Nitrogen, Water, Weeds and Beetles:

Applying Science to the Art of Vegetable Gardening

2009 LRES Capstone Class:

Matt Atkinson-Adams, Amy Dethlefs, Amy Fitzpatrick, Carol Froseth, Meagan Iott, Kara Johnson, Alexey Kalinin, Keyne Kensiger, Dan Kettman, Ron Lodgepole, Scott Pulfer, Ron Quinn, Allison Ramsey, Adam Sarvey

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Abstract

A small-scale agricultural production garden faces many challenges in the management of insect pests, soil nutrients, water, and weeds. This paper presents an interdisciplinary approach taken by the LRES Capstone class to address these issues. A bait crop approach was taken to reduce flea beetle damage, planting Mustard and Collard plants around *Brassica* greens. Intercropping was implemented with beans and potatoes as a way to reduce weeding time and increase yield. Straw and clover mulch treatments were applied to broccoli and onion beds as a way to prevent weeds, and increase soil nitrogen and water retention. Results were mixed, but offered insights for further research and provided valuable lessons in experimental design in an uncontrolled setting. Collards appeared to be an effective bait crop in the early season, judged by the number of flea beetles captured on sticky cards; although some of the effect may be due to location in the garden with respect to other *Brassica* vegetables. Intercropping did not appear successful in the bean-potato system, showing lower yields than mono crop plants. Mulching was effective in increasing total soil nitrogen and showed potential in reducing nitrate leaching. There was no effect of mulching on plant growth rate, other than a later season decline in onion growth with the clover mulch, and an early season increase in leek growth the mulch. The water efficiency study showed the advantage of gravimetric measurements over time domain reflectometry (TDR) probes when dealing with buried irrigation tape and found inconclusive results concerning mulch effects on soil moisture.

Consumers are becoming increasingly conscious of sustainability in food systems; they are interested in how their food was produced and where it comes from. In Montana alone, farmers' markets increased from five in 1990 to over 39 as of 2007 (Grow MT 2005). The demand for more Farmer's Markets indicates that both producer and consumer interest in locally grown produce has been increasing. Small farms and market gardens comprise one of the fastest growing sectors of agriculture in the United States today. A market garden can be defined as an area of land several acres in size that grows a wide variety of crops, then sells them to local markets. The biggest attraction to market gardens is their ability to provide a constant supply of fresh produce through out the growing season. Fresh produce not only has superior taste, but may also contain more nutrients.

There are various challenges that go along with small farms. Like any farm scenario, weed and insect pests and nutrients are the biggest concerns. Pests reduce yield, which results in less income. Nutrients such as nitrogen, phosphorus and potassium are also an issue. Irrigation issues are also a concern. The reason these factors are especially challenging for small market gardens is because of the scale of farming techniques and technologies. Practices that can easily control these challenges in large or small-scale agriculture settings will not apply to a market garden. Since the industrialization of agriculture in the 1950's, most of the investigations into agricultural management practices have been aimed toward large-scale production. Methods used in a large scale farming operation will not apply to a much smaller sustainable farm. Yet a method used on a personal garden will not be appropriate for a several acre garden, for example one person could not harvest the garden in one afternoon. There is currently a gap in knowledge demanded by this new fast-growing sector of agriculture; small scale diverse vegetable farming have many of the same production efficiency needs necessary on a large farm but many of the challenges faced by backyard gardeners.

These gardens have a unique financial situation as well. Because production is relatively low, produce sales often come from small contracts, roadside stands, or farmer's markets. Community Supported Agriculture (CSA) programs, such as at Towne's Harvest Garden, are a popular source of income for the market gardening industry. CSA's allow community members to buy a "share" of produce from the farm.

For a set price at the beginning of the season, CSA members receive a weekly box of produce through the growing season. This provides the farm with capital at the beginning of the season when they need it for material costs and provides members with a supply of fresh, seasonal produce.

Towne's Harvest Garden (THG) is a 2-acre diversified vegetable farm located on the Montana State University (MSU) – Bozeman Agricultural Research and Teaching Farm (BART Farm), one mile west of campus. THG was started in 2006 by an MSU student group, Friends of Local Foods (FLF), as a response to growing awareness of supporting locally produced food. The students' enthusiasm and motivation inspired a strong multi-disciplinary partnership between students and faculty and the farm is managed by a combination of students, faculty and volunteers. After three successful growing seasons, Towne's Harvest Garden has now been integrated as a cornerstone of the Sustainable Food and Bioenergy Systems degree program at MSU. The garden is fulfilling the goals set by FLF by being a valuable tool for teaching students about food systems and providing fresh, locally grown produce to the campus and the community.

The 2009 Land Resources and Environmental Science Capstone class undertook research projects in Town's Harvest Garden. Interdisciplinary groups addressed different challenges that the garden faces. The LRES Capstone class chose to study the possibilities of intercropping, the effects of pests on leafy cropping systems, mulching effects on a crops growth rate, and the effect of mulching on nitrogen and water in the soil. The seven questions for the 2009 growing season at Towne's Harvest Garden follow. (1) How do intercrop and monocrop systems compare in time weeding, weed biomass, and crop yield? (2) Also, what is the land use value of the intercrop system. (3) Does flea beetle abundance differ between two crops, arugula or pac choi? (4) And, does flea beetle abundance differ between crop species over time? (5) How do living or straw mulch treatments affect the growth rate of onion, broccoli, and leeks? (6) How do these mulch treatments affect the nitrogen cycle, specifically PMN, total N, nitrate and ammonia? (7) How will mulching treatments affect soil water content?

This is the first time research has been conducted on Towne's Harvest Garden. The goal of these research projects is to provide useful information to the Towne's Harvest Garden, to aid in management decisions.

1. Intercropping of Potatoes and Beans

Our proposed research examines the effects of intercropping, which is the practice of growing multiple crops in the same space and time. Forms of intercropping include relay, where one crop is sown into another; mixed, when both crops are sown at the same time; row, crops are planted in rows close enough for interaction; and strip, crops are grown together in strips wide enough to accommodate machinery (Kantor 1999). Intercropping design takes into account biological time lines, nutrient use, and spatial attributes.

Scientific studies on intercropping effects are particularly rare in the United Sates, and most vegetable intercropping advice is from small-backyard gardeners. Intercropping allelopathic crops such as beets, millet, or cucumber with a main crop can increase weed suppression (Kantor 1999). Disease suppression also occurs when crops are planted in multi-species associations with species that are not closely related. The disease will not spread as rapidly in a multi-species system because most diseases attack a certain type of plant.

Intercropping uses space efficiently. Root systems that differ morphologically are capable of taking up nutrients and water at different depths. Aboveground, a sun-loving plant can be intercropped with a plant which is shade tolerant. Also, large canopy plants can shade the ground for small canopy plants to reduce weed growth. Legumes are capable of fixing their own nitrogen and may provide nitrogen to the intercrop the following season, reducing nitrogen fertilizer costs and making them a great companion for nitrogen-loving crops. Economically, intercropping utilizes multiple aspects of money management and the security that if one crop fails, the field is not a total loss.

Intercropping incompatible crops can increase competition for nutrients and water, causing a yield loss. Another common yield loss is during harvest, when the harvest of the first crop disturbs the growth of the other crop. To reduce this type of yield loss intercrops are sown with an early season crop and a late season crop. Increased time for planting and harvesting crops is necessary for an intercropping system.

Study Site

One of the concerns expressed by Towne's Harvest Garden managers was the high volume of weeds and time spent weeding in the garden. For our project, beans and potatoes were grown together as companion crops. The leguminous beans could potentially provide nitrogen to the potatoes, leading to an increase in the yield of the potatoes the following year. Our intercropping experiment addressed the following questions: (1) does weed biomass and time spent weeding differ between intercropped and monocropped systems; and (2) how does total yield differ between the intercropped and monocropped systems?

The Towne's Harvest Garden requires volunteers to provide a successful cropping season, and most commonly these volunteers are asked to spend their time on their knees pulling weeds. This volunteer job description creates difficulty in finding returning volunteers. If the amount of total weed biomass is decreased, the amount of time spent weeding should decrease as well. Weeds also compete for nutrients with crop species. However, the possibility for a single higher crop yield in an intercropping system is uncommon. More common is a depression in yield of an individual crop, relative to yield of a monocrop, but an increase in efficient use of the land (Okoli et al. 1996). The remaining concern is how much yield must be maintained to keep the shareholders of the garden happy with the products they receive. This concern may determine how much intercrop and how much monocrop will be used in the following years of the garden.

