Investigating the Effects of Legume Mulching on Carbon and Nitrogen Fluxes of Small Scale Agriculture

Emily Neel
eneel@wellesley.edu

Follow this and additional works at: https://repository.wellesley.edu/thesiscollection

Recommended Citation
https://repository.wellesley.edu/thesiscollection/557
Investigating the Effects of Legume Mulching on Carbon and Nitrogen Fluxes of Small Scale Agriculture

Emily Jane Neel

Submitted in Partial Fulfillment of the Prerequisite for Honors in Environmental Studies under the advisement of Jaclyn Hatala Matthes

April 2018

© 2018 Emily Neel
### Table of Contents

1. **Executive Summary** ................................................................................................................. 3

2. **Acknowledgements** .................................................................................................................. 6

3. **Introduction** .............................................................................................................................. 7
   i) Project overview: ......................................................................................................................... 8
   ii) Research question and hypotheses: ......................................................................................... 13

4. **Background** ............................................................................................................................... 18
   i) Biological importance of nitrogen: ............................................................................................ 18
   ii) Introduction of synthetic fertilizers and their effects: ............................................................. 19
   iii) Exploring synthetic fertilizer alternatives: .............................................................................. 22
   iv) Negative Impacts of industrial agriculture: ........................................................................... 24
   v) Rising influence of agroecology: ............................................................................................... 24
   vi) Scope of this research in agroecology: ..................................................................................... 28

5. **Methods** .................................................................................................................................... 31
   i) Study design: ............................................................................................................................... 31
   ii) Soil inorganic nitrogen measurements: .................................................................................... 33
   iii) Plant structure and biomass measurements: ......................................................................... 34
   iv) Soil Flux Measurements: .......................................................................................................... 35

6. **Results** ....................................................................................................................................... 36
   i) Effects on soil nitrogen availability: .......................................................................................... 36
   ii) Effects on total plant biomass: .................................................................................................. 38
   iii) Effects on ecosystem feedbacks: ............................................................................................. 42

7. **Discussion & Conclusion** ......................................................................................................... 45
   i) Effects on soil nitrogen availability: .......................................................................................... 45
   ii) Effects on total plant biomass: .................................................................................................. 46
   iii) Effects on ecosystem feedbacks: ............................................................................................. 49
   iv) Conclusion: ............................................................................................................................... 51

8. **Works Cited** ............................................................................................................................. 53
1. Executive Summary

Introduction:

In the United States, we often rely on large-scale agricultural processes to produce food in large amounts. These processes require heavy external inputs, including chemical synthetic fertilizers. In some communities, however, these fertilizers are not easily accessible. Their overuse can also damage the environment. Due to the ecological and social effects of large-scale agriculture, effective and accessible alternatives to synthetic fertilizers are needed. The field of agroecology implements sustainable farming practices. This transdisciplinary field incorporates both natural and social science perspectives and relies heavily on traditional and local knowledge of agriculture (Mendez et al., 2013, p. 6-12).

Agroecological practices incorporate low-input agricultural systems. This means that it incorporates synthetic fertilizer alternatives in order to add nutrients, especially nitrogen, to soils. One important practice is using legume plants as cover crops. Legumes are termed “nitrogen fixers”, because they have a symbiotic relationship with rhizobia bacteria that convert, or “fix”, atmospheric nitrogen to forms available for plant use as nitrate (NO$_3^-$) and ammonium (NH$_4^+$). Legumes have high levels of nitrogen, and so their decomposition increases soil reactive nitrogen. Mulching is another important agroecological practice where farmers add plant matter in topsoil to suppress weed growth, prevent erosion, and increase soil nutrients. This thesis was inspired by and attempted to model these practices by using mulch made from a legume plant to increase soil nutrients. I investigated the effects of adding a legume, nitrogen-fixer mulch on small-scale agricultural productivity. There are documented applications of using legumes as cover crops in agricultural systems, but this research explores their applications in mulching.

This research aimed to help gardeners and small-scale agriculture managers understand connections between agroecosystem nutrient cycling and the potential for using already available resources to increase crop productivity. I hypothesized that decreased nutrient deficiency would lead to increased plant productivity by increasing soil inorganic nitrogen content, increasing aboveground plant growth and above to belowground growth ratio, and increasing soil respiration rates (or carbon dioxide flux) in the treatment group.

Background:

Nitrogen is one of the most limiting nutrients for plants, meaning that increasing its availability to plants would increase plant growth (Blumenthal et al., 2008, p. 51). Even though the element is abundant in the atmosphere as N$_2$ gas, plants can only use nitrogen in the reactive forms nitrate (NO$_3^-$) and ammonium (NH$_4^+$). Before the 20th century, reactive nitrogen entered terrestrial ecosystems through biological processes involving nitrogen-fixing bacteria, such as those carried out by legumes.

Since the discovery of the Haber-Bosch process in 1913, humans have been able to synthetically produce fertilizers. This has led to an overall 40 percent per capita increase in food production (Mosier et al., 2004, p. 4). This began the rise of industrial scale agriculture. The nitrogen influx in ecosystems due to overuse, and subsequent leaching, of synthetic fertilizers
has negative ecological effects. These include water contamination and acidification, eutrophication, and subsequent oxygen depletion, in aquatic systems, and release of nitrous oxide, a greenhouse gas (Peoples et al., 2004, p. 57-65). There are also social consequences associated with the industrial agriculture paradigm. Though crop production has increased, the distribution of income, food, and agricultural resources is not equitable and global hunger persists. Industrial agriculture also undermines local farming and food sovereignty by replacing valuable traditional and indigenous knowledge (Hecht, 1995, p. 16).

Methods:

The experiment was conducted in the Wellesley College Edible Ecosystem Garden in 24 pre-existing barrel collars, diameter ~60 cm. In each barrel, I planted two spinach and two lettuce plants. In half of the barrels, I incorporated the dried biomass of crown vetch as a legume mulch, with the goal of minimizing soil nutrient deficiency in a treatment group.

Due to their ability to fix inorganic nitrogen, legumes have a higher nitrogen concentration in their shoots and leaves than many other plants. I hypothesized legumes would release this nitrogen if decomposed in soils. Crown vetch grows abundantly and invasively in all states except North Dakota, Alaska, and Hawaii (Losure et al., 2009, p. 240). Crown vetch is readily available, accessible, and creates few economic barriers to farmers. Spinach and lettuce were chosen for this experiment for their short growth cycle and high nitrogen demand (Citak & Sonmez, 2010, p. 415).

Over the course of plant growing season, September-November, I examined three variables related to agroecosystem productivity: soil inorganic nitrogen concentrations, plant biomass, or growth, and root length, and soil respiration, or carbon dioxide release. I hypothesized the following effects due to legume mulch decomposition in treatment group barrels: soil nitrogen concentrations, which reflect the availability of the limiting nutrient, would increase; total plant biomass, describing the total mass of the plant after the growing season, would be higher; soil respiration rates, describing soil microbial activity and root growth through carbon dioxide (CO\textsubscript{2}) flux, would be higher.

Results & Discussion:

Soil samples collected after plant growing season had significantly higher nitrate (NO\textsubscript{3}\textsuperscript{-}) concentrations, and only slightly higher ammonium (NH\textsubscript{4}\textsuperscript{+}) concentrations in treatment groups. The hypothesis that soil reactive nitrogen concentrations would rise was partially supported. Higher reactive nitrogen concentrations in treatment group may be due to the mulch decomposition. This indicates support for the overall hypothesis that soil nutrient availability would increase in the treatment group.

Lettuce aboveground biomass was lower in the treatment group. Spinach aboveground biomass was also lower in treatment, though not significantly. This was opposite of the predicted results, and so the hypothesis was not supported. I noticed an impact of herbivory from deer, small rodents, and slugs on plants during their growth. Results of lower biomass in the treatment
group is likely attributable to preferential herbivory. Research has shown that herbivores have adapted to consume plants with higher leaf nitrogen levels (Ritchie & Tilman, 1995, p. 2648; Mattson, 1980, p. 132), suggesting there were higher leaf nitrogen levels in treatment plants compared to the control plants due to mulch addition in soils. Data on leaf carbon and nitrogen levels, as a measurement of leaf nutrients, would support this new hypothesis if nutrient levels were higher in treatment plants. The overall hypothesis that the addition of legume mulch would increase soil nutrients would then be more strongly supported.

For both spinach and lettuce plants in the control group, roots were significantly longer. The hypothesis that root length would be shorter in the less nutrient deficient treatment barrels was supported. Control plants’ longer, thinner roots may indicate that plants are “searching” for nutrients and were more nutrient deficient than treatment plants (Chapin et al., 2011, p. 241). This partially supports the overall hypothesis that nutrient deficiency decreased for the treatment group as a result of legume mulch addition. A better indication of nutrient deficiency is lateral (horizontal) root length and root hair growth, which could be explored in future research (Giehl & von Wirén, 2014, p. 513-515; López-Bucio et al., 2003, p. 280).

There was no significant difference in soil respiration, CO₂ flux, between the treatment and the control during plant growth, and therefore the null hypothesis cannot be rejected. On the first sampling date, the soil respiration rate was higher in the treatment group, though not significantly. This higher rate may reflect the microbial processes involved in mulch decomposition (Liu et al., 2005, p. 285; Schlesinger & Andrews, 2000, p. 8). Soil respiration results provides little support that addition of a legume mulch increases productivity in the long-term, though its reflection of the mulch’s initial decomposition may indicate soil nutrient release.

