Using Arbuscular Mycorrhizae to Influence Yield, Available Soil Nutrients and Soil Quality in Conventional VS. Organic Vegetable Production

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USING ARBUSCULAR MYCORRHIZAE TO INFLUENCE YIELD, AVAILABLE SOIL NUTRIENTS AND SOIL QUALITY IN CONVENTIONAL VS. ORGANIC VEGETABLE PRODUCTION

A Thesis
Presented to
The Faculty of the Department of Agriculture
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
Gary Thomas Cundiff

May 2012
USING ARBUSCULAR MYCORRHIZAE TO INFLUENCE YIELD, AVAILABLE SOIL NUTRIENTS AND SOIL QUALITY IN CONVENTIONAL VS. ORGANIC VEGETABLE PRODUCTION

Date Recommended April 13th, 2012

Dr. Becky Gifford, Director of Thesis

Dr. Todd Willian

Dr. Elmer Gray

Dr. Annesly Netthisinghe

Krischel C. Derrrer 21-May-2012
Dean, Graduate Studies and Research Date
I dedicate this thesis to my grandfather, Milton Cundiff, who passed away at the age of 93 on April 4th 2012. My grandfather was the first in our family to graduate from college and was an inspiration to me my entire life. Before I began the journey for my Masters, he wrote to me:

“Hello Gary T., Hope things are going better for you. Sometimes it takes a long time for the worm to turn. I don’t know if your dad ever told you that I was in an orphanage for seventeen years. As soon as some people hear this, they think that it was a hard life, but it was the best thing that ever happened to me. The woman who was the superintendent took an interest in me in every way she could. She got the board of directors to help me my first semester at Georgetown until I could get an athletic scholarship. I just wanted to point out some things that could happen even when things are bad. I wish you the best in your job and in your life and when life gets to the lowest point, that’s usually when the worm turns.

Good Luck,

Grandpa”
ACKNOWLEDGEMENTS

To my parents, Gary Cundiff and Ruth Oglesby, who always gave me the ability to have an open mind and allowed me to explore and make my own mistakes, learning from them along the way.

To Pete and Michelle, thank you for getting me through the tough times.

To Deanna, without what we went through, this journey would have seemed hard.

To Neil White, without your help and wit, I would have never kept my sanity!

To Dr. Gilfillen, thank you for all of your help, inspiration and friendship; I couldn’t have made it without you.

To Dr. Gray, your knowledge is astounding and your dedication is an inspiration.

To Dr. Willian, the “Jedi Weed Master”, without you, I wouldn’t be joining to the “dark side”.

To Dr. Netthisinghe, thank you for always having time for me with the tough questions.

To Dr. Rudolph, where do I begin? All I have to say is, if you don’t know WKU Agriculture, then you don’t know Jack!

To the faculty and staff of the Department of Agriculture, thank you for all your support!

To the WKU USDA ARS UNIT, thank you for allowing me the opportunity to further explore research in the agronomy world.

To Ollie, my wonky eyed companion, you’re the best friend a man could ever ask for.
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This research is a two year study on the effects of endomycorrhizae on vegetable production using conventional vs. organic practices. Objective of this study was initiated to determine if mycorrhizae improve yield, available soil nutrients and soil quality from two different fertilizer sources. Measurements were taken on yield, available soil nutrients, and soil quality in comparison of glomalin production and soil loss percentage. Two plant species were chosen, Tomatoes (‘Big Beef’) and Bush Beans (‘Tenderette’). A randomized split block 2 x 3 factorial treatment arrangement was used with two crops and three different inputs: Mo- 0 mycorrhizae, M1- recommended rate, and M2- 2x recommended rate of mycorrhizae. Each mycorrhizal input was replicated three times in both the conventional and organic system. Results show there was no difference in yield based on mycorrhizae additions at any rate.

There was a significant yield difference based on conventional production over organic production in tomatoes and snap beans in 2010 and tomatoes in 2011. Possible explanations for yield difference in the organic production system include: different insect controls and a slower release of nutrients from poultry litter.

Available soil nutrients were not influenced in the study based on mycorrhizal inputs in inorganic or organic tomato production. Soil available nutrients were significantly influenced in organic tomato when compared to inorganic tomato
Mycorrhizae did not influence soil fertility in inorganic snap bean or organic snap bean production. Soil available nutrients were significantly influenced in organic snap bean when compared to inorganic snap bean production at selected sampling dates.

Glomalin production and soil loss percentage were not shown to be significantly different within organic or inorganic treatments based on mycorrhizae inputs. However, glomalin production was shown to be significantly greater in organic production compared to inorganic in 2011. An explanation of this could be due to the use of leaf mulch as organic weed control. Although a numerical decrease was observed in soil loss percentage in organic production compared to inorganic production from the first year to the second, it was not shown to be a significant amount.
CHAPTER I

INTRODUCTION

The use of a soil microorganism to influence soil fertility for the benefit of the producer is an intriguing possibility. With the ever increasing price of inorganic fertilizers and the use of natural resources to produce fertilizers, an increase of soil fertility due to a symbiotic source, such as mycorrhizae, could prove to be a valuable ally. Use of mycorrhizae to influence nutrients such as N, P, K, Fe, and Zn (Podila and Varma, 2006) could possibly lead to an increase in yield in a reduced input system. This could prove to be beneficial for small scale farmers in underdeveloped regions of the world who may not have immediate access to inorganic fertilizers.

Mycorrhizae may also improve soil tilth and aggregate stability, thus reducing soil erosion potential (Rillig, 2004). We lose more soil due to erosion factors than is created across the globe every year. If mycorrhizae can be shown to improve soil aggregate stability, it can be a useful amendment not only for Agriculture but also for reclamation of disturbed lands.

Mycorrhizae is sold and marketed in the United States as a product that is meant to enhance nutrient uptake. The objective of this research was to determine if mycorrhizae influence nutrient uptake, vegetable yield, and soil quality in aggregate stability, along with glomalin production.
CHAPTER II

LITERATURE REVIEW

Mycorrhizae

Mycorrhizae are a symbiotic soil fungus that have been shown to interact with many plant and tree species, benefiting both the fungus and plant in nutrient exchange. Mycorrhizae are endophytes which mean they obtain their nourishment from within the root cortex. They are considered to be parasitic and live in or around the host plant’s root cortex but cause no symptoms of disease. Arbuscular Mycorrhizal Fungi (AM Fungi) are obligate biotrophs, being unable to complete their life cycle in the absence of a host plant (Azcón-Aguilar et al., 1998). Four hundred million years ago when the continents were virtually deserted, plants and fungi formed symbiotic systems where plants used solar energy to grow, while the fungus specialized in absorbing nutrients from the soil (Podila and Varma, 2006).

A diverse community of AM Fungi produces a beneficial and stable symbiosis with most plant communities (Podila and Varma, 2006). More than 6000 fungal species are capable of establishing mycorrhizae associations, with approximately 2,040,000 plant species (Sharma, 2001). Arbuscular mycorrhizae belong to a very old order of fungus, the Zygomycetes, and have been regrouped into a single order, the Glomerales (Morton and Benny, 1990). The bulk of known species belong to the family Glomaceae which includes the genera Glomus and Sclerocystis (Pirozynski and Dalp’e, 1989). Arbuscular
mycorrhizae fungi consist of approximately 160 species belonging to 3 families and 8 genera and have a worldwide distribution (Podila and Varma, 2006). Arbuscular mycorrhizae fungi simultaneously colonize roots and the surrounding rhizosphere, spreading out over several centimeters in the form of ramified filaments (Podila and Varma, 2006). This filamentous network which is dispersed inside as well as outside the roots allows the plant to have greater access to water and soil nutrients and in return the plant provides the fungus with sugars, amino acids and vitamins essential to its growth (Harly and Smith, 1983). This relationship involves formation of an extraradical hyphal phase that colonizes the soil in vicinity of the host root (Bago et al., 2004). These hyphae form characteristic structures including branched absorbing structures (BAS, formerly named arbuscule-like structures, ALS; Bago et al., 1998), spore-associated BAS (Bago et al., 1998) and spores. Extraradical mycelial network increases the nutrient uptake surface of the host plant and allows a more efficient extraction of phosphorus, nitrogen and certain micronutrients (Smith and Read, 1997).

In an endo-mycorrhizal association, hyphae do not penetrate the root cell’s protoplast but rather invaginate the cell membrane (Podila and Varma, 2006). Arbuscular mycorrhizal symbiosis is responsible for huge fluxes of photosynthetically fixed carbon from plants to soil and have been shown to consume up to 20% of photosynthetic carbon and in return provide the plants with large amounts of nutrients (P, N, K, Zn) and water from the soil (Jakobsen and Rosendahl, 1991). Buwalda and Goh (1982) suggested that host fungus competition for carbon may lead to growth depressions and yield declines in mycorrhizal plants. Lipid, which is the dominant form of stored carbon in the fungal partner and which fuels spore germination, is made by the fungus within the root and
exported to the extraradical mycelium (Raudaskoski et al., 2004; Solaiman and Abbott, 2004).

