The Role of Soil Type, Nitrogen, and Mycorrhizae in Pea Aphid (*Acyrthosiphon pisum*) Reproduction

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ABSTRACT

To understand what leads to high pest densities in agricultural systems, experiments have compared conventional and organic conditions. Conventional management has been strongly linked to high pest densities, however less is known about reproduction rates under these conditions. Organic soils generally differ from conventional in their beneficial fungi. Experiments on the relationship between mycorrhizal fungi and pest reproduction have been inconclusive, which highlights a major gap in agricultural research. To fill these knowledge gaps, I conducted an experiment to examine soil type, nitrogen, and mycorrhizal fungi in aphid reproduction. In two rounds I planted fava beans in six different soil conditions. Round 1: organic, conventional, organic with ammonium nitrate (N), and conventional with N. Round 2: conventional with mycorrhizae and conventional with N and mycorrhizae. I added one adult aphid to each plant in individual cages. I counted offspring each day over five days to get an average reproduction rate. Plants in conventional soils hosted significantly higher reproduction rates than the other treatments in round 1, followed by organic, conventional + N, and lastly organic + N. These results were unexpected because it shows that increased nitrogen may decrease pest problems in either organic or conventional conditions. This may be due to the amount of nitrogen applied or possible plant defenses. These results also showed that organic soils best reduce reproduction. I found no significant difference between the treatments of round 2, which implies that the mycorrhizal fungi may be beneficial for aphid reproduction and detrimental for pest management.

KEYWORDS

Pest control, soil content, belowground and aboveground interactions, organic, conventional

INTRODUCTION

Pests are a primary issue in agricultural management; attempts to control populations have led to considerable ecosystem disruption and environmental pollution (Bengtsson et al. 2005, Stopes et al. 2006). Conventional farms rely on heavy pesticide use to diminish pest densities (Debach and Rosen 1991). Approximately 2.5 million tons are applied each year in the US, and each year US farmers spend $20 billion on pesticides, leading federal and state governments to spend $200 million on pesticide pollution control (Pimentel et al. 1994). Considerable pesticide usage has been strongly linked to groundwater pollution and numerous human health issues (Hallberg 1989, Ward and Allanson 1996, Gorell 1998). Pesticides are estimated to cause 20,000 deaths a year and have been linked to cancers, neurological diseases, infertility, and more (Pimentel et al. 1994). In addition, pesticide use is largely ineffective in long term management; it creates a cycle of pest resistance and the need to develop stronger pesticides (Nicholls and Altieri 1997, Ruberson et al. 1998). Pesticides also kill and disrupt the reproduction of natural enemies, which exacerbates the problem of crop destruction (Ruberson et al. 1998). In an effort to combat pesticide application, scientists have begun investigating how agricultural management may affect pest densities.

Synthetic fertilizers used in conventional farms have clear associations with increased aphid densities (Bengtsson et al. 2005, Garratt et al. 2010). Aphids benefit from the increased amino acid concentration and elevated C:N ratio of plants treated with nitrogen fertilizers (Nawoke and Komor 2010). As a result, aphids are attracted to the potential nutrients in the fields, which creates a strong association between conventional management and high aphid densities (Bengtsson et al. 2005, Garratt et al. 2010). Furthermore, aphid populations grow more rapidly on plants with increased soil nitrogen because of the beneficial increase in foliar concentrations of nitrate (Jansson and Smilowitz 1986). However, greenhouse experiments are far less common than field experiments. More is known about pest attraction to certain field plots than how quickly they colonize once there. Thus a knowledge gap exists between soil conditions and aphid reproduction.