Conclusion:

This research supports that crown vetch can add limiting nutrients to small scale agricultural systems where other fertilizing options are not economically or physically feasible. There is potential for this research to be extended to other legume plants, broadening fertilizer source availability and alternatives for specific farm needs. Future research can also focus on matching the nutrient release of legume mulch with crop nutrient requirements to maximize nutrient use efficiency and minimize negative ecological effects. In conclusion, higher soil nitrogen concentrations, possible preferential herbivory of treatment plants, and longer roots in control plants support the overall hypothesis that crown vetch legume mulch may have positive effects on small-scale agroecosystem productivity.
2. Acknowledgements

Thank you to…

My thesis advisor, Professor Jackie Hatala Matthes, for helping me realize my passion for plant ecology, for her invaluable advice, and for her constant supportive and encouraging mentorship;

Other members of my thesis committee, Professor Beth DeSombre, Professor Kristina Jones, and Honors Visitor Professor Charlene Galarneau for taking the time to give (often-sought) advice and meeting for my thesis defense;

Professor Alden Griffith for helping me run and analyze my samples on the discrete analyzer, and for answering my other numerous questions about nitrogen;

My fellow lab members, with special thanks to Lyba Khan ’20 and Sulaikha Buuh ’20 for their enthusiasm and optimism during early morning sample collections and our countless other research tasks, and to Lara Jones ’18 and Emma Conrad-Rooney ’20 for their help during seedling transplant day;

EcoLab Manager Sarah Russell for helping with plant harvest and for her guidance with R Studio;

My family and friends, who listened to my concerns and excitements throughout the year, and who gave me valuable feedback on thesis drafts;

The Jerome A. Schiff Fellowship and the Wellesley College Provost’s Office for essential funding support.
3. Introduction

The sustainability of agricultural systems is vital to creating a food supply that is globally accessible to current and future generations. There are many metrics of “sustainability”, including the potential for short-term and long-term crop productivity and the ability of farmers to utilize already available resources without causing significant environmental or economic harm. The goal of this project was to gain information on the short-term crop productivity, specifically by measuring carbon and nitrogen fluxes, of leafy green plants growing with and without the addition of a legume mulch. Legumes are plants whose roots have a symbiotic relationship with species of rhizobia bacteria in the soil that allows for the fixation of nitrogen (Peoples et al., 2009, p.1; Ledgard, 2001, p. 43). Legumes are known for increasing limiting soil nutrients, such as nitrogen, and so are often used in agricultural systems (Crews, 1999, p. 232; Hartwig & Ammon, 2002, p. 690), while simultaneously posing fewer environmental risks than those of synthesized fertilizers (Jensen et al., 2012, p. 330; Crews & Peoples, 2003, p. 279).

This project focused on combining legume use in agriculture with the agroecological practice of mulching, covering topsoil with plant and organic materials. In this research project, I conducted an experiment on the Wellesley College campus. In the Edible Ecosystem garden, there are 24 pre-installed bottomless barrels forming “collars” in the ground at various locations. In these barrels, I planted leafy greens in two treatments: with and without the presence of legume mulch. Mulching is known for various small-scale agricultural benefits, including the mitigation of erosion due to improved soil composition and increased resource and nutrient availability for crops (IFOAM Organics International). I incorporated plant matter from a legume, nitrogen-fixer as a mulch in soils in order to enhance soil nutrient content and better understand the impacts of legume and mulching applications on plant productivity.
As mentioned above, the practices of legume cover-cropping and mulching are incorporated into the field of agroecology. In addition to applying science of ecological systems to agriculture, agroecology incorporates a necessary social and cultural component, including the incorporation of traditional agricultural practices and the growth of farming communities (Altieri et al., 2015, p. 874; Mendez et al., 2013, p. 6). While a central component of this thesis was based in data collection and processing from a controlled experiment, a basis of understanding agroecology as a field and mulching practices was vital to the development of the thesis as a whole. In the Background section, I describe the biological and subsequent social importance of nitrogen, and its effects on the environment. I then review the impacts of industrial scale agriculture and how agroecology has grown as a recognized field in response to industrial agriculture. Finally, I interpret the role of this research within the field of agroecology as a mulching practice.

Though I use the first person “I” in this thesis, methods were carried out with the support of Lyba Khan ’20 and Sulaikha Buuh ’20, and major decisions were made with the support of my advisor, Jackie Matthes.

i) Project overview:

The applied goal of this research was help gardeners and small-scale agriculture managers understand the connections between agroecosystem carbon and nitrogen cycling and the potential for using management techniques to enhance productivity and sequester and conserve soil carbon and nitrogen. Therefore, to provide contextual support for findings, I included a literature review of the historical and cultural background of agroecological practices,
specifically mulching, and how they respond to the impacts of inefficient and industrial scale agriculture.

Legumes are often used in agricultural practices as a cover crop. Cover crops serve a similar purpose as mulch, and are a crop grown before or with the target harvest crop to enrich soil nutrients and protect soil from erosion. Simultaneously planting legumes with leafy greens as a cover crop is not likely to raise soil nitrogen content as the fixed nitrogen would be sequestered within the legume plant. To match the experiment time scale, a dried legume mulch was used in this research as opposed to a cover crop. Furthermore, Ledgard (2001) indicates that the highest incorporation of nitrogen into the soil occurs when the entire legume plant is used as green manure, a form of mulching (p. 47). Therefore, for this study I incorporated legume plant material into soil rather than growing legumes and leafy green plants concurrently.

Creating mulch from mature legumes incorporates the nitrogen into the soil, making the limiting nutrient accessible to the leafy green plant. The legume used in this experiment was crown vetch (*Securigera varia*). It grows abundantly in the Edible Ecosystem late spring through early fall and is easily harvestable. The use of vetch, specifically hairy vetch, as cover crops in other in Massachusetts and New England area has been documented (Silva & Moore, 2017, p. 5). However, cover crops may not be economically sounds for farmers who face fertile land constraints (Silva & Moore, 2017, p. 10). This research attempts to use an already present legume, crown vetch, as a mulch with the potential to provide similar agroecosystem benefits for nutrient addition as allowing cover crops to fallow. This removes economic and access barriers for farmers to obtaining fertilizers. Crown vetch is also considered an invasive species in much of the United States, and so using it as a mulch may be productive for both mitigating unwanted crown vetch populations and increasing soil nutrients. Crown vetch is very difficult to eradicate,
and so invasive species mitigation impacts of using it for mulching may be minimal (Losure et al., 2009, p. 240). At Wellesley College, crown vetch is managed by mowing, so its use as a mulch is readily available and does not interfere with, and may even support, other landscaping goals.

To retain soil moisture and prevent weed growth, this experiment also incorporated salt hay mulch in all treatments. Nutrient addition is not an advertised benefit of salt hay mulch, and so I assumed it would not affect treatment results. Furthermore, it is a good mulch because seeds cannot germinate without saltwater inundation.

The leafy green plants used in this experiment were spinach (Spinacia oleracea, variety ‘Tyee’) and lettuce (Lactuca sativa, variety ‘Romaine’). Spinach and lettuce were chosen for this experiment for their fast growth cycle and high nitrogen demand. Leafy green plants have a high nitrogen demand, as their leaves contain high levels of nitrate (Citak & Sonmez, 2010, p. 415). Lettuce and spinach in specific have higher tissue nitrogen concentrations, and thus higher nitrogen demand (Mattson, 1980, p. 121). Plants with high nitrogen demand were required for this research in the hope of attaining more profound effects in the nitrogen supplemented treatment group. The short fall growing season of spinach and lettuce allowed for fall data collection and winter data interpretation in order to complete research within the academic year 2017-2018.

The 24 barrels in the Edible Ecosystem Garden were split into two groups: 1) salt marsh hay mulch (control), and 2) legume crown vetch mulch with salt marsh hay mulch (treatment). The control and treatment groups were spread across the Edible Ecosystem Garden barrels to account for variability in incoming sunlight and slope effects (Fig. 1, Fig. 2). After reviewing the collected summer data and using visual observations, all plot groups appeared to be in direct
sunlight except plot group 1 towards the afternoon. Two spinach and two lettuce plants were planted within each barrel. Plants were widely spaced to minimize competition effects. Additionally, it was beneficial to interplant the two species because it ensured more equal soil and weather conditions for lettuce and spinach. The measurements were collected until mid-November (see Methods).
Figure 1. Barrel groups in August, before spinach and lettuce transplant. Upper left: Group 3, upper right: Group 2, lower left: Group 1, lower right: Group 5.

Figure 2. Barrel Group 4 in August, before spinach and lettuce transplant.
ii) Research question and hypotheses:

Figure 3. Visual representation of hypotheses related to plant growth processes affected by addition of a legume mulch. While only treatment barrels received legume, legume mulch, both treatment and control barrels included a salt hay mulch with potential to decompose.

I investigated the question how will adding a dried mulch from a nitrogen-fixing legume affect 1) the soil nitrogen availability, 2) the biomass and structure of leafy greens, and 3) the rates of soil respiration in small scale agriculture plots? To address these questions, I investigated these three groups of effects. Effects on soil nitrogen availability describe the amount of a limiting nutrient, or necessary component in limited supply, for plant growth. Effects on total plant biomass describe the total mass of the plant after the growing season. Effects on ecosystem feedbacks describe soil respiration rates, the release of carbon dioxide as a result of microbial decomposition of soil organic matter and root processes (Rochette et al., 1991, p. 190; Schlesinger & Andrews, 1999, p. 7).

Overall, I hypothesized that nutrient limitations would decrease, and plant productivity
would increase, with the addition of a legume mulch. This would support the goal that the incorporation of agroecological mulching practices with already available legume source can improve agroecosystem productivity and crop output.

**Effects on soil nitrogen availability:** I measured soil pools of ammonium (NH$_4^+$) and nitrate (NO$_3^-$), forms of reactive inorganic nitrogen immediately available for plant uptake.