Methods

Crop Outline and Planting

The intercropping experiment at Towne's Harvest Garden used Fresh-pick and Provider beans intercropped with Yellow Gold potatoes. The potatoes came from White's farm in Manhattan, MT and were planted as starts, cut two days prior to planting to reduce the chance of rotting before the seedlings germinated and emerged. The monocrop potatoes were planted May 18th in four 200-foot (61 m) rows spaced at 8 inches between plants. The intercrop potatoes were planted May 20th, in four 100-foot (30.5 m) rows. Two of these rows were planted in parallel lengths with potato starts spacing of 8 inches on alternating sides. The other two of these rows had a single length with potato starts planted every 12-16 inches.

The bean seeds came from Johnny's Selected Seeds located in Maine and Garden City Seeds. The beans were planted May 26th with an Earthway Precision Garden Seeder, Model 1001-B, 1002-14 disk, #3 seeder. The beans were seeded on both sides of each row of the intercrop potatoes. Also two 100-foot (30.5 m) rows of beans with two lengths seeded in each row were planted as the monocrop beans.

Weed Management

The entire garden was tilled in May to reduce weed populations and two drip irrigation lines were buried within each row. The potato crops were hilled the week of the 15th of June. On June 27th the intercrop rows and the monocrop bean rows were weeded with a hoe, and the amount of time to weed each row and each aisle was recorded. The next weeding took place on August 18th.

Data Collection

On August 18th, weed biomass was collected throughout the experiment. Weeds were harvested in 10 1-m^2 plots in each of the cropping systems. The harvest entailed hand pulling plants, including shoots and attached roots, with no attempt to obtain a complete root sample. To test for differences in weed biomass between the three cropping systems, data were analyzed using a one-way ANOVA (SPSS 18.0, Chicago Illinois), if data passed the Levene's test for homogeneity of variances.

Beans and potatoes were harvested at multiple and different times, washed of excess dirt, and weighed. Potato and bean harvests began on August 17th and 18th, respectively. Harvested yield biomass was used comparatively without a statistical analysis. The yield data was also applied to the Land Use Equation to determine whether intercropping is advantageous in this system.

Results

Time Weeding

The average time spent weeding for the intercrop and monocrop bean systems is shown in Table 1.1. The intercrop system took longer to hoe in comparison to the monocropped beans. This result is logical since the method of weeding was hoeing. It is easier to hoe a bed that has two distinct separate rows like that in the beans, whereas, the intercrop system was planted with an alternating pattern. In turn, this required the person who weeded to be more careful and therefore spend more time weeding.

Table 1.1: The average amount of time spent weeding for all the intercropping data and monocrop bean system in minutes along with the corresponding standard error.

Type	Mean (min)	Std. Error
Intercrop	51	3.95
Beans	30	3.49

Weed Biomass

Weed biomass is defined here as the entire weed (root included) after the dirt was removed, dried, and weighed. The monocrop bean beds had the highest weed biomass, while the monocrop potato beds had the least amount of weeds (Table 1.2). The amount of biomass in the intercrop system was intermediate to the two monocrop systems, with an average of 170 grams of weeds collected.

Table 1.2: The average weed biomass collected from each of the cropping systems and the corresponding standard error.

Crop Type	Mean	Std. Error
Beans	225	52.21
Intercrop	170	41.03
Potatoes	107	37.21

Crop Yield

Yield was analyzed as crop yield per row meter (Figure 1.1a) and yield per plant (Figure 1.1b). Monocrop potatoes and monocrop beans did substantially better in yield compared to either crop in the intercrop systems. The intercrop beans showed low establishment, we suspect this was due to the hilling of the potatoes after the beans were planted. The bean seeds or sprouts would have been turned around in the soil and buried deeper than good seeding depth. Visual observations between the beans in the intercrops, which were spindly and sparse, versus the monocrop, which were robust and plentiful, suggested a much higher yield production from the monocrop bean system. Intercrop 1 with a higher seeding rate than Intercrop 2 did substantially better in potato production. If the beans did not provide much competition, the higher seeding rate of potatoes would result in greater production.

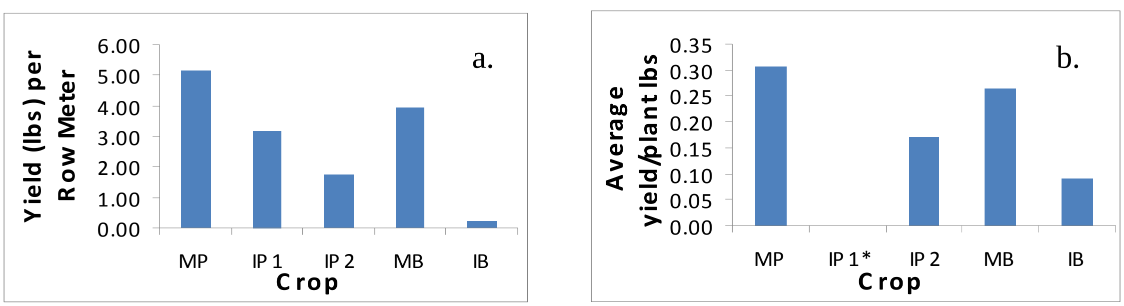

Figure 1.1: a. Yield per Row Meter (MP, Monocrop Potatoes; IP1, Intercrop Potatoes 1 start every 8 inches; IP2, Intercrop Potatoes 1 start every 12 inches; MB, Monocrop Beans; Intercrop Beans) b. Yield Per Plant
* No plant counts available for this cropping system.

The beans appear to have provided competition with the potatoes, as the yield of the monocrop potatoes was 313 lbs/200m and the intercrop yield with the same seeding rate was 194 lbs/200m, about 60% of the monocrop yield. Within monocrops less interspecific competition occurs and more intraspecific competition takes place. With the intercrop we hoped to see less intraspecific and not a lot of interspecific competition due to the crops morphological attributes concerning above and underground space, also nutrient requirements. However, our results suggest that competition from the beans on the potatoes reduced the intercropped potato yield. Plant performance (Figure 1b) is highest in the monocrop system. Interspecific competition could account for this if competition was high in the growing season. Plant density data of the intercrop 1 system was not collected. This resulted in the lack of a direct potato seeding rate to plant establishment comparison.

Incorporating the Land Use Equation

The Land Use Equation is a quantitative analysis of the benefits or lack of benefits for intercropping. It utilizes the additive fractions of the intercrop relative to the monocrop to determine whether the intercrop or monocrop provides an advantage.

$$\frac{\text{Intercrop1}}{\text{Monocrop 1}} + \frac{\text{Intercrop2}}{\text{Monocrop2}} = \text{Land Equivalency Ratio (LER)}$$

When LER > 1, the intercrop system is advantageous, and when LER < 1, the monocrop systems are advantageous.

The LER using the intercrop potato, 8-inch spacing, is 0.67, meaning the intercrop systems produced 67% of the production of the monocrop systems. The LER using the intercrop potato, 12-inch spacing, is 0.39, or 39%. Neither intercrop system is advantageous. However, it should be noted that the intercrop potato, 8-inch spacing system provided approximately two-thirds the required amount to produced an advantageous intercrop. Because of the low establishment of beans for unknown reasons, we can only hypothesize that this system could be advantageous with different bean management.

Discussion

Time Weeding

Time spent weeding was greater for the intercropping system than for the monocrop system of beans. This could be due in part to the method of weeding, which was hoeing. An intercrop system makes hoeing more difficult since the crops are not situated in two distinct rows; instead they are in an alternating pattern. It would be interesting to assess the difference in weeding time if hand weeding was done for both systems.

Ideally, to compare the monocrop systems to the intercrop system, we would have compared the averages for both of the bean and potato monocrops and compared this value with the average intercrop time. We expected the combined monocrop average to be higher than the intercrop average time spent weeding. However, we do not have the amount of time spent weeding the monocrop potatoes, so we cannot support our prediction.

Weed Biomass

We expected that weed biomass would be lower for the intercrop system. Because the increase in crop biomass results in less available area for the weeds to grow, the weed biomass in the intercrop system was intermediate to that of the monocrop bean and potato systems, since the intercrop was a combination of the monocrops. Intercropping potatoes with the beans decreased the amount of weeds that would have established in a monocrop bean system, and slightly increased the amount of weeds that would have established in a monocrop potato system. The monocrop potato system had the least amount of weeds, even less than the intercrop system.