Another major difference between organic and conventional farms is that fertilizers used in organic farms differ from synthetic fertilizers, specifically in the presence of different species of beneficial mycorrhizal fungi. Mycorrhizal fungi form a beneficial interaction with the plant’s rhizosphere and help with disease resistance, drought resistance, and nutrient absorption (Davies et al. 1992, Pozo and Azcon-Aguilar 2007). This mycorrhizal association may additionally help with plant defense again pests, however multiple literature reviews have demonstrated the inconsistency in findings (Gehring and Whitham 2003, Bennett et al. 2006). Some species of aphids can show decreased fitness after feeding on mycorrhizal plants, whereas other species benefitted (Gehring and Whitham 2003, Bennett et al. 2006). Results also differ depending on species of mycorrhizal fungi (Koricheva et al. 2009). More detailed understanding of this interaction and the importance of mycorrhizal fungi is necessary to further determine the implications for management. Pea aphids (*Acyrthosiphon pisum*) specifically are of great agronomical importance as they affect numerous crops including pea, clover, alfalfa, and broad bean crops, however there is minimal research on how mycorrhizae affects their reproduction (van Emden and Harrington 2007).

In this study, I ask: what are the roles of organic and conventional soil, nitrogen contents, and mycorrhizal fungi in pest abundance? To answer this question, I will: (1) determine the available nitrogen contents of conventional and organic soils, and (2) determine the role of available nitrogen contents and mycorrhizal fungi in pea aphid (*Acyrthosiphon pisum*) abundance. I will achieve these objectives by measuring population growth under six different soil conditions. I hypothesize available nitrogen content will be higher in untreated organic soils than in untreated conventional soils. I hypothesize aphid abundance will be highest in conventional soils with added available nitrogen and lowest in untreated organic soils. Finally, I hypothesize that conventional soil with mycorrhizae will have lower aphid reproductive rates than conventional soil with mycorrhizea and nitrogen.

METHODS

Study Site

I conducted this experiment in the Mills Laboratory insectary and greenhouse at the University of California, Berkeley. The insectary was kept at 74 degrees F for the duration of the experiment.

Study Population: Acyrthosiphon pisum

I looked at changes in population of the pea aphid. Aphids reproduce parthenogenetically (asexually), which allows for rapid reproduction after colonization. Fifth instars (fully developed aphids) are the only instars with wings to allow colonization over large distances and are also the only instars that can reproduce. Not all fifth instars develop wings.

Data Collection

To determine the available (ammonia and nitrates) nitrogen contents of the potting soils used, I sent samples to the Silver Laboratory at the University of California, Berkeley. I purchased organic Sun Go Sunshine potting soil by Sun Gro Horticulture Canada Ltd. and conventional SuperSoil potting soil by Scotts Miracle Grow. Organic potting soil contained composted pine bark, peanut hulls, peat moss, and Dolomitic limestone for pH adjustment. The organic soil additionally contained a mycorrhizal starter. Conventional potting soil contained peat, forest products compost, a wetting agent, and additional synthetic fertilizer of 0.43-0.12-0.15 (Nitrogen-Phosphorous-Potassium). I took samples from the top, middle, and bottom sections of the bags of potting soils to fill a gallon plastic bag and mixed them before giving samples to the Silver Laboratory. I picked out the roots from the organic potting soil to ensure results were not skewed by organic material present. Then I sieved the soil samples through a 2mm sieve to define the remaining contents as soil before running the tests. Three different carbon:nitrogen [C:N] tests were run for each conventional and organic potting soils, with three replicates run per test for accuracy. Three different samples were also run for each potting soil to determine available nitrogen contents. I weighed these samples after processing to determine the amount of available nitrogen per gram of soil.

To create consistent growing conditions, I planted fava beans in waves of 40-60 seeds at a time in individual pots, half in organic potting soil and half in conventional soil. Plants were grown in a greenhouse under lighting 24 hours a day, and I watered them every other day. Each week I selected plants from the organic and conventional pots. I randomly chose half of each soil type to treat with nitrogen. I treated these pots with 400 ml of ammonium nitrate water (1g Fisher Scientific ammonium nitrate dissolved in 2 liters of water) every three days in the week leading up to use. I separately potted 60 conventional fava seeds in conventional soil mixed with 20 grams of soil from a field known to have mycorrhizal fungi. I treated half of these pots with the same nitrogen treatment as previously stated.