Most land plants, including the major crops, are able to establish endo-symbiotic partnerships with AM Fungi that enhance uptake of phosphate (Harrison, 1999). Arbuscular mycorrhizae can translocate phosphate from the soil to the plant root (Pearson and Jakobson, 1993). Inorganic phosphorus (Pi) is in such a low concentration in the soil solution (1-10μM) and its relative immobility leads to the formation of zone depleted of Pi around actively absorbing roots (Podila and Varma, 2006). Symbiotic associations formed between plants and arbuscular mycorrhizal fungi allows plants to access Pi beyond the depletion zone as extraradical hyphae extend to explore a greater volume of soil (Rosewaine et al., 1999). Inorganic P obtained by the fungus is then translocated through hyphae and effluxed in the interfacial apoplast before uptake by the plant cell across the plasma membrane (Podila and Varma, 2006). Mycorrhizal plants thus have two pathways by which Pi is obtained, direct and indirect uptake (Podila and Varma, 2006). Uptake of P is likely to take place partly via proton co-transport, which is derived by a membrane bound proton ATPase (Smith and Read, 1997). A high affinity phosphate transporter has been identified in the extraradical mycelium of *Glomus versiforme* named GvPT which encodes a high affinity fungal phosphate transporter (K = 18μM) in external hyphae (Harrison and van Burren, 1995). These mycorrhizae receptor genes are presumed to activate the common symbiotic signaling pathway (Zhang et al., 2009) that allows phosphate and nitrate to pass from fungus to plant.
Mycorrhizae in Relation to Tillage

Soil disturbance is perhaps the most direct and drastic among agricultural practices that pose stresses on Mycorrhizae formation (Bethlenfalvay, 1992). Several factors may be responsible for the decrease in root and soil colonization as a result of soil disturbance (Abbott and Robson, 1991a). Severity of disturbance effects varies with soils from different vegetation types and is related to the incidence of infective propagules available for the reestablishment of colonization after soil disturbance (Jasper et al., 1991). Agricultural practices result in maximum disturbances of mycorrhizal propagules (Read and Birch, 1998). Studies in Ontario have shown that a reduction in P uptake by corn (*Zea mays* L.) following the plowing of no-till soils is related to disruption of the AM hyphal network, which caused both a delay and reduction in mycorrhizal colonization (O’Halloran et al., 1986; Evans and Miller, 1988). Tillage can result in both a delay and reduction in mycorrhizal colonization because of physical disruption of the AM hyphal network in the soil (Miller and Jastrow, 1992). Tillage systems may affect mycorrhizae indirectly by influencing biotic factors that interact with AM, such as soil fauna, which are vectors of AM propagules (Johnson and Pfleger, 1992). Rabatin and Stinner (1989) found that conventional tillage decreased interactions between earthworms, macroarthropods, and AM Fungi. In a field experiment in Ohio, 33% of invertebrates examined from a no-till system contained AM spores, whereas only 8.6% of invertebrates from a conventionally tilled field contained spores (Rabatin and Stinner, 1989).
Mycorrhizae in Vegetable Production

There have been few attempts to relate vegetable yield or growth to mycorrhizae inoculation in field research. This is largely due to non-specific effects of fumigants, fungicide or sterilization treatments used to establish such controls or those that arise from the use of different plant species that are either constitutively mycorrhizal or non-mycorrhizal in a single experiment (Cavagnaro et al., 2006). Although usually considered important primarily for P uptake, arbuscular mycorrhizae can also increase both NH$_4^+$ and NO$_3^-$ uptake (Frey and Schuepp, 1993; Johansen et al., 1993) and that of other nutrients including Zn, Cu, and K (Marschner and Dell, 1994). Such improvements in plant nutrition are of particular significance in soils of low nutrient status (Hetrich, 1991; Menge, 1983) and heterogeneous nutrient distribution, (Cavagnaro et al., 2005; Tibbett, 2000). They may also be important for soils receiving frequent organic matter inputs as the primary source of nutrients, and those for which a complex soil food web regulates nutrient availability (de Deyn et al., 2001), such as organic farming systems. It has been shown by Saif (1977) that AM Fungi infect vegetable roots in three phases’, a lag phase, a phase of rapid development and a constant phase. In most cases 55-92% of the root system was colonized by mycorrhizae by the time of flowering fruit stage of the host (Saif, 1977).

Effects of Inorganic Fertilizers in Vegetable Production

Currently conventional vegetable production is based on intensive fertilizer use and often irrigation. Excessive nutrient application is an economic loss for vegetable
growers, and may also result in greater pest management problems (Neeteson et al., 1999). From an environmental perspective, overuse of chemical N fertilizer has been associated with increased levels of NO$_3^-$ in groundwater and surface waters (Wehrman and Scharpf, 1989). In agricultural areas with intensive farming, excessive application of P has led to increased incidence of high P, thus increasing risk of P enrichment of surface runoff, most notably in sandy soils and losses during drainage (Stanley et al., 1995). It is well known that good contact between roots and nutrients with low mobility in the soil such as PO$_4^{3-}$ and NH$_4^+$ is essential (Sørensen, 1996), because their diffusion rates are very low (Nye and Tinker, 1977). Methods exist for farmers to estimate soil minimum N content at pre-planting, by using soil test laboratories and carefully designed field experiments that are required so that this N contribution to crop nutrition can be taken into account in fertilizer strategies for vegetable crops (Chen et al., 2004).

### Effects of Organic Fertilizer (Poultry Litter) in Vegetable Production

Organic production is used to improve the soil condition over the long term (Asani et al., 2003; Woese et al., 1997). Soil is amended with materials from organic sources, and if not available on farm, they must be transported to the site and can impart additional costs in production of organic vegetables (Stanhill, 1990). These costs may be alleviated if the use of manures as organic sources is performed on site. According to the National Organic Program (NOP), animal manure can be used in the raw form with restrictions (U.S. Department of Agriculture, 2004) or as aged compost. Organic production adds to labor because of the hands-on nature and in turn leads to a premium market price to ensure economic sustainability. Surface water runoff of particulate P and
soluble P are major environmental concerns especially from manures which may cause eutrophication (U.S. Department of Agriculture, 2004).

Sellen et al. (1995) has shown that in the second and third years of the transition to organic vegetable production, yields and economics of crops under study were less than for conventionally produced crops. Russo and Taylor (2006) determined that although yields were generally increasing for vegetables during the 3-year transition period, costs were higher than for conventionally grown vegetables.

There are several materials derived from organic sources that can be used in organic production, including those from plant and animal wastes (U.S. Department of Agriculture, 2004). Manures provide nutrients over time, increase rhizosphere microbial populations, and improve soil tilth (Lalande et al., 2005; Nardi et al., 2004). Poultry litter can increase soil phosphorus in large amounts, which can cause nutrient imbalances in the soil solution (Roberts et al., 2004; Verma et al., 2005). Compared to conventional vegetable production, nutrients from animal waste may be released slowly over a period of time and permitting un-degraded manure to remain in the soil for the next growing season.

**Effects of Inorganic Fertilizers on Mycorrhizae**

Phosphorus fertilizers have varied effects on AM symbiosis and on the fungi themselves (Abbott and Robson, 1991b; Sylvia and Neal, 1990). Effects appear to be mediated by the plant at low and medium levels of soil P, but are mediated by the soil at high levels of soil P (Thompson et al., 1991). Root colonization may be reduced at very
high or very low P availabilities (Amijee et al., 1989; Koide and Li, 1990), whereas spore production is generally depressed by P availability above the levels at which the host plant benefits from AM colonization (Menge et al., 1978; Nelson et al., 1981). The cost benefit relationship for the plant, in terms of P gained from and C lost to the endophyte (Same et al., 1983), may be favorable only under certain P regimes or during certain times of the plant’s life cycle (Fitter, 1991). The superior P-uptake capability of the mycorrhizae (Bolan, 1991) is needed to satisfy P demand during heavy growth periods.

Nitrogen can also suppress (Buwalda and Goh, 1982; Johnson et al., 1984) or enhance (Aziz and Habte, 1989; Furlan and Bernier-Cardou, 1989) root colonization, and is itself taken up by AM Fungi (Azc'on and Barea, 1992). Plant P nutrition is important in determining the direction of the N effect (Sylvia and Neal, 1990), while the intensity of the effect is influenced by both P and N (Happer, 1983), by the source of N ($\text{NH}_4^+$ or $\text{NO}_3^-$), and by its effect on rhizosphere pH (Li et al., 1991; Chambers et al., 1980; Johnson et al., 1984). Several studies indicate that the ratio of nutrients within fertilizer influences mycorrhizal responses (Johnson and Pfleger, 1992). Gryndler et al. (1990) showed that balanced fertilizer stimulated mycorrhizal colonization of corn, while fertilization with unusually high or unusually low levels of N decreased colonization. Similarly, in field trials with tropical forage species, Saif (1986) showed that application of P alone reduced mycorrhizal infection; fertilization with a balanced N-P-K fertilizer did not, which may show that when P alone is added, the symbiotic association is not needed by the plant. Nitrogen status of host plant’s influences mycorrhizal responses to P (Sylvia and Neal, 1990). There is also evidence that K may be important in mediation of
mycorrhizal responses to P (Johnson and Pfleger, 1992). Plenchette and Corpron (1987) examined propagule densities in a fescue (Festuca sp.) field treated with different levels of P and K fertilizer; individually, P and K fertilizers decreased propagule densities, but when applied together, the magnitude of the negative effect was reduced.

**Effects of Organic Fertilizer (Poultry Litter) on Mycorrhizae**

It is known that poultry litter applications improve soil quality compared to chemical fertilizers (Nyakatawa et al., 2001; Grandy et al., 2002). It has been shown by Kingery et al., (1994) that extractable P concentrations in littered soils were more than six times greater than in non-littered soils, to a depth of 60 cm, poultry litter also elevated levels of extractable K, Ca, and Mg to a depth greater than 60 cm, and Cu and Zn were found to a depth of 45 cm. Sharpley et al. (2004) showed that concentrations of Pi were significantly greater in soils receiving manures compared with untreated soils and that organic fractions of organic P (occluded Pi and stable organic P) were also significantly greater in manured soils but the Pi form was greater than the organic P forms found in manured soils.

Plants can, to differing degrees, influence their P uptake by increasing the soil P availability through exudation of organic acids and protons, which acidify the soil and mineralize P compounds, resulting in the mobilization of P and some micronutrients (Strom et al., 1994; Marschner, 1995). Plants must have specialized transporters at the root/soil interface for extraction of Pi from solution of micromolar concentrations, as well as other mechanisms for transporting Pi across membranes between intracellular compartments, where the concentration of Pi may be 1000-fold higher than the external...
solution (Podila and Varma, 2006). This form in which the Pi exists in solution changes according to pH (Podila and Varma, 2006).

Arbuscular mycorrhizae colonized plants often exhibit an increased nutrient uptake, compared to non-mycorrhizal plants, which can be achieved by the development of large extraradical mycelium or by the release of organic acids or enzymes (Bolan, 1991). The role of AM Fungi in nutrient acquisition of their host seems to be inversely related to the development of root system architecture (Newshan et al., 1995; Schweiger et al., 1995). In general, AM Fungi improve the P uptake of their host plant, especially under P limited conditions (Smith and Read, 1997; Dickson et al., 1999). In nature, there is, however, a variation in P uptake in relation to colonization by different AM Fungi (Ravnkov and Jakobson, 1995), since isolates differ in P transfer efficiency and also in P supply to the plant (Pearson and Jakobson, 1993). Isolates can exhibit similar efficiencies in mineral acquisition in one soil type, while the same isolates exhibit different efficiencies in another soil type (Clark and Zeto, 1996).

