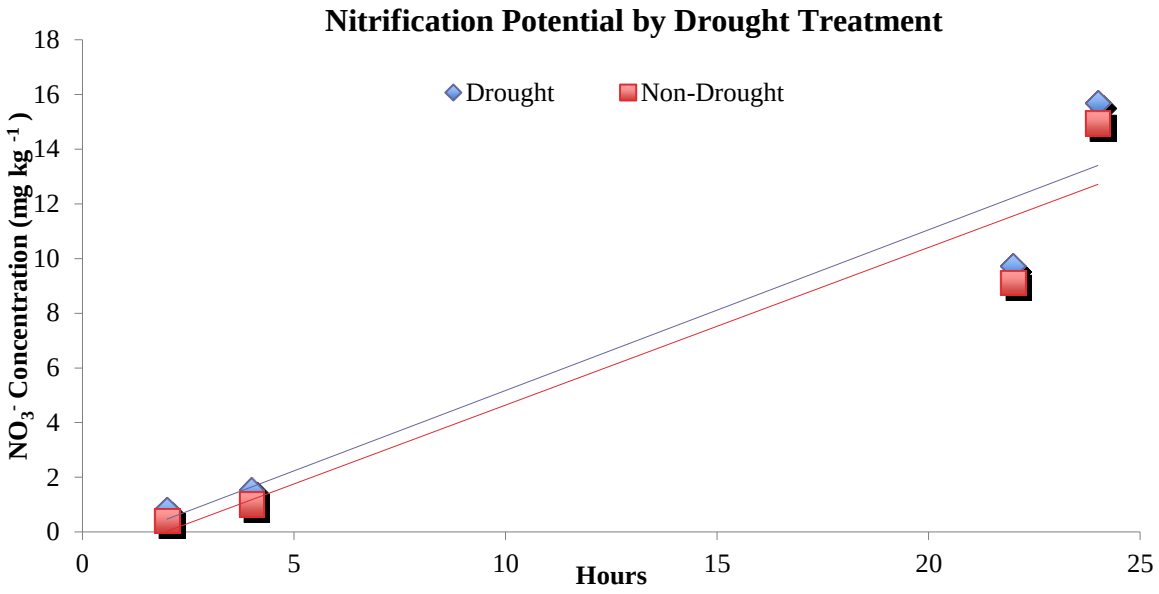


Figure 19. Plot of average NO_3^- concentration in mg kg-1 at hours 2, 4, 22, and 24 of the shaken soil-slurry by drought treatment.

Table 5. Average nitrification potential in mg kg^{-1} d^{-1} and linear regression equations for the drought and non-drought samples.

Drought Treatment	Linear Regression Equation	Nitrification Potential (mg kg^{-1} d^{-1})
Drought	y = 0.5874x - 0.6983	14.1
Non-Drought	y = 0.5764x - 1.1242	13.8

Appendix C

Cover Crop Biomass

Wet Weights: Total Biomass

Table 6. Wet weights of total cover crop biomass.

Cover Crop Treatment	Weight (g)
Field pea	20.90
Cowpea	13.18
Canola	90.31
Cereal Rye	32.61
Barley	35.82

Dry Weights: Biomass Subsamples

Table 7. Wet and dry weights for subsamples of cover crop biomass.

Cover Crop Treatment	Wet Weight (g)	Dry Weight (g)
Field pea	0.96	0.18
Cowpea	0.98	0.12
Canola	3.03	0.37
Cereal Rye	2.55	0.40
Barley	2.60	0.41

Appendix D

Laboratory Study Soil Sampling Data and Gravimetric Water Content

Weekly Drought Analysis:

Table 8. Data for soil samples that underwent a one-week drought period.