Inorganic nitrogen concentrations are important variables to measure as changes can give insight into availability of the limiting nutrient. Fertilization of soils can increase inorganic nitrogen levels (Mattson, 1980, p. 126). I hypothesized that the decomposition of the legume mulch would act as a fertilizer. I hypothesized its decomposition would increase soil NO$_3^-$ and NH$_4^+$ as the mulch organic matter is decomposed and release free reactive inorganic nitrogen. Nitrogen mineralization rates are higher when the carbon to nitrogen ratio is lower. In other words, organic nitrogen (that plants cannot use) is more quickly converted to inorganic nitrogen (that plants can use) as the mulch organic material decomposes (Chapin et al., 2011, p. 276). As a response to this, I predicted an overall plant biomass increase due to the conversion of reactive nitrogen to amino acids, which increase plant material and biomass.

**Effects on total plant biomass:** I measured dried aboveground (leaves and stems) and belowground (root) biomass for all surviving spinach and lettuce plants at the end of the experiment’s growing season.

**Aboveground:** I hypothesized that the presence of a legume mulch would increase the aboveground biomass of leafy green plant species. The higher nutrient levels would reduce nitrogen limitations and allow for increased aboveground plant growth. Studies have found that
aboveground and belowground biomass increases with increasing nutrients, specifically nitrogen (Müller et al., 2000, p. 119; Mattson, 1980, p. 119). Photosynthetic capacities also increase with increasing nitrogen availability and content in leaves (Chapin et al., 2011, p. 142; Mattson, 1980, p. 126). As photosynthesis is the process by which plants convert light energy for plant growth, biomass increases as photosynthesis increases.

*Belowground and Biomass Ratio (above to belowground):* More plant growth resources are dedicated to root production to increase nutrient uptake capacity in low nutrient environments (Müller et al., 2000, p. 115). Nutrient uptake capacity is the ability and efficiency of plants to use nutrients. Therefore, plants with adequate nutrients allocate fewer resources to root production and can dedicate more to leaf and stem production. As discussed earlier, belowground biomass also increases when a plant is nutrient deprived. Belowground biomass would increase proportionally larger than aboveground in plants that are nutrient deprived, and plants in the same species with a higher leaf to root ratio are likely less nutrient deprived. Research has also supported that for herbaceous species, aboveground to belowground biomass ratios are higher in high nutrient conditions (Müller et al., 2000, p. 115). I hypothesized that the aboveground to belowground biomass ratio would be higher in treatment plants than in the control plants because treatment plants would allocate fewer resources to root production.

*Root length:* One of the most important factors in determining plant nutrient absorption is their root length, even more important than root biomass (Chapin et al., 2011, p. 241). Just as increased root biomass may indicate nutrient deprived plants, root length and depth are indicators that a plant is “searching” for nutrients. Plants of the same species grow longer and thinner roots with more root hairs as a response to low nutrient supply (Chapin et al., 2011, p. 242). A stronger measurement of nutrient deficiency is lateral root elongation as opposed to vertical elongation,
and increased root hair growth (Giehl & von Wirén, 2014, p. 513-515; López-Bucio et al., 2003, p. 280). However, these methods to obtain this were not feasible in the scope of this research, and so I focused on root length. I hypothesized that root length will be lower in treatment groups because nutrient availability will be higher.

**Effects on ecosystem feedbacks**: Soil respiration rates (carbon dioxide (CO₂) flux) were measured weekly.

Soil respiration is a combined measurement of root respiration and soil microbial activity and represents CO₂ release. It is a process that provides energy and nutrients to plants, in order to generate biomass in other processes (Chapin et al., 2011, p. 158). Therefore, it is an important measurement to describe plant productivity, especially as it positively correlates with gross primary productivity (GPP), or total ecosystem photosynthesis (Chapin et al., 2011, p. 161). Soil respiration is also an important metric when considering total greenhouse gas emission of agriculture, specifically CO₂. Schlesinger & Andrews (1999) note that small changes in soil respiration scale up to more significant global carbon cycle effects (p. 7). Therefore, changes in agricultural practices, such as reducing soil tillage practices by allowing crop fallow, are important factors to consider when manipulating agroecosystems. I hypothesized that soil respiration would increase with the addition of a legume mulch. This would be due to the higher nitrogen content of the mulch substrate for microbes, resulting in a larger carbon loss from soils than from non-legume mulch treatments. There is a direct relationship between respiration and net primary production (NPP) (GPP – respiration), meaning respiration increases with increasing soil organic carbon (from decomposition of the legume mulch) as long as temperature is high enough for decomposition (Schlesinger & Andrews, 1999, p. 8; Chapin et al., 2011, p. 161).
**Broader Impacts:**

The goal of the experimental portion of this research was to provide a quantitative understanding of the immediate and small-scale effects of mulching treatments on carbon and nitrogen dynamics. While most often the concept of nitrogen fixation from the Haber Bosch process, an industrial chemical process that creates synthetic fertilizers, and subsequent fertilizer application is connected to large scale, industrial agricultural practices, the same knowledge of nitrogen can be applied to small scale agroecosystems, such as home gardens. To my knowledge there has been little research into the effects of specifically applying a dried legume mulch in small scale agroecosystems on nitrogen and carbon fluxes. This research has potential to provide insight into a possible method to improve small scale agricultural productivity and sustainability through accessible means of legume mulching. The specific use of the invasive species crown vetch as the legume mulch may provide the concurrent benefits of soil fertilization while simultaneously reducing the local population of a plant considered “weedy” and invasive.
4. Background

i) Biological importance of nitrogen:

By adding a legume mulch (*Securigera varia*) to the treatment barrels, this research is intending to incorporate additional inorganic reactive nitrogen to these barrels. Therefore, the importance of nitrogen for plant growth and agricultural systems is of central concern for the research of this thesis. Among other nutrients such as phosphorous, potassium, magnesium, and others, nitrogen is generally the most limiting nutrient for plant growth (Blumenthal et al., 2008, p. 51; López-Bucio et al., 2003, p. 280). In other words, the supply or availability of this nutrient restricts possible plant productivity and growth. Nitrogen is vital in the creation of amino acids that are important protein building blocks, and nucleic acids that determine genetic characteristics (Blumenthal et al., 2008, p. 51; Galloway & Cowling, 2002, p. 64). Nitrogen is necessary in many processes of plant tissue growth, and is one of the bases for plant life, and therefore, all life.

Nitrogen is abundant as nitrogen gas (N₂), comprising about 80 percent of the atmosphere (Galloway & Cowling, 2002, p. 64). However, plants are only able to utilize nitrogen in the inorganic reactive forms of ammonium (NH₄⁺) and nitrate (NO₃⁻) (Ribaudo, 2011, p. 1; Galloway & Cowling, 2002, p. 64). Plants assimilate NH₄⁺ after NO₃⁻ has been reduced (Masclaux-Daubresse et al., 2010, p. 1143). The conversion of the gaseous nitrogen to reactive, inorganic nitrogen is termed “nitrogen fixation”. The strength of the triple bond between the two nitrogen atoms in N₂ makes breaking this bond energy intensive and so nitrogen fixation is only carried out in specialized biological processes. Until humans discovered a way to fix nitrogen industrially, plants and anthropogenic agriculture relied entirely on these biological processes.
Microorganism nitrogen fixation supplies reactive nitrogen in the form of ammonia (NH₃). The most relevant nitrogen-fixing organisms to agriculture are rhizobia bacteria; they inhabit plant root nodules in a symbiotic relationship where the bacteria fix nitrogen available for plant use as NH₃ and in return the rhizobia receive carbohydrates (Snyder et al., 2009, p. 258; Morgan & Connolly, 2013, p. 6-7). Legumes are plants that support this symbiotic relationship between such bacteria and plant roots, and so are termed “nitrogen-fixers”.

Natural nitrogen fixation processes limited possible biological productivity; limited supply of nitrogen restricts maximum plant growth, which means limited food supply to sustain larger animal populations. In anthropogenic terms, this limited agricultural production, and thus the human population. The limiting nutrient nitrogen thus created organismal competition (Galloway & Cowling, 2002, p. 64; Mattson, 1980, p. 119). In the mid-19th century humans realized the importance of reactive nitrogen for plant growth and agriculture, and in the same century, humans became aware of the process of biological nitrogen fixation (Galloway & Cowling, 2002, p. 64). Before synthetic fertilizers, humans adapted other mechanisms to obtain reactive nitrogen. Often up to half of farmland contained legume or cover crops (Peoples et al., 2004, p. 53). Crop residue, manure application, and nitrate obtained from guano and nitrate deposit mines were other ways of introducing reactive nitrogen to farm systems (Galloway & Cowling, 2002, p. 64). Legume growth was the primary method by which “new” nitrogen could be incorporated into an agroecosystem, and therefore inorganic nitrogen limited human population growth.