Mycorrhizal roots are able to take up Pi from solutions containing up to 100mM Pi (Smith and Read, 1997), concentrations far above that likely to be encountered in the soil (Podila and Varma, 2006). High external Pi concentration (up to 16 mM) had little adverse effect on germination and growth of germ tubes in the AM Fungus, G. margarita, which suggest that the low level of colonization seen in plants growing in soils with high P status may not be the result of direct regulation of the activity of the fungus by soil Pi, but rather that specific signals of the plant regulate the activity of the fungus (Podila and Varma, 2006). In other words, the plant mycorrhizal interaction is completely variable depending, just as in inorganic fertilizers, upon the balance of N to P.
in soil solution, soil type, and true need for the plant to create the mycorrhizal symbiosis based on N to P need.

Organic phosphorus metabolism is a regulation of cell function and activity requiring tight control of the concentration of the metabolites, including various P-esters, and surpluses that are transported into vacuoles and metabolized there (Klionsky et al., 1990). Among hydrolase type enzymes found in fungal vacuoles, phosphatases are responsible for the conversion of P-esters into Pi (Podila and Varma, 2006). Nonspecific alkaline and acid phosphatase (ACPase and ALPase) have been demonstrated in AM Fungi by biochemical electrophoresis (Ezawa et al., 1999), histochemical (Ezawa et al., 1995; Tisserant et al., 1993) and cytochemical studies (Gianinazzi et al., 1979). Both ALP and ACP have been observed in the vacuole of AM Fungi and most of the activities of these enzymes are associated with the insoluble fraction (Ezawa et al., 1999), possibly the tonoplast, as also revealed in yeast (Klionsky et al., 1990). There are also a number of reports on the effect of organic amendment application on indigenous AM populations (Prakash and Adholeya, 2004). Douds et al. (1997) reported an increase in AM Fungi Spore populations of certain AM species in soils receiving organic amendments in the form of chicken litter/leaf compost in comparison to those soils receiving raw dairy manure and conventional fertilizers (Mäder et al., 2000).

Effects of Herbicides, Insecticides and Fungicides on Mycorrhizae

Numerous reports of pesticide by mycorrhizae interactions indicate that pesticides have profound effects on AM, but it is difficult to make simple generalizations from these
studies because of variability in pesticide formulations and experimental conditions (Johnson and Pfleger, 1992).

Fungicides include a tremendous variety of compounds differing greatly in their modes of action and effects on AM Fungi and conflicting reports are common, even with a single class of fungicide (Johnson and Pfleger, 1992). For example Captan and Captafol are dicarboximides and are typically applied as foliar sprays but occasionally used as seed treatments or soil drenches and reports of dicarboximides effects on AM Fungi range from detrimental to beneficial (Johnson and Pfleger, 1992).

By their nature, herbicides are designed to antagonize unwanted plants but not fungi; thus, it is not surprising that many studies report no adverse effects of herbicides on AM Fungi (Johnson and Pfleger, 1992). For example, when applied at recommended rates, the phenylurea herbicides Diuron and Chlorotoluron do not adversely affect sporulation or root colonization (Smith et al., 1981; Nenec and Tucker, 1983; Ocampo and Hayman, 1980; Dodd and Jeffries, 1989). At high application rates Diuron® actually increased soil densities of AM Fungal Spores (Smith et al., 1981).

**Leaf Mulch in Relation to Weed Control**

Mulches can be divided into organic, such as grass clippings, and inorganic, such as black plastic. Mulches can be the easiest and most effective way to control annual weeds in the garden. Mulches may also suppress perennial weeds. Mulches control weeds by preventing sunlight from reaching the soil surface. Since mature weeds remove large quantities of moisture and nutrients from the soil, removing the weeds when they are young is important. Organic mulches cool the soil surface, improve water holding
capacity, but may reduce crop growth in the spring due to cooler soil temperatures (Clemson Cooperative Extension, 2006).

**Leaf Mulch in Relation to Mycorrhizae**

Leaf mulch tends to contain a wide variety of bacteria, fungi, and other microorganisms that play a role in mycorrhizal growth and stimulation. Along with interaction with disease causing soil organisms, AM Fungi also interact with a whole range of other microorganisms in soils (Gorling et al., 2006). Bacterial communities and specific bacterial strains promote germination of AM Fungal Spores and can increase rate and extent of root colonization by AM Fungi (Johansson et al., 2004).

Daniels and Trappe (1980) showed that spores of *Glomus epigaes* (*Glomus versiforme*) did not germinate in autoclaved or gamma-irradiated soils, but did in non-sterile soils. The addition of autoclaved kaolin or activated charcoal to the autoclaved soil enhanced spore germination, suggesting that the spores contained self-inhibitors, which were inactivated by soil microbes, or were absorbed or immobilized by substances with a high ion exchange capacity.

Mayo et al. (1986) showed that spores of *G. versiforme* that were completely surface disinfected and incubated on water agar germinated less than spores that were contaminated with bacteria. Antibiotics added to inhibit bacterial growth suppressed AM fungal spore germination. Bacteria isolated from the contaminated spores, which belonged to several genera including *Pseudomonas* and *Corynebacterium*, enhanced spore germination, and enhanced germ-tube hyphal growth and branching.
Glomalin Production and Aggregate Stability in Respect to Mycorrhizae

Glomalin, a glycoprotein produced by hyphae of AM Fungi was discovered in 1996. It is thought that there is a relationship between the protein and ability to bind soil colloids thus improving soil aggregate stability (Wright et al., 1996). High concentrations of glomalin were found in Mid-Atlantic States Soils and have been related to aggregate stability across a number of soil types (Wright et al., 1996). Higher levels of glomalin give greater water infiltration, more permeability to air, better root development, higher microbial activity, resistance to surface sealing (crusts) and erosion (wind/water) (Wright et al., 1996).

Arbuscular mycorrhizae exist in two different phases, inside the plant root and in the soil (Rillig, 2004). The intraradical mycelium consists of hyphae and other fungal structures, such as arbuscules (sites of nutrient and carbon exchange between the symbionts) and vesicles (sites of lipid storage for the fungus) (Rillig, 2004). This phase is connected to the soil mycelium; the extraradical mycelium forms spores, explores soil and new areas for colonization, and absorbs nutrients (Rillig, 2004). In mycorrhizal biology, much research has been focused on the phase of the fungus inside the root; in the root, fungal abundance is relatively easily assessed by measuring percent root colonization (Rillig, 2004). However, it is the extraradical mycelium that must take on a central role in discussions of the contribution of AM Fungi to soil quality. In the past several years, attention has begun to shift to a more intensive scrutiny of the biology of this AM Fungi soil mycelium (Rillig, 2004). The extraradical mycelium is more difficult to study, since it is embedded in soil (Rillig, 2004). One way in which to study glomalin
production is with a Total Glomalin (TG) Extraction using the Bradford-Reactive Soil Protein (BRSP) assay.

There are several problems in glomalin research; it should be made clear, though, that none of these problems pertain to the operational definition of glomalin-related soil protein (GRSP), but to the link between GRSP and AM Fungi (Rillig, 2004). Since we presently have only one promising detection system in the BRSP assays, this link is by necessity somewhat weak (Rillig, 2004). In fact, in a complex medium such as soil it is impossible to demonstrate that there are no other significantly cross-reactive substances present and having a secondary specific detection system would clearly enhance the confidence in the association between GRSP and AMF (Rillig, 2004).

However, in the absence of such a system there are still several pieces of evidence that are supportive of the hypothesis that at least some portion of GRSP is of AMF origin. When taken together, while not conclusive, they provide a considerable weight of evidence in favor of this hypothesis, and there is also no piece of experimental or observational evidence to date that has conclusively refuted it (Rillig, 2004). There is increasing circumstantial evidence accumulating from decomposition studies that GRSP is of AMF origin (Rillig, 2004). When AMF growth is eliminated, e.g., by incubating soil without host plants, we have observed that GRSP concentrations decline, along with AMF Hyphae (Steinberg and Rillig 2003).

The process of soil aggregation is a complex, hierarchically structured one, in which numerous organisms and binding agents play a role (Tisdall and Oades 1982; Miller and Jastrow 2000), as well as abiotic factors (such as wetting-drying and freeze-thaw cycles). However, there are several theoretical considerations that place particular
importance on AM Fungi in this process. First, AM Fungi are very abundant (Miller et al. 1995) and ubiquitous soil organisms. Second, unlike Saprobic Fungi, AM Fungi have direct, intraradical access to plant carbon, and hence do not have to compete for soil organic matter carbon (Rillig, 2004). Third, the hyphal growth form lends itself to stabilizing structures and the relative persistence of hyphae and their products make AM Fungi important in longer-term aggregate stabilization (Miller and Jastrow 2000).

The ability to influence soil fertility by use of a soil fungus, which is symbiotic in nature, is intriguing. The ability for mycorrhizae to influence soil fertility has been shown in soil-less and soil media in greenhouse studies in the past, but has yet to show favor in field vegetable production. This study investigates available soil nutrient influence due to mycorrhizae in two different production systems in the forms of inorganic and organic fertilizers. The goal is to observe any increases among treatments in vegetable production so that one day mycorrhizae could be used in a low input agriculture system to enhance fertility. Another aspect of the study is to observe possible use of mycorrhizae as a soil amendment with respect to soil glomalin. If soil glomalin actually improves soil aggregate stability, this would be a significant input to help prevent soil loss across the globe.
CHAPTER III

MATERIALS AND METHODS

From March 2010 until October 2011, a study was conducted at the Agricultural Research and Education Complex of Western Kentucky University in Bowling Green, Kentucky. A randomized split block 2x3 factorial treatment arrangement replicated three times was used in this study.

The soil is a Crider silt loam (Typic Paleudalf). Applications of inorganic fertilizers were compared to organic fertilizers based on vegetative yield. All inorganic and organic fertilizers used are listed in (Table 1a, 1b & 1c). This study was conducted on an area that measured .07 ha⁻¹. Each plot measured 3.05 m wide and 3.05 m in length with 3.05 m alleys between each replication. The entire research area was moldboard plowed, disked and then rototilled in 2010. The entire research area was rototilled in 2011 incorporating a cover crop of winter wheat across all plots.