Week 1						
				Extraction	**Soil + cup**	**Soil + cup**
Treatment	**Analysis**	**Block**	**Label**	**cup (g)**	**wet (g)**	**dry (g)**
Rye	Inorganic	1	Rye1A-1	12.30	32.10	31.32
Rye	Inorganic	2	Rye2A-1	12.38	32.21	31.45
Rye	Inorganic	3	Rye3A-1	12.43	32.37	31.63
Rye	Inorganic	4	Rye4A-1	12.39	32.34	31.53
Rye	Slurry w/ C8	1	Rye1B-1	12.41	27.24	26.36
Rye	Slurry w/ C8	2	Rye2B-1	12.33	27.54	26.85
Rye	Slurry w/ C8	3	Rye3B-1	12.47	27.66	27.03
Rye	Slurry w/ C8	4	Rye4B-1	12.30	27.30	26.67
Rye	Slurry w/o C8	1	Rye1C-1	12.48	27.29	26.56
Rye	Slurry w/o C8	2	Rye2C-1	12.38	27.27	26.52
Rye	Slurry w/o C8	3	Rye3C-1	12.35	27.31	26.62
Rye	Slurry w/o C8	4	Rye4C-1	12.44	27.66	27.08
Field pea	Inorganic	1	FP1A-1	12.20	32.38	31.87
Field pea	Inorganic	2	FP2A-1	12.41	32.51	32
Field pea	Inorganic	3	FP3A-1	12.48	32.52	32.01
Field pea	Inorganic	4	FP4A-1	12.29	32.42	31.83
Field pea	Slurry w/ C8	1	FP1B-1	12.31	27.07	26.46
Field pea	Slurry w/ C8	2	FP2B-1	12.45	27.47	26.94
Field pea	Slurry w/ C8	3	FP3B-1	12.35	27.53	27.04
Field pea	Slurry w/ C8	4	FP4B-1	12.43	27.38	26.86
Field pea	Slurry w/o C8	1	FP1C-1	12.43	27.61	25.15
Field pea	Slurry w/o C8	2	FP2C-1	12.49	27.46	26.83
Field pea	Slurry w/o C8	3	FP3C-1	12.27	27.34	26.67
Field pea	Slurry w/o C8	4	FP4C-1	12.47	27.63	26.99
Canola	Inorganic	1	CA1A-1	12.51	32.63	32.12
Canola	Inorganic	2	CA2A-1	12.31	32.44	31.93
Canola	Inorganic	3	CA3A-1	12.26	32.51	31.91
Canola	Inorganic	4	CA4A-1	12.57	32.78	32.2
Canola	Slurry w/ C8	1	CA1B-1	12.46	27.44	26.98
Canola	Slurry w/ C8	2	CA2B-1	12.37	27.41	26.97

Canola	Slurry w/ C8	3	CA3B-1	12.33	27.28	26.85
Canola	Slurry w/ C8	4	CA4B-1	12.34	27.43	26.97
Canola	Slurry w/o C8	1	CA1C-1	12.43	27.23	26.7
Canola	Slurry w/o C8	2	CA2C-1	12.46	27.65	27.12
Canola	Slurry w/o C8	3	CA3C-1	12.37	27.24	26.79
Canola	Slurry w/o C8	4	CA4C-1	12.43	27.31	26.9
Control	Inorganic	1	CO1A-1	12.38	32.27	31.89
Control	Inorganic	2	CO2A-1	12.44	32.63	32.24
Control	Inorganic	3	CO3A-1	12.44	32.36	31.88
Control	Inorganic	4	CO4A-1	12.38	32.27	31.77
Control	Slurry w/ C8	1	CO1B-1	12.30	27.62	27.14
Control	Slurry w/ C8	2	CO2B-1	12.45	27.69	27.21
Control	Slurry w/ C8	3	CO3B-1	12.29	27.50	27.04
Control	Slurry w/ C8	4	CO4B-1	12.19	27.40	26.9
Control	Slurry w/o C8	1	CO1C-1	12.24	27.41	26.62
Control	Slurry w/o C8	2	CO2C-1	12.32	27.16	26.46
Control	Slurry w/o C8	3	CO3C-1	12.32	27.17	26.53
Control	Slurry w/o C8	4	CO4C-1	12.21	27.13	26.44

Table 9. Data for soil samples that underwent a two-week drought period.

