EVALUATING ORGANIC AND CONVENTIONAL MANAGEMENT AND NITROGEN RATE FOR EFFECTS ON YIELD, SOIL AND PLANT NUTRIENT OF TOMATO AND PAC CHOI GROWN UNDER HIGH TUNNEL AND IN THE FIELD

by

MAY ELFAR ALTAMIMI

M.S., Kansas State University, 2010

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Horticulture Forestry and Recreation Resources
College of Agriculture

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Abstract

The goal of this study is to clarify the influence of organic fertilizer sources on vegetable crop yield under different production systems. This research hypothesized that organic soil amendments will produce healthy and vigorous plants with similar or higher yields while improving soil organic matter levels compared to conventional amendments. Applying organic fertilizer sources can be cost-prohibitive; moreover, synchronizing timing of crop nitrogen demand with soil plant available nitrogen is essential to maximizing yield and reducing nitrogen pollution to the environment. The objectives of this study are to evaluate yield in relation to soil fertility status at different fertility rates for organic and conventional management in field and high tunnel production systems, to measure plant nutrient status in crop petioles and compare it to available mineral N levels in soil at different growing stages, and to determine the effect of nitrogen availability of organic compared to conventional fertilization on plant available nitrogen and crop yield under both systems. A latin square experimental design was conducted from 2008 to 2010 at Kansas State University Research Center in Olathe KS to evaluate an organically managed vegetable rotation of tomato (*Solanum lycopersicum* L. ‘Bush Celebrity’) and pac choi (*Brassica rapa* L. ‘Mei Qing’) under three fertility rates; control, low (composted poultry manure), and high (composted poultry manure and fish hydrolyzate) in contrast with conventionally managed soils under two production systems (field and high tunnel). The effect of these four contrasting systems was measured on plant and soil nutrient status. All plots had cover crops of rye during the winter and buckwheat in the summer between pac choi crops. Soil nitrate-N (NO_3-N) and ammonium-N (NH_4-N) were measured, as well as petiole sap nitrate (NO_3^-). In tomato, additional soluble fertilizers had no direct effect on yield in both field and high tunnel. Compost application had a positive effect on organic matter. In pac choi, additional liquid fertilizer helped organic field plots obtain maximum yield. Soil mineral nitrogen were affected by production system and fertility source, but statistical significance varied by crop and stage. Petiole sap reflected treatment regimens but not necessarily soil N status at each plant stage. The study also addressed long term management practices on organic and conventional available nitrogen. An incubation study on the soil at the conclusion of the field experiment explored the relationship between N mineralization from potentially mineralizable nitrogen (PMN) compared to Illinois Soil Nitrogen Test (ISNT) in control and pre-plant application fertility treatment for both field and high tunnel systems. The results indicated that ISNT concentration values for all soils were below the proposed value for corn crop suggested by (Khan, 2001). ISNT correlated with PMN with the stronger correlation being in field plots. ISNT also correlated with OM in field. Fertility rate showed a significant effect on total carbon and total nitrogen in organic systems of both field and high tunnel plots. This study supports composted poultry manure to improve the fertility status of the soil and to obtain a yield equal to that of conventionally managed soil.

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"God will exalt those who believe among you, and those who have been granted knowledge to high ranks”. (Quran 58:11).

May

Dedication

To my beloved Father and Mother

Whose love, encouragement and prayers make me able to get such success and honor. My dad always believed that we could accomplish anything, and his unyielding support provided a foundation that continues to inspire our family to reach for the stars

To the soul of my grandmother

Though not here in her body, you live in my heart

To my husband and children

Whom have provided prayers, encouraging words, hugs, and smiles that gave me the strength to make this dream a reality

May

Chapter 1 - Impact of organic fertilizers on yield and soil nutrient status of tomatoes grown in field and high tunnel systems compared to that of inorganic fertilizer

Introduction

The United States is one of the world's leading producers of tomatoes, second only to China (U.S. Department of Agriculture, National Agricultural Statistics Services, 2016). In fact, tomato production in the U.S. represented the third largest crop (fresh and processed) in terms of area planted after potatoes and sweet corn with 160,925 hectares of tomatoes grown in the open field. Of those, 112,271 hectares of tomatoes were harvested for processing, and 48,654 hectares were harvested for the fresh market (NASS, 2016). Reports also show that the total area of tomato production has dropped 10 percent since 2007 while the number of farms producing tomatoes rose by 20 percent. In 2012, 512.6 hectares of tomatoes were grown under glass or other protection, a 20% increase from the 2007 census where only 408.3 hectares of tomato were grown under protection.

Furthermore, tomatoes rank second to potatoes in dollar value among all vegetables produced in the United States with fresh and processed accounting for more than $2 billion in annual farm cash receipts including $424 million from tomatoes grown under glass or other protection (U.S. Department of Agriculture, Economic Research Service, 2015). Moreover, fresh market tomatoes are produced in every state in the nation, with large scale production in about 20 States. Meanwhile, per capita consumption of fresh tomatoes has been increasing from an average annual per capita consumption in 1981 of 12.3 pounds to 20.6 pounds in 2014 (ERS, 2015). During the past 100 years, the location of the production of tomatoes has changed significantly. In the early years, the industry was centered in Maryland; then it moved to Indiana, and at present, Florida has edged out California as the largest producer due to the drought in California where production dropped in the last few years. Nevertheless, California and Florida together produce almost two-thirds of total U.S. fresh-market tomatoes, a share that has not changed much since the 1960s (ERS, 2014). Next, Ohio, Virginia, Georgia, and Tennessee round out the top six in terms of area planted, with Ohio as the leader in the Midwest. Additionally, average tomato yield per acre from the open field has gone up in the United States from 7.0 tons (17 tons per hectare) in 1960 to over 29 tons in 2005 (72 tons per hectare). In particular, California and Ohio have been the leading states in tomatoes in yield per acre (Gould, 2013).