Table 1a. Inorganic fertilizer nutrients added on a dry weight basis.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Inorganic Tomatoes</th>
<th>Inorganic Beans</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2011</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>101</td>
<td>101</td>
</tr>
<tr>
<td>K₂O</td>
<td>168</td>
<td>56</td>
</tr>
<tr>
<td>N</td>
<td>157</td>
<td>224</td>
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</table>
Table 1b. Total nutrient content of poultry litter added on a dry weight basis.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>22</td>
<td>31</td>
</tr>
<tr>
<td>S</td>
<td>11</td>
<td>12</td>
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<tr>
<td>Mg</td>
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<td>Ca</td>
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<tr>
<td>Fe</td>
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<tr>
<td>Mn</td>
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<td>0.50</td>
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<tr>
<td>Cu</td>
<td>0.36</td>
<td>0.39</td>
</tr>
<tr>
<td>Zn</td>
<td>0.50</td>
<td>0.56</td>
</tr>
<tr>
<td>B</td>
<td>0.06</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 1c. Total poultry litter and total N, P, K added on a dry weight basis.

<table>
<thead>
<tr>
<th></th>
<th>Organic Tomatoes</th>
<th></th>
<th>Organic Beans</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2011</td>
<td>2010</td>
<td>2011</td>
</tr>
<tr>
<td>Total</td>
<td>8496</td>
<td>14724</td>
<td>3641</td>
<td>4417</td>
</tr>
<tr>
<td>N</td>
<td>314</td>
<td>449</td>
<td>134</td>
<td>134</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>250</td>
<td>412</td>
<td>107</td>
<td>124</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>187</td>
<td>449</td>
<td>80</td>
<td>135</td>
</tr>
</tbody>
</table>
Table 1d. Total nutrient content in leaf mulch added on a dry weight basis.

<table>
<thead>
<tr>
<th>Total Nutrient Content</th>
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<tbody>
<tr>
<td>2011</td>
</tr>
<tr>
<td>g/kg mulch</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>N 10.6</td>
</tr>
<tr>
<td>P₂O₅ 3.5</td>
</tr>
<tr>
<td>K₂O 4.1</td>
</tr>
<tr>
<td>S 1.7</td>
</tr>
<tr>
<td>Mg 3.7</td>
</tr>
<tr>
<td>Ca 45.3</td>
</tr>
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<td>Fe 5.2</td>
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<tr>
<td>Mn 1.07</td>
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<tr>
<td>Cu 0.009</td>
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<tr>
<td>Zn 0.055</td>
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<td>B 0.045</td>
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</tbody>
</table>

*Solanum lycopersicum* (Big Beef) and *Phaseolus vulgaris* (Tenderette) were used in the study. This study had “A” and “B” treatments with three sub-treatments (Mo, M1 & M2) in each replication. With (Mo) being based on no inoculation taking place, while (M1) is an inoculation of the recommended rate of 1.19 kg/m³ and (M2) is a double inoculation of recommended rate. The “A” treatments consisted of conventional fertilizer applications in 2010 & 2011 in both tomato and snap bean (Table 1a). The “B” treatments consisted of poultry litter and leaf mulch applications in 2010 & 2011 in both tomato and snap bean (Table 1b & 1c). “B” treatments were covered with leaf mulch at a 2” depth for weed control (Table 1d). A random soil sample (15cm) was taken from the entire area in May 2010 to determine soil fertility levels for the entire area. At the end of
each season, fall 2010, spring 2011, and fall 2011, fifteen random soil samples (15cm) from each plot were taken to determine available soil nutrient levels. Soil nutrient analysis was prepared by A&L Analytical Laboratories Memphis, TN using the Mehlich 3 Method. “A” treatments were sprayed with conventional herbicides, pesticides and insecticides. Dates and treatments of inorganic herbicides, fungicides and insecticides are listed in Table 2a, 2b & 2c. “B” treatments were sprayed with organic fungicides and insecticides (Table 3a & 3b). Herbicides, fungicides and insecticides were chosen due to availability and ease of use with both crops.

Table 2a. Inorganic herbicides applied to tomato and bean plots.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Rate ai/ha</td>
</tr>
<tr>
<td>Rimsulfuron</td>
<td>6/16</td>
<td>52.7 g</td>
</tr>
<tr>
<td>Sethoxydim</td>
<td>6/16 &amp; 6/30</td>
<td>148 ml</td>
</tr>
<tr>
<td>Crop Oil</td>
<td>6/16 &amp; 6/30</td>
<td>6 L</td>
</tr>
</tbody>
</table>
Table 2b. Inorganic fungicides applied to tomato and bean plots.

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Rate ai/ha</td>
</tr>
<tr>
<td><strong>Zinc ion and Manganese ethylene bisdithiocarbonate</strong></td>
<td>6/5, 7/2 &amp; 8/6</td>
<td>7.4 L</td>
</tr>
<tr>
<td><strong>Clorothalonil</strong></td>
<td>6/17</td>
<td>1.7 kg</td>
</tr>
<tr>
<td><strong>Azoxystrobin</strong></td>
<td>6/28, 7/13 &amp; 8/5</td>
<td>280 g</td>
</tr>
<tr>
<td><strong>Pyrimidinamine</strong></td>
<td>7/7 &amp; 8/18</td>
<td>303 g</td>
</tr>
</tbody>
</table>

Table 2c. Inorganic insecticides applied to tomato and bean plots.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Rate ai/ha</td>
</tr>
<tr>
<td><strong>Carbaryl</strong></td>
<td>6/25, 7/1, 8/3</td>
<td>2 L</td>
</tr>
<tr>
<td></td>
<td>6/25 &amp; 9/3</td>
<td></td>
</tr>
<tr>
<td><strong>Bifenthrin</strong></td>
<td>7/21</td>
<td>90 g</td>
</tr>
<tr>
<td><strong>Thiamethoxam</strong></td>
<td>8/6</td>
<td>70 g</td>
</tr>
<tr>
<td><strong>Malathion</strong></td>
<td>8/24</td>
<td>1.7 kg</td>
</tr>
</tbody>
</table>
Table 3a. Organic fungicides applied to tomato and bean plots.

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Date</th>
<th>Rate ai/ha</th>
<th>Date</th>
<th>Rate ai/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper Sulphate</td>
<td>6/5, 6/17, 7/2 &amp; 7/27</td>
<td>5.3 kg</td>
<td>6/15 &amp; 8/5</td>
<td>5.3 kg</td>
</tr>
<tr>
<td>Hydrated Lime</td>
<td></td>
<td>17.5 kg</td>
<td></td>
<td>17.5 kg</td>
</tr>
<tr>
<td>Neem Oil</td>
<td>6/25, 7/20 &amp; 8/3</td>
<td>2.4 kg</td>
<td>6/28 &amp; 7/13</td>
<td>2.4 kg</td>
</tr>
<tr>
<td>Paraffinic Oil</td>
<td>--------------</td>
<td>-----------</td>
<td>6/7 &amp; 7/25</td>
<td>3.4 L</td>
</tr>
</tbody>
</table>

Table 3b. Organic insecticides applied to tomato and bean plots.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Date</th>
<th>Rate ai/ha</th>
<th>Date</th>
<th>Rate ai/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacillus thuringiensis</td>
<td>7/1 &amp; 7/21, 8/6 &amp; 8/24</td>
<td>1.2 kg</td>
<td>6/20, 7/19 &amp; 8/18</td>
<td>1.2 kg</td>
</tr>
<tr>
<td>Paraffinic Oil</td>
<td>--------------</td>
<td>-----------</td>
<td>8/12</td>
<td>3.4 L</td>
</tr>
</tbody>
</table>

Applications of different levels of Mycorrhizal inoculations (Mo, M1 & M2) were compared based on glomalin extractions and soil aggregate stability tests. The four *Glomus* species used in the inoculation were *G. inearadices*, *G. mosseae*, *G. aggregatum*, and *G. eiunieatum* with 33 propagules/g each. Propagules were obtained from Mycorrhizal Applications INC. Grants Pass, OR
Tomato plants were established from seed in March of 2010 and 2011 in a greenhouse setting. Four flats, each containing .006 m$^3$ of potting soil were used. Each flat contained roughly 60 plants and were inoculated accordingly. The Mo treatment was grown throughout without inoculation. The M1 and M2 treatments were inoculated at the time of establishment with 7 g/ .006 m$^3$ of potting soil. In April of 2010 and 2011, tomato plants were transplanted into larger plug containers and M2 was inoculated again, giving M2 plants a total of 14 g/ .006 m$^3$ of potting soil. Tomato plants were transplanted into the field at the end of May 2010 and 2011. Snap beans were seeded in the field at the same time as tomato transplants. The M1 snap beans were inoculated in the field with .075 g per seed to equal 7g per 96 plants. The M2 snap beans were inoculated in the field with 0.145 g per seed to equal 14 g per 96 plants. The Mo snap beans were not inoculated but also equaled 96 plants. Tomato plants were spaced 0.91 m on center for a total of 9 plants per plot. Bean plants were sown at 0.61 m on center for a total of 16 plants per plot. Tomato and snap bean harvests were conducted on a weekly basis throughout the harvest seasons. Tomatoes were rated according to their marketability. Weights were taken and tomatoes were rated by standards including a rating of either 1 or 2 or cull with 1 and 2’s combined as marketable. Defects included: cat-face, cracks, skin, shape, size, rot, and insect damage. Tomatoes were weighed per treatment and per plot. Snap beans were harvested and weighed per plot.