Week 2						
				Extraction	**Soil + cup**	**Soil + cup**
Treatment	**Analysis**	**Block**	**Label**	**cup (g)**	**wet (g)**	**dry (g)**
Rye	Inorganic	1	Rye1A-2	12.3	32.15	30.52
Rye	Inorganic	2	Rye2A-2	12.38	32.27	30.68
Rye	Inorganic	3	Rye3A-2	12.3	32.3	30.66
Rye	Inorganic	4	Rye4A-2	12.42	32.45	30.74
Rye	Slurry w/ C8	1	Rye1B-2	12.27	27.29	25.7
Rye	Slurry w/ C8	2	Rye2B-2	12.37	27.38	25.9
Rye	Slurry w/ C8	3	Rye3B-2	12.3	27.26	25.95
Rye	Slurry w/ C8	4	Rye4B-2	12.38	27.26	25.99
Rye	Slurry w/o C8	1	Rye1C-2	12.24	27.41	26.05
Rye	Slurry w/o C8	2	Rye2C-2	12.4	27.27	25.86
Rye	Slurry w/o C8	3	Rye3C-2	12.3	27.3	25.72
Rye	Slurry w/o C8	4	Rye4C-2	12.41	27.55	26.03
Field pea	Inorganic	1	FP1A-2	12.36	32.37	31.1
Field pea	Inorganic	2	FP2A-2	12.49	32.56	31.3
Field pea	Inorganic	3	FP3A-2	12.23	32.43	31.13
Field pea	Inorganic	4	FP4A-2	12.46	32.32	30.98
Field pea	Slurry w/ C8	1	FP1B-2	12.35	27.5	26.32
Field pea	Slurry w/ C8	2	FP2B-2	12.48	27.45	26.3
Field pea	Slurry w/ C8	3	FP3B-2	12.29	27.18	26
Field pea	Slurry w/ C8	4	FP4B-2	12.37	27.3	26.22

Field pea	Slurry w/o C8	1	FP1C-2	12.45	27.3	26.28
Field pea	Slurry w/o C8	2	FP2C-2	12.45	27.59	26.52
Field pea	Slurry w/o C8	3	FP3C-2	12.57	27.36	26.32
Field pea	Slurry w/o C8	4	FP4C-2	12.41	27.29	26.17
Canola	Inorganic	1	CA1A-2	12.1	32.31	30.93
Canola	Inorganic	2	CA2A-2	12.42	32.6	31.21
Canola	Inorganic	3	CA3A-2	12.23	32.41	30.92
Canola	Inorganic	4	CA4A-2	12.07	32.17	30.69
Canola	Slurry w/ C8	1	CA1B-2	12.26	27.13	25.66
Canola	Slurry w/ C8	2	CA2B-2	12.27	27.35	25.86
Canola	Slurry w/ C8	3	CA3B-2	12.41	27.26	25.87
Canola	Slurry w/ C8	4	CA4B-2	12.21	27.11	25.6
Canola	Slurry w/o C8	1	CA1C-2	12.12	27.19	25.49
Canola	Slurry w/o C8	2	CA2C-2	12.24	27.26	25.7
Canola	Slurry w/o C8	3	CA3C-2	12.28	27.4	25.77
Canola	Slurry w/o C8	4	CA4C-2	12.03	27.23	25.68
Control	Inorganic	1	CO1A-2	12.33	32.28	30.08
Control	Inorganic	2	CO2A-2	12.34	32.14	30.01
Control	Inorganic	3	CO3A-2	12.38	32.19	30.19
Control	Inorganic	4	CO4A-2	12.34	32.24	30.31
Control	Slurry w/ C8	1	CO1B-2	12.52	27.54	25.64
Control	Slurry w/ C8	2	CO2B-2	12.5	27.58	25.9
Control	Slurry w/ C8	3	CO3B-2	12.32	27.27	25.32
Control	Slurry w/ C8	4	CO4B-2	12.29	27.46	25.39
Control	Slurry w/o C8	1	CO1C-2	12.25	27.27	25.33
Control	Slurry w/o C8	2	CO2C-2	12.24	27.07	25.14
Control	Slurry w/o C8	3	CO3C-2	12.39	27.58	25.76
Control	Slurry w/o C8	4	CO4C-2	12.24	27.07	25.22

Periodic Inorganic N Analysis:

Table 10. Data for soil samples that underwent analysis for periodic inorganic N.