**ii) Introduction of synthetic fertilizers and their effects:**

In 1913, the Haber-Bosch process was discovered (Galloway & Cowling, 2002, p. 65). This process is the method by which humans are able to fix reactive nitrogen in the form of synthetic
fertilizers on industrial scales. This chemical process requires high temperature and high pressure conditions. The balanced chemical equation is as follows:

1. \[0.88\text{CH}_4 + 1.26\text{air} + 1.24\text{H}_2\text{O} \rightarrow 0.88\text{CO}_2 + \text{N}_2 + 3\text{H}_2\text{O}\]
2. \[\text{N}_2 + \text{H}_2 \rightarrow 2\text{NH}_3\]

Therefore, the production ratio of the greenhouse gas \(\text{CO}_2\) to \(\text{NH}_3\) is 0.88:2 (Snyder et al., 2009, p. 256). Fertilizers made through the Haber-Bosch process can be applied in various forms, such as urea, anhydrous ammonia, and fluid urea-ammonium nitrate (Snyder et al., 2009, p. 256). These fertilizers became invaluable to increasing crop yields. Now, synthetic fertilizers are closely tied to industrial-scale agriculture. Of the \(~140\) Tg of nitrogen fixed each year, \(~80\) Tg comes from synthetic fertilizers (Crews & Peoples, 2004, p. 281). From the 1890 value of \(~15\) Tg, this is a significant increase in reactive nitrogen produced by humans (Galloway & Cowling, 2002, p. 65). Synthetic fertilizer accounts for a little more than half of input nitrogen for crops, and the remaining comes from biological fixation, crop residues, and manure (Mosier et al., 2004, p. 6). On average, fertilizer has led to a 40 percent per capita increase in food production (Mosier et al., 2004, p. 4). Research has indicated that at least 40 percent of our current global population is alive due to agricultural increases made possible by the Haber-Bosch process (Crews & Peoples, 2004, p. 279).

Despite apparent success of synthetic fertilizers, which provide a less labor-intensive alternative to legume cropping, nitrogen use efficiency (NUE) is rarely optimized and overuse leads to ecological degradation. NUE is the ratio of total nitrogen in plants and their biomass after growth to the total nitrogen supplied to the system before plant growth (Masclaux-Daubresse et al., 2010, p. 1141). Plant species and external conditions, such as soil pH and water availability, affect the nutrient requirements. Masclaux-Daubresse et al. (2010) estimate that 50 to 70 percent of reactive nitrogen available in soils is lost (p. 1141). Galloway & Cowling (2002)
estimate that of the ~14 percent nitrogen transport efficiency, this large loss occurs in the field to crop stage (p. 66). This is partly due to the volatile, mobile nature of reactive nitrogen as ions (Peoples et al., 2004, p. 53). Nitrogen is lost to the environment through soil erosion, runoff, ammonia volatilization, denitrification/nitrification, and leaching, therefore affecting water, terrestrial, and atmospheric systems both locally and more globally (Ribaudo, 2011, p. 3; Peoples et al., 2004, p. 57).

The Haber-Bosch process and subsequent synthetic fertilizer production and use has positively improved food production and crop nutritional value (Peoples et al., 2004, p. 63). However, there are overwhelming negative ecological effects on ecosystems of over-applying reactive nitrogen sources. Denitrification, caused by soil microorganisms at higher temperatures, create nitrous oxide (N\textsubscript{2}O) (Snyder et al., 2009, p. 259). N\textsubscript{2}O depletes stratospheric ozone, acts as an air pollutant, and contributes to climate change as a potent greenhouse gas (Peoples et al., 2004, p. 64; Crews & Peoples, 2004, p. 284). Leaching of reactive nitrogen causes soil and water acidification through the release of H\textsuperscript{+} ions from NH\textsubscript{4}\textsuperscript{+} (Peoples et al., 2004, p. 62). The most well-known effect of fertilizer use is eutrophication, an excess of nutrients in an aquatic ecosystem. Nitrogen is not only a limiting nutrient for terrestrial plant systems, but also estuary aquatic ecosystems (Peoples et al., 2004, p. 65). Runoff water carrying excess reactive nitrogen not only affects local water systems, but eventually becomes deposited in larger estuarine systems. The nitrogen nutrient influx creates algal blooms that deplete oxygen levels, causing hypoxia. Starved of oxygen, many marine populations crash, causing biodiversity shifts. A striking example of this is the New Jersey sized algal bloom that occurs in the Gulf of Mexico (Crews & Peoples, 2004, p. 283).
iii) Exploring synthetic fertilizer alternatives:

Though it may be true that the effects of nitrogen loss may remain comparable between the same amounts of applied inorganic fertilizers and naturally-occurring nitrogen sources (Crews & Peoples, 2003, p. 279), there are ecological benefits to mulching and related systems. The application of synthetic fertilizers leaves soil microbes without a source of organic carbon matter to break down as energy. The result is that soil microbes break down crop roots, which creates less productive plants, which requires more synthetic inputs, creating an unsustainable cycle. The use of crops for fallow and mulching practices provides microbes with additional organic matter, requiring fewer external outputs, and can therefore be more sustainable agricultural options. These ecological effects and scarcity of further arable land expansion indicate the necessity of increasing NUE to avoid excess levels of reactive nitrogen. As stated by Mosier et al. (2004), “Because of the limitation on arable land area and the need to minimize the pollution of waters and the atmosphere, the efficiency of the use of fertilizer N must be improved to sustain land quality to feed the growing population” (p. 3-4). Best management practices (BMP) focus on improving source, timing, and method of fertilizer applications (Masclaux-Daubresse et al., 2010, p. 1153; Crews & Peoples, 2004, p. 285). This research explores legume mulch as a method of BMP.

There are further social incentives to explore reactive nitrogen application through legumes. The distribution of fertilizer availability is uneven, particularly in Sub-Saharan Africa (Mosier et al, 2004, p. 3-4). These countries’ total nitrogen balance is negative, indicating a need to introduce reactive nitrogen through fertilizers or fixation (Ledgard, 2001, p. 43). According to Crews & Peoples (2004), “the level of poverty in this region is such that use of fertilizers and other expensive inputs is prohibitive” (p. 287). Some countries are almost completely dependent
on synthetic fertilizers. Europe and North America produce the majority of reactive nitrogen, both in total and per capita (Galloway & Cowling, 2002, p. 70). In some global regions, synthetic fertilizers are a less desirable option. Regions that still rely heavily on legume rotations include sparsely populated areas and resource poor regions with marginal lands (Crews & Peoples, 2004, p. 280). Furthermore, with raised awareness of the effects of over-application of nitrogen fertilizers, there is increased demand of organically grown produce (Crews & Peoples, 2004, p. 280).

This research explores the possible viability of incorporating an already available nitrogen source in the majority of the United States, crown vetch, as soil organic matter to increase nitrogen levels. This research and related legume practices may show potential to provide a low cost, naturally occurring, readily available sources of reactive nitrogen for small scale agriculture. Legume incorporation and mulching practices have strong and important historical usage, as will be discussed below. For these reasons, this research explores the possible effects of legume mulch on plant productivity, rather than synthetic fertilizers. This thesis is not to argue that all food production needs to be done without synthetic fertilizers, but it advocates exploration of naturally occurring sources of nitrogen that can be efficiently and effectively applied to agroecosystems in some cases. There may not be a strong ecological argument to prefer legume fertilization over synthetic fertilizers when similar concentrations of nitrogen are applied. But because synthetic fertilizer is not equally accessible to all, knowledge of proper application may be less available to small scale farmers, and they are more energetically and financially demanding, there are benefits to legume produced reactive nitrogen.
iv) Negative Impacts of industrial agriculture:

The above section discussed the importance of synthetic fertilizers in the growth of industrial agriculture, and the ecological and social effects of these fertilizers. Industrial agriculture has been touted as the necessary method of creating enough food to feed the world’s rapidly growing population (Altieri & Toledo, 2011, p. 589). While it has been successful in raising crop production, it doesn’t fulfill the promise of reducing global hunger (Hecht, 1995, p. 16). The distribution of income, food, and agricultural resources is not equal. In some areas industrial agriculture actually undermines food security by usurping smallholder land and replacing it with unsustainable monoculture and biofuel crops, increasing rural inequality (Hecht, 1995, p. 16). By 2008, a rise in staple food prices created food insecurity for over 75 million people, and prices continue to rise 10 percent annually (Altieri & Toledo, 2011, p. 589-590). Industrial agriculture removes the vital social component of agriculture that takes into account the effects and value of regional economies and cultural significance in agriculture. According to Hecht (1995), the growth of agriculture “shifted the view of nature from that of an organic, living entity to one of a machine…[industrial agriculture] essentially dismissed other forms of scientific knowledge as superstitions” (p. 3). Industrial agriculture undermines the importance of other ways of knowing, such as indigenous agricultural practices, representing a form of societal harm.

v) Rising influence of agroecology:

The field of agroecology responds as an alternative to the now dominant paradigm of industrial agriculture (Mendez et al., 2013, p. 12). It is a transdisciplinary field that explores sustainable agricultural processes and researches the ecological factors that influence agricultural outcomes. Mendez et al. (2013) argue transdisciplinary approaches “value and integrate different
types of knowledge systems” and apply “conditions of mutual respect between cultures and knowledge systems” (p. 8). In the case of agroecology, these knowledge systems include, but are not limited to, natural sciences like ecology and climate studies, political and economic studies, and knowledge of traditional and indigenous agriculture. It is important that this field incorporate both natural sciences and social sciences perspectives (Mendez et al., 2013, p. 6). Vandermeer & Perfecto (2013) argue “The intersection of traditional knowledge with modern ecology could result in the generation of knowledge that is simultaneously deep and broad” (p. 76).

Agroecology is based on a bottom up approach that values traditional and indigenous agricultural practices that are driven by both social and economic factors (Altieri & Toledo, 2011, p. 588; Hecht, 1995, p. 14). Traditionally, farmers globally have adapted to the specific needs of the climate, soils, and other ecosystem factors. The history of this accumulated knowledge from centuries of trial and error creates a knowledge base that modern science would be hollow without. For example, coffee is naturally an understory plant, and rather than grown as a monoculture model typical of industrial agriculture, farmers in Latin America continue to grow the crop in forested areas (Vandermeer & Perfecto, 2013, p. 85).