Another interesting observation regarding weed biomass was that the density of crop plants did not affect the biomass of weeds present. There was no difference between the weed biomass per plot when there was only one bean plant established compared to a plot where 34 bean plants were established. In the intercrop row, both the highest and lowest weed biomass was collected when the amount of beans and potatoes established was relatively the same. In other words, the amount of weed biomass collected in the intercropped system is independent of the number of crop plants established. A trend in the amount of weed biomass collected in the monocrop potatoes shows that with more potatoes established there were less weeds collected.

Crop Production

The yield from monocrop cropping systems benefited the garden more than the intercropping systems. Individual crop yield in the intercrop system decreased, as was expected, however the sum of the two individual crops, were expected to be advantageous in crop yield. A large factor in the small intercrop yield was the poor establishment of the bean crop. Between the two seeding rates of potatoes, the higher seeding rate did produce a higher yield. Individual plant yield success also occurred in the monocrop system. The intercrop systems provided more space for the potatoes, therefore the bean crop appeared to have applied interspecific competition on the potato plants. The nitrogen fixing bean crop produces nitrogen for itself during the growing season and leaves nitrogen in the ground for the following season. Thus, the symbiotic interaction does not occur until the following season. With this in mind, the initial season of intercropping beans and potatoes provided more competition and lack of establishment of the bean crop, for the two crops resulting in lower yields and a disadvantage to the garden.

Land Use Equation

Using the Land Use Equation neither of the intercrops were advantageous, intercrop 1 (potatoes, 8-inch) system at 67% and intercrop 2 (potatoes, 12-inch) system at 39% of the monocrop systems. That intercrop bean production only added 5% to the cumulative total is a key factor in recognizing the low percentages of the combined intercropped systems. The hilling of potatoes with bean sprouts was an unforeseen complication. In future research with bean and potato intercropping, beans should be planted or transplanted after hilling of the potatoes occurs.

Many small backyard gardens have found success with intercropping. Multiple variations of crop combinations should be tested and may be found to work successfully together. In this case beans were chosen since they are a leguminous plant. Whereas, many different combinations should be tried to receive the overall benefits of intercropping, which include disease reduction, increase weed suppression, and more efficient land use and space of a garden.

2. Bait Crop Experiment

The Towne's Harvest Garden (THG) has a flea beetle infestation. Flea beetles cost North American growers millions of dollars in damage annually (Dosdall et. al. 1999). At the market garden last year, flea beetles completely destroyed the harvestable crop of cruciferous greens, including pac choi and arugula. The flea beetle species causing the damage is the crucifer flea beetle, *Phylotretta cruciferae*. This beetle feeds only on plants in the *Brassicaceae* family (Gruber et al. 2009).

P. cruciferae only does damage in the adult stage. In Montana, the adult stage is present in mid June, and again in August. Because most cruciferous crops are harvested by August, the beetles are primarily a problem in June when the plants are to be harvested. There are many ways to control flea beetles organically, but many methods are either too expensive or impractical for the Montana environment (Dosdall et al. 1999). There has been much research conducted on "bait crops" as a natural control for flea beetles (Anderson et al. 2006). This method of control takes advantage of the flea beetles' feeding preferences for the bait crop to lessen the damage to the harvested crop. Most research addressing *P. cruciferae* host preference was completed either in a controlled lab setting or in another region of the world using different plants (Tridan et al. 2005, Andersen et al. 2006), therefore the results generated in these experiments are not completely applicable to THG. That flea beetles exhibit preference between host plants and that this trait has been used successfully to organically manage flea beetle infestations via bait crops allowed us to develop a useful experiment at THG.

Collards were selected as a bait crop because of their potential above-ground leaf area, and *B. juncia* (mustard) was selected because preference has been demonstrated in previous research (Altier and Schmidt 1986). The planting scheme of intercropping the bait crop with the harvested crop, although not scientifically proven to be effective, was chosen because of the garden setting within which our research was conducted.

The questions we addressed include:

- Does *P. cruciferae* abundance differ within crop species through time?
- Does *P. cruciferae* abundance change differently through time depending on the crop species?

Methods

Planting Regime

We used two beds within the "Leafy" section of THG for our experiment. The beds were 40 inches wide and approximately 210 feet long. One bed was planted with pac choi as the harvestable crop while the other was planted with arugula. Each bed was divided into nine treatment blocks and three replicates of each of three bait crop treatments were established: mustard, collard, and control. There were two rows of the harvest crop along the outside of each bed, and one row of treatment crop down the middle. Each treatment block was separated by a 4-foot x 3-foot piece of plastic sheeting stretched between two poles. The treatment crops were randomly assigned to blocks. Pac choi, arugula, and mustard were planted with a push seeder at approximately four inches per seed. The collards were transplanted at the same time after 3 weeks of greenhouse growth and were spaced eight inches apart.

Pest Abundance

To monitor flea beetle abundance, four yellow sticky cards (Great Lakes IPM) were placed in each treatment block and suspended about 8 inches above the soil. The cards were five feet and six inches apart and were placed between the treatment row and harvest rows alternating between sides of the bed. Cards were collected and replaced once per week between June 22 and Aug. 17 2009.

Visual Damage

To monitor visual damage to crop leaves, two pictures were taken at randomly determined photospots in each treatment block once a week for eight weeks during the same eight weeks as the pest abundance analysis.

Data Analysis

The flea beetles collected on the cards were counted and averages were produced for each treatment each week. These averages were analyzed with a Levene's test of variance and a Repeated Measures ANOVA to look for differences between flea beetle abundance each week and between treatments through time. The photographs were not used for any quantitative analysis.

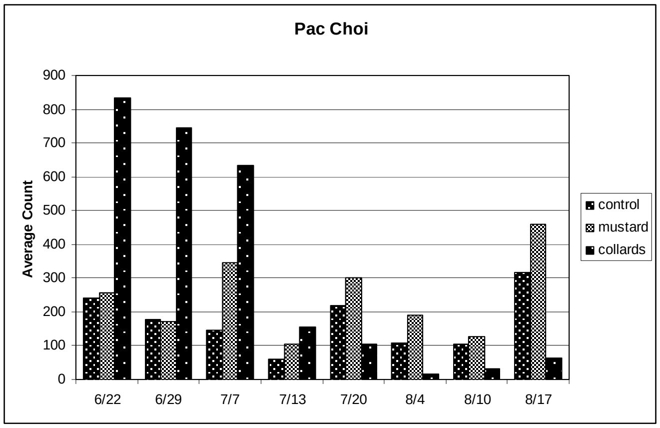

Figure 2.1. Average number of flea beetles per treatment each week in pac choi.

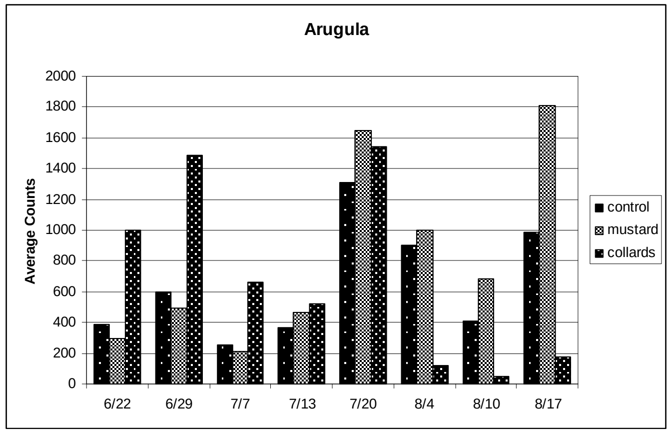

Figure 2.2. Average number of flea beetles per treatment each week in arugula.

Results

P. cruciferae presence in the garden was relatively high throughout the growing season, but the abundance changed through time and between the different bait crop treatments. The totals for each of the replications were averaged for each treatment each week. There was a trend of decreasing *P. cruciferae* abundance through time for the Collard treatment on pac choi (Figure 2.1). In contrast, *P. cruciferae* abundance in the mustard and control treatments did not show any trend through time (Figure 2.1).

In arugula, similar trends were found to those in pac choi. In the collard treatments, *P. cruciferae* abundance decreased through time while remaining relatively steady in the mustard and control treatments (Figure 2.2). Total *P. cruciferae* abundance was much higher in the arugula treatments compared to the pac choi treatments. The largest number recorded in any pac choi treatment was 800 beetles, while in arugula we found up to 1,750 beetles in one treatment. Statistical Repeated measures ANOVA showed that *P. cruciferae* abundance differed between weeks (Table 2.1). *P. cruciferae* shows a preference to collards in both pac choi and arugula in the beginning of the summer (Figures 2.1 and 2.2) by having high numbers in the collard treatments. In contrast, *P. cruciferae* shows preference to mustard and the control later in the growing season for both pac choi and arugula (Figures 2.1 and 2.2).