				Extraction	**Soil + cup**	**Soil + cup**
Date	**Treatment**	**Rep**	**Label**	**cup (g)**	**wet (g)**	**dry (g)**
3/21/2014	Rye	1	RYE1-1	12.43	32.29	32.29
3/21/2014	Rye	2	RYE2-1	12.39	32.59	32.59
3/21/2014	Rye	3	RYE3-1	12.27	32.28	32.28
3/21/2014	Field pea	1	FP1-1	12.3	32.15	32.15
3/21/2014	Field pea	2	FP2-1	12.24	32.42	32.42
3/21/2014	Field pea	3	FP3-1	12.38	32.53	32.53
3/21/2014	Canola	1	CA1-1	12.27	32.23	32.23
3/21/2014	Canola	2	CA2-1	12.3	32.32	32.32

3/21/2014	Canola	3	CA3-1	12.26	32.37	32.37
3/21/2014	Control	1	CO1-1	12.4	32.2	32.2
3/21/2014	Control	2	CO2-1	12.31	32.47	32.47
3/21/2014	Control	3	CO3-1	12.39	32.26	32.26
3/24/2014	Rye	1	RYE1-2	12.23	32.5	31.78
3/24/2014	Rye	2	RYE2-2	12.43	32.56	31.86
3/24/2014	Rye	3	RYE3-2	12.28	32.43	31.71
3/24/2014	Field pea	1	FP1-2	12.27	32.14	31.45
3/24/2014	Field pea	2	FP2-2	12.29	32.34	31.62
3/24/2014	Field pea	3	FP3-2	12.39	32.33	31.67
3/24/2014	Canola	1	CA1-2	12.42	32.55	31.83
3/24/2014	Canola	2	CA2-2	12.41	32.42	31.7
3/24/2014	Canola	3	CA3-2	12.41	32.34	31.54
3/24/2014	Control	1	CO1-2	12.31	32.38	31.49
3/24/2014	Control	2	CO2-2	12.44	32.62	31.73
3/24/2014	Control	3	CO3-2	12.34	32.22	31.28
3/27/2014	Rye	1	RYE1-3	12.29	32.23	30.34
3/27/2014	Rye	2	RYE2-3	12.45	32.21	30.51
3/27/2014	Rye	3	RYE3-3	12.24	32.47	30.79
3/27/2014	Field pea	1	FP1-3	12.27	32.39	30.99
3/27/2014	Field pea	2	FP2-3	12.4	32.25	30.77
3/27/2014	Field pea	3	FP3-3	12.38	32.33	30.97
3/27/2014	Canola	1	CA1-3	12.31	32.15	30.5
3/27/2014	Canola	2	CA2-3	12.38	32.48	30.79
3/27/2014	Canola	3	CA3-3	12.25	32.11	30.25
3/27/2014	Control	1	CO1-3	12.36	32.23	30.17
3/27/2014	Control	2	CO2-3	12.35	32.24	30.25
3/27/2014	Control	3	CO3-3	12.26	32.38	30.58
3/30/2014	Rye	1	RYE1-4	12.31	32.47	29.91
3/30/2014	Rye	2	RYE2-4	12.38	32.23	29.78
3/30/2014	Rye	3	RYE3-4	12.26	32.46	29.95
3/30/2014	Field pea	1	FP1-4	12.34	32.33	30.49
3/30/2014	Field pea	2	FP2-4	12.43	32.54	30.61
3/30/2014	Field pea	3	FP3-4	12.38	32.21	30.3
3/30/2014	Canola	1	CA1-4	12.23	32.27	29.17
3/30/2014	Canola	2	CA2-4	12.41	32.53	29.21
3/30/2014	Canola	3	CA3-4	12.3	32.19	29.03
3/30/2014	Control	1	CO1-4	12.27	32.35	29.08
3/30/2014	Control	2	CO2-4	12.35	32.27	28.97
3/30/2014	Control	3	CO3-4	12.24	32.29	28.99

Gravimetric Water Content:

Cover Crop Treatment	Replicate	Tin Weight (g)	Soil Wet Weight (g)	Soil Dry Weight (g)	GWC fw	GWC dw	Gravimetric Water Content
Control	1	1.27	11.54	9.51	10.27	8.24	0.246
Control	2	1.30	11.35	9.30	10.05	8.00	0.256
Control	3	1.31	11.59	9.57	10.28	8.26	0.245
Canola	1	1.32	11.79	9.72	10.47	8.40	0.246
Canola	2	1.33	11.25	9.23	9.92	7.90	0.256
Canola	3	1.33	11.18	9.12	9.85	7.79	0.264
Cereal Rye	1	1.34	11.17	9.58	9.83	8.24	0.193
Cereal Rye	2	1.33	11.28	9.68	9.95	8.35	0.192
Cereal Rye	3	1.28	11.32	9.67	10.04	8.39	0.197
Field pea	1	1.27	11.50	10.22	10.23	8.95	0.143
Field pea	2	1.28	11.56	10.34	10.28	9.06	0.135
Field pea	3	1.26	11.29	10.05	10.03	8.79	0.141

Appendix E

Field Study 24-Hour Shaken Soil-Slurry NO_3^- Concentrations and Nitrification Potential

Table 11. Laboratory study data: NO_3^- concentrations during the 24-hour shaken soil-slurry and nitrification potential after one week of drought.