At the end of each growing season, three random bulk density core samples were taken from each plot to determine glomalin production and soil aggregate stability. Glomalin (Total Glomalin) extractions were performed at the USDA-ARS Unit in Bowling Green, KY during 2010 and 2012 using the Bradford-Reactive Soil Protein
(BRSP) (Wright and Upadhyaya, 1998). All bulk density samples were sieved into six aggregate sizes (<1mm, 1-2mm, >2-4mm, 4-6.3mm, 6.3-9.5mm, >9.5mm) using a sieve shaker. Using the 1-2 mm soil aggregate, 1.0 g of soil from each plot was placed in a centrifuge tube with 8 ml of 50 mM sodium pyrophosphate and shaken for 10 seconds. All samples were autoclaved for an hour at 120°C. Each sample was centrifuged at 4000 RPM for 15 minutes. Supernatant containing the protein was removed by pouring into screw-capped tubes and stored at 4°C. This step was performed 10 times per 1 g of soil sample for each plot, for a total of 360 extractions and then replicated for a total of 720 extractions per year. After the extractions were completed, 100 μl was taken from each extraction and placed in micro-tubes and diluted at a 10x rate with 1 ml of Pyrophosphate Buffer Solution (PBS) and mixed for ten seconds. Before analysis, 100 μl of each dilution was added to a micro-well on a well plate along with BSA standards for a background comparison of known protein. A Bio-Rad Dye Reagent was added to each micro-well for spectrophotometer analysis at a wavelength of 595 nanometers. This procedure was performed 2 times per sample to give an overall average of total protein extracted.

The determination of water stable aggregates was performed using a rainfall simulator. The 6.3-9.5 mm aggregates were used from each plot to determine water-stabled aggregation using a portable rainfall simulator. Both 2010 and 2011 soil samples were analyzed at the USDA-ARS Unit in Bowling Green, KY. A 50 cm rainfall simulator was suspended above the sieve stand and filled with deionized water to a level of 43 cm. A 30 g sample of aggregates measuring 6.3-9.5 mm from each plot was spread over a 4 mm mesh sieve placed 0.5 m below the 0.25 m diameter rainfall simulator. The simulator was calibrated to deliver 1.0 J of energy over 300-s (5 minutes) to each sample. Soil and
water that was slaked through the sieve was collected in a pre-weighed 1000 ml beaker then dried and weighed. Each beaker’s pre-weighed number was then subtracted by the beaker’s oven dried weight to determine soil percentage loss. The procedure was then replicated and compared based on the two main effects of fertilizer type and mycorrhizal treatment.

For the entirety of this project, all data were analyzed using the Means Separation Model procedure of SPSS.
CHAPTER IV

RESULTS AND DISCUSSION

Tomato Yields As Influenced by Fertility

Total tomato yield was significantly greater in inorganic treatments than organic treatments in both years. In 2010, total yields were 46% greater in inorganic treatment when compared to organic treatment ($p \leq 0.05$) (Figure 1) (Table 4). In 2011, total tomato yields were 86% greater in inorganic treatment compared to organic treatment ($p \leq 0.05$) (Figure 1) (Table 4). Total yield was decreased in inorganic and organic tomato production in 2011 due to early season damage from hail storms. One possible explanation for yield differences between treatments may be due to glomalin production, with respect to amount extracted from the soil in the second year. If mycorrhizae are responsible for glomalin production, then glomalin extractions show a decrease in the second year inorganic treatment compared to the first year ($p \leq 0.05$) (Figure 2) (Table 5). Jakobsen and Rosendahl (1991) showed that Arbuscular mycorrhizal symbiosis is responsible for huge fluxes of photosynthetically fixed carbon from plants to soil and have been shown to consume up to 20% of photosynthetic carbon, but Buwalda and Goh (1982) suggested that the symbiotic host fungus competition for carbon may lead to growth depressions and yield declines in mycorrhizal plants. If there was a mycorrhizal decline in the second year, the decline may explain the 86% decline in total yield in 2011. In 2010 marketable yields were 89% greater in inorganic treatment compared to those of the organic treatment ($p \leq 0.05$) (Figure 3) (Table 4).
Figure 1. Tomato total Yield 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
Table 4. Descriptive Statistics of tomato and snap bean yield.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Variables</th>
<th>Treatment</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Weight 2010</td>
<td>Inorganic</td>
<td>5528.3</td>
<td>1133.8</td>
<td>377.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>3780.1</td>
<td>600.1</td>
<td>200</td>
</tr>
<tr>
<td>1</td>
<td>Total Weight 2011</td>
<td>Inorganic</td>
<td>3546.1</td>
<td>1113</td>
<td>371</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>1935.5</td>
<td>843.9</td>
<td>281.3</td>
</tr>
<tr>
<td>3</td>
<td>Marketable Weight 2010</td>
<td>Inorganic</td>
<td>43.5</td>
<td>8.82</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>23.01</td>
<td>5.95</td>
<td>1.98</td>
</tr>
<tr>
<td>3</td>
<td>Marketable Weight 2011</td>
<td>Inorganic</td>
<td>27.8</td>
<td>9.15</td>
<td>3.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>14.1</td>
<td>6.13</td>
<td>2.04</td>
</tr>
<tr>
<td>4</td>
<td>Cull Weight 2010</td>
<td>Inorganic</td>
<td>2.6</td>
<td>1</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>8.5</td>
<td>1.5</td>
<td>0.52</td>
</tr>
<tr>
<td>29</td>
<td>Bean Weight 2010</td>
<td>Inorganic</td>
<td>9.1</td>
<td>1.3</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>5.9</td>
<td>1.3</td>
<td>0.46</td>
</tr>
</tbody>
</table>
Figure 2. Tomato soil glomalin in 2011.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.
Table 5. Descriptive statistics of soil glomalin production in tomato treatments.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Variables</th>
<th>Mycorrhizae Levels</th>
<th>Treatment</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Tomato 2011</td>
<td>0</td>
<td>Inorganic</td>
<td>1.9</td>
<td>0.11</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Organic</td>
<td>3.9</td>
<td>0.16</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Inorganic</td>
<td>2</td>
<td>0.20</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Organic</td>
<td>4.2</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Inorganic</td>
<td>1.9</td>
<td>0.19</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Organic</td>
<td>4</td>
<td>0.21</td>
<td>0.12</td>
</tr>
<tr>
<td>23</td>
<td>Tomato 2010</td>
<td>0</td>
<td>Inorganic</td>
<td>3</td>
<td>0.47</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>Tomato 2011</td>
<td>0</td>
<td>Inorganic</td>
<td>2</td>
<td>0.19</td>
<td>0.07</td>
</tr>
</tbody>
</table>
FIGURE 3. Tomato marketable yield 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the p≤0.05 level of significance.
In 2011, marketable yields were 97% greater in inorganic treatment compared to organic treatment \((p \leq 0.05)\) (Figure 3) (Table 4). For 2010, differences may have been due to only half of the nitrogen from the poultry litter in the organic treatments thought to be available to the plant. In 2011, the differences may be due to glomalin differences and mycorrhizal population decrease as was suggested with total yield differences.

Cull weights in organic treatment were found to be 225% greater in 2010 than that of inorganic treatment \((p \leq 0.05)\) (Figure 4) (Table 4). In 2011, treatment did not influence cull weight \((p > 0.05)\). Cull weight difference from the two years may be explained due to seasonal influence of high temperatures and low amounts of rain increasing insect populations and lack of an effective organic insecticide in 2010. The majority of fruit damage was due to the Western Yellowstriped Armyworm, *Spodoptera praefica*, and the Tomato Fruitworm, *Helicoverpa (Heliothis) zea*. By 2011 populations had been decreased due to an effective organic insecticide program and this is represented in organic cull weights in 2011 (Figure 4).

In 2010, defects of catface, skin and shape were significantly greater in inorganic tomatoes and defects of rot and insect were significantly greater in organic tomatoes \((p \leq 0.05)\) (Table 6). In 2011, the only defect that was found to be significant was size in the inorganic treatment compared to the organic treatment \((p \leq 0.05)\) (Table 6).

Within the inorganic and organic tomato treatments were three different levels of mycorrhizae, which were inoculated at the time of seeding. Marketable yields from each level were compared to each other within fertility treatments. Marketable yields and culls were not found to be significantly influenced by mycorrhizal inoculation within inorganic or organic treatment in either year \((p > 0.05)\) (Appendix A1-A4).
Figure 4. Tomato cull weights based on fertility 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
Table 6. Tomato defect observations as influenced by fertility treatments.

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Cat-face</th>
<th>Skin</th>
<th>Shape</th>
<th>Rot</th>
<th>Insect</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>I</td>
<td>46a</td>
<td>334a</td>
<td>38a</td>
<td>43b</td>
<td>74b</td>
<td>19a</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>17b</td>
<td>125b</td>
<td>13b</td>
<td>123a</td>
<td>392a</td>
<td>10a</td>
</tr>
<tr>
<td>2011</td>
<td>I</td>
<td>10a</td>
<td>201a</td>
<td>0a</td>
<td>34a</td>
<td>87a</td>
<td>77a</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>5a</td>
<td>154a</td>
<td>0a</td>
<td>27a</td>
<td>127a</td>
<td>49b</td>
</tr>
</tbody>
</table>

*Means followed by the same letter within year and treatment do not differ at the p≤0.05 level of significance.*
Nutrient Content in Tomato Soils

Table 7 shows initial soil nutrient availability in 2010 before the study began. Soil samples were taken in October 2010, April 2011, and in October 2011 to determine nutrient availability in each plot.

Figure 5 shows soil pH in respect to inorganic and organic tomato treatments. Organic plots had a general increase in soil pH throughout but are not significantly greater (p>0.05). An increase in soil pH may be due to the addition of poultry litter but should eventually lead to a decrease in soil pH due to organic matter increasing acidity due to composition and high ammonium nitrate (NH$_4^+$) concentrations related to long term poultry litter applications (Sharpley et al., 1992).

Available soil phosphorus (P) in organic tomato treatment was observed to be significantly greater than inorganic tomato treatment by 68% in fall 2011 (p≤0.05) (Figure 6) (Table 8a). These values may be explained due to high amounts of poultry litter used to fulfill plant N requirements, thereby increasing P applied nutrients. Because of large amounts of accumulated soil P associated with litter applications, P-accumulation may have taken place. With a large pool of organic soil P observed, it is possible that most of the P was not in an available form for the plant. Differences observed by fall of 2011 may also be explained by a larger amount of required plant available N needed for tomatoes in 2011 which increased total poultry litter applied, thus increasing soil P (Table 1c.).

Soil available potassium (K) showed a significant increase among organic tomato soils compared to inorganic tomato soils at every observed sampling date (p≤0.05) (Figure 7) (Table 8a). Soil available K was more than adequate to fulfill required plant
Table 7. Soil nutrient availability across all plots at beginning of study (pre-plant data).