There are 1,847 fresh organic tomato farms (certified and exempt), with 3,752 acres and 196,278 pounds of fresh organic tomato produced in the open field (NASS, 2014), and those grown under protected cultivation accounted for 253,650 pounds from 973 farms. Since the USDA National Agricultural Statistics Services, NASS, didn’t include a category for high tunnels, we don’t know if the tomatoes were grown in a high tunnel, greenhouse, or other structure.

Tomato is a warm season crop, reasonably resistant to heat and drought, and grows under a wide range of climate and soil conditions and requires three to four months from the time of seeding to produce the first ripe fruit. Tomato thrives best when the weather is clear and rather dry, and temperatures are moderate 65-85^{o}F (18-30^{o}C). Also, it is sensitive to frost at any stage, and below 32^{o}F (0^{o}C), the plants freeze which can damage new plants and cause decline of mature plants. Thus, field planting in temperate climates occurs after the threat of frost is past in the spring, or transplants are planted under row cover or high tunnels (Gould, 2013).

High tunnels can offer improved tomato yield and quality over that of field production (Jensen and Malter, 1995). By enabling earlier planting dates and later harvests, high tunnel systems can extend the growing season, protect crops from rain and wind damage, and diminish some pests and diseases (Blomgren and Frisch, 2007). Varying with geographical area and number of harvests, tomato yield from high tunnels is approximately 150 tons per hectare (61 tons per acre) compared to 72 tons per hectare (30 tons per acre) average tomato yield from open fields. This is an excellent yield considering it requires little control over the environment and little investment (Jensen and Malter, 1995; Jett, 2004; Galinato, 2012).

Many researchers have discussed the influence of high tunnels on different components of tomato production, specifically yield, quality, and disease pressure. For example, (Rogers and Wszelaki, 2012) found that small to midsize organic growers who sell tomatoes for the fresh market can benefit from lower disease pressure and higher marketable yields achievable with high tunnels.

O'Connell et al., (2012) compared field production of organic heirloom tomatoes to high tunnel production for yield, fruit quality, and disease. The high tunnel and field system yields were similar the first year but 33% greater for the high tunnel system than for the field the second year. Also, disease incidence was lower for the high tunnel than for the field in both years. Meanwhile, Zhao et al., (2014) studied the effect of planting date on yield of tomato and other vegetable crops in high tunnels in Starkville, Mississippi and found no effect on the total marketable yield for tomato, which indicated earlier plantings provided earlier harvests without yield loss. Previously, Reeve and Drost, (2012a) had measured the yield and fruit quality in transition organic and conventional tomato in intensively managed high tunnels over three growing seasons. Marketable yield of organically grown tomatoes was lower in year 1, but differences between organic and conventional tomato yield were insignificant in years 2 and 3. More recently, Warren et al., (2015) conducted a high tunnel tomato cultivar trial over 3 years in New Hampshire, with 15 indeterminate cultivars using organic fertilizers and pesticides to evaluate yield, yield components, and susceptibility to two common diseases, leaf mold and powdery mildew. The results showed some differences among cultivars in yield and disease onset; however, several tomato cultivars appear to be well-suited for high tunnel production. Earlier, Hajime et al., (2009) studied the effect on yield of planting cover crops before tomato in high tunnels. Specifically, two cover crops were planted in separate plots: legume (hairy vetch) and non-legume (wild oat) resulting in higher yields for bare ground and hairy vetch plots and higher carbon for plots with cover crop mulch than for the bare plot. Results show even with reduction of nitrogen fertilizer, acceptable yield and increased soil carbon are still possible.

Not only does high tunnel production provide higher yield and quality, but it also uses less energy per kilogram of product. For example, Villiers et al., (2011) compared energy use and yield for trellised field tomato crop, a high tunnel crop, and a modern greenhouse tomato crop in upstate NY. Of the three production systems, the high tunnel used the least energy per kg of product and a small portion of that as direct energy. In fact, high tunnel productivity was found to be double that productivity in open field. However, the shortness of tomato production season, which is controlled by climate, is the major limitation on expanding this production system in New York State.

Organic production in high tunnel systems requires focus on long-term soil health, based on SOM management and maintenance of the soil food web. Increased SOM has been shown to improve physical, chemical, and biological soil quality indicators, such as water absorption and retention, soil biological activity, cation exchange capacity, nutrient availability, microbial biomass, carbon and nitrogen pools, and disease suppression (Gaskell et al., 2000). To achieve success and reduce the potential for soil exhaustion requires a balance in the active, short-term and long-term organic matter pools (Magdoff and Van Es, 2000).

Also, fertility in high tunnel systems is different from that in field production due to rain exclusion and the absence of leaching in these structures. However, animal manure based compost should be managed to minimize excessive soluble salt and nutrient levels (Montri and Biernbaum, 2009). Reeve and Drost (2012a) measured the soil quality of organically and conventionally grown tomato under high tunnels after applying composted poultry manure once a year for the organic system and controlled-release fertilizer for the conventional system. Soil quality was greater for organic tomato production at the end of the three year study according to indicators such as total carbon, nitrogen, and microbial activity. Meanwhile, the phosphorus and potassium applied to the composted manure resulted in high soil P and K levels in organically managed high tunnels after three years. Ghorbani et al., (2008) conducted a field experiment to study the effects of organic amendments, synthetic fertilizers, and compost extracts on crop health and productivity of tomato. Treatments included different fertilizers of cattle, sheep and poultry manures, green-waste and household composts, and chemical fertilizers of urea and superphosphate. The results show that poultry manure caused lower disease incidence (early blight, fruit rot, septoria leaf spot, bacterial canker, and light blight), as shown by significant healthier tomato, compared with the chemical fertilizers. However, the use of organic fertilizers did not lead to higher yields than the utilization of chemical fertilizers.