Week 1		NO_3^- Concentration per Hour (mg kg^{-1})				Nitrification Potential
Sample	Treatment	2	4	22	24	(mg kg^{-1} d^{-1})
Rye1B-1	Cereal Rye	61.45693	63.37934	58.49094	57.65341	-5.1
Rye2B-1	Cereal Rye	62.42256	60.27912	57.65341	58.93948	-3.6792
Rye3B-1	Cereal Rye	62.28815	62.50277	58.10308	59.65907	-4.0704
Rye4B-1	Cereal Rye	62.89519	61.80883	58.3868	55.72522	-6.516
Rye1C-1	Cereal Rye	67.47779	67.0928	90.46708	96.90188	31.7256
Rye2C-1	Cereal Rye	62.14517	60.66801	82.05952	88.07759	28.3824
Rye3C-1	Cereal Rye	67.68845	64.25748	91.43291	91.81413	30.2952
Rye4C-1	Cereal Rye	63.66777	63.29291	85.57034	86.26651	26.6784
FP1B-1	Field pea	93.22107	89.39776	88.40265	82.32726	-7.6512
FP2B-1	Field pea	96.93886	96.47551	87.67181	92.66572	-7.5
FP3B-1	Field pea	94.40704	93.84658	82.89217	93.08232	-6.7224
FP4B-1	Field pea	95.67779	95.00542	88.17834	94.22962	-4.596
FP1C-1	Field pea	84.57354	82.38266	99.75687	100.0626	19.4112
FP2C-1	Field pea	96.06878	95.91383	112.7525	117.4013	22.944
FP3C-1	Field pea	92.41514	96.98225	110.2218	121.4086	26.0256
FP4C-1	Field pea	93.20288	95.7027	108.2018	115.5482	21.2856
CA1B-1	Canola	48.33511	47.47189	44.30674	46.83886	-2.6712
CA2B-1	Canola	44.24987	44.82312	44.76579	42.93138	-0.8928
CA3B-1	Canola	49.40946	45.31558	46.41113	45.31558	-2.0904
CA4B-1	Canola	55.93581	51.13595	51.4788	47.70749	-5.1936
CA1C-1	Canola	55.5435	53.97136	76.68004	79.06736	27.5136
CA2C-1	Canola	49.21961	47.45955	72.10039	74.42821	29.6472
CA3C-1	Canola	56.4489	54.6521	84.03848	85.37159	34.6104
CA4C-1	Canola	63.47875	62.84159	94.00442	96.03175	37.9344
CO1B-1	Control	109.6122	103.2859	100.7666	99.8149	-7.7496
CO2B-1	Control	106.6255	102.0114	100.2108	100.1545	-5.1912
CO3B-1	Control	112.4673	111.6217	107.0551	110.0995	-3.9888
CO4B-1	Control	103.7289	106.886	104.9692	109.9304	3.0288

CO1C-1	Control	109.0247	105.9726	120.7247	126.1508	19.0776
CO2C-1	Control	107.7403	106.8164	112.937	124.543	14.2536
CO3C-1	Control	103.919	104.4961	117.364	120.3646	17.6256
CO4C-1	Control	103.4455	103.7902	113.8423	119.012	15.5472

Table 12. Laboratory study data: NO_3^- concentrations during the 24-hour shaken soil-slurry and nitrification potential after two weeks of drought.