Table 2.1. Repeated measures ANOVA for arugula. Significant difference between weeks and weeks per treatment.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Week Sphericity Assumed	1238207.278	7	176886.754	5.900	.000
Week * Bait Sphericity Assumed	1793977.806	14	128141.272	4.274	.000
Error (week) Sphericity Assumed	1259235.167	42	29981.790		

Discussion

The collard treatment for both the pac choi and arugula had the highest abundance of *P. cruciferae* in the beginning of the summer. The high abundance may be due to flea beetle preference and/or the life cycle of the collard plants. Because the collard plants were transplanted into the site while the mustard, arugula, and pac choi were seeded, the collard plants were the only plants available in the beginning of the summer. The abundance of *P. cruciferae* in collards decreased with time through the 8 weeks. This may be due to other plants becoming available or *P. cruciferae* losing its attraction as the collards matured. Additionally, as the collards grew larger, their leaves may have obstructed the sticky traps from flea beetles.

There was no apparent difference between the mustard and control treatments in either arugula or pac choi. Our results also might have been different if the crops in our experiment had been harvested. All of the crops went to seed except for collards. When crops are harvested they produce more leaves instead of going to seed, which may affect their appeal to flea beetles.

The bed planted with arugula had a consistently higher abundance of *P. cruciferae* compared to the bed planted with pac choi. This may be due to preference or it may be due to the location of the experimental beds within the farm. The experimental bed containing arugula was located near several other beds that contained *Brassicas*, the preferred food of *P. cruciferae*. The pac choi bed, however, was isolated from the *Brassica* beds which may have caused the lower abundance of *P. cruciferae*.

Using bait crops as a sustainable control for *P. cruciferae* has potential to be a feasible management practice at Towne's Harvest Garden. Even though our results did show a higher abundance of *P. cruciferae* in arugula compared to pac choi and in the collard treatments compared to the other treatments, the higher abundance may not necessarily be due to preference. In order for any bait crop to be useful, a clear preference would have to be shown and the bait crop would have to be used in an effective manner. We don't believe that we satisfied either of these requirements during the experiment. If Towne's Harvest Garden were to want to use a bait crop, we would recommend further research either using the crops we studied, or testing new bait crop candidates. We would also recommend testing different planting schemes that vary temporally or spatially.

3. The Effects of Mulching in a Small Scale Vegetable Garden

A particular challenge of small-scale vegetable farming is finding scale-appropriate technologies and techniques. For example, a common weed control method for a home garden may be appropriate for one that is a couple of acres. Additionally, technologies that are appropriate for a large-scale agricultural operation could be transferred to this much smaller farm. Alternatively, some technologies from large-scale or home-scale systems may not be appropriate for the small-scale vegetable farm.

Challenges for THG are shared by many small vegetable farms, including weed management; weeds can take valuable nutrients away from the crops and decrease yields. Management concerns of THG are centered around crop yields, weeds, nitrogen availability and water use. A potential strategy for investigating some of these questions is to implement techniques usually used on other scales; then comparing crop growth rate, nitrogen cycling and soil water, between crops. Information collected could then be used to determine what is appropriate for THG's small scale system.

Mulch is an intentionally placed protective covering of the soil. Covering the soil impacts many facets of the garden ecosystem. Mulch can reduce time spent weeding, reduce soil erosion and boost soil organic matter. It can also influence nutrient cycles by contributing essential nutrients, binding up excess nutrients and improving habitat for the underground ecosystem. Covering the soil also influences its water content, in many cases decreasing water loss by evaporation. Mulch can be organic material, synthetic material or a living plant. In the home garden, common mulches include organic material such as, leaves, straw, grass clippings as well as black plastic (NRCS 2009).

Living mulch are plants which grow among the crop plants, and serve many of the same functions as other forms of mulch. It may also provide habitat for beneficial insects (Brainard et al. 2008). Living mulch is typically seeded directly into the ground and as a result it may be less labor intensive to implement than spreading organic or plastic mulches over the desired area. Many different plants can be used as living mulch, therefore, species are often selected based on the desired management goals. Living mulches can compete with the desired crop so they are often managed in a way that attempts to decrease this effect. Appropriate strategies vary based on the type of living mulch, the desired crop and the timeline of the cropping system. Common practices that can be used include, timing the seeding of the living mulch with that of the crop, cutting the mulch, and variety selection of the mulch. Variety selection is very important with living mulches. For optimum weed management the crop and mulch should be synergistic rather than competing (den Hollander 2007). Leguminous plants are often selected because of their nitrogen fixing capability. Clovers in particular have been shown to fix higher rates of di-nitrogen gas than other legume species (Quispel 1982). The variety White Dutch clover, used in this study, demonstrates a high rate of weed suppression with a lower rate of crop competition (den Hollander 2007).

Both living mulch and straw mulch can decrease weed numbers (den Hollander et al. 2007, Hooks et al. 2004, Shock et al. 1999), and straw mulch can increase the yields of some crops (Kirnak et al. 2006) along with many of the other benefits shared with other mulches. Additionally, it is generally inexpensive and readily available in many areas.

The goal of this study was to see if organic mulch or living mulch was more useful for the scale of the THG system. The first research question was: how do mulch treatments affect the growth rates of broccoli, onions, and leeks? Growth rate was measured as an indicator of yield, because a strong correlation has been established between the two characteristics (Maji et al. 2006).

The expected results for the experiment were: a) the growth rate of onions in the straw mulch treatment would have a comparable growth rate to the weeded control; b) onions with White Dutch clover living mulch would have a lower growth rate than the control (Boyhan et al. 2006); c) leeks were expected to have a similar growth rate between the straw and the control (den Hollander 2007); d) the broccoli with straw was expected to have a higher growth rate than the control; e) the broccoli with clover living mulch was expected to have the same growth rate as the control (Chase et al. 2008).

Methods

This experiment took place at Towne's Harvest Garden in Bozeman, MT. The semi-arid site averages 15-19 inches of precipitation annually. The growing season typically consists of 90-100 frost-free days. The soil on the THG is Turner loam consisting of loamy, deep, well-drained soils. The experiment was implemented over the vegetable growing season (May through September) of 2009.

Three treatments were applied within the garden to crop beds where broccoli, leeks and onions were being grown. The treatments were wheat straw mulch and White Dutch clover (*Trifolium repens)* living mulch which were compared to a weeded, bare ground control. The leek crop only had the straw treatment and control due to errors in seeding of the clover. The control was weeded according to the garden management standards. The straw mulch was applied to an approximate depth of seven centimeters. The living mulch was broadcast seeded by hand and then lightly raked into the soil. The three treatments were randomized within each bed. Straw mulch was applied around the crops on June 22. White Dutch clover was seeded at a rate of 5lbs/acre between the transplanted vegetables on June 4th.

The growth rates of the crops were collected each week from each of the treatments throughout the summer. Data collection in the onion and leek plots began on June 22nd and ended on Aug 22nd. Data collection in the broccoli plots began on June 22nd and ended on August 1st when the broccoli was harvested. The growth rates were collected by using an electronic caliper to measure the basal diameter of the vegetables.

For the onions and leeks each treatment contained fifteen plants that were randomly selected. The basal diameter (mm) was measured at the lowest leaf of the plant by holding the caliper perpendicular to the row. For broccoli each treatment contained three plots with four broccoli plants each. The basal diameter (mm) was measured at the lowest leaf by holding the caliper perpendicular to the row.

The data for the growth rates of the broccoli, onions, and leeks in the different treatments was analyzed by performing an analysis of variance between the treatments for specific weeks.

Results

Onions

The onions showed no difference in growth rate between the mulching treatments for weeks one through four (Figure 3.1, p= 0.31).

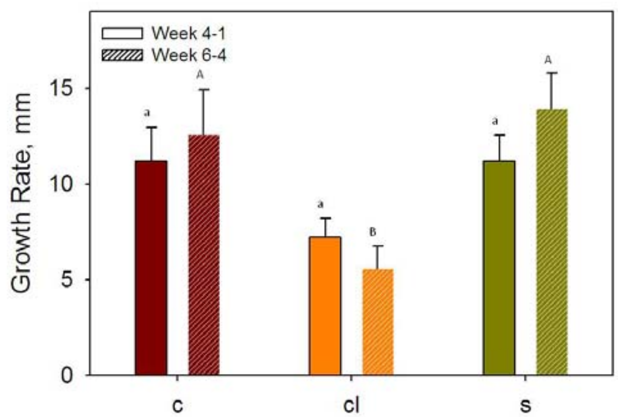

Figure 3.1. The growth rate (y-axis, mm) of onions between weeks 1-4 (solid bars) and weeks 4-6 (hatched bars). The three treatments (x-axis) are the control (C), living mulch (CL), and straw (S).). The lower case 'a's show that there is no difference between the treatments between weeks one and four. The upper case 'A's show that between weeks four and six the control and straw are higher than the clover shown by 'B'.