Repeated compost and manure applications in high tunnel can cause mineral accumulation such as salinity buildup. Knewtson et al., (2012) studied soil quality after eight years of high tunnel production under conventional and organic management measuring soil pH, salinity, total carbon, and particulate organic matter. Results for conventional management after eight years under high tunnels showed an increase in soil pH and salinity but didn't affect soil carbon. In the organic management system, high tunnels didn't affect soil pH, but did increase soil salinity and soil carbon pools, in particular POM carbon.

With respect to weather, Kansas has a typical continental climate (i.e. lacking the influence of any major bodies of water). Average annual precipitation ranges from slightly more than 40 inches (102 cm) in the southeastern counties to 30-35 inches (76-90 cm) in the northeast, decreasing gradually westward to the Colorado line where the average is 16-18 inches (41-46 cm). Precipitation in Kansas sometimes results in numerous, severe floods and long, severe droughts. Meanwhile, extreme temperatures in the state range from a high of 121^{o}F (50^{o}C) to a low of $^{-}40^{o}$F ($^{-}40^{o}$C) and on average 173 frost free days in the growing season with the last killing frost occurring from April 8th (in Iola) to May 8th (in Atwood). Finally, the average frost killing freeze in the fall ranges from September 29th (in Atwood) to October 28th (in Iola).

Naturally then, high value horticultural crops such as tomato are a common choice for high tunnel production since they generate greater revenue than other crops. Knewtson et al., (2010) reported in a 2005-2007 survey that tomatoes were the most common crops grown in high tunnels in the Midwest. Kansas growers' objective for constructing high tunnels is to offer plants protection from wet, saturated soils and low temperatures in the spring and fall, thereby extending the growing season. In addition, high tunnels can reduce the insect and disease incidence in tomatoes (Zhao, 2009).

Ultimately, however, information regarding high tunnel production systems in Kansas for tomatoes under organic production is limited, research of such systems would help growers to take advantage of a lengthy, growing season. Therefore, this study focuses on improving the understanding of the influence of organic fertilizer sources on crop yield and quality of tomatoes under high tunnels compared to in the field. The objectives of this study were to: 1) Evaluate tomato production in relation to soil fertility status at different fertility rates of organic and inorganic nitrogen fertilizers in field and high tunnel production systems, 2) Measure plant nutrient status in tomato petioles and compare it to available mineral nitrogen levels in soil at different growing stages, and 3) Determine the effect of N availability of organic compared to conventional fertilization on plant available N and determine the impact on crop yield for both field and high tunnel systems.

Materials and Methods

Sampling design and methodology:

Trials were conducted at the Kansas State University Horticulture and Extension Center in Olathe, KS (USDA hardiness zone 5b). The soil was Kennebec silt loam under six 9.8 m x 6.1 m high tunnels with 1.5m sidewalls (Stuppy, North Kansas City, MO) and in six adjacent 9.8 m x 6.1 m field plots. High tunnels were covered with a single layer 6-mil (0.153mm) K-50 polyethylene film (Klerk’s Plastic Product Manufacturing, Inc., Richburg, SC). Three replications each of organic and conventional management were established in the six field and six high tunnel plots in 2002 and arranged in a randomized complete block design while organic plots were managed in compliance with USDA National Organic Program standards, and were inspected and certified in 2003, 2006, 2007 and 2008.

For this study, beginning in 2007, each high tunnel or field plot was subdivided into three 3.2 x 6.1 m subplots to which one of three fertilizer levels was assigned following a latin square design to account for the gradient effect of light in the high-tunnels (Figure 1-1). Fertilizer rates were determined based on soil analysis at the beginning of the study in 2007 and recommendations for vegetable crops in Kansas (Marr et al., 1998) with compost applied to organic plots and synthetic fertilizer applied to conventional plots. Control plots received no supplemental fertilizer while the low treatment plots received pre-plant fertilizer amendment once per year (in the spring). Low and high fertility plots were fertilized with equal amounts of compost or synthetic fertilizer at the beginning of the growing season, and high fertility plots received additional fertilization during the growing season. Plots from both field and high tunnel were tilled using earth fork, followed by wheel harrowing and raking to re-form beds at 30 cm depth.

Two crops were grown in these plots (tomato and pac choi), one each in one half of either field or in a high tunnel plot with a rotation between the two crops each year to meet organic certification criteria (Figure 1-2). In our studies, field and high tunnel experiments with tomato (*Solanum lycopersicum* 'Bush Celebrity') (Totally Tomatoes, Randolph, WI, U.S.A) were conducted in 2008, 2009 and 2010, with a rotation between pac choi and tomato plots each year. HighAlso, a single crop of tomato was grown each summer with an annual cover crop of winter rye (*Secale cereale*) (Albert Lea Seed, Albert Lea, MN, U.S.A.) at a rate of 229 kg /hectare seeded in late fall. Between the spring and fall pac choi crops, plots were seeded with a summer cover crop of buckwheat (Fagopyrum sagittatum) (Albert Lea Seed, Albert Lea, MN, U.S.A.) at a rate of 134 kg /hectare. Organic and conventional fertility systems received the same cropping rotation.

Application rates were based on an initial (2007) soil test and on the assumption that 50% of the nitrogen from compost would be available to plants during the growing season while 100% would be available from conventional fertilizers (Warman and Havard, 1997). Compost was analyzed annually before application, analysis performed by Servi-tech Laboratories, (Dodge City, KS) in 2008, and by Oklahoma State University Soil, Water and Forage Analytical Laboratory, (Stillwater, OK) in 2009 and 2010. The result of the compost analysis are presented in (Table 1-1).