Data Collection: Aphid Reproduction Rates

To determine the role of soil type and available nitrogen in aphid reproduction, I kept plants in individual cages. Each week of the 9 week experiment I had 16 plants, 4 of each treatment (organic, organic + N, conventional, and conventional + N). I added one adult aphid (fifth instar) raised in organic soil colonies per organic or organic + N treated plant. I added one adult aphid from conventional colonies to each conventional or conventional + N treated plant. Each day for five days I counted the number of offspring and removed them. I additionally collected data on plant height (cm) and number of leaves. I did this for 120 plants, 30 for each treatment.

To determine the role of mycorrhizae in aphid reproduction, I had 48 plants, 24 of each treatment (conventional + mycorrhizae, conventional + N + mycorrhizae). I repeated the previous methods to determine reproductive rates. Aphids were taken from conventional + mycorrhizae and conventional + N + mycorrhizae colonies.

Data Analysis: Nitrogen Contents

For all analysis, I used RStudio (R Development Core Team 2012). To analyze differences between organic and conventional soil available and total nitrogen, I used an unpaired t-test because I compared the means of two unmatched groups. I used the p-value $p < 0.05$ as significant. The assumptions met to use an unpaired t-test are instrumentation (scale of measurement), random sampling, normality, sample size, and homogeneity of variance. I expect to see higher total and available nitrogen contents in organic potting soil based off other research.

Data Analysis: Aphid Reproduction Rates

I also used RStudio to analyze reproduction rates for rounds 1 and 2 of my experiment (R Development Core Team 2012). I used three analysis of variance (ANOVA) tests in RStudio to compare the differences in aphid reproduction rates, height, and leaf count among the four soil treatments for round 1 (R Development Core Team 2012). Major assumptions met to perform ANOVA are independence, normality, and homogeneity of variances. I lastly used RStudio to run an unpaired t-test to determine the role of mycorrhizae in aphid abundance (R Development Core Team 2012). The assumptions met to use a t-test are instrumentation (scale of measurement), random sampling, normality, sample size, and homogeneity of variance.

RESULTS

Soil Nitrogen Content

The available nitrogen content in organic potting soil was significantly higher than the available nitrogen content in the conventional potting soil (unpaired t-test, $p < 0.001$). The organic potting soil contained an average 0.0931 mg of available nitrogen per gram of soil. The conventional potting soil contained an average 0.0587 mg of available nitrogen per gram of soil.

Aphid Reproduction Rates: Nitrogen Treatments

I found that average aphid offspring per day was significantly higher in conventional soils without additional nitrogen than the other soil types. I found the conventional soils significantly higher than conventional + N (ANOVA, $p = 0.00261$), organic (ANOVA, $p = 0.04425$), and organic + N (ANOVA, $p < 0.001$) treatments (Figure 1). I found no significant differences between conventional + N, organic, and organic + N treatments. I specifically found that mean daily offspring in conventional treatment was the highest (5.566092 ± 1.847668 offspring/day), followed by organic (4.308333 ± 2.095442 offspring/day), conventional + N (3.847222 ± 1.715112 offspring/day), and lastly organic + N (3.516667 ± 1.574826 offspring/day).