Between weeks four and six the growth rate of the onions was higher in the control and straw treatments than in the living mulch (p=0.04). This is suggested by the mean growth rates (Figure 3.1) and in the Post Hoc Test. However, this analysis does not pass the Levene's Test. Between weeks six and eight, onion growth rate was the same between mulch treatments (Figure 3.1; p= 0.357).

Leeks

The growth rate of the leeks from weeks one to five is different between the straw and control treatments (Figure 3.2, p=0.002). The leeks grown in the straw treatment had a higher mean value than those grown in the control (Figure 3.2). However, for weeks five to seven there is no difference (p=0.47). The mean growth rates and standard deviations for weeks five to seven are similar (Figure 3.2).

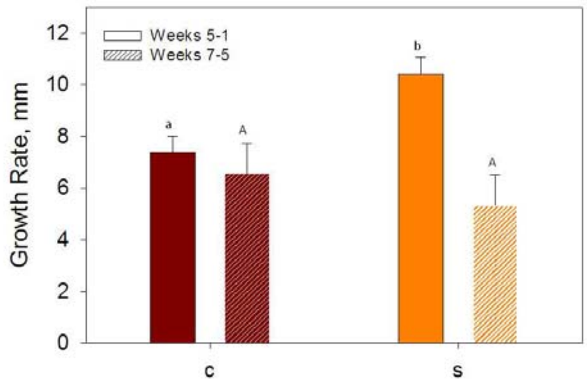

Figure 3.2. The growth rate (y-axis, mm) of leeks between weeks 1 to 5 (solid bars) and weeks 5 to 7 (filled bars). The two treatments (x-axis) are the control (C) and straw mulch (S).). The lower case ‘a’ shows that between weeks one and five the growth rate of the control was lower than that of the straw (‘b’). The uppercase ‘A’s show that there is no difference between treatments between weeks five and seven.

Broccoli

The broccoli data was first averaged per plot (four plant growth rates were averaged) and then ANOVA was performed to test for differences in growth rate between treatments. The growth rate of broccoli in the three treatments did not differ between week one to two (Figure 3.3, p=0.94). The mean growth rates and standard deviations are similar (Figure 3.3).

Between weeks two to three there was no difference in the growth rates between the treatments (p=0.78). The growth rates between weeks three and four showed the same trend (p=0.70). The means and standard deviations for this time are similar (Figure 3.3).

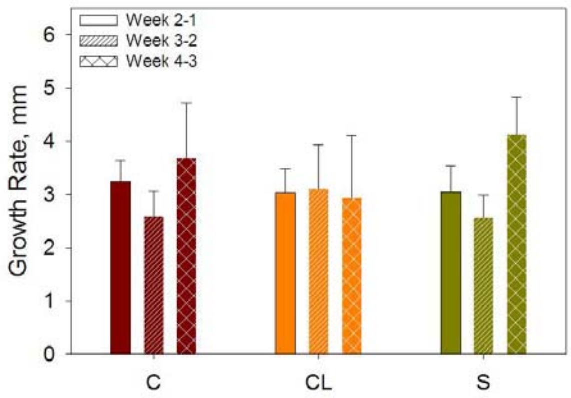

Figure 3.3. The growth rate (mm) of broccoli between weeks 1 and 2 (solid fill), weeks 2 and 3 (hatched fill) and weeks 3 and 4 (crosshatch fill). The three treatments are control (C), living mulch (CL) and straw mulch (S).

Discussion

The onions were expected to have lower growth rates in the living mulch treatment and the same growth rates in the straw treatment relative to the control. After mid-season the onion growth rate slowed in the living mulch treatment. This has been shown before by Boyhan et al. (2006). It is thought that the living mulch competes with the onions and therefore slows the growth rate. The straw treatment has been shown to decrease weeds (Abouzina et al. 2008) and therefore weed competition, but can tie up nutrients in the soil by increasing the carbon to nitrogen ratio leading to less available nutrients for the crop. This could have led to the equal growth rates of the onions in the control and in the straw.

The leeks were expected to have similar growth rates between the straw and control treatments. This was proven incorrect--the straw actually gave the leeks an advantage over those growing in the control plot. This finding is supported by studies done by Kirnak et al. (2006) where straw was shown to increase crop yield. The increase in yield could be due to the decreased weed competition or other factors such as the heterogeneous nature of the study site.

The mulching treatments had no effect on the broccoli. This has been shown in other experiments using mulches and broccoli (Hooks and Johnson 2004). Broccoli was expected to have higher growth rates in the straw and equal growth rates in the living mulch relative to the control. For all weeks and all treatments the growth rates were the same. This suggests that the living mulch does not compete with the broccoli or that it is comparable to the competition of the weeds that were growing in the control plot. It also means that the straw does not negatively or positively affect the growth rates of broccoli as it seemed to do with the leeks.

There were several possible sources of error, mostly stemming from data collection. Several people measured the basal diameter of the plants throughout the season. This could have caused measurement errors. Also, storm occurrence and the heterogeneous nature of the farm soils caused absent data and variability of weed occurrence, and therefore variability in competition.

An aspect of this experiment that could have changed the outcome of the results was the timing of the seeding of the clover. The clover was not planted until the crops had been transplanted into the ground. This caused a lot of labor early in the season to keep weeds down while the clover was germinating. If the clover had been seeded as early as possible in the season it may have been established early enough to reduce weed numbers more effectively from the start (Chase and Mbuya 2008).

Overall, mulch is a potentially valuable tool to be used in a small scale vegetable farm. While there was little yield benefit with the addition of mulch, other benefits were observed. These include reduced weed numbers and the attraction of pollinators to the clover. There is the potential for further research regarding mulches in small-scale vegetable farming. Many aspects could be studied including species of the living mulch, timing of seeding, timing the application of organic mulches to take advantage of weaknesses within weed life cycles, and applying mulches to different crop species. Seeding rate of living mulch could be increased and choosing a shorter growing legume could help to completely cover the soil while still allowing light to reach the crop (Infante et al. 1996).

4. Holistic approach to N-mineralization: seasonal study with resin capsules

Understanding nitrogen mineralization in the field setting is important for agricultural production and efficiency. Quantification of mineralization, which is the transformation of organic N to inorganic N, can lead to more accurate fertilizer applications that reduce N leaching. One way to influence this transformation is by applying mulch to the soil. By altering soil moisture properties, microbial processes and nutrient dynamics, mulch has the potential to influence the mineralization process, either increasing or decreasing the amount of available nitrogen in the soil (Agehara 2005). Predicting potential mineralization of N based on mulch treatments could assist in establishing holistic and organic practices (Kolberg et al. 1997, Bhogal et al. 1999). Potential mineralization can be measured using both lab and *in situ* techniques. Lab methodology requires anaerobic soil incubation to estimate seasonal mineralization (Bundy and Meisinger 1994). In situ measurement can be done with resin capsules that are buried on site and sorb NO_3^- and NH_4^+ as the ions become available (Agehara and Warncke 2005, Hatch et al. 2000, DiStefano and Gholz 1986, Lehmann et al., 2000, Kolberg 1997). Both of these techniques have limitations. The lab method integrates mineralization over a certain depth in the soil profile and doesn't always relate well to field conditions, while the resin capsules integrate time but represent point measurements in the soil, subject to heterogeneity (Hatch 2000, Kolberg 1997). For these reasons, we combine the two methods in our study of N mineralization under different mulch treatments at Townes Harvest Garden. The aim of this study is to observe differences in inorganic and total N between mulched and control soil plots after 8 weeks.

Methods

Experimental Setup

The study was carried out beginning July 14th, in three 200-foot rows planted with broccoli. Each row was divided into three sections where mulch and control treatments were randomly applied. Within each section, three half-meter plots were randomly selected for placing resin capsules. Two capsules were placed in each plot at a 6-inch depth using a soil auger. Capsules were left in the soil for eight weeks and were removed September 8th and analyzed. At this time soil samples were taken for lab analysis of potentially mineralizeable nitrogen (PMN), soil nitrate and total nitrogen.