Jack's Peat-Lite, 20N: 4.4P: 16.6K, J. R. Peters, Inc., (Allentown, MO) was applied at a rate of 98 kg N /hectare to conventional plots on the assumption that 100% of the nitrogen would be available to plants during the growing season, and a poultry litter source compost (Microleverage 0.6N: 0.4P: 4.4K, Hughesville, MO.) at a rate of 197 kg N /hectare was applied to organic plots on the assumption that 50% of the nitrogen would be available to plants during the growing season. Starting at planting, high fertility treatment plots received additional soluble fertilizer at a rate of 7.24 kg N/hectare six times during tomato growing season while organic plots received fish hydrolyzate 2.23N- 4.35P- 0.3K (Neptune's Harvest, Gloucester, MA.), and the conventional plots received 11.2 kg/ ha KNO_3 and 36.6 kg/ ha $Ca(NO_3)_{2;}$ this rate was calculated to apply an amount of calcium equivalent to that present in the fish hydrolyzate (Figure1-3).

Tomato seeds were started in a 13x26 propagation tray using commercial media, Sunshine Mix Special blend E6340 (SunGro Horticulture, Bellevue, WA) supplemented with MicroLeverage compost until transplanted. All seedlings were supplemented with fish hydrolyzate 2.23N- 4.35P2O5- 0.3K2O (Neptune's Harvest, Gloucester, MA.), at a rate of 60 ml/4L until transplanted. Tomato seedlings were transplanted to high-tunnel or field plots (3 x 3.2m) with drip irrigation and plastic mulch. Each fertility sub-plot had six plants/ row and three rows, and irrigation was delivered through a single drip tape (per row) in the high tunnel and field systems and was administered as needed depending on crop growth stage and weather. Each high fertility plot received additional soluble fertilizer six times during the growing season.

Dates for seeding, fertilizer application and transplanting of tomato crop in 2008, 2009 and 2010 are listed in (Table 1-2).

Wire cages supported the tomato plants, and pest management decisions were based on weekly scouting of sentinel plants in each plot. Insecticides were applied only in the first season (summer 2008) in a mixture of Triact and Entrust or M-Pede. Plants sampled were from the center of the two inner rows, avoiding the plants at the borders between fertility rates and the plants at the outside row (Figure 1-4).

Tissue sampling protocol and analysis:

Leaf samples were taken at different growing stages (vegetative stage, first flowering stage, fruit set, and fruit development) where three plants from each plot from each fertility level were sampled. The youngest fully expanded leaf was collected from the sampled plants, the blades separated from the petioles. Petioles were chopped and pressed with a garlic press to extract plant sap, and the sap was analyzed immediately for NO_3-N with a handheld ion-specific electrode (Cardy nitrate NO_3^{-} meter, Horiba, Ltd., Kyoto, Japan) (Hochmuth, 1994a). The meter was calibrated before analysis and after every 10 measurements with a standard of 2,000 mg L^{-1} NO_3^-, and slope was adjusted with a 150 mg L^{-1} NO_3^- solution. A few drops of the petiole sap were placed on a sampling sheet; the reading was recorded after the value had stabilized. Meter readings were in units of mg·L^{-1} NO_3^- and were converted to NO_3-N (Hartz et al., 2007).

Soil sampling protocol and analysis:

Soil samples were taken annually for complete analysis and three times during the tomato growing season for nitrogen (Table1-3). Six cores from each fertility level were taken using a soil probe at two soil measurement depths (0-15) and (15-30) cm for annual analysis and at one depth (0-15) cm during the growing season for analysis. The soil samples were placed in sterile polypropylene bags, transported to the laboratory, and stored at 4°C Meanwhile, soil cores were passed through a sieve of 2-mm screen diameter and oven dried at 60°C for 48 hours. After drying, soil samples were ground to fine powder and analyzed by Kansas State University (KSU) soil and nutritional analyses service lab in KSU Department of Agronomy for pH with a Skalar SP50 Robotic Analyzer. (Skalar Inc. Buford, GA 30518). A Bray-1 Phosphorus (P) test was performed using a Lachat Quickchem 8000 (Brinkmann Instruments, Inc., Westbury, NY), and Potassium (K) was tested using a Model 3110 Flame Atomic Absorption Spectrometer (Perkin Elmer Corp., Norwalk, CT). For organic matter (O.M), the Walkley-Black method was used, with the "heat of dilution" modification. Colorimetric analysis of the solution was tested by a (Model PC910 Fiber Optic Spectrophotometer from Brinkmann Instruments, Inc., Westbury, NY). Finally, ammonium (NH_4-N) and nitrate (NO_3-N), analyses were performed on a Rapid Flow Analyzer, Model RFA-300 (Alpkem Corporation, Clackamas, OR 97015). (Dahnike, 1975).

Harvesting method:

The crops were harvested weekly from both field and high tunnel production systems. Tomatoes were picked from pink (when the tomato shows from one-half to three-fourths of the surface in the aggregate covered with pink or red color), to firm (when the tomato shows three-fourths or more of the surface in the aggregate covered with red color characteristic of reasonably well ripened tomatoes) stages. Qualitative judgments relating to marketable and non-marketable (cull) fruits were based on observations by trained staff. Data recorded based on fruit weight.

Statistical analysis:

The data analysis for baseline soil tests was generated using a non-repeated measures (one time analysis) ANOVA (Proc GLIMMX, SAS 9.3; SAS Institute, Cary, NC). The data for each growing season was analyzed as repeated measures in a split plot factorial ANOVA (Proc GLIMMEX, SAS 9.3; SAS Institute, Cary, NC). Means for significant effects; management (organic and conventional), fertility level treatments (control, low and high), and their interactions then were compared using Tukey's significant different test when $P< 0.05$ (Proc LSMEANS, SAS, 9.3; SAS Institute). Due to the limitations of the experimental design that had been set since 2002 and couldn't be altered due to the organic certification requirement, the fertility level treatments arranged by forced randomization and data from the two systems (field and high tunnel) were treated in a similar manner but were analyzed independently.