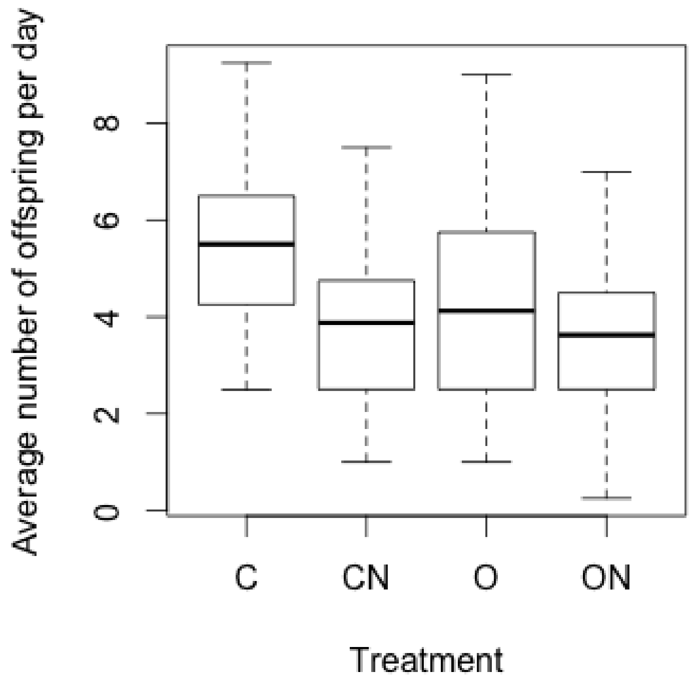

Figure 1. Effect of soil type and increased nitrogen content on aphid reproduction rates. I found aphid reproductive rates to be significantly higher than all other soil treatments: conventional + N, organic, and organic + N

Height: Nitrogen Treatments

I found the heights of the nitrogen treatment plants were significantly higher than the conventional treatment plants. Organic + N treatment plants were significantly taller than conventional treatment plants (ANOVA, $p = 0.00038$). Conventional + N treatment plants were also significantly taller than conventional treatment plants (ANOVA, $p = 0.00129$). There were no significant differences between the other treatment heights. The mean height for organic plants was 27.2241 cm and the mean height of the conventional plants was 23.259 cm. The mean height for organic + N was 30.4333 cm and the mean height for conventional + N was 29.0333 cm.

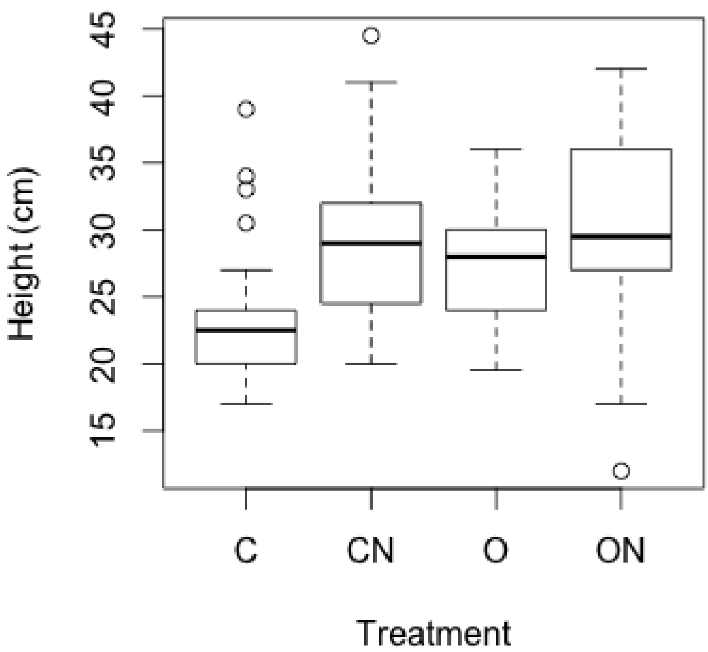

Figure 2. Effect of soil type on plant height (cm). I found conventional treatment plants to be significantly shorter than conventional + N and organic + N treatments.

Leaves: Nitrogen Treatments

Organic + N and conventional + N plants had significantly more leaves. Organic + N treatment plants had significantly more leaves than conventional treatment (ANOVA, p = 0.0006012) and organic treatment plants (ANOVA, p = 0.0001853). Conventional + N treatment plants had significantly more leaves than conventional (ANOVA, p = 0.008229) and organic treatment plants (ANOVA, p = 0.0002581). The mean number of leaves per plant for each treatment were: organic 9.7241 leaves, conventional 9.9655 leaves, organic + N 13.0667 leaves, and conventional + N 13.0000 leaves.