Resin Capsule Analysis

Resin capsules were removed from the soil with gloves to avoid any contamination and washed off with double de ionized water. The capsules were gently kneaded between fingers while washing to rinse off the dirt. NO_3^- and NH_4^+ were extracted from capsules with 1M KCl using a serial extraction technique (Johnson 2005). The extractions were analyzed for NO_3^- and NH_4^+ on the SEAL Quaatro flow through analyzer.

Soil Sampling

A composite soil core sample, consisting of three cores, was taken within each plot with a soil probe where resin capsules were buried, in order to correlate results with resin data. Taking a composite core was a means to reduce effect of heterogeneity. Enough soil was taken for PMN, nitrate and total nitrogen analysis.

PMN, nitrate and total nitrogen analysis

A standard 7-day water logged incubation at 40 °C was used to determine PMN (Bundy and Meisinger 1994). The resulting slurry was filtered and analyzed on the LATCHET flow through analyzer. Soil nitrate was extracted with 1M KCl and analyzed on the LATCHET as well (Keeny and Nelson 1982). Total nitrogen was analyzed in a LECO combustion analyzer where 0.2g of soil were required (Soil Sampling and Methods).

Results

Analysis of resin capsules shows that treatment effect of mulch is not significant for NO_3^- and only marginally significant for NH_4^+ ($p< 0.1$; Figure 4.1). There was a lot of heterogeneity but no overall difference in NO_3^- concentrations between mulch treatments. Ammonium

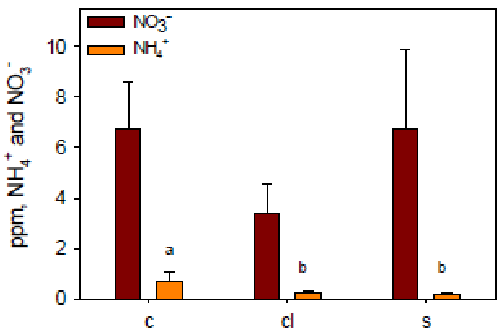

Figure 4.1: NH_4^+ and NO_3^- from Resin Capsules. NH_4^+ and NO_3^- sorbed on resin capsules in soils with mulch treatments of control, clover and straw. There is no difference in NO_3^- concentrations between mulch treatments, but NH_4^+ is higher in the control plot. Bars with the same letter designation are not statistically different.

concentrations were higher in the control than in either of the mulch treatments. Soil PMN measurements do not differ between treatments (Figure 4.2). Soil NO_3^- results indicate a strong effect of straw mulch treatment (Figure 4.3). There was much less NO_3^- in the straw mulch treatment than in either control or clover. No difference was observed between control and clover mulch. Total nitrogen was slightly higher in the straw and clover treatments (Figure 4.4).

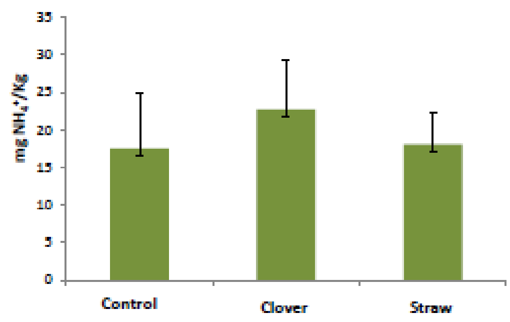

Figure 4.2: Soil PMN with three mulch treatments. There is no difference between treatments.

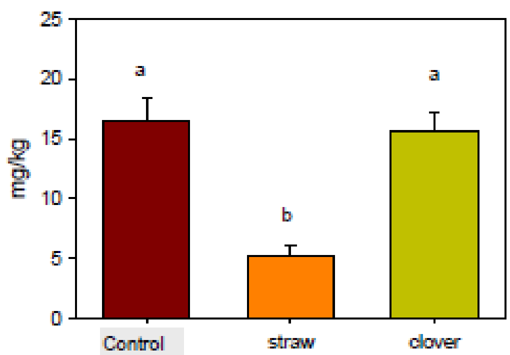

Figure 4.3: Soil NO_3^- in September 2009, from soils with three mulch treatments. Bars with the same letter designation are not statistically different.

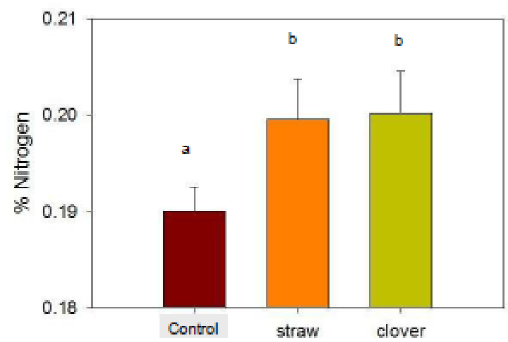

Figure 4.4: Soil Total N in three mulch treatments. Bars with the same letter designation are not statistically different.

Discussion

The results from resin capsule analysis and soil testing are complementary in that there is higher total N in mulch treatments and less available nitrogen in the straw mulch. The effect of mulch on total nitrogen was predictable. Total N increased in mulch treatments from the addition of organic matter. Impacts of the straw mulch are more interesting.

Straw impacts the nitrogen cycle by stimulating microbial growth with carbon input. Microbes immobilize ammonium in their biomass. With less NH_4^+, there is less NO_3^- , since it is a direct product of NH_4^+ through the nitrification process. Carbon from the straw can enter the soil profile with rain water as leachate from surface decomposition. Alternatively, it can be incorporated directly at the soil interface. In either case the effect of NH_4^+ immobilization would be more pronounced closer to the surface, since there is more carbon near the straw-soil interface. This could be the explanation for not seeing the effect of straw on resin capsules. They were buried at a six inch depth and carbon may not have reached that depth in significant quantities. Another explanation is soil heterogeneity. Resin capsules are point measurements and thus susceptible to localized heterogeneity. Pockets of high and low nitrate concentrations could have altered the measurements of adjacent capsules. Soil analysis of nitrate is less subject to this heterogeneity because samples are homogenized from composite soil cores and integrate nitrate concentrations from the surface to the six-inch depth.

We expected to see a similar effect from clover, due to potential root exudates that could stimulate microbial growth, but it was not apparent in the results. A likely explanation is that clover matured quite late; it produced a dense cover only by mid august. This may not have given plants enough time to significantly influence the microbial population. The effect on microbes may also have been localized to the immediate root zone. Additionally, clover is a nitrogen storing crop and the stored nitrogen is not released until biomass decomposes. Considering these points, effects of clover on the nitrogen cycle may best be assessed in a multiple year study.

It was strange to note the lack of mulch treatment effect in the lab analysis of potentially mineralizeable nitrogen (Figure 4.2). One plausible explanation is the difference in activity of microbial communities between the anaerobic environment during PMN incubation and field conditions. While microbes grow on the carbon from the straw and immobilize ammonium in the field, the same microbes may not be active without oxygen. If the dominant microbial community is releasing ammonium, then we would not expect to see a strong impact from straw or clover mulch. The dominant driver of PMN in this case would be the amount of organic matter in the soil sample and how recalcitrant it is. The added mulch would comprise only a small part of total organic matter. If this is the case, than soil heterogeneity in organic matter composition may be behind the PMN numbers shown in Figure 4.2.

What is more surprising is that there is no correlation between PMN measured by the lab method and *in situ* PMN measurements provided by the resin capsules (Figure 4.5). Lab PMN results give us an upper bound on the amount of inorganic nitrogen released in a growing season based on incubation under ideal conditions. Even if this number is not accurate, if there is more organic matter in the soil it should be reflected in both lab and resin capsule measurements. In this case however, the lack of correlation may be due to lab PMN and resin capsule PMN measuring different parts of the soil, subject to different rates of mineralization. The process of mineralization at a six-inch depth in the soil may be significantly slower than at the surface due to less oxygen and colder temperature. Cooler than average temperatures and frequent rains during the time of the experiment may have further exacerbated those differences.

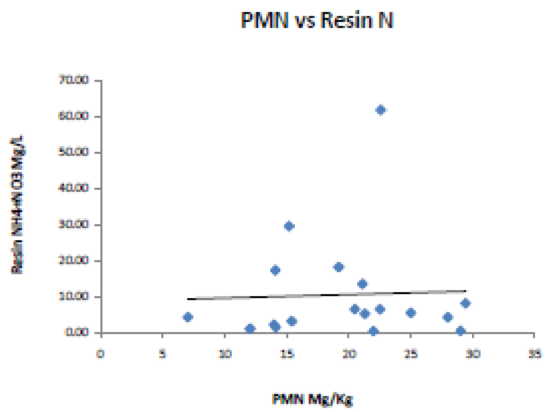

Figure 4.5: Lab PMN is shown on the x axis and resin capsule PMN on the Y axis. There is no apparent correlation for samples at the same locations.