Results and discussion

Yield analysis

Yield data collected from this study were analyzed independently for each year for field and high tunnel and showed that conditions during the growing seasons varied greatly among the three years and were a contributing factor in crop maturation. The accumulated precipitation for the growing seasons was 11.82 inch (300.23mm), 6.92 inch (175.77mm), and 9.24 inch (234.69 mm) in 2008, 2009, and 2010, respectively. On average, 2009 was drier than 2008 and 2010. The growing degree days varied between 3,140 in 2009 and 3655 in 2010 (Table 1-4)

Field plots: In 2008, tomato harvest started on July 7th and lasted only 19 days compared to 38 days in 2009 and 32 days in 2010. The frequent rain events and the high relative humidity in 2008 caused tomatoes to be infect with septoria and early blight that attacked field tomatoes and caused heavy defoliation and withering of tomato plants. (Figure 1-5). Overall, however, MGT had no significant effect on marketable yield across the three years (Table 1-5), which means no significant differences between organic and conventional management system (Figure 1-8). Meanwhile, FRT effect was significant in 2008 (*P=0.01*), where high fertility treatment had higher yield than control and 2009 (*P=0.002)* where high and low fertility treatments had higher yield than control (Figure 1-6). The lack of FRT response in 2010 is likely attributable to the timing of nitrogen release relative to the needs of the crop and nutrient carry over from 2009 (a dry season) that reduced nitrate loss through denitrification and leaching.

High tunnel plots: Tomato harvesting started at the same time as for the field plots and lasted 67 days, 60 days, and 87 days for 2008, 2009, and 2010, respectively. In 2008, MGT showed a significant effect on marketable yield (*P=0.01*), where organic had higher yield than in conventional MGT (Figure 1-7), but had no significant effect on marketable yield in 2009 and 2010. Tomato yield in high tunnel plots was not significantly affected by FRT treatments across the three years (Table 1-5).

Notably, prior to the initiation of this study (fall, 2007), both field and high tunnel plots were under another leafy green experiment since 2002 with no FRT rate treatments. The plots were managed either organically or conventionally. The organically managed plots were receiving composted cattle manure and alfalfa hay applied twice a year with fish emulsion fertigation several times during the growing seasons while conventional plots were receiving NPK 13-13-13 as a pre-plant application with calcium nitrate several times during the growing season. (Zhao, 2006; Knewtson, 2008). Thus, the presence of considerable soil reserves of essential plant nutrients from fertilization of previous crops most likely limited yield responses to FRT treatments in this study.

In general, marketable yield for tomato was high due to the extended growing season; the average length of tomato production for the three years was 71 days for high tunnel compared to 29 days for field. Also, tomato in the high tunnel system had better disease protection than field.

In our study, although organically grown tomato has similar yield to that of conventional, the organically managed tomatoes produced around 78.6 % (field) and 80% (high tunnel) grade #1 fruits while the conventionally fertilized tomatoes yielded around 59.1 % (field) and 62.3% (high tunnel) grade #1 fruits (Table 1-6). This might be due to the lower potassium levels in conventionally managed plots (Figure 1-8) and (Table 1-7). Based on Kansas State University soil test interpretations and recommendations of fertilizer additions (Marr, 1998), the potassium concentration levels (0-125 mg kg $^{-1}$) is low, (125-250 mg kg $^{-1}$) is medium and (>250 mg kg $^{-1}$) is high.

In a study to evaluate the effects of potassium rates on fruit yield quality, the results showed marketable and weighted yield increased with K rates reaching 200 ppm (Fontes, 2000; Martin, 1994).

Soil analysis

Management system (MGT) (organic or conventional), and fertility rate (FRT) (control, low, and high), influenced the concentration of soil inorganic N, nutrients, and chemical properties.

First, soil pH was in the normal range in both field (6.5-7.5) and high tunnel (7.2-7.7) with significant differences between organic and conventional MGT only in the field in 2008, 2009, and 2010 (Figure 1-9). However, a number of studies comparing organic and conventional MGT systems have reported higher pH in organic managed soils (Drinkwater et al., 1995; Clark et al., 1998). Next, FRT rate had no significant effect on pH in either field or high tunnel (Table

1-8). Since altering pH, especially in soil with a large buffering capacity, takes time, not surprisingly, Castro et al., (2009) did not report significant changes in soil pH after applying 40 t ha^{-1} of air dried sewage sludge, municipal solid waste compost, or 1 t ha^{-1}synthetic fertilizer for three consecutive lettuce growing seasons. Moreover, Fließbach et al., (2007) did not observe significant differences in pH within the first 7 years of their 21 year study when soils were treated with composted manure, mineral fertilizer, or manure.

Next, organic MGT showed higher levels of soil P than conventional in all years in both field (Figure 1-10) and high tunnel (Figure 1-11) plots but were only significant in 2010. Also, significant differences in FRT rate occurred in both field and high tunnel (Table 1-9) in 2010. In fact, interaction between MGT and FRT was significant at high tunnel plots in 2010 and in field plots in 2009. This is because organic production systems that use manures and composts as their primary N sources will generally have a P surplus (Mikkelsen, 2000). Indeed, several studies have shown an increase in the concentration of total P in organic production systems (Lotter, 2003). Specifically, organic P compounds present in organic matter can be mineralized during organic matter decomposition, thereby increasing P availability (Nelson and Janke, 2007).