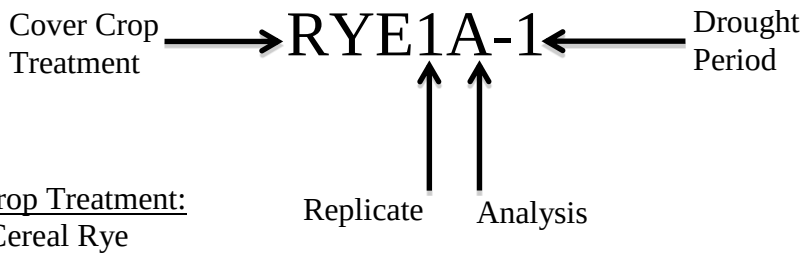
Week 2		NO_3^- **Concentration per Hour (mg kg^{-1})**				**Nitrification Potential**
Sample	**Treatment**	**2**	**4**	**22**	**24**	**(mg kg-1 d-1)**
Rye1B-2	Cereal Rye	60.71589	61.52612	51.70796	51.6603	-11.1672
Rye2B-2	Cereal Rye	66.47886	65.28656	58.60964	58.03733	-9.0864
Rye3B-2	Cereal Rye	68.03783	63.77922	59.47276	55.11846	-10.7448
Rye4B-2	Cereal Rye	66.81128	58.4894	60.70215	59.8844	-3.3432
Rye1C-2	Cereal Rye	71.68671	71.21475	91.50907	99.24923	28.8624
Rye2C-2	Cereal Rye	71.86167	69.55118	92.70422	96.31436	28.3584
Rye3C-2	Cereal Rye	71.96308	67.38161	89.9549	95.92036	27.7248
Rye4C-2	Cereal Rye	72.48885	70.17173	92.44453	94.00505	25.968
FP1B-2	Field pea	89.2643	88.94186	81.01918	77.51846	-11.9112
FP2B-2	Field pea	95.12706	88.88131	85.19911	85.89826	-7.9992
FP3B-2	Field pea	106.5507	102.3335	93.43047	97.78825	-10.4856
FP4B-2	Field pea	93.7903	95.33251	87.9486	88.97674	-7.0944
FP1C-2	Field pea	90.53166	86.86701	107.6804	109.6067	23.592
FP2C-2	Field pea	100.1543	98.58716	110.8477	113.4288	15.2304
FP3C-2	Field pea	94.99902	93.67822	106.7919	114.0563	19.464
FP4C-2	Field pea	101.7451	97.43128	103.3393	114.6396	11.5848
CA1B-2	Canola	46.24776	44.12788	39.06906	39.2136	-7.3008
CA2B-2	Canola	51.97976	47.13299	46.99044	47.37058	-3.0888
CA3B-2	Canola	52.43609	50.60285	47.51528	45.10312	-6.4416
CA4B-2	Canola	48.46391	45.67507	39.90505	37.98171	-9.9336
CA1C-2	Canola	71.46108	64.13862	92.90541	95.75831	31.2576
CA2C-2	Canola	52.04144	47.08017	72.93602	73.03143	27.54
CA3C-2	Canola	55.30385	51.65456	73.21852	71.79672	22.3056
CA4C-2	Canola	59.0243	54.12098	73.35708	75.14868	20.8224
CO1B-2	Control	105.2891	98.97344	98.43069	100.0096	-3.7392
CO2B-2	Control	99.07803	96.66978	92.73794	92.4922	-6.4056
CO3B-2	Control	99.97397	99.08175	93.82756	97.69385	-4.2984
CO4B-2	Control	97.52334	99.03805	93.17467	93.76101	-5.5944

CO1C-2	Control	101.8845	93.84199	104.549	109.8778	10.9488
CO2C-2	Control	99.61968	96.52204	107.6136	116.257	16.8024
CO3C-2	Control	97.54361	94.03013	105.5465	111.4023	15.2136
CO4C-2	Control	99.56972	96.47208	109.0125	110.6113	13.92

Appendix F

Labeling Mechanism for Laboratory Study Samples

Weekly Drought Samplings:

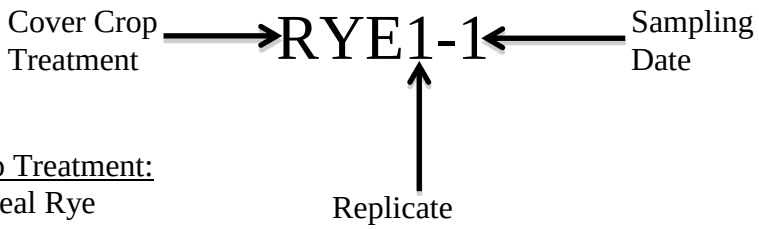


Cover Crop Treatment:
RYE = Cereal Rye
FP = Field pea
CA = Canola
CO = Control

Analysis:
A = Inorganic N
B = Nitrification Potential with C_8
C = Nitrification Potential without C_8