Agroecology began to grow as a recognized field in the 1970s as a social component that was more frequently incorporated into agricultural literature (Hecht, 1995, p. 1). It is being more often and more broadly recognized, as evidenced by its implementation in policy fields, agroecology degrees at universities, and its use in farm workers organizations (Mendez et al., 2013, p. 4-5). This perspective sees agroecology as a newly emerging field closely tied to the natural and social sciences. Another perspective views agroecology as a political movement, from which grew the concept of food sovereignty (Altieri & Toledo, 2011, p. 587). One of the most influential organizations fighting for food sovereignty through the lens of agroecology is La
*Via Campesina,* arguing against the dominant perspective of food as a commodity (Vandermeer & Perfecto, 2013, p. 77). Finally, another perspective recognizes agroecology as having grown in parallel with traditional agriculture. Despite its relatively recent recognition in Western academia, agroecological practices have been implemented since humans began pursuing agriculture (Hecht, 1995, p. 1). Agroecology is a combination of these perspectives, growing in the academic science field and a rising political movement rooted in traditional agriculture.

The transdisciplinary nature and the integral role traditional, indigenous agricultural knowledge plays in agroecology create a participatory and representative field. There are social benefits to agroecology, as it gives voice to populations typically with less clout. The participatory nature intends to empower smallholder farmers and communities that grow and consume food at a more local level. Mendez et al. (2013) remind readers that agricultural organization at any level requires careful examination of power dynamics and ability to access resources so that all participants benefit (p. 10). The emphasis on sustainable methods in agroecology create ecological benefits. According to Altieri (1995), fundamental practices in sustainable agriculture include mulch and cover crop farming, organic matter soil addition, and legume intercropping (p. 92). This thesis attempts to incorporate the motivations of these practices through vetch mulching. Some sustainable agricultural examples implementing vetch include hairy vetch to improve nitrogen fixation, spring vetch to suppress weeds, and common vetch to increase microbial activity (Silva & Moore, 2017, p. 5). These ecological benefits expand to economic benefits when local farmers can use already available materials for agroecosystem services rather than purchasing fertilizers, pesticides, and other agroecosystem enhancements. The broad importance of incorporating agroecological practices is to actively
oppose the industrial agricultural model that is ecologically and socially unsustainable (Altieri & Toledo, 2011, p. 591).

In addition to incorporating ideas of sustainable agricultural practices, this research focuses on the importance of small-scale agriculture. Today, the implementation of agroecology is embodied through the work of smallholder farming. Over one billion farmers work without adequate supplies or funds in “extreme marginality” (Hecht, 1995, p. 17) and smallholder farms are generally characterized by low income agriculture (Altieri, 1995, p. 143). However, there are approximately 750 million sustainable smallholder farmers practicing resource conservation practices, “a testament to the remarkable resiliency of traditional agroecosystems in the face of continuous environmental and economic change” (Altieri & Toledo, 2011, p. 591). Additionally, Altieri (1995) cites that more than 60 percent of agriculture is done using traditional and subsistence methods, based on “centuries of cultural and biological evolution that has adapted it to local conditions” (p. 107). Evolved to the local climate and land systems, smallholder agricultural systems are often more resilient. For example, their crop and soil biodiversity are linked with climate resiliency (Altieri & Toledo, 2011, p. 596).

Another model of sustainable agriculture is low-input agriculture, which attempts to reduce chemical inputs such as fertilizer and pesticides. As explored above, motivations include environmental concerns, economic stressors, and preserving crop quality. Local farming models, implementing small scale and low-input agriculture, are slowly becoming more economically feasible in the United States (Johnson, 2012). There is also more community engagement through the occurrence of Community Supported Agriculture (CSAs), where people can buy shares of small farms in return for produce (Mass.gov: CSA, n.d.). According to the 2012 Census of Agriculture Report, Massachusetts has 431 CSAs (the highest percentage CSAs of total farms
in the country), and 198 organic farms (Mass.gov: Organic Farms, n.d.). This indicates that alternatives to synthetic fertilizers are relevant to agricultural systems both globally and locally.

vi) Scope of this research in agroecology:

Depending on the definitions used of agroecological agriculture and organic farming, the two fields can intersect greatly. Both are based on the principle of reducing inputs from synthetic sources and reducing ecological impacts. According to the International Federation of Agricultural Movements (IFOAM), organic agriculture “relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved” (Silva & Moore, 2017, p. 2). Definitions such as this would suggest agroecology and organic agriculture are more similar than distinct. However, while agroecological approaches are often organic, organic farming does not always incorporate the societal or cultural components of agroecology as strongly (Altieri & Toledo, 2011, p. 588). I loosely associate the research of this paper as “agroecological” in that it incorporates a plant, crown vetch, that is already introduced into the local Northeastern United States landscape. This research also aligns with agroecological practice of adding green manure and other mulching practices (Silva & Moore, 2017, p. 3). However, future research on this topic could increase the incorporation of agroecology by considering the societal implications and knowledge of the local community of the New England area.

There are common ecological components to traditional agricultural practices that address issues from soil fertility to water and climate concerns to pests (Altieri, 1995, p. 110).
Related to this research is the objective to maintain soil fertility through the recycling of nutrients as manure and plant debris or integrated crop systems that include legumes (Altieri, 1995, p. 111). The two agroecological processes most applicable to this research are cover cropping and mulching. Altieri (1995) defines cover cropping as "the practice of growing pure of mixed strands of annual or perennial herbaceous plants to cover the soil of croplands for part or all of the year" (p. 219) and living mulches are “legume cover crops used in association with annual crops” (p. 226). Cover crop benefits include improving soil structure and reducing erosion impact, incorporating and making available biologically fixed nitrogen and recycling nutrients, and suppressing pests and weeds (Stivers-Young, 1998, p. 60; Altieri, 1995, p. 219, Silva & Moore, 2017, p. 4). Vegetable systems are particularly benefitted by cover crops because they provide little soil structure, and once harvested, they returned little litter for soil organic matter the following season.

Because crown vetch, the nitrogen input of this research, was not grown in the same soils as the output crops (spinach and lettuce), the nitrogen input of this research is defined as “mulch” rather than “cover crop”. However, the same ecological principles that allow cover crops to increase soil nutrients are applicable to this study. Specifically, the ecosystem services are most similar to living mulches, defined above, through its incorporation of legumes. Winter killed cover crops best convert reactive nitrogen to nitrogen-rich biomass, which can be more easily incorporated into the soil for spring vegetable crops (Stivers-Young, 1998, p. 62). Therefore, the incorporation and decomposition of this nutrient rich biomass is the important factor. This parallels the decomposition of crown vetch in this research to increase soil nutrients. There is also overlap of using vetch plants as cover crops, including hairy vetch (Vicia villosa), in the Northeast and that of the crown vetch used as a nutrient addition in this research (Stivers-Young,
In summary, cover crops are often left to decompose, producing some of the same ecosystem services as mulch. One missing component, however, is that cover crop growth initially sequesters more nutrients that would have otherwise been leached out of the soils (Silva & Moore, 2017, p. 6).

In summary, this research recognizes the remarkable impact synthetic fertilizers have historically had on increasing agricultural productivity, and the necessity of improving NUE to minimize the negative ecological consequences that come with this impact. Due to the economic and social barriers of synthetic fertilizer use, this research attempts to identify an already available, natural alternative for small scale agriculture through the application of a legume mulch. This research is inspired by the conceptual framework of the agroecology movement and historical cover crop and living mulch practices.
5. Methods

i) Study design:

We conducted this study in the Edible Ecosystem, an experimental garden, at Wellesley College in Wellesley, MA, USA. The site is within a temperate climate, where mean annual temperature is 9.28°C and mean annual precipitation is 120.0cm (“Data Tools: 1981-2010 Normals”). Soils at the experimental plots were not replaced at the time of barrel installation in Spring 2015, though the area had been sheet-mulched (smothered in cardboard held down by a tarp) for the previous 2 years. In 2015, the barrels were planted with tomatoes and in 2016 soils were mixed with biochar (a soil enhancer and carbon storing product). Over the summer, students in Professor Jackie Matthes’ lab determined background data measurements: ammonium (NH$_4^+$) and nitrate (NO$_3^-$) concentrations in soil, as well as soil pH, temperature, and moisture. I conducted the experiment across 24 replicated open-bottomed barrels with a diameter of 55cm and with sides ~43 cm length into the soil (Figure M1). I used a random number generating algorithm to assign barrels to either the control group (received salt marsh hay mulch but not crown vetch mulch) or the treatment group (received both salt marsh hay and crown vetch mulches).
Figure 4. Barrel layout diagram. Treatment groups were assigned randomly using a number generating algorithm.

On 12 September by 16:00, I programmed 22 Onset HOBO Pendant® loggers and implanted them 6 cm from the soil surface in 23 of the 25 barrels to monitor hourly soil temperature for the duration of the experiment. A nearby campus weather station continuously measured ambient humidity, temperature, and precipitation.

One month prior to the start of the experiment, I harvested crown vetch (Securigera varia) from the Wellesley College campus for the mulch treatment preparation. It is an invasive species growing on garden hillsides. I harvested aboveground biomass while plants were still green to optimize nutrient content and removed seeds to avoid accidental growth and subsequent nutrient uptake of vetch seedlings. I left the mulch to air-dry under low humidity conditions for approximately two weeks. I finely chopped about half of the dried mulch plant with a lawnmower, and finely chopped the other half into 1-5cm long pieces with garden shears. The small size of the crown vetch incorporated in soil allowed for more rapid decomposition, and
subsequent nutrient deposition, with more evenly distributed nutrients. I used salt hay, trimmed to ~8cm pieces, as a mulch topper for both control and treatment plots to reduce weed growth and retain soil moisture.