Additionally, K levels were significantly different between organic and conventional MGT systems in 2008, 2009, and 2010 in the field and in all years but 2010 in the high tunnel (Table 1-10). Also, organic MGT systems where plots were amended with compost had higher K levels than conventional in both field (Figure 1-12) and high tunnel (Figure 1-13). Also, Hao and Chang (2002) reported higher K concentration in soil after repeated annual applications of cattle manure to both irrigated and non-irrigated soil. Notably, differences in soil chemical and physical properties due to changes in soil MGT techniques can vary. Significantly, an eight year study comparing organic, low input and conventional production systems involving animal manure, winter crops, and synthetic fertilizers (Clark et al., 1999) didn't find consistent differences in soil EC, Ca, and Mg levels; however, organic treatments led to higher soil organic C, soluble P, and exchangeable K.

Management had a significant effect on organic matter (O.M) (Table 1-11) showing significant differences between organic and conventional approaches in both field (Figure 1-14) and high tunnel (Figure 1-15) in 2008, 2009, and 2010.

Soil chemical annual analyses indicated no MGT or FRT effect on ammonium (NH_4-N) in the field plots except for 2009 (Table 1-12) where organic had higher ammonium levels (3.3 mg. kg $^{-1}$) than conventional plots (2.7 mg. kg $^{-1}$). However, high tunnel had a statistically significant MGT and FRT effect in 2009 (Figure 1-16) and a significant MGT effect in 2010 (Figure 1-17).

For NO_3-N, MGT and FRT effects were significant in 2010 only at the field (Table 1-13) where organic nitrate was higher (5.32 mg. kg $^{-1}$) than in conventional (3.62 mg. kg $^{-1}$), and low FRT treatments had higher soil nitrate levels (5.2 mg. kg $^{-1}$) than either control (4.23 mg.kg^{-1}) or high (4.0 mg. kg $^{-1}$) treatments

Nitrate and ammonium are the two major inorganic sources of N that can be taken up by plants directly. However, nitrate is more available for plant uptake due to its predominance and mobility in the soil (Miller and Cramer, 2005). During the tomato production seasons, date of soil analysis for the three years showed significant higher levels of ammonium at the vegetative stage of each year in both systems (field and high tunnel), in both MGT practices (organic and conventional), with the levels decreasing as the plants grew. Plants use nitrogen in nitrate or ammonium forms, but if they have a choice, plants prefer ammonium early and nitrate late in the season (Magdoff, 2000). Research has shown that growth is optimized with a mixture of both, ammonium being used for synthesis of amino acids and proteins (Epstein, 1972).

The field plots registered no significant effect of MGT or FRT on ammonium levels at any growth stage in 2008 or 2009 (Table 1-14). Conversely, in 2010, the MGT effect was significant *(P=0.001),* where conventionally managed soils had a higher ammonium level (7.9 mg kg^{-1}) than organic (5.9 mg kg^{-1}) at the fruit development stage. In the high tunnel plots, MGT had no significant effect on ammonium level at all growth stages except at the first flowering stage in 2008 ($p= 0.03$) where organic had a higher ammonium level (6.65 mg kg^{-1}) than conventional fertility treatment (6.25 mg kg^{-1}) (Table 1-15). No significant fertility effect on ammonium in all three years at any growing stage in high tunnel. However, interaction between MGT and FRT was significant in 2010 at fruit development stage.

Soil assessment for nitrate during the growing seasons was variable among the three years in both field and high tunnel. MGT showed no significant effect on nitrate levels of tomato growing in field plots at any growth stage in 2008 (Table 1-16). In contrast, in 2009, soil nitrate level at first flowering stage showed significant MGT effect, where organically managed soils had significantly higher levels of nitrate (6.35 mg kg^{-1}) than in conventionally managed soils (4.78 mg kg^{-1}), In 2010, MGT effect was also significant at the fruit development stage, where conventionally managed soils had higher nitrate levels (5.3 mg kg^{-1}) than organically managed soils (4.0 mg kg^{-1}). FRT had no significant effect on nitrate at any growth stage in any year except the flowering stage in 2009 *($P< .0001$)* where high fertility treatment had a higher nitrate level (7.79 mg kg^{-1}) than low (5.19 mg kg^{-1}), and control (3.7 mg kg^{-1}).

As for high tunnel soil analysis during the growing season, MGT showed no significant effect on nitrate levels at any growth stage in any of the three years however, FRT effect was significant at all three stages in 2009 where high fertility treatment showed higher nitrate levels than control (Table 1-17).

Agriculture MGT practices can significantly influence the amount of nitrogen in the soil, for example, in the control plots, in addition to the decomposition of soil organic matter the other source of nitrogen comes through the decomposition of rye residue during the growing season. Incorporating rye into the control FRT treatments does add to the soil organic nitrogen reserves, but this doesn’t always increase nitrogen availability or crop yield (Kuo et al., 1996). In addition, incorporating rye might also lead to net nitrogen immobilization, which could affect successive crop growth and yield. High C:N ratio and low nitrogen concentration in residues of crops such as rye can cause net nitrogen immobilization in the soil (Quemada and Cabrera, 1995). Therefore, the tomato crop in the control treatment without any pre-plant application could have been affected by decreased nitrogen availability during initial growth stages due to nitrogen immobilization. In an incubation study, (Kuo and Sainju, 1998) found that it took 30 weeks for the amount of nitrogen mineralization from rye residue amended soil to catch up with the nitrogen mineralization from a soil without residue amended. This result was based on added rye residue at a rate of 10 g kg^{-1} soil (dry weight basis), which is four times greater than the average amount of residue generated by rye cover crops in field conditions (Clark et al., 2007). Nitrogen immobilization from cover crop residue depends upon a number of factors such as soil type, moisture, temperature, and microbial activity. Based on (Kuo and Sainju, 1998) study, we can assume that in our study the time for nitrogen mineralization would be much less than 30 weeks and mineralization would have affected only the early growth stages of tomato plants as they were planted generally 3-4 weeks after rye incorporation.