Another reason for the lack of correlation between resin and lab PMN is the resin capsules' disconnect from a large part of the soil profile. The nitrogen captured by the resin capsules is largely dependent on the flow of soil water. Capsules sorb ions as water flows over them. In this case, the irrigation drip tape was buried at a 5-inch depth, so the resin capsules were not receiving the inorganic nitrogen that mineralized above the drip tape except when it was leached down by rain. This required that ammonium be first oxidized to nitrate, a form of inorganic nitrogen that can leach downwards. So while in lab PMN incubation all of the incubated soil contributes to the ammonium yield, with resin capsules, only the part of the soil that is hydrologically connected to the resin capsules contributes. This may be the more important reason for lower PMN values from resin capsules.

Conclusion

Resin capsules and soil sample analysis are complementary techniques in the study of nitrogen availability. Resins integrate temporal processes at point locations while soil cores can better integrate spatial distributions of processes. Using both approaches helps to overcome some of the natural heterogeneity and uncertainty that is inherent to soil systems. While the data from resins and lab measurement did not line up as closely as it could have in this experiment, a lot of insight was gained from using both methods. It was observed that straw mulch reduced availability of nitrate in the soil and total nitrogen content of the soil increased with mulch application. The first point suggests that straw mulch could potentially be used to slow the downward movement of nitrogen in the soil profile while the latter suggests that mulching may be useful in long term storage and increase of nitrogen stores in the soil.

5. Mulch Treatments vs. Soil Moisture

Water is the driving force for success in nutrient transport and sustainable plant growth (Simons 2009). In the drier climate of southwest Montana, many gardening situations require efficient use of water (Perrin 1991). The Capstone research project at the Towne's Harvest Garden dealt with several issues that influence production and maintenance for small farm operations. In order to support the group investigating mulching treatments, there was a need to quantify soil moisture content in relation to each treatment. What is the difference in soil water content between straw mulch and the living mulch of clover? Is there a difference in soil moisture between species of vegetables under the mulching treatments? How is water in the soil measured or quantified? These are the questions brought up by the soil water group for Montana State University LRES Capstone class.

Methods

An experiment was designed to quantify the mulch treatments' ability to retain soil moisture. The mulch treatments were straw mulch, living mulch (clover) and the control (no mulch). The experiment also attempted to differentiate soil moisture retention between two crops, broccoli and onion. Each row of crops had three segments, equal in length. Each segment was assigned a mulch treatment.

Volumetric water content refers to the percentage of a given volume of a soil occupied by water (Sinclair 1991). Volumetric water content was found by using TDR probes in the mulch treatments. The probes were placed in random locations towards the center of the crops rows. All 20 cm of the probe's length was inserted into the soil (Figure 5.1). On July 27th and September

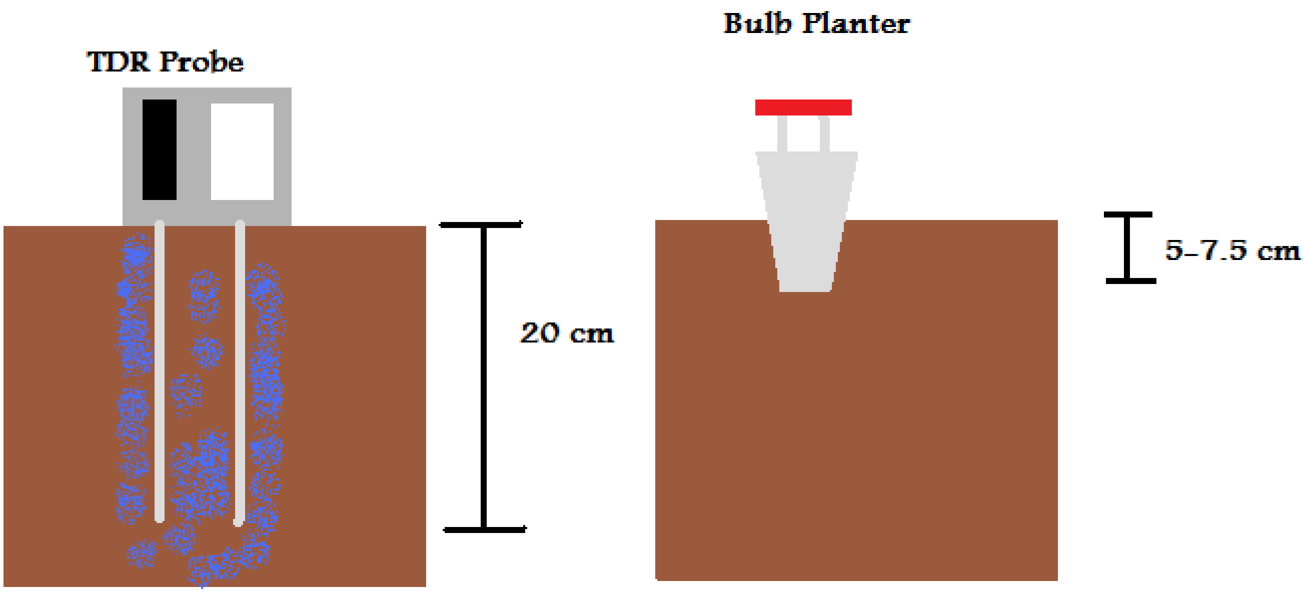

Figure 5.1. Diagram of TDR probe placement within soil profile (left) relative to portion of the soil profile sampled for gravimetric water content (right).

12th, three replicates were recorded from each mulch treatment with in two of the broccoli rows. Soil moisture in an onion row was measured on September 17th.

Gravimetric water content refers to the percentage of a given mass of soil derived from water (Sinclair 1991). Gravimetric water content is measured by weighing extracted soil. The soil was weighed as it occurred in the field and again after it had been dried. The difference in the weight from wet to dry is the weight of the water. The difference is divided by the wet weight to calculate the percentage. The soil was removed using a bulb planter. The bulb planter extracted the samples at 5-7.5 cm from the soil's surface in a

2.7cm diameter (Figure 5.1). Once the samples were removed, they were placed in tins and sealed with wax paper and a lid. The samples were then promptly transported to the lab to be weighed and dried. The samples were taken on September 12th and 17th in the same rows and measurement sites as the volumetric measurements.

ANOVA was used to analyze the data. Post hoc analysis determined whether the treatment's effects on soil moisture differed. A Levene's Test was use to test one of the assumptions of ANOVA, that the error variance is similar between groups.

Results

Volumetric water content measurements were taken in mid-July for mulch treatments within the broccoli rows. There was no significant difference between the bare ground control and straw mulch (Figure 5.2). However, there was a significant difference between the clover mulch and both the control and straw mulch. There was a lower volume of water in the clover mulch treatment. This is probably due to the vigorous growth of the clover consuming more water in the soil.

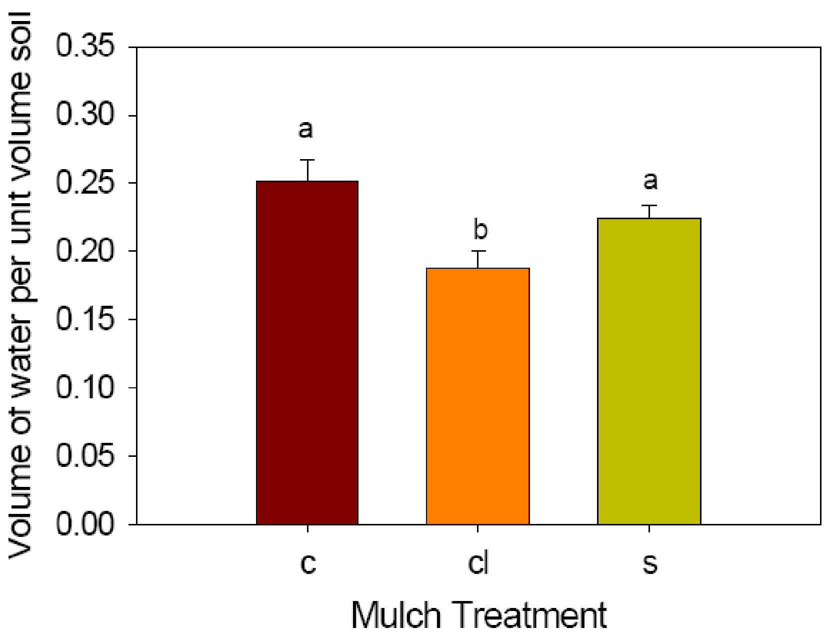

Figure 5.2. Soil moisture content and the mulch treatments in July. c=control, cl=clover, and s=straw

Volumetric water content was measured again in September in the onions and broccoli (Figure 5.3). Volumetric water content is volume of water, per unit volume of soil and is expressed as a percentage. There is no difference in water content between species but a significant difference between treatments within broccoli.