One day prior to planting (6 September 2017), I turned the soils within each barrel to a depth of 10cm. On planting day (7 September 2017), the treatment plots received 83.3 ± 2.41g of mulched crown vetch. I mixed mulch into the top 5cm of the soil of each barrel. In control plots, I turned the soils to a depth of 5cm, but did not add crown vetch. Both control and treatment plots received a top layer of salt marsh hay with approximately 115g dry biomass. I planted two spinach (*Spinacia oleracea*, variety ‘Tyee’) and two lettuce (*Lactuca sativa*, variety ‘Romaine’) seedlings in each barrel, with spinach and lettuce plants diagonally paired (Fig. 4). I constructed a protective mesh sheeting secured to the barrel exterior to deter herbivory. I replaced these on 21 September with an organic chemical herbivory repellant. After planting, I applied an approximately 30 second stream of water to each barrel. After transplant, I applied approximately 15-20 seconds (1.00-1.25L) of water daily to each barrel. Plants were harvested 07, 08, and 10 November 2017.

**ii) Soil inorganic nitrogen measurements:**

The Matthes EcoLab summer research group collected soils before planting (8 July 2017) and I collected soils after the plant harvest (11 November 2017) for soil nitrate (NO₃⁻) and ammonium (NH₄⁺) concentrations. Inorganic nitrogen of field wet soils from each barrel was extracted by adding 40 mL 2 M KCl to 14 g soil in a centrifuge tube. I placed tubes on a shaker tray for one hour. I filtered tube contents and stored extracts at 10°C for a month until measurement. I dried a field wet soil sub-sample from each barrel to constant mass in order to
determine the water content within each soil sample. An Astoria-Pacific Discrete Analyzer (Astoria-Pacific, Inc., Clackamas, OR, USA) determined soil nitrate (NO$_3^-$) and ammonium (NH$_4^+$) concentrations by colorimetric analysis, with two replicates per sample. Concentrations of NO$_3^-$ and NH$_4^+$ in ppm from the analyzer output were converted to mg/kg soil, correcting for field wet soil water content. I analyzed differences in inorganic nitrogen concentrations between control and treatment groups in R Studio using a Student’s t-test.

iii) Plant structure and biomass measurements:

I took downward-looking photo of each of the 24 barrels weekly to determine approximate plant coverage and growth. Starting on 7 November 2017, I harvested all spinach and lettuce plants within a period of four days. In the lab, I separated the aboveground (stems and leaves) and belowground (roots) portions of the plant. I weighed leaf samples at field weight and then dried to constant mass and weighed again for dry biomass. I added weights from weekly leaf collections (collected to preventing bolting) to the dry biomass values to find approximate total produced biomass throughout the growing season. I measured only dry biomass for the roots. I analyzed differences in plant biomass among groups using a linear mixed effects model with random effects captured by the five barrel spatial groups, which likely occurred due to herbivory (described in the Discussion & Conclusion). At the time of harvest, I measured root length as the approximate longest root, collected without dislodging soil structure of roots (before cleaning). I analyzed differences among plant root length by treatment group using a Student’s t-test.
iv) Soil Flux Measurements:

On 15 September 2017, I installed a PVC collar 7.62cm in diameter and 5cm in height into the center of each barrel. I measured the height above the soil of each chamber after installation to find the chamber volume above the soil surface. I measured soil carbon dioxide (CO₂) & methane (CH₄) fluxes weekly using a Picarro cavity ring-down spectrometer greenhouse gas analyzer by attaching a PVC cap to each chamber with fittings to ensure a closed circulation between the chamber and analyzer. The Picarro measured each chamber for two minutes at each weekly sampling event. I noted the start time of each flux measurement, and calculated fluxes as the change in CO₂ or CH₄ concentration over the two-minute interval for each measurement. Concurrent with flux measurement, I measured soil moisture weekly with a single point measurement near the center of the barrel using a handheld TDR probe.

CH₄ fluxes were highly variable with no clear pattern, so I did not analyze them in this research. I analyzed soil respiration (CO₂ flux) using a linear mixed effects model with random effects on each barrel, to appropriately account for the weekly repeated measures design. Fixed effects within the model were soil temperature and soil moisture at the time of each measurement, and treatment group. I conducted The ANOVA for soil flux without a log transform of CO₂ because variables were normally distributed.
6. Results

i) Effects on soil nitrogen availability:

Soil reactive inorganic nitrogen concentrations:

Figure 5. Soil inorganic nitrogen pools measured immediately following plant harvest. Left: Ammonium (NH$_4^+$) concentrations were not significantly different between the control (n=12) and treatment (n=12) groups (Student’s t-test, p > 0.05). Right: Soil nitrate (NO$_3^-$) concentrations were marginally significantly different between the control (n=12) and treatment (n=12) groups (Student’s t-test, p = 0.07).

There was no significant difference between treatment group NH$_4^+$ concentrations, but there was for NO$_3^-$ (Fig. 5). In post-experiment soils, the concentration of NO$_3^-$ was significantly higher in the treatment group than the control group. The mean concentration of NO$_3^-$ in the treatment (5.59 ± 1.70 mg/kg) was higher than the mean concentration of the control group (4.56 ± 0.872 mg/kg) (Fig. 5 right). The mean concentration of NH$_4^+$ in the control group (26.0 ± 7.52 mg/kg) was lower than the mean concentration of the treatment (27.2 ± 8.64 mg/kg), although the difference was not significant (Fig. 5 left).
Figure 6. Changes in soil inorganic nitrogen pools pre- and post-experiment. Left: Changes in soil ammonium (NH$_4^+$) concentrations pre- and post-experiment were not significantly different between the control (n=12) and treatment (n=12) groups (Student’s t-test, p > 0.05). Right: Changes in soil nitrate (NO$_3^-$) concentrations pre and post experiment were not significantly different between the control (n=12) and treatment (n=12) groups (Student’s t-test, p > 0.05). Pre-experiment NH$_4^+$ and NO$_3^-$ concentrations were measured when barrels were unplanted in July 2017. Post-experiment concentrations were measured immediately following plant harvest.

There was no significant difference between treatment or control group NO$_3^-$ concentrations or NH$_4^+$ concentrations (Fig 6). NO$_3^-$ concentrations remained similar between pre- and post-experiment samples (Fig. 6 right). The difference between NH$_4^+$ pre- and post-experiment samples was more profound (Fig. 6 left). The mean concentration of NO$_3^-$ in the control group (0.448 ± 2.45 mg/kg) was also lower than the mean concentration of the treatment (1.39 ± 3.59 mg/kg), though this difference was not significant (Fig. 6 right). Similarly, the mean concentration of NH$_4^+$ in the control group (21.62 ± 7.86 mg/kg) was lower than the mean concentration of the treatment (24.05 ± 9.37 mg/kg), though this difference was not significant (Fig. 6 left).
Table 1. Summary of nitrogen availability Student’s t-test results. `not significant, *marginally significant (p<0.1), **significant (p<0.05)

<table>
<thead>
<tr>
<th>response variable</th>
<th>p-value</th>
<th>mean ± stdev (treatment)</th>
<th>mean ± stdev (control)</th>
<th>effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>soil NH4+ post experiment (mg/kg)</td>
<td>0.713*</td>
<td>27.2 ± 8.64</td>
<td>26.0 ± 7.52</td>
<td>1.23 ± 3.31</td>
</tr>
<tr>
<td>soil NH4+ pre-post experiment (mg/kg)</td>
<td>0.498*</td>
<td>24.1 ± 9.37</td>
<td>21.6 ± 7.86</td>
<td>2.43 ± 3.53</td>
</tr>
<tr>
<td>soil NO3- post experiment (mg/kg)</td>
<td>0.074*</td>
<td>5.59 ± 1.69</td>
<td>4.56 ± 0.872</td>
<td>1.03 ± 0.549</td>
</tr>
<tr>
<td>soil NO3- pre-post experiment (mg/kg)</td>
<td>0.46*</td>
<td>1.39 ± 3.59</td>
<td>0.448 ± 2.45</td>
<td>0.943 ± 1.25</td>
</tr>
</tbody>
</table>

ii) Effects on total plant biomass:

**Biomass:**

![Figure 7. Total post-experiment spinach and lettuce aboveground dry biomass. Left: Total spinach aboveground biomass. The treatment spinach plants (n = 18) and control spinach plants (n = 22) were harvested within a period of five days. Right: Total lettuce aboveground biomass. The treatment lettuce plants (n = 24) and control lettuce plants (n = 24) were harvested within a period of five days. When testing for biomass differences by species, the treatment group was marginally significantly lower than the control group for lettuce (linear mixed effects model with random effects captured, p = 0.09), but not significantly so for spinach (linear mixed effects model with random effects, p > 0.05).

Aboveground biomass was marginally significantly lower in the treatment group for lettuce (Fig. 7 right) and not significantly lower in the treatment group for spinach (Fig. 7 left). I applied a Student’s t-test model with random effects at the barrel spatial level (groups) to capture...
clustered herbivory during the experiment. The barrel group random effect size was an important factor in describing aboveground biomass, though much larger for lettuce than spinach (Table 2).

The biomass of lettuce leaves was also significantly lower in the treatment (mean = 6.06 ± 3.78 g) than the control (mean = 9.81 ± 4.32 g) (Fig. 7). The biomass of spinach leaves was lower in the treatment (mean = 2.85 ± 2.95 g) than the control (mean = 3.41 ± 2.51 g) (Fig. 7), although not significantly.