Soil nitrate concentrations in 2009 and 2010were higher at the beginning of the season before the tomato plants started utilizing nitrate available in the soil. This may correlate with studies that have shown a significant increase in nitrogen mineralization and nitrification rates through cover crop, animal manure, and compost incorporation (Nahm, 2003; Habteselassie et al., 2006).

Petiole sap nitrate analysis

Field plots showed a significant effect of MGT on petiole sap nitrate for 2008 (fruit development stage) and 2010 (flowering stage) (Table 1-18). Also, FRT showed a significant effect on petiole sap nitrate concentration at flowering stage in 2009 and both flowering and fruit development stages in 2010 where high fertility treatment had a higher petiole sap nitrate level than did low fertility treatment and control. Furthermore, interaction between MGT and FRT was significant in 2009 (flowering stage) where conventional high fertility treatment had a higher petiole sap nitrate than any other treatment and in 2010 (fruit development stage) where organic high fertility treatment had higher petiole sap nitrate than any other treatment.

In high tunnel plots, MGT and FRT had no significant effect on high tunnel petiole sap nitrate in 2008 (Table 1-19). However, petiole sap nitrate levels at fruit set stage showed a significant effect caused by MGT and FRT in both 2009 and 2010 where conventional had a higher petiole sap nitrate than organic, while fruit development level showed only a significant FRT effect where high fertility treatment had significantly higher petiole sap nitrate than low, and control.

All FRT treatments showed a similar trend where petiole sap nitrate concentrations declined as the plants got bigger (flowering and fruit set), but remained sufficient (Table 1-20) (Hochmuth, 1994a). Hartz and Hochmuth (1996) reported that most of nitrogen uptake occurs during the last half of the cropping period. The decline in petiole sap nitrate concentration observed in all treatments was presumably due to the increasing biomass of the plant. Petiole sap nitrate remained substantially above the recommended sufficiency levels during the growing seasons (Hartz and Hochmuth, 1996). The control treatments which received no pre-plant application of compost had high early season petiole sap nitrate levels. This supports suggestions in the literature (Hartz and Hochmuth, 1996; Hartz et al., 1996) that soils previously cropped to cover crop have pre-plant soil nitrate levels that are often sufficient for early growth. The pattern of petiole sap nitrate concentration was similar in all treatments, whether the soil received pre-tomato cover crop only or the applied nitrogen in the form of compost.

Conclusion

Crop productivity represents the outcome of complex interactions among soil, plant, and management practices. In this study, our data showed that yields in organically managed tomato can equal or even exceed (2008) those of conventionally managed soil; this means that soil mineralization from soil organic matter in addition to compost application can fulfill a significant portion of the tomato crop nitrogen requirement.

Though management practices didn’t affect the yield, they did affect some of the chemical properties in the soil. Specifically, organic matter percent, potassium concentration, and pH levels were affected by management practices. In fact, soil managed organically had slightly greater levels of soil organic matter than did comparable conventional soils; this might be due to compost incorporation during the three years of production as the effect of compost can significantly influence the amount of soil organic matter according to some studies. For instance, the effect of compost on soil organic matter has been reviewed by (Stratton and Rechcigl, 1998) who reported different levels of increase in soil organic matter depending upon the type of compost used. Also, Schlegel (1992a) reported a smaller increase (0.26%) in soil organic matter as compared to that of control plots after application of cattle manure compost for three consecutive years at an initial rate of 16 t ha^{-1} and observed that the increase in soil organic matter was linearly related to the rate of compost application. Also, Evanylo et al. (2008) reported 50% increase in soil organic carbon with annual application of compost compared to that of control treatments (no-compost). Finally, various studies have reported large increases in soil organic carbon with repeated compost applications (Habteselassie et al., 2006; Zaman et al., 1999).

In our study, four years of compost application in addition to the compost applied in the previous studies increased soil organic matter under both field and high tunnel MGT. Soils that received no compost also had a slight increase in organic matter, showing the positive effects of rye cover crop on soil organic matter accumulation.

The greatest concentration of K in organic soils most likely resulted from composted animal manure compared to concentration of synthetic fertilizers in the conventional plots. Also, phosphorus levels in organically managed soil significantly increased by 2010 as a result of a continuous compost application. Although elevated P is not considered harmful to the plants, it can pose a threat to the environment as a result of runoff and leaching of the organically bound forms found in compost (Rosen and Allan, 2007).

Importantly, our study showed, adding soluble fertilizer during the growing season to organically or conventionally managed tomatoes had no direct effect on increasing the yield, implying that nitrogen application can be reduced to pre-plant application only to both improve economic outcome and reduce potential for nutrient loss.

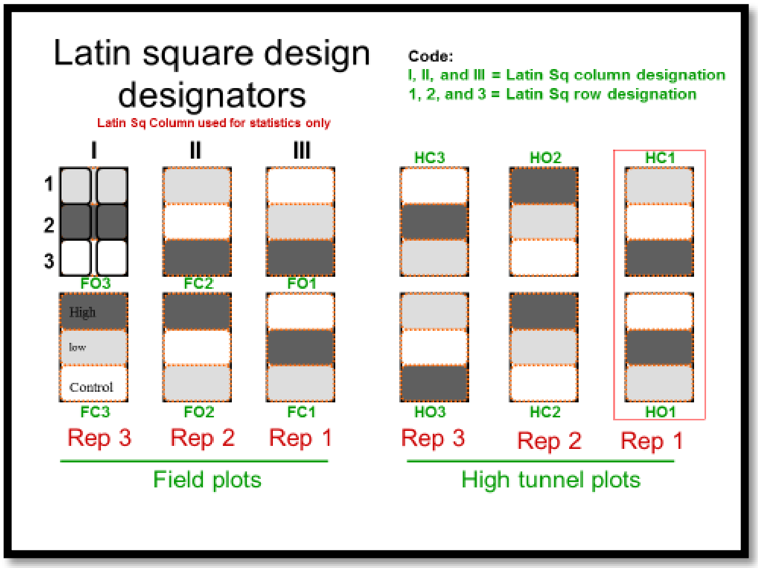

Figure 1-1: Latin square design for the high tunnel (H) or field (F) plots in Olathe, KS with the organic (O) or conventional (C) management systems at the three fertility treatment level control, low, and high