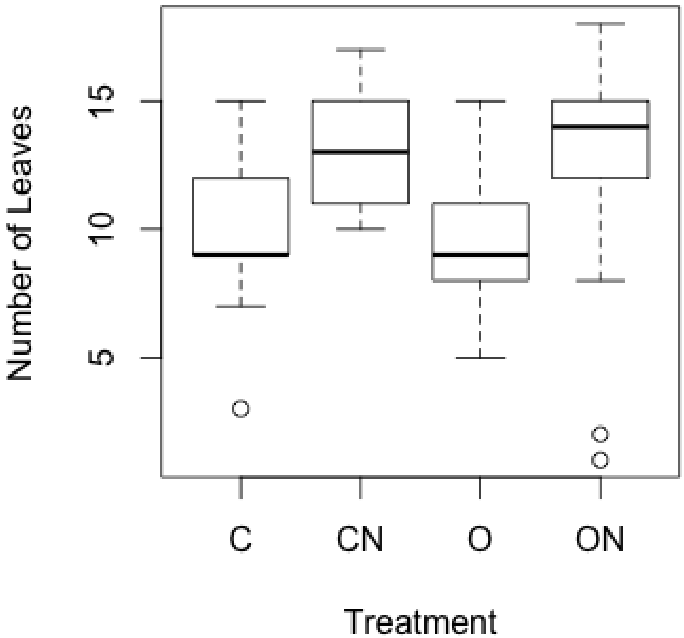

Figure 3. Effect of soil type on number of leaves. I found that plants with nitrogen treatments had significantly more leaves than soil without additional nitrogen.

Aphid Reproductive Rates: Nitrogen + Mycorrhizae Treatment

I found no significant differences between conventional soils treated with mycorrhizae and conventional soils with mycorrhizae and nitrogen (unpaired t-test, 44 d.f., $p = 0.485$). Mean daily offspring was 4.2607 offspring per day for conventional + mycorrhizae and 3.851 offspring per day for conventional + N + mycorrhizae.

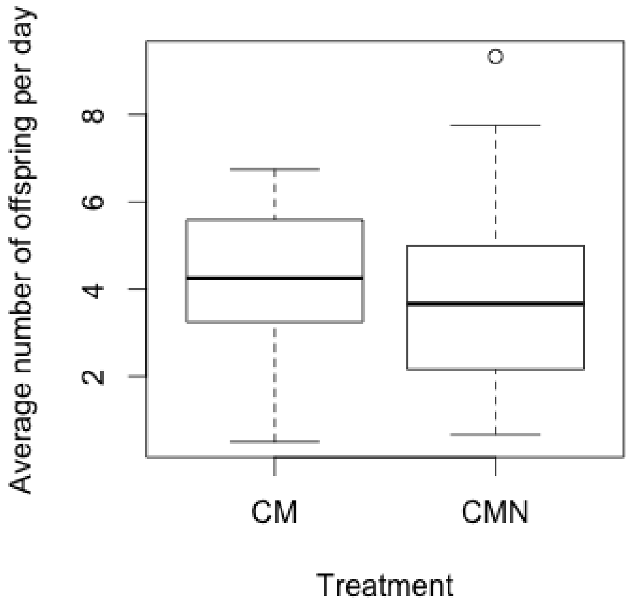

Figure 4. Effect of mycorrhizae and nitrogen on aphid reproduction. I found no differences in aphid reproduction rates between the two treatments.

Height and Leaves: Nitrogen + Mycorrhizae Treatment

I found no significant differences between the height (unpaired t-test, 44 d.f., $p = 0.61$) and number of leaves (unpaired t-test, 44 d.f., $p = 0.654$) between conventional + M and conventional + MN. The mean height for conventional + M plants was 24.7609 cm. The mean height for conventional + MN plants was 23.8670 cm. The average number of leaves per plant for conventional + M was 13.0000 leaves and the average number of leaves for the conventional + MN plants were 13.3478.