Belowground biomass was not significantly different between in the treatment group and control group for lettuce (Fig. 8 right) or spinach (Fig. 8 left). I applied a Student’s t-test model with random effects at the barrel spatial level (groups) to capture clustered herbivory during the experiment. The barrel group random effect size was an important factor in describing belowground biomass (Table 2). Though not significant, the biomass of spinach roots was slightly lower in the treatment (mean = 0.444 ± 0.277 g) than the control (mean = 0.476 ± 0.387

![Figure 8. Total post-experiment spinach and lettuce belowground dry biomass. Left: Total spinach belowground biomass of treatment (n = 17) and control (n = 22) plants. Right: Total lettuce belowground biomass of treatment (n = 24) and control (n = 22) plants. When testing for biomass differences by species, there was no significant difference in root weight between the treatment group and the control group for lettuce or spinach (linear mixed effects model with random effects, p > 0.05).](image-url)
The biomass of lettuce roots was also slightly lower in the treatment (mean = 1.58 ± 1.04 g) than the control (mean = 1.75 ± 0.659 g) (Fig. 8).

Figure 9. Aboveground to belowground biomass ratio. Left: Spinach biomass ratio of treatment (n = 17) and control (n = 21) plants. Right: Lettuce biomass ratio of treatment (n = 24) and control (n = 22) plants. When testing for aboveground to belowground biomass ratio differences by species, the treatment group was significantly lower than the control group for lettuce (linear mixed effects model with random effects, p = 0.02), but not significantly so for spinach (linear mixed effects model with random effects, p > 0.05).

Aboveground to belowground biomass ratio was significantly lower in the treatment group for lettuce and not significantly lower in the treatment group for spinach (Fig. 9). I applied a Student’s t-test model with random effects at the barrel spatial level (groups) to capture clustered herbivory during the experiment. The barrel group random effect size was an important factor in describing aboveground to belowground biomass ratio (Table 2). The biomass ratio of lettuce was significantly lower in the treatment (mean = 4.15 ± 1.29 g) than the control (mean = 5.59 ± 2.20 g) (Fig. 9). Though not significant, the biomass ratio of spinach was lower in the treatment (mean = 6.65 ± 4.25 g) than the control (mean = 7.31 ± 3.98 g) (Fig. 9).
### Table 2. Summary of plant biomass linear mixed effects model with random effects. *not significant, *marginally significant (p<0.1), **significant (p<0.05)

<table>
<thead>
<tr>
<th>Response variable</th>
<th>p-value</th>
<th>mean ± stdev (treatment)</th>
<th>mean ± stdev (control)</th>
<th>effect size</th>
<th>barrel group effect</th>
<th>replicates (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>lettuce aboveground biomass (g)</td>
<td>0.0915*</td>
<td>6.06 ± 3.78</td>
<td>9.81 ± 4.32</td>
<td>-1.49 ± 0.861</td>
<td>9.04 ± 3.01</td>
<td>48</td>
</tr>
<tr>
<td>spinach aboveground biomass (g)</td>
<td>0.771*</td>
<td>2.85 ± 2.96</td>
<td>3.41 ± 2.51</td>
<td>-0.259 ± 0.882</td>
<td>0.473 ± 0.688</td>
<td>40</td>
</tr>
<tr>
<td>lettuce belowground biomass (g)</td>
<td>0.527*</td>
<td>1.58 ± 1.04</td>
<td>1.75 ± 0.659</td>
<td>0.148 ± 0.232</td>
<td>0.236 ± 0.486</td>
<td>46</td>
</tr>
<tr>
<td>spinach belowground biomass (g)</td>
<td>0.763*</td>
<td>0.444 ± 0.277</td>
<td>0.476 ± 0.387</td>
<td>-0.0328 ± 0.108</td>
<td>4.80e-17 ± 6.93e-09</td>
<td>39</td>
</tr>
<tr>
<td>lettuce above:below biomass ratio</td>
<td>0.0212**</td>
<td>4.15 ± 1.29</td>
<td>5.59 ± 2.20</td>
<td>-1.19 ± 0.497</td>
<td>0.487 ± 0.698</td>
<td>46</td>
</tr>
<tr>
<td>spinach above:below biomass ratio</td>
<td>0.983*</td>
<td>6.65 ± 4.25</td>
<td>7.31 ± 3.98</td>
<td>-0.0295 ± 1.37</td>
<td>0.976 ± 0.988</td>
<td>38</td>
</tr>
</tbody>
</table>

**Root length:**

Figure 10. Plant root length. Left: Spinach root length of treatment (n = 18) and control (n = 23) plants. Right: Lettuce root length of treatment (n = 24) and control (n = 24) plants. Spinach root length was marginally significantly shorter in treatment groups than control groups (Student’s t-test, p = 0.08). Lettuce root length was marginally significantly shorter in treatment groups than control groups (Student’s t-test, p = 0.07).

Root length was marginally significantly shorter in treatment groups compared to control groups for both spinach and lettuce (Fig. 10). The root length of spinach was marginally
significantly lower in the treatment (mean = 15.3 ± 4.30 cm) than the control (mean = 18.8 ± 7.15 cm) (Fig. 10 left). The root length of lettuce was marginally significantly lower in the treatment (mean = 15.0 ± 3.00 cm) than the control (mean = 16.6 ± 3.07 cm) (Fig. 10 right).

<table>
<thead>
<tr>
<th>response variable</th>
<th>p-value</th>
<th>mean ± stdev (treatment)</th>
<th>mean ± stdev (control)</th>
<th>effect size</th>
<th>replicates (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>spinach root length</td>
<td>0.0751*</td>
<td>15.3 ± 4.3</td>
<td>18.8 ± 7.16</td>
<td>-3.50 ± 1.91</td>
<td>41</td>
</tr>
<tr>
<td>lettuce root length</td>
<td>0.0709*</td>
<td>15.0 ± 3.00</td>
<td>16.6 ± 3.07</td>
<td>-1.62 ± 0.877</td>
<td>48</td>
</tr>
</tbody>
</table>

Table 3. Summary of root length Student’s t-test results. `not significant, *marginally significant (p<0.1), **significant (p<0.05)

iii) Effects on ecosystem feedbacks:

Soil Respiration:

Figure 11. Soil respiration rates throughout experiment in treatment (n=12) and control (n=12) barrels. Accounting for temperature and soil moisture and barrel effects, there was no significant difference between CO₂ flux in the treatment group and the control group (linear mixed effects model with random effects on each barrel, p > 0.05). The effect of temperature with CO₂ flux was significant (p < 0.05).

There was no significant difference of soil carbon flux between treatment and control groups over the lettuce and spinach growing season (Fig. 11). The largest difference occurred on
22 September, though still not significant (linear mixed effects model with random effects on each barrel, p = 0.130).

![Graph of soil temperature over time](image)

Figure 12. Soil temperature at the time of soil respiration measurements. Soil temperature declined in the first four weeks of the experiment, with much higher average values for the last two dates due to unseasonably warm late-fall weather.

<table>
<thead>
<tr>
<th>CO2 flux</th>
<th>p-value</th>
<th>effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>treatment/control (CO2 m⁻² s⁻¹)</td>
<td>0.608*</td>
<td>0.0604 ± 0.116</td>
</tr>
<tr>
<td>temperature (C)</td>
<td>1.69E⁻⁰⁷**</td>
<td>0.0513 ± 0.00922</td>
</tr>
<tr>
<td>soil moisture (%)</td>
<td>0.228*</td>
<td>-0.00768 ± 0.00635</td>
</tr>
<tr>
<td>barrel effect (CO2 m⁻² s⁻¹)</td>
<td>NA</td>
<td>0.0658 ± 0.257</td>
</tr>
</tbody>
</table>

Table 4. Summary of soil respiration linear mixed effects model with random effects on each barrel. `not significant, *marginally significant (p<0.1), **significant (p<0.05)`
Table 5. Summary of 22 September soil respiration linear mixed effects model with random effects on each barrel results. Mean respiration rates for control were 1.11 ± 0.361 and for treatment were 1.61 ± 0.620 (CO₂ m⁻² s⁻¹). `not significant, *marginally significant (p<0.1), **significant (p<0.05)

<table>
<thead>
<tr>
<th>22 Sept. CO2 flux</th>
<th>p-value</th>
<th>effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>treatment/control (CO2 m⁻² s⁻¹)</td>
<td>0.130`</td>
<td>0.323 ± 0.204</td>
</tr>
<tr>
<td>temperature (C)</td>
<td>0.0199**</td>
<td>0.571 ± 0.226</td>
</tr>
<tr>
<td>soil moisture (%)</td>
<td>0.804`</td>
<td>-0.00503 ± 0.0200</td>
</tr>
</tbody>
</table>
7. Discussion & Conclusion

i) Effects on soil nitrogen availability:

Post-experiment NO$_3^-$ concentrations were significantly higher in treatment groups, and NH$_4^+$ concentrations were higher in treatment, though not significantly (Fig. 5). NH$_4^+$ concentrations increased greatly from pre-experiment to post-experiment, while NO$_3^-$ remained similar (Fig. 6). Therefore, the hypothesis that inorganic nitrogen concentrations would rise was partially supported.

One potential factor that could have led to variability in inorganic nitrogen pools is that both ammonium (NH$_4^+$) and nitrate (NO$_3^-$) are dynamic within soils. NH$_4^+$ concentrations are extremely variable; the cation easily adsorbs on soil anions, can be converted to NO$_3^-$ during nitrification, returned to the atmosphere by oxidation, or absorbed by plants. As an anion, NO$_3^-$ doesn’t bind to cation exchange sites, but can be denitrified or leached out of soil into water systems. (Chapin et al., 2011, p. 277-285). I controlled for the dynamic nature of inorganic soil nitrogen by sampling all barrels at the same time point, minimizing the effects of differences in soil moisture and temperature; nonetheless, variability could have remained. Despite the numerous factors that cause high variability in inorganic nitrogen concentrations, significance between nitrogen concentrations at the same time point are still valid and warrant interpretation.