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Available Soil Nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kg/ha</td>
</tr>
<tr>
<td>P</td>
<td>82.9</td>
</tr>
<tr>
<td>K</td>
<td>305</td>
</tr>
<tr>
<td>Ca</td>
<td>2864</td>
</tr>
<tr>
<td>Mg</td>
<td>302.7</td>
</tr>
<tr>
<td>S</td>
<td>26.9</td>
</tr>
<tr>
<td>B</td>
<td>1.3</td>
</tr>
<tr>
<td>Cu</td>
<td>8.3</td>
</tr>
<tr>
<td>Fe</td>
<td>186.2</td>
</tr>
<tr>
<td>Mn</td>
<td>589.9</td>
</tr>
<tr>
<td>Zn</td>
<td>8.1</td>
</tr>
<tr>
<td>Na</td>
<td>65</td>
</tr>
<tr>
<td>OM</td>
<td>28000 mg/kg</td>
</tr>
<tr>
<td>CEC</td>
<td>6.7 cmolc/kg</td>
</tr>
</tbody>
</table>
Figure 5. Tomato soil pH.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 6. Tomato soil P concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Table 8a. Descriptive statistics of soil P and K in tomato.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Variables</th>
<th>Treatment</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Phosphorus</td>
<td>Inorganic</td>
<td>97.9</td>
<td>42.6</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td>Fall 2011</td>
<td>Organic</td>
<td>164.7</td>
<td>28.9</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>Potassium</td>
<td>Inorganic</td>
<td>278.1</td>
<td>76.3</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td>Fall 2010</td>
<td>Organic</td>
<td>417.4</td>
<td>63.0</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td>Potassium</td>
<td>Inorganic</td>
<td>382.5</td>
<td>32.2</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>Spring 2011</td>
<td>Organic</td>
<td>508.8</td>
<td>57.5</td>
<td>19.1</td>
</tr>
<tr>
<td>7</td>
<td>Potassium</td>
<td>Inorganic</td>
<td>292.3</td>
<td>47.9</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>Fall 2011</td>
<td>Organic</td>
<td>643.6</td>
<td>87.4</td>
<td>29.1</td>
</tr>
</tbody>
</table>
Figure 7. Tomato soil K concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
needs in all treatments. Impact of poultry litter on soil available K can be observed in the fall 2011 sampling data where organic treatment is more than 100% greater than inorganic treatment. It may be possible that added leaf mulch to the organic treatment for the purpose of weed control may have given soil available K an abundant amount of exchange sites, not only on the inorganic colloid but on the organic colloid as well. The increase in fall 2011 may also be explained by the increase in poultry litter used from 2010 to 2011. The poultry litter used in 2011 showed a greater total K content of 31 g/kg of litter compared to 22 g/kg of litter in 2010 (Table 1b) but did not improve yield.

Soil available calcium (Ca), magnesium (Mg), and sulfur (S) all showed significant differences among organic tomato treatments with poultry litter compared to those of inorganic treatments. Elevated levels of these elements may reflect on use of poultry litter in both years and the overabundance of plant available Ca, Mg, and S left in soil solution that was not absorbed by the plant. Soil available Ca showed an increase in spring and fall of 2011 for organic treatment (p≤0.05) (Figure 8) (Table 8b). An increase in soil Ca in spring 2011 in organic treatment may be due to winter wheat and leaf mulch incorporation and soil Ca becoming available from initial litter and leaf mulch applications. An increase in soil Ca in fall 2011 in organic treatment may be due to increase in poultry litter application to fulfill plant N requirements for 2011 (Table 1c) and leaf mulch application (Table 1d).

Magnesium concentrations showed a significant increase between organic tomato soils compared to inorganic tomato soils in all three sampling dates (p≤0.05) (Figure 9) (Table 8b). Increased Mg concentrations in organic treatments from fall 2010 to fall 2011
Figure 8. Tomato soil Ca concentration.

*SMeans of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Table 8b. Descriptive statistics of soil Ca, Mg, S and B in tomato.

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Figure 9. Tomato soil Mg concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
may be due to a poultry litter by leaf mulch effect. Increase in soil Mg shows a correlation with increase in total poultry litter applied from one year to the next. Jackson et al. (1975) showed a correlation between an increase in total poultry litter application and increasing soil Mg concentrations that were more than 80% soluble in the soil profile by the second year of a three year poultry litter study.

Sulfur concentrations showed a significant increase between organic tomato treatment and inorganic tomato treatment in the last sampling date of the study (p≤0.05) (Figure 10) (Table 8b), while all other dates were equal. An explanation as to why the levels of sulfur remained similar in the organic treatment compared to inorganic treatment is that of the organic amendments added in poultry litter and leaf mulch. Another explanation could be due to organic fungicide applications of copper sulfate and hydrated lime known as the “Bordeaux mix”.

Soil micronutrients in the form of boron (B), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were analyzed among tomato treatments. Boron showed a significant increase in organic tomato treatment when compared to those of inorganic tomato treatment at all sampling dates (p≤0.05) (Figure 11) (Table 8b & 8c). Although soils derive some B from gradual erosion and leaching of minerals and rocks, the explanation for increased B may be explained by decaying organic matter in plant residue and leaf mulch.

Heavy metal concentrations in soil solution for Cu, Fe, Mn, and Zn (Figures 12, 13, 14 & 15) (Table 8c) showed significant increase in organic versus inorganic tomato treatments (p≤0.05), with the one exception of Mn showing no difference among treatments (p>0.05). Copper showed significant increases in all sampling dates (p≤0.05)
Figure 10. Tomato soil S concentration.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.
Figure 11. Tomato soil B concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 12. Tomato soil Cu concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 13. Tomato soil Fe concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 14. Tomato soil Mn concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 15. Tomato soil Zn concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Table 8c. Descriptive statistics of soil B, Cu, Fe and Zn in tomato.

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Iron showed significant increases in spring 2011 and fall 2011 (p≤0.05) (Figure 13) (Table 8c), while Zn showed a significant increase in fall 2011 (p≤0.05) (Figure 15) (Table 8c). These data would be consistent with the diets used in poultry production. Tufft and Nockels (1991) indicated that heavy metals such as Cu, Fe, Mn, and Zn are added to feed to help prevent diseases, improve weight gains, and increase egg production. Most of the metals added pass directly through the bird, which leads to elevated levels in the manure (Tufft and Nockels, 1991).

Organic matter (OM) and cation exchange capacity (CEC) were both increased significantly in organic tomato treatment compared to inorganic tomato treatment in both spring and fall of 2011 (p≤0.05) (Figures 16 & 17) (Table 8d). This data would be consistent considering that an increase in organic matter should lead to an increase in CEC. Increases in organic matter in the organic tomato treatment are likely due to addition of poultry litter and leaf mulch.

Influence of soil K due to mycorrhizal inoculation in tomato was not observed in inorganic tomato treatment but was observed by the fall of 2011 in organic treatment (p≤0.05) (Figure 18) (Table 9). In fall of 2011, M2 treated soils had an increase of soil K significantly greater than M1 treatment soils, but not greater than uninoculated Mo soils. Other than soil K, mycorrhizae showed no significant influence on soil fertility in tomato treatments in either year of the study (p>0.05) (Appendix A5-A29).

**Tomato Production in Relation to Soil Glomalin and Soil Aggregate Stability**

In 2010, soil glomalin extractions showed no significant difference among inorganic or organic tomato treatments (p>0.05) (Figure 19). In 2011, soil glomalin was
Figure 16. Tomato soil organic matter concentration.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.
Figure 17. Tomato soil CEC.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Table 8d. Descriptive statistics of soil organic matter and cec in tomato.

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Table 9. Descriptive statistics in soil K based on mycorrhizae inputs.

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Figure 18. Mycorrhizae influence on organic tomato soil K concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 19. Tomato soil glomalin in 2010.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.

*Protein (mg/g)*

![Bar chart showing protein levels in different treatments.](image)
found to be significantly greater among organic tomato soils compared to those of inorganic tomato soils \((p \leq 0.05)\) (Figure 2) (Table 5). Figure 20 shows a decrease of soil glomalin production in all three levels of mycorrhizal inoculation for inorganic tomato and contrasts the slight increase in organic glomalin production in all three levels which is significant \((p \leq 0.05)\) (Table 5).

Differences among treatments with respect to glomalin may be partially explained by the use of leaf mulch in organic treatment areas. After the first year of production and before the second year began, all organic matter was incorporated back into the soil by tillage. In between years, winter wheat was sown in all plots and eventually incorporated along with the leaf mulch in the organic plots from the first year. It was believed that second year glomalin extractions \#1 of 10, for each organic plot, appeared to be darker because of this leaf mulch incorporation from 2010, which may have given a false reading of the extraction by the spectrophotometer (Figure 21). Initial dilution of extract \#1 across all plots with the Pyrophosphate Buffer Solution (PBS) at a factor of 10x dilution was moved further to a 20x dilution rate to investigate variations among treatments in the first extraction. Figure 22 shows the well plate and color difference from a dilution factor of 10x to 20x. As a result of spectrophotometer readings from the new dilution factor it was shown that the darker colored samples did not have a larger rate of change than the lighter samples, so most likely the color did not influence the readings at a 10x dilution factor. Increase in soil glomalin among organic extractions may be explained by leaf mulch and poultry litter in organic treatment. Valarini et al. (2009) showed in a three year study that the addition of compost from animal manure or mulches increased mycorrhizal inoculation and soil glomalin.
Figure 20. Tomato soil glomalin in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
Figure 21. 2011 glomalin extraction 1 (10x dilution) before the addition of Bradford reagent.
Figure 22. 2011 glomalin extraction 1 (20x dilution) before the addition of Bradford reagent.
Mycorrhizal influence in inorganic tomato treatment over both years exhibited only a significant difference at the Mo level, although there is a numerical decline in all levels in the second year which is not significant ($p\leq0.05$) (Figure 23) (Table 5). Influence in organic treatment and among both years only shows a slight increase in glomalin production which is not a significant difference ($p>0.05$) (Figure 24).