DISCUSSION

My study found that conventional soil, with the lowest available nitrogen content, hosted the highest aphid reproduction rate, and the two nitrogen treatments had the lowest reproduction rates. This implies that nitrogen may be detrimental for pea aphid reproduction, which opposes past research on pest abundance and nitrogen. These differences may be explained by the sheer amount of available nitrogen in the soil or by chemical defenses enhanced by nitrogen treatments.

Conventional treatments hosted higher reproductive rates than organic treatments, which coincides with previous studies. Insignificant results between mycorrhizae and mycorrhizae + N treatments implies that the mycorrhizal fungi may be beneficial to pea aphids to offset the detriments of ammonium nitrate. To further understand how these factors may influence reproduction, we must first establish the nitrogen contents of the untreated organic and conventional soil.

Available Nitrogen Content

Significantly higher available nitrogen content in organic potting soil suggests that conventional soil does not benefit greatly from added synthetic fertilizer. Finding higher available nitrogen in organic soil composed of compost and organic matter coincides with my hypothesis and with literature. Numerous studies comparing the ammonium nitrate content of organic and conventional fields have found higher content in organic soils (Jackson et al. 2004, Marinari et al. 2005, Herencia et al. 2008, Peck et al. 2011). This demonstrates that even though conventional soil is treated explicitly with additional ammonium nitrate, it may more beneficial for plants to have ammonium nitrate from organic sources such as compost because there is simply more of it to extract from the soil (Stamatiadis, et al. 1999). To investigate the role of nitrogen more fully, I added nitrogen treatments to both organic and conventional potting soils.

Aphid Reproduction Rates: Nitrogen Treatments

I found significantly higher aphid reproduction in conventional soil and lower reproduction in the nitrogen treatments, suggesting that nitrogen does not automatically lead to increased reproduction. Finding the lowest reproduction in the highest nitrogen treatments opposes my hypothesis and previous studies that have shown that increased nitrogen content directly correlates to larger aphid populations (van Emden and Bashford 1969, Cisneros and Godfrey 2001, Nevo 2001). These studies used smaller increments of additional available nitrogen to find this relationship, which greatly differs from my single nitrogen treatment (Nevo 2001, Jahn et al. 2005, Jiang and Sculthess 2005). This brings to light the possibility that there is a ceiling for beneficial nitrogen content for aphids, after which additional nitrogen may become detrimental and slow reproduction. It also implies that beneficial plant conditions may adversely affect aphid fecundity to a certain degree.

Finding the adverse effects of nitrogen on aphid reproduction may also imply additional chemical defenses with ammonium nitrate treatments that enhance plant defenses to stifle reproduction. Nitrogen may affect chemical defense by facilitating the synthesis of nitrogen-based defense chemicals such as alkaloids, cyanogenic glycosides, glucosinolates, and benzoxazinoids (Bennett and Wallsgrove 1994). With additional nitrogen treatment, these plants may be more capable of emitting volatile nitrogen compounds that resist further herbivory (Karban and Myers 1989, Pare and Tumlinson 1999). These chemicals may be leading to decreased aphid preference or performance, affecting fecundity (Karvan and Myers 1989). Unfortunately the effect of ammonium nitrate on chemical defenses has not been determined in literature, so no full conclusions can be drawn from these results.

This round also found that organic potting soil and organic + N potting soil hosted lower aphid reproductive rates than their respective conventional counterparts, which may imply that soil type is the second biggest influence on aphid reproduction. Finding lower aphid abundance on organic than conventional soils agrees with previous research (Culliney and Pimentel 1986, Bengtsson et al. 2005, Garrat et al. 2010). Few greenhouse experiments have been conducted comparing the two soil types, however field experiments have consistently shown these results (Bengtsson et al. 2005, Garrat et al. 2010). One field experiment however did not find any sort of correlation between tissue nitrogen in management systems and pest damage, however they attributed this to external factors and did not draw any management conclusions (Letourneau et al. 1996). To further isolate the beneficial attribute of organic soil, I extended my experiment to examine the role of mycorrhizae fungi in aphid reproduction.