The decomposition of a legume mulch would mobilize soil organic matter, which provides nitrogen to soil microbes, which in turn supplies nitrogen to plants. Knops et al. (2002) argue that there is a time lag between the addition of mulch and its decomposition, which leads to increased soil nutrients (p. 454). It is possible that the higher NO$_3^-$ concentrations post-experiment in the treatment group can be attributed the decomposition of the legume mulch. High nitrification rates (NH$_4^+ \rightarrow$ NO$_3^-$) are indications of productive ecosystems (Chapin et al.,
However, nitrogen concentrations do not predict nitrification rates well, and so soil incubation would be an informative component to future research.

Overall NH$_4^+$ concentrations increased greatly from pre- to post-experiment, while NO$_3^-$ concentrations changed little. This indicates that 1) plants were absorbing more NO$_3^-$ than NH$_4^+$ or 2) there were low rates of nitrification. The increase in NH$_4^+$ concentrations suggest there was a nitrogen input source, possibly from the salt hay mulch or rain acidifying NO$_3^-$ or ammonia (NH$_3$). However, it is not likely caused by the legume mulch because change was not significant between treatment and control groups.

There is variability between which form of inorganic nitrogen plants prefer to utilize and when the process of nitrogen reduction occurs (Chapin et al., 2011, p. 160; Mattson, 1980, p. 126). This study did not examine further whether the crown vetch created a higher influx of NO$_3^-$ or NH$_4^+$ and whether the leafy greens energetically preferred NO$_3^-$ or NH$_4^+$ uptake. These questions could be studied in the future to apply more specific knowledge when choosing appropriately paired mulch and leafy green species. Finally, more extensive sampling of soil inorganic nitrogen levels would give insight into peak levels of nitrogen availability.

**ii) Effects on total plant biomass:**

**Aboveground biomass:**

Lettuce aboveground biomass was marginally significantly lower in the treatment group, and spinach aboveground biomass was also lower in treatment, though not significantly (Fig. 7). Therefore, results were opposite of the predicted hypothesis for lettuce, and the null hypothesis cannot be rejected for either lettuce or spinach.

These results can most likely be attributed to herbivory. Through observation during the experiment, I noticed that local herbivores, primarily deer, small rodents, and slugs, consumed
the leafy green plants in the field. Nitrogen is also an important nutrient for herbivores, which consume nitrogen from plant material. Mattson (1980) reports, “In response to this selection pressure, many herbivores have evolved specific behavioral, morphological, physiological, and other adaptation to cope with and utilize the ambient N levels of their normal haunts” (p. 119). Studies suggest that as a response, herbivores preferentially consume plants with higher leaf nitrogen levels (Ritchie & Tilman, 1995, p. 2648; Mattson, 1980, p. 132). This suggests treatment group plants may have had higher leaf nitrogen levels than the control plants as a result of legume mulch application. Legume mulch addition in treatment groups may have led to higher nitrogen soils, and higher nitrogen soils lead to higher leaf nitrogen concentrations (Chapin et al., 2011, p. 142; Hobbie, 2015, p. 357). Ultimately, this would support the overall hypothesis that incorporating a legume mulch has a positive impact on plant productivity. In order to support the conclusion of preferential herbivory due to higher leaf nutrient levels, it would be valuable to analyze and compare leaf carbon and nitrogen levels between treatment and control plants at various time points during plant growth.

It is also possible that more treatment plants were randomly consumed by herbivores due to location. While herbivory was more impactful in some barrel groups, I accounted for the barrel grouping random effects when testing for statistical significance and so is not a likely cause of the significantly lower biomass of treatment group plants. It is also possible that treatment plants produced less overall biomass than the control plants. There is research that crown vetch leaves and stems can be toxic to nonruminant herbivores (Gustine et al., 1997, p. 1107), but I have not found evidence that it is toxic to plants. As other research supports that, separately, legume cover crops and general mulching are beneficial for increasing soil nutrients (Altieri, 1995, p. 111; Silva & Moore, 2017, p. 5; Stivers-Young, 1998, p. 60; Hartwig &
Ammon, 2002, p. 689), this conclusion is also less likely.

Belowground and Ratio above to belowground:

There was no significant difference between treatment and control groups for belowground biomass for either spinach or lettuce (Fig. 8). This implies that the addition of crown vetch had no specific effect when looking solely at root biomass. However, a better indicator of plant productivity and nutrient availability is the ratio of above to belowground biomass.

The lettuce above to belowground biomass ratio in the treatment group was significantly lower than the control group, and the spinach above to belowground biomass ratio is also lower in the treatment than the control group, though not significantly (Fig. 9). These results are opposite of those hypothesized, and so the null hypothesis cannot be rejected. Interpreted on their own, these trends would suggest that treatment group plants experienced higher levels of nutrient deprivation and dedicated more resources to root growth (Müller et al., 2000, p. 115). However, because root biomass was similar between treatment and control groups, the biomass ratio is due to lower treatment aboveground biomass, likely due to preferential herbivory. Therefore, the conclusions of ratio biomass results are the same as aboveground biomass: treatment plants experienced preferential herbivory.
Root length:

Roots were significantly longer in the control group for both spinach and lettuce (Fig. 10). This supports the hypothesis that lower nutrient soils would produce longer roots to search for limiting nutrients.

The root biomass of control and treatment groups were comparable for lettuce and spinach, but root length was significantly shorter in treatment groups for both species. This indicates that treatment group plants had thicker, shorter roots and control group plants had thinner, longer roots. Thinner, longer roots may indicate the control group plants were exploring for nutrients (Chapin et al., 2011, p. 241). This supports the overall hypothesis that nutrient deficiency was lower for the treatment group as a result of legume mulch addition. However, as mentioned in the Introduction, lateral root length and root hair growth are more indicative of nutrient availability (Giehl & von Wirén, 2014, p. 513-515; López-Bucio et al., 2003, p. 280). A deeper understanding of root structural differences is necessary to fully support the hypothesis.

iii) Effects on ecosystem feedbacks:

Respiration:

Throughout plant growth, there was no significant difference between CO₂ flux in the treatment group and the control group (Fig. 11). Therefore, the null hypothesis cannot be rejected. The effect of temperature with CO₂ flux was significant (Fig. 12). The significant interaction between soil respiration and soil temperature in this research was expected, as respiration is positively correlated with increasing temperature, which increases soil microbial activity (Schlesinger & Andrews, 1999, p. 10; Liu et al., 2005, p. 284). Research also supports a strong positive correlation between soil moisture and soil respiration (Rochette et al., 1991, p.
190), and so it was surprising there was no significant interaction between these two variables. However, this could have been due to the fact that the plots were watered throughout the experiment, so soil moisture remained relatively constant.

There are two primary factors that affect soil respiration rates: root respiration and microbial activity (Liu et al., 2005, p. 285). Research suggests that morphological traits, including root length and diameter, may affect soil respiration rates (Jia et al., 2013, p. 579; Makita et al., 2009, p. 579). Due to longer root length, control group root respiration rates may be higher. On the other hand, soil respiration due to microbial processes in the treatment group may be higher due to the decomposition of the legume mulch. These two effects on total soil respiration may have balanced out to produce similar soil respiration rates between treatment and control groups. However, research specifically linking root length and root respiration of leafy greens is minimal and so I conclude that soil respiration alone does not support the overall hypothesis.

The largest difference between soil respiration in treatment and control groups occurred on 22 September, though still not significant. Soil respiration rates may have been higher in the treatment groups due to the microbial incorporation of crown vetch into the soil, as decomposition of organic matter is associated with higher soil respiration (Liu et al., 2005, p. 285; Schlesinger & Andrews, 2000, p. 8). In summary, soil respiration was highest in treatment groups during the first date as predicted, but long-term soil respiration rates between treatment and control groups remained similar likely due to their similar root biomass. Therefore, there is little support from soil respiration data that addition of a legume mulch increases productivity in the long-term, though the mulch’s initial decomposition likely increased soil nutrients. For future
research, it would be interesting to determine the rate of mulch decomposition to measure soil respiration with more frequency during this period.

iv) Conclusion:

This research produced a variety of interesting results. In barrels with legume mulch, inorganic reactive nitrogen concentrations increased as predicted, indicating nutrient release from legume decomposition. Aboveground biomass was lower in plants grown with legume mulch. This was likely because they experienced preferential herbivory during growth, possibly due to higher nutrient concentrations in leaves. Root length was longer for plants grown without legume mulch, indicating these plants were more nutrient deprived than those grown with the legume mulch. Finally, soil respiration rates were similar in barrels with and without the addition of legume mulch, and so results did not contribute greatly to supporting the overall hypothesis.

Further research on nitrogen concentrations in soils and plant leaves, lateral root growth, and knowledge of mulch decomposition mechanisms would help to better understand nutrient dispersion and allocation after the addition of a legume mulch to soil. Furthermore, this research was conducted during only one growing season, and more profound effects on agricultural systems are often observed on a longer time scale. Despite this, higher soil nitrogen concentrations, possible preferential herbivory of treatment plants, and longer roots in control plants support the overall hypothesis that the use of crown vetch as a mulch may have positive effects on small-scale agroecosystem productivity.

Crown vetch can act as a non-cost prohibitive fertilizer option for small scale agriculture. It grows in the wild in all lower-48 states except North Dakota, and so is widely accessible (Losure et al., 2009, p. 233). This research could be repeated for other legumes to offer more
extensive options for farmers depending on their individual farming goals and needs. To more definitely mitigate the ecological effects any fertilizer causes if used in excess, research on pairing the nutrient release of legume mulch and crop nutrient requirements is needed. Legume mulching is a strong synthetic fertilizer alternative for farmers using organic methods or low-input agroecosystems.
8. Works Cited