Drought Period:
1 = One Week
2 = Two Weeks

Periodic Inorganic N Samplings:



Cover Crop Treatment:
RYE = Cereal Rye
FP = Field pea
CA = Canola
CO = Control

Sampling Date:
1 = March 21st, 2014
2 = March 24th, 2014
3 = March 27th, 2014
4 = March 30th, 2014

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ACADEMIC VITA

JENA TROLIO

jena.trolio@gmail.com; (610) 883-6520
Current Address: 329 E. Beaver Avenue 202 Diplomat State College, PA 16801
Permanent Address: 921 Crum Creek Road Media, PA 19063

EDUCATION

The Pennsylvania State University
University Park, PA
The College of Agricultural Sciences, Schreyer Honors College
Class of May 2014
Bachelor of Science, Environmental Resource Management
Minors in Environmental Engineering, International Agriculture, and Watersheds and Water Resources

Ugyen Wangchuck Institute for Conservation and Environment
Bumthang, Bhutan
Summer 2013
Studied Environmental Science and Sustainable Development

RELATED EXPERIENCE

Jason Kaye Soil Biogeochemistry Lab-Undergraduate Research Assistant
October 2011-Present

- Working with graduate and doctoral students to study the effect of cover crops on soil nutrients
- Executing and analyzing various lab and field work procedures to test soil and soil extracts for nutrient levels
- Performing various field work in soil, water, plant biomass, and gas sampling

Schreyer Honors Independent Thesis
August 2013-Present

- Studying the effects of cover crops and climate change on the process of soil nitrification
- Performing and analyzing soil nitrate procedures to determine the nitrification potential of soils in the study

Humanitarian Engineering and Social Entrepreneurship Low-Cost Greenhouse Team
January 2014-Present

- Working to expand our low-cost greenhouse design to Sierra Leone to increase nutrition and food security
- Researching the capabilities of using globalization and modern agriculture to revive lost indigenous foods
- Drafting proposals and summary documents to apply for venture funding and communicate with stakeholders

Biophysical Directed Research
Summer 2013

- Completed an analysis on the feasibility of starting a Payment for Environmental Services scheme for either carbon sequestration or ecotourism in a rural farming community in Bhutan
- Performed, analyzed, and reported to the Royal Government of Bhutan a flora biodiversity assessment of forested land in use by a rural farming community

LEADERSHIP EXPERIENCE

THON Hospitality Committee Member-Administrative Assistant
September 2013-Present

- Penn State Dance Marathon, affectionately known as THON, is the largest student run philanthropy in the world, which to date has risen over $100 million for pediatric cancer support and research since 1973.
- Acting as the means of communication and organization between the captains and fellow committee members
- Serving and supplying food and drink to all of the dancers and Four Diamonds Families during THON Weekend

THON Independent-Dancer Chair-Co-Captain
September 2012-February 2013
- Planned 4 alternative fundraisers to raise awareness and funds for THON and the Four Diamonds Fund
- Raised funds by soliciting donations and writing letters to family members and friends

THON Special Events Committee Member-Public Relations Chair
September 2012-February 2013
- Worked to help prepare for THON alternative fundraisers and special events throughout the year

THON Morale Committee Member-Family Relations Chair
September 2010-February2011, September 2011-February 2012
- Provided emotional and physical support to the approximately 708 dancers throughout the duration of THON weekend.
- Prepared letters, gifts, and souvenirs for a pen pal Four Diamonds Family.

WORK EXPERIENCE

Pyramid Staffing-Office Assistant
Summers 2009-2013
- Worked in data entry, answered phone calls and organized and filed paperwork

Rita's Water Ice-Cashier/Server
Summers 2009-2012
- Handled money, managed the register, worked with general customers and catering orders

SKILLS

Computer: Microsoft Office, Statistics, Ascent Microplating
Language: Basic Spanish

ACADEMIC AWARDS AND RECOGNITION

Renaissance Scholarship on behalf of Penn State University Office of Student Aid – Student Speaker at the 2013 Banquet
A. Hartman Trustee Scholarship on behalf of the College of Agricultural Sciences
2014 Gamma Sigma Delta Research Exhibition First Place Winner (Undergraduate Plant-Related Systems Category)
Environmental Resource Management Department Student Marshal for Spring Commencement