Aphid Reproductive Rates: Nitrogen + Mycorrhizae Treatment

Finding no significant difference between the two mycorrhizae treatments (conventional + M and conventional + MN), suggests that the mycorrhizal fungi added may be beneficial for pea aphid reproduction to offset the negative affects of the nitrogen treatments. There is minimal research specifically on the interactions between pea aphids and mycorrhizal fungi, however research has established that arbuscular mycorrhizal fungi are generally beneficial to sap-sucking herbivores such as pea aphids (Gehring and Bennett 2009). This is likely due to mycorrhizal fungi-aphid interactions via the host plant (Gehring and Whitham 2003). It could be that this species of mycorrhizal fungi increases the amount of sucrose and alters the diffusion gradient to escalate the availability of sucrose, effectively enhancing aphid performance on these plants (Ponder et al. 2000, Koricheva et al. 2009). Unfortunately there is no research affirming these interactions regarding pea aphids specifically.

Limitations and Future Directions

Because I conducted a greenhouse experiment with packaged soils, I cannot necessarily apply my conclusions to greater agricultural systems. For example, packaged soil may have different characteristics than soils from agricultural land. I also controlled for many factors in my greenhouse experiment that cannot be controlled in larger agricultural plots. Unanticipated results revealed that my experiment should have been more focused rather than looking for general trends in such a complex system, notably with regards to nitrogen additions. The amount of available nitrogen I added may have been too much, which would have come to light if I had added nitrogen in smaller increments. Additionally, I think I should have measured leaf nitrogen content to establish how much nitrogen the plants were absorbing. I was also limited in my study because I was unable to determine the species of mycorrhizal fungi in the soil, which likely affected my results. To better understand the interactions between soil attributes, plants, and pests, similar research should be conducted with these issues accounted for.

My findings suggest that there are more complex interactions in soil-plant-pest systems than previously assumed, which implies that more specific research should be conducted. Because my study uncovered a potentially beneficial effect of nitrogen on agricultural management, establishing a specific amount of nitrogen may prove beneficial as well as determining its effects on chemical defenses. More research into this area is also suggested since my findings contradicted most literature. I additionally suggest more research to determine exactly how pea aphids may or may not benefit from different species of mycorrhizae since the species is of agronomical importance.

Broader Implications/Conclusions

Finding results contrary to previous studies demonstrates the complexities of agricultural systems. There are many interacting factors in agricultural systems that play integral roles in ecosystem health. This study suggests that conventional management will likely yield higher pest densities regardless of nitrogen addition, which is important for pest management. It also suggests that additional nitrogen beyond a certain amount may also stifle aphid reproduction, however the inconsistency with past research and potential for environmental pollution begs further investigation in both greenhouse and field systems. These results also imply that the mycorrhizal fungi used is beneficial for aphid reproduction, however the role of mycorrhizae in agricultural systems is vast and there is little literature on its impact on pea aphids. Overall, this experiment demonstrates that organic soil management can lead to decreased pest abundance, however individual features of soil such as nitrogen and mycorrhizae are less definitive in their roles.

ACKNOWLEDGEMENTS

My thesis mentor Kevi Mace was an incredible mentor and helped me more than I could have imagined. The entire Mills Laboratory was so generous in letting me use their facilities and consoling me during all of my failed attempts at different experiments. Thank you to the entire ESPM 175 team and class (specifically the Cal Bohrs, Anne, and Tina) for looking over all of my work and listening to my ideas. My parents, friends, and boyfriend were amazing and supportive through this entire endeavor.

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