Soil loss among inorganic and organic tomato treatments did not show significant differences in 2010 ($p>0.05$) (Figure 25). Although there were no significant differences observed in 2011, soil percent loss in organic tomato treatment remained around 60% in all M treatments, while the inorganic treatment was increasing according to increasing M treatments and peaking around 71% soil loss in M2 ($p>0.05$) (Figure 26). Percent soil loss within inorganic tomato treatment shows a general increase in loss for 2011 compared to 2010 ($p>0.05$) (Figure 27), even though these numbers are not significant it appears that soil glomalin in an inorganic production system may not improve soil aggregate stability. In contrast, soil percent losses within organic treatment were equal in 2010 ($p>0.05$) (Figure 28). Although these numbers are not significant to one another, there exists a trend that a higher soil glomalin concentration in an organic production system may lead to a smaller percentage of soil loss.

**Snap Bean Yields based on Fertility**

Snap bean yields were significantly greater with inorganic treatment compared to organic in 2010. In 2010, inorganic snap beans had a 53% greater yield than that of organic snap beans ($p\leq0.05$) (Figure 29) (Table 4). In 2011, there was no difference observed in yields between fertility treatments.
Figure 23. Inorganic tomato soil glomalin in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
Figure 24. Organic tomato soil glomalin in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the \( p \leq 0.05 \) level of significance.
Figure 25. Tomato soil loss percentage in 2010.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.
Figure 26. Tomato soil loss percentage in 2011.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.
Figure 27. Inorganic tomato soil loss percentage 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
Figure 28. Organic tomato soil loss percentage 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
Figure 29. Snap bean yields 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the p≤0.05 level of significance.
Snap bean yields based on mycorrhizal inoculation in inorganic or organic treatments were not significantly different in either year (p>0.05) (Appendix B1 & B2).

**Nutrient Content in Snap Bean Soils**

Snap bean production required far less nutrients when compared to tomato production which is typical of this plant (Table 1a & 1c). Although requiring a smaller amount of nutrients, soil analysis showed some of the same trends among treatments as tomato production. Increases in soil fertility with the organic treatment compared to inorganic treatment may be due to poultry litter and leaf mulch addition, which increased soil nutrient content similar to organic tomato production.

Figure 30 illustrates soil pH in respect to inorganic and organic bean treatments. Organic soils show an increasing trend in soil pH in the spring and fall of 2011 but are not significantly different (p>0.05). Organic treatment pH in spring 2010 was much lower in comparison with spring and fall 2011 which may be due to sampling error.

Available soil P was equivalent in each sampling date and was not found to be different among inorganic and organic bean treatments (p>0.05) (Figure 31). This may indicate a contrast between organic tomato and organic bean production. Although not significant, organic treatment had a trend to increase in all sampling dates compared to inorganic treatment based on fertility needs. Snap bean fertility requirements were less than one half of tomato in 2010 and less than one third in 2011, which may explain lack of significant differences.

Soil available K showed higher concentrations in organic bean treatment in the fall of 2011 and was similar in all other treatments at other sampling dates (p≤0.05)
Figure 30. Snap bean soil pH concentration.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure 31. Snap bean soil P concentration.

*Means of treatments followed by the same letters within season do not differ at the \( p \leq 0.05 \) level of significance.
A reduction in fall 2011 is unexplainable considering that fertility treatments were the same in both years. Although, the difference between treatments in fall 2011 may be explained by total K in poultry litter increasing from 22 g/kg in 2010 to 31 g/kg in 2011 (Table 1b).

Soil available Ca and Mg in organic bean treatment soils showed significant increase among treatments in fall 2011 ($p \leq 0.05$) (Figure 33 & 34) (Table 10a). Concentrations of soil Mg were also significant in spring of 2011 ($p \leq 0.05$). Elevated levels of these elements may reflect on use of poultry litter in both years and overabundance of plant available Ca and Mg left in soil solution, which was not absorbed by the plant in the previous growing year.

Soil available S did not show differences among treatments ($p > 0.05$) (Figure 35). In the second year of the study there was a decreased need to spray organic Bordeaux mix on snap beans, which could explain some of the decrease in organic treatment in fall 2011, but does not explain the decrease in inorganic treatment in fall 2011.

Soil micronutrients in the forms of B, Cu, Fe, Mn, and Zn were analyzed among bean treatments. Boron showed significant increase in organic bean treatment when compared to those of inorganic bean treatment in spring and fall 2011 sampling dates ($p \leq 0.05$) (Figure 36) (Table 10a). The increased B may possibly be explained by the decaying organic matter in plant residue and leaf mulch.

Heavy metal concentrations in soil solution such as Cu, Fe, Mn, and Zn only showed significant differences among inorganic and organic bean treatments for Fe in spring and fall 2011 and for Zn in fall 2011 ($p \leq 0.05$) (Figures 37 & 38) (Table 10a & 10b). Just as in organic tomato treatment heavy metal concentrations in poultry litter...
*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Table 10a. Descriptive statistics of soil $K$, $Ca$, $Mg$, $B$, $Fe$ in snap bean.

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</tr>
<tr>
<td></td>
<td>Boron</td>
<td>Inorganic</td>
<td>1.2</td>
<td>0.35</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Fall 2011</td>
<td>Organic</td>
<td>2</td>
<td>0.31</td>
<td>0.10</td>
</tr>
<tr>
<td>37</td>
<td>Iron</td>
<td>Inorganic</td>
<td>210</td>
<td>11.2</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Spring 2011</td>
<td>Organic</td>
<td>238.2</td>
<td>16.8</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>Inorganic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron</td>
<td>Inorganic</td>
<td>183.6</td>
<td>14.7</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Fall 2011</td>
<td>Organic</td>
<td>211.8</td>
<td>16.9</td>
<td>5.6</td>
</tr>
</tbody>
</table>
Figure 33. Snap bean soil Ca concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 34. Snap bean soil Mg concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 35. Snap bean soil S concentration.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.
Figure 36. Snap bean soil B concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 37. Snap bean soil Fe concentration.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure 38. Snap bean soil Zn concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Table 10b. Descriptive statistics of soil Zn, OM, and CEC in snap bean.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Variables</th>
<th>Treatment</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>Zinc</td>
<td>Inorganic</td>
<td>6.5</td>
<td>1.7</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>8.9</td>
<td>1.7</td>
<td>0.58</td>
</tr>
<tr>
<td>41</td>
<td>OM</td>
<td>Inorganic</td>
<td>15500</td>
<td>1590</td>
<td>530</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>19300</td>
<td>1320</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>OM</td>
<td>Inorganic</td>
<td>18100</td>
<td>1450</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>23800</td>
<td>2150</td>
<td>720</td>
</tr>
<tr>
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<td>OM</td>
<td>Inorganic</td>
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<td>2540</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>36100</td>
<td>4680</td>
<td>1560</td>
</tr>
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<td>42</td>
<td>CEC</td>
<td>Inorganic</td>
<td>7.9</td>
<td>0.68</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Organic</td>
<td>9.1</td>
<td>1.1</td>
<td>0.39</td>
</tr>
</tbody>
</table>
amendments may be influencing Fe and Zn differences. Copper and Mn did not differ significantly among bean treatments (p>0.05) (Figures 39 & 40).

Organic matter and CEC showed significant differences in inorganic and organic bean treatments (p≤0.05) (Figure 41 & 42) (Table 10b). Organic matter was significantly higher in organic bean treatment compared to inorganic bean throughout, while CEC was not significantly different until fall 2011. Organic matter among treatments does not show an increase equal to or above the initial soil analysis until fall 2011. This result is unexplainable considering that plant material, poultry litter and leaf mulch amendments were incorporated in the soil in both years.

Mycorrhizae treatments showed no significant influence on soil fertility in snap bean treatments in either year of the study (p>0.05) (Appendix B3-B28).

**Snap Bean Production in Relation to Soil Glomalin and Soil Aggregate Stability**

In 2010, glomalin extractions showed no significant difference among inorganic bean and organic bean treatments (p>0.05) (Figure 43). In 2011, soil glomalin was found to be significantly greater among the organic bean treatment compared to those of inorganic bean treatments (p≤0.05) (Figure 44) (Table 11). Figure 45 shows 2010-2011 differences which illustrate the sharp drop in inorganic bean treatment glomalin in 2011. This drop in glomalin production may be due to a lack of organic matter concentration in inorganic bean treatment compared to organic bean treatment. Mycorrhizal influence in inorganic bean treatment shows a declining trend of soil glomalin extracted from 2010 to 2011, but does not show a significant decrease (p>0.05) (Figure 46). Mycorrhizal influence within organic bean treatment showed an overall decline in soil glomalin
Figure 39. Snap bean soil Cu concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 40. Snap bean soil Mn concentration.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 41. Snap bean soil organic matter concentration.

OM (mg/kg)  
2010 spring 2010 fall 2011 spring 2011 fall

*SMeans of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure 42. Snap bean soil CEC.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.

*CEC cmol+/kg

SAMPLING DATE

2010 spring  2010 fall  2011 spring  2011 fall

INORGANIC

ORGANIC

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.
Figure 43. Snap bean soil glomalin in 2010.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.
Figure 44. Snap bean soil glomalin in 2011.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.
Table 11. Descriptive statistics of soil glomalin production in snap bean treatments.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Variables</th>
<th>Mycorrhizae Levels</th>
<th>Treatment</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
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<td>Snap Bean</td>
<td>0</td>
<td>Inorganic</td>
<td>2.2</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Organic</td>
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<td>0.16</td>
<td>0.09</td>
</tr>
<tr>
<td>44</td>
<td>Glomalin</td>
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<td>Inorganic</td>
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<td>0.25</td>
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<td></td>
<td></td>
<td></td>
<td>Organic</td>
<td>3</td>
<td>0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>44</td>
<td>2011</td>
<td>2</td>
<td>Inorganic</td>
<td>2.1</td>
<td>0.22</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Organic</td>
<td>3.1</td>
<td>0.24</td>
<td>0.13</td>
</tr>
</tbody>
</table>
Figure 45. Snap bean soil glomalin in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the \( p \leq 0.05 \) level of significance.
Figure 46. Inorganic snap bean soil glomalin in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
between 2010 and 2011 with the sharpest decline coming in the Mo level; however none of these declines were significantly different (p>0.05) (Figure 47).

After the first year of production and before the second year began, all organic matter was incorporated back into the soil by tillage. In between years, winter wheat was sown in all plots and eventually incorporated along with the leaf mulch in the organic plots from the first year. Differences among treatments with respect to glomalin may be partially explained by the use of leaf mulch in organic treatment areas just as in organic tomato.

Soil loss among inorganic and organic bean treatments did not show significant differences in 2010 (p>0.05) (Figure 48). Although there were no significant differences observed in 2011, soil loss percentage in the organic bean treatment remained around 62-63% loss in all mycorrhizae treatments, while the inorganic bean treatment was similar to the inorganic tomato treatment which increased according to fertility treatment and peaking around 69% soil loss (p>0.05) (Figure 49). Figure 50 may illustrate a trend of inorganic bean soil loss increasing in 2011 compared to 2010 just as seen in the inorganic tomato comparison, although these numbers are not significant (p>0.05). This may indicate a trend in this study that the reduction in soil glomalin in an inorganic production system decreases soil aggregate stability. Looking at soil loss percentage in organic bean treatment (p>0.05) (Figure 51) there’s no significant decrease in percent soil loss from 2010 to 2011. These results are not significant but may indicate a potential correlation between soil loss percentages remaining the same with an increasing glomalin production. That may help hold together soil aggregate stability in an organic production system compared to an inorganic production system. Soil loss percentage remaining the
Figure 47. Organic snap bean soil glomalin in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the p≤0.05 level of significance.
Figure 48. Snap bean soil loss percentage in 2010.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.
Figure 49. Snap bean soil loss percentage in 2011.

*Means followed by the same letters within treatment do not differ at the $p \leq 0.05$ level of significance.
Figure 50. Inorganic snap bean soil loss percentage in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
Figure 51. Organic snap bean soil loss percentage in 2010-2011.

*Means followed by the same letters within treatment within year do not differ at the $p \leq 0.05$ level of significance.
same and not increasing may be due to poultry litter and leaf mulch incorporation adding
organic matter in organic bean treatment improving soil aggregate stability.
CHAPTER V

SUMMARY

Objectives of this research were to assess differences in yield, soil fertility and soil quality based on mycorrhizae inputs within and across inorganic and organic vegetable production systems. This field study indicated that mycorrhizae do not play a significant role in influencing yield in inorganic or organic vegetable production. However, the data showed that inorganic tomato production was significantly greater than organic production. Inorganic snap bean production was greater in the first year of the study with the second showing no difference among treatments.

With the exception of soil available K within organic tomato treatment soils in the final sampling date, mycorrhizae did not influence soil fertility inorganically or organically. Application of poultry litter in organic tomato production in general showed significantly higher amounts of soil available P, K, Ca, Mg, S, B, Cu, Fe, and Zn when compared to inorganic production at selected sampling dates. Available soil P in organic tomatoes was observed to be significantly greater than inorganic tomatoes by 68% in fall 2011. Soil available K showed a significant increase in organic tomato soils compared to inorganic tomato soils in every observed sampling date. Calcium showed an increase in organic tomato soils in spring and fall 2011 and was increased by 58% from initial soil tests. Magnesium concentrations showed a significant increase between organic tomato soils compared to inorganic tomato soils in all three sampling dates. Sulfur
concentrations showed a significant increase between organic tomato treatment and inorganic tomato treatment in the last sampling date of the study, while all other dates were equal. Boron showed a significant increase in organic tomato treatment when compared to inorganic tomato treatment at all sampling dates. Heavy metal concentrations in the soil solution were observed to significantly increase with the addition of poultry litter. Copper showed significant differences in all sampling dates. Soil available Fe showed significant increases in spring and fall 2011, while Zn showed significant differences in fall 2011.

In organic tomato production soil organic matter concentrations along with cation exchange capacity were both significantly greater when compared to inorganic production in spring and fall 2011. Higher amounts of soil available nutrients in poultry litter application were expected but did not lower or influence soil pH in organic tomato production.

Mycorrhizae did not influence soil fertility in inorganic snap bean or organic snap bean production. In general, while snap bean production required far less nutrients when compared to tomato production, application of poultry litter in organic snap beans showed significantly higher amounts of soil available K, Ca, Mg, B, Fe, and Zn when compared to inorganic production at selected sampling dates. Soil available K showed higher concentrations in organic bean treatment in the fall of 2011 and was similar in all other treatments at other sampling dates. Calcium concentrations in organic snap bean soils showed a significant increase in fall 2011. Soil Mg concentrations in organic snap bean soils were significantly different in spring and fall 2011. Boron showed significant increase in organic bean treatment when compared to those of inorganic bean treatment.
in spring and fall 2011 sampling dates. Heavy metal concentrations in organic soil solution such as Fe and Zn only showed significant differences among inorganic and organic bean treatments for Fe in spring and fall 2011 and for Zn in fall 2011.

In organic snap bean production soil organic matter concentrations, along with cation exchange capacity, were both significantly greater when compared to inorganic production. Organic matter was significantly higher in organic bean treatment compared to inorganic bean throughout, while CEC was not significantly different until fall 2011. As in organic tomato production, poultry litter applications in organic snap bean production did not show a lowering or influence on pH. In both organic tomato and snap bean production the influence on soil nutrients, soil organic matter and cation exchange capacity is probably more closely related to poultry litter and the addition and incorporation of leaf mulch used as a weed control.

Glomalin production was not influenced to a significant amount by different levels of mycorrhizal inputs within treatments. Organic vegetable production showed a significant difference in glomalin production in the second year of the study compared to the first year, most notably there was not a significant increase in glomalin production on the organic side but instead a significant decrease in the inorganic production system in relation to glomalin. Soil loss percentage did not show a significant difference due to mycorrhizae or due to production inputs. However, along with the decrease of glomalin production in inorganic treatments, soil loss showed an increase as well when compared to organic treatments that remained relatively similar.

After assessing poultry litter effects in organic vegetable production, it can be determined that applying litter based on plant N requirements will increase soil P and K
in sufficient amounts for plant growth, but will also lead to a buildup of macronutrients in soil solution. The data do not indicate that this fertility regime improves vegetable yield in tomatoes or snap beans. From a producer’s aspect, applying both litter and leaf mulch will increase soil fertility in both macronutrients and micronutrients, but will not immediately increase yield. Therefore a producer may want to incorporate the use of poultry litter, leaf mulch and inorganic amendments to supplement the rising cost of inorganic fertilizers. If a producer were to use this balanced amendment approach, the data indicate that the organic amendments of poultry litter and leaf mulch would improve organic matter concentrations and cation exchange capacities. The data do not indicate that mycorrhizae would immediately improve soil fertility or vegetable yield in inorganic or organic vegetable production. However, in organic vegetable production, soil glomalin was shown to increase in the second year of the study. From a producer’s aspect, mycorrhizae may not immediately improve soil fertility or yield, but in conjunction with poultry litter and leaf mulch amendments may improve soil aggregate stability decreasing soil loss potential.
Figure A1. Inorganic tomato marketable yield based on mycorrhizae inputs in 2010-2011.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A2. Organic tomato marketable yield based on mycorrhizae inputs in 2010-2011.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A3. Inorganic tomato culls based on mycorrhizae inputs in 2010-2011.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A4. Organic tomato culls based on mycorrhizae inputs in 2010-2011.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.
Figure A5. Inorganic tomato soil pH concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A6. Organic tomato soil pH concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure A7. Inorganic tomato soil P concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A8. Organic tomato soil P concentration based on mycorrhizae inputs.

*Slopes of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure A9. Inorganic tomato soil K concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A10. Inorganic tomato soil Ca concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A11. Organic tomato soil Ca concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A12. Inorganic tomato soil Mg concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A13. Organic tomato soil Mg concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A14. Inorganic tomato soil S concentration based on mycorrhizae inputs.

*SMeans of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A15. Organic tomato soil S concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A16. Inorganic tomato soil B concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A17. Organic tomato soil B concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure A18. Inorganic tomato soil Cu concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure A19. Organic tomato soil Cu concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p\leq0.05$ level of significance.
Figure A20. Inorganic tomato soil Fe concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.

* Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure A21. Organic tomato soil Fe concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A22. Inorganic tomato soil Mn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure A23. Organic tomato soil Mn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A24. Inorganic tomato soil Zn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A25. Organic tomato soil Zn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.
Figure A26. Inorganic tomato soil organic matter concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A27. Organic tomato soil organic matter concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the \( p \leq 0.05 \) level of significance.
Figure A28. Inorganic tomato soil CEC based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure A29. Organic tomato soil CEC based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B1. Inorganic snap bean yield based on mycorrhizae inputs in 2010-2011.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B2. Organic snap bean yield based on mycorrhizae inputs in 2010-2011.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B3. Inorganic snap bean soil pH concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B4. Organic snap bean soil pH concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B5. Inorganic snap bean soil P concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.*
Figure B6. Organic snap bean soil P concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B7. Inorganic snap bean soil K concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B8. Organic snap bean soil K concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B9. Inorganic snap bean soil Ca concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B10. Organic snap bean soil Ca concentration based on mycorrhizae inputs.

*SMeans of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.*
Figure B11. Inorganic snap bean soil Mg concentration based on mycorrhizae inputs.

*SMeans of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B12. Organic snap bean soil Mg concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B13. Inorganic snap bean soil S concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B14. Organic snap bean soil S concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B15. Inorganic snap bean soil B concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B16. Organic snap bean soil B concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B17. Inorganic snap bean soil Cu concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p ≤ 0.05 level of significance.
Figure B18. Organic snap bean soil Cu concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B19. Inorganic snap bean soil Fe concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B20. Organic snap bean soil Fe concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B21. Inorganic snap bean soil Mn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B22. Organic snap bean soil Mn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B23. Inorganic snap bean soil Zn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B24. Organic snap bean soil Zn concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the \( p \leq 0.05 \) level of significance.
Figure B25. Inorganic snap bean soil organic matter concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B26. Organic snap bean soil organic matter concentration based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.
Figure B27. Inorganic snap bean soil CEC based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the p≤0.05 level of significance.
Figure B28. Organic snap bean soil CEC based on mycorrhizae inputs.

*Means of treatments followed by the same letters within season do not differ at the $p \leq 0.05$ level of significance.