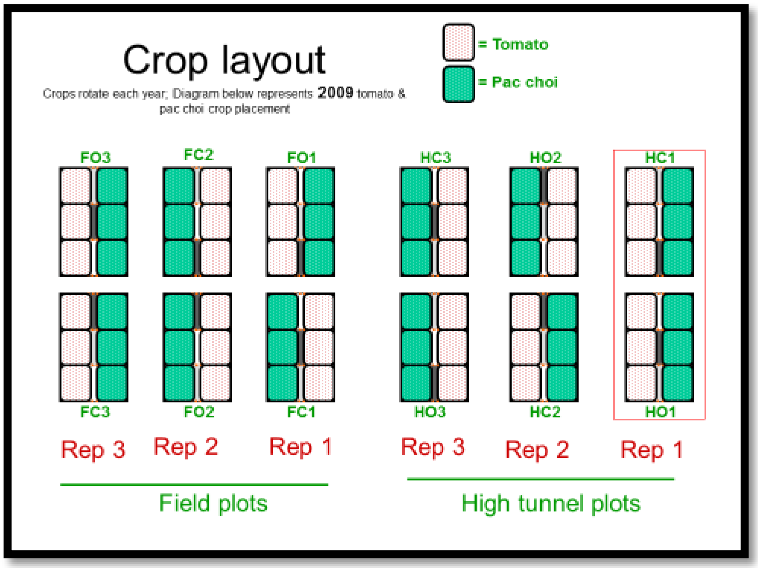

Figure 1-2: Crops (tomato and pac choi) rotate each year with cover crop in between seasons

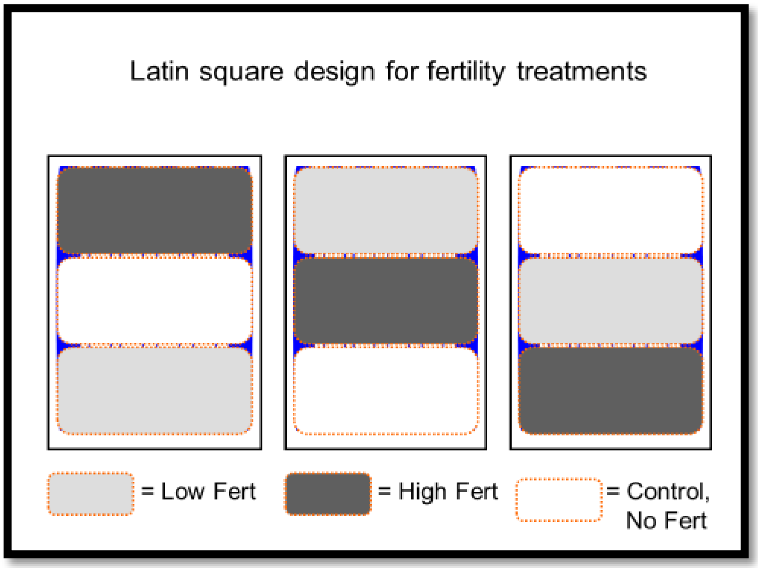

Figure 1-3: Fertility treatments. Control: cover crop, Low: cover crop plus pre-plant fertilizer amendment, High: cover crop plus pre-plant fertilizer amendment plus liquid fertilizer during the growing season

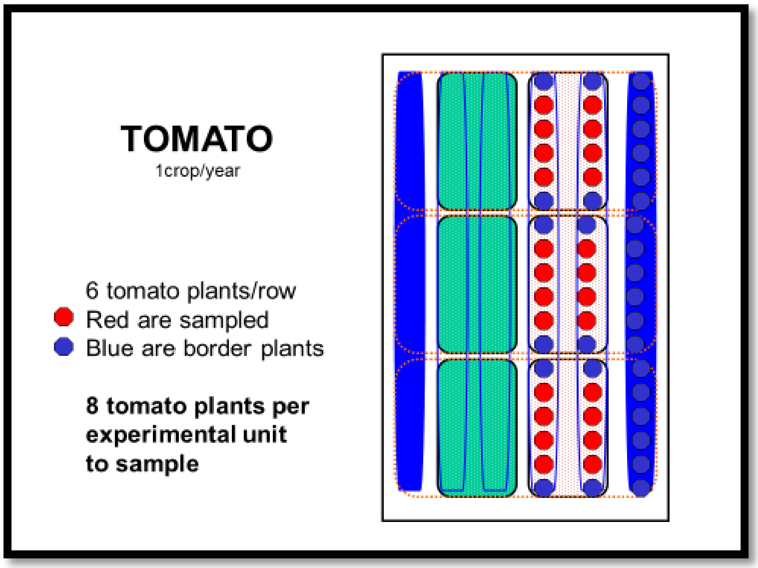

Figure 1-4: Tomato layout in high tunnel or field plots. Sampling for data analysis is from the eight tomato plants in the two inner rows avoiding the border plants (buffer)

Figure 1-5: Tomato plants in high tunnel and field plots in 2008 at June 17th, July 3rd and July 23rd. Tomato plants in field plots were infected by Septoria leaf spot but not in high tunnel.