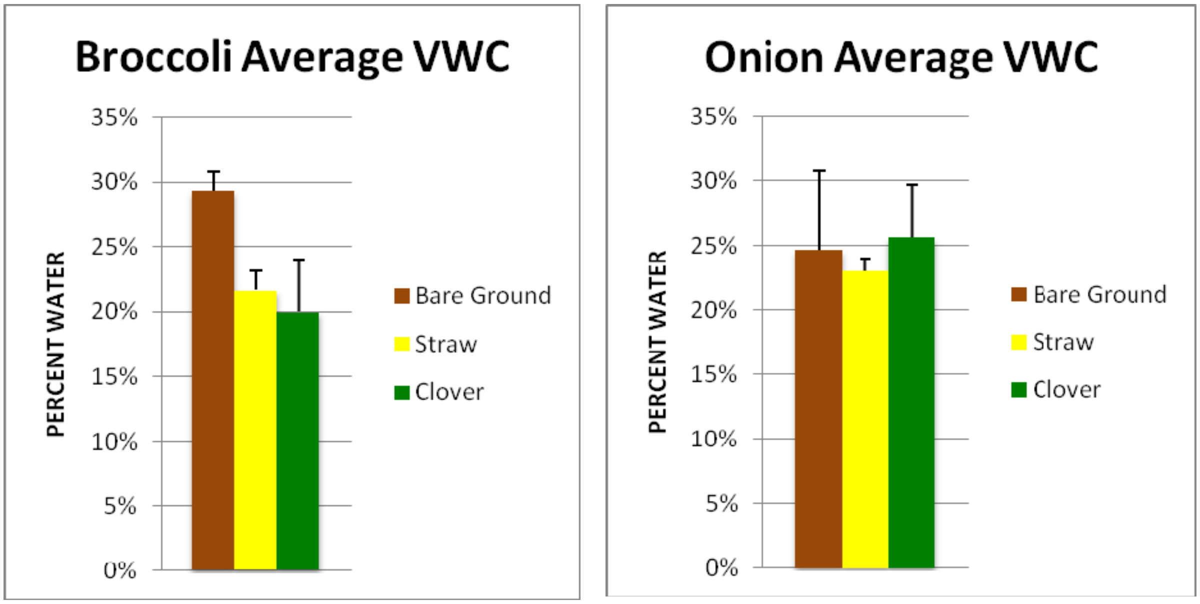

Figure 5.3. Volumetric soil moisture percentage in the mulch treatments for onion and broccoli, measured in September.

Gravimetric water content, the mass of water per unit mass of dry soil, was measured in the species onion and broccoli in September, 2009 (Figure 5.4). The soil in the onion row contained more water than the broccoli. However there was no difference between the treatments within the species. The trends suggest higher water content under straw than mulch treatment, but the variance is so high that it is not statistically different.

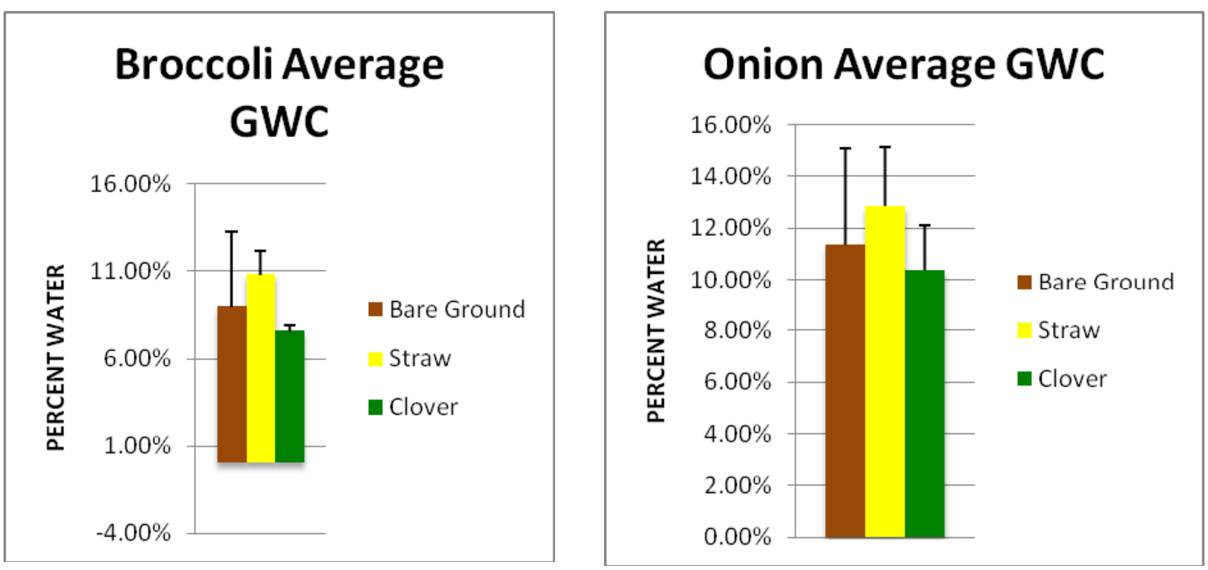

Figure 5.4. Gravimetric water content soil in the mulch treatments for onion and broccoli,

Discussion

The hypothesis that mulch treatments would retain more soil moisture than the control, was not supported. The September measurements indicated that bare ground had the highest volumetric water content average for the depth of 20 cm. This could be the result of excess water delivery due to punctured water line when inserting TDR probes in the soil profile. Also, some of the results may be misleading because the TDR probes measured to 20 cm depth. The measured depth was likely too great to record differences caused by surface conditions, in soil water content. The July measurements show less water content in the clover treatment, which could be due to the clover's consumption of water.

The gravimetric readings showed no significant difference between mulching treatments. Though the trend is not statistically conclusive, the data does show a slightly higher average percentage of water content for straw mulch. The lack of statistical significance is likely due to our small sample size and the inherent variability in soil parameters, but could suggest that straw mulch was more effective at retaining surface soil moisture. The onion and broccoli soil water percentage averages were similar, though the broccoli had a lesser average. Morphological differences in the root structures of the species could explain the slightly lower percentages for the deeper rooting broccoli. The crops' canopy cover could have also caused differences in soil moisture retention.

We suggest that analyses on volumetric and gravimetric measurement methods and results should be done to further knowledge on the consistency of the measurements. The similarity of results in a controlled experiment could show their utility when comparing results.

6. Conclusion of Capstone Experience

To conclude we will briefly summarize the major findings by the 2009-2010 Capstone class. Intercropping beans with potatoes over the summer of 2009 was not advantageous. Flea beetles (*P. cruciferae*) demonstrated preference for collards at the beginning of the summer, but avoided them at the end. Mulching broccoli, leeks, and onions with either clover or straw affects each crop differently throughout the growing season. Neither mulching treatment produced a net effect on the crop growth rates, with one exception: straw mulch caused a decrease in yield in onions by the end of the season. Total N increased with either straw or clover mulch, and straw reduced the amount of nitrate in the soil at the end of the growing season. We also explored the advantages and disadvantages of using both gravimetric and volumetric methods of measuring soil water in the context of THG.

The success of intercropping depends on several physical and biological factors that are not easy to account for. Intercropping crops other than potatoes and beans, or intercropping potatoes and beans in another area of the farm may produce different results than ours. Using collards as a bait crop may reduce flea beetle damage to pac choi and/or arugula, but we would recommend more experimentation with the placement and timing of bait crops in order to conclusively determine their positive effects. The fact that adding straw mulch reduced soil nitrate may be beneficial in reducing nitrogen leaching to groundwater.

Overall our class learned many lessons regarding the complexity and struggles associated with implementing field experiments. We also learned about the difficulties of doing precise scientific experiments on a production-focused garden where the researchers have very little control of how the farm is run. We had to re-plan, improvise, and refocus our experimental goals multiple times during the experiment and data analysis process. Perhaps the most important lesson we learned is the importance of doing experiments in the field where the results will be implemented. Lab experiments do not always produce results that will apply to real life scenarios. The only way to know that scientific principles found through experimentation will apply to a given scenario is to conduct the experiments in the specific scenario. This is precisely what we did and the lessons we learned through our experience are definitely lessons we will be able to use in each of our own personal scientific careers.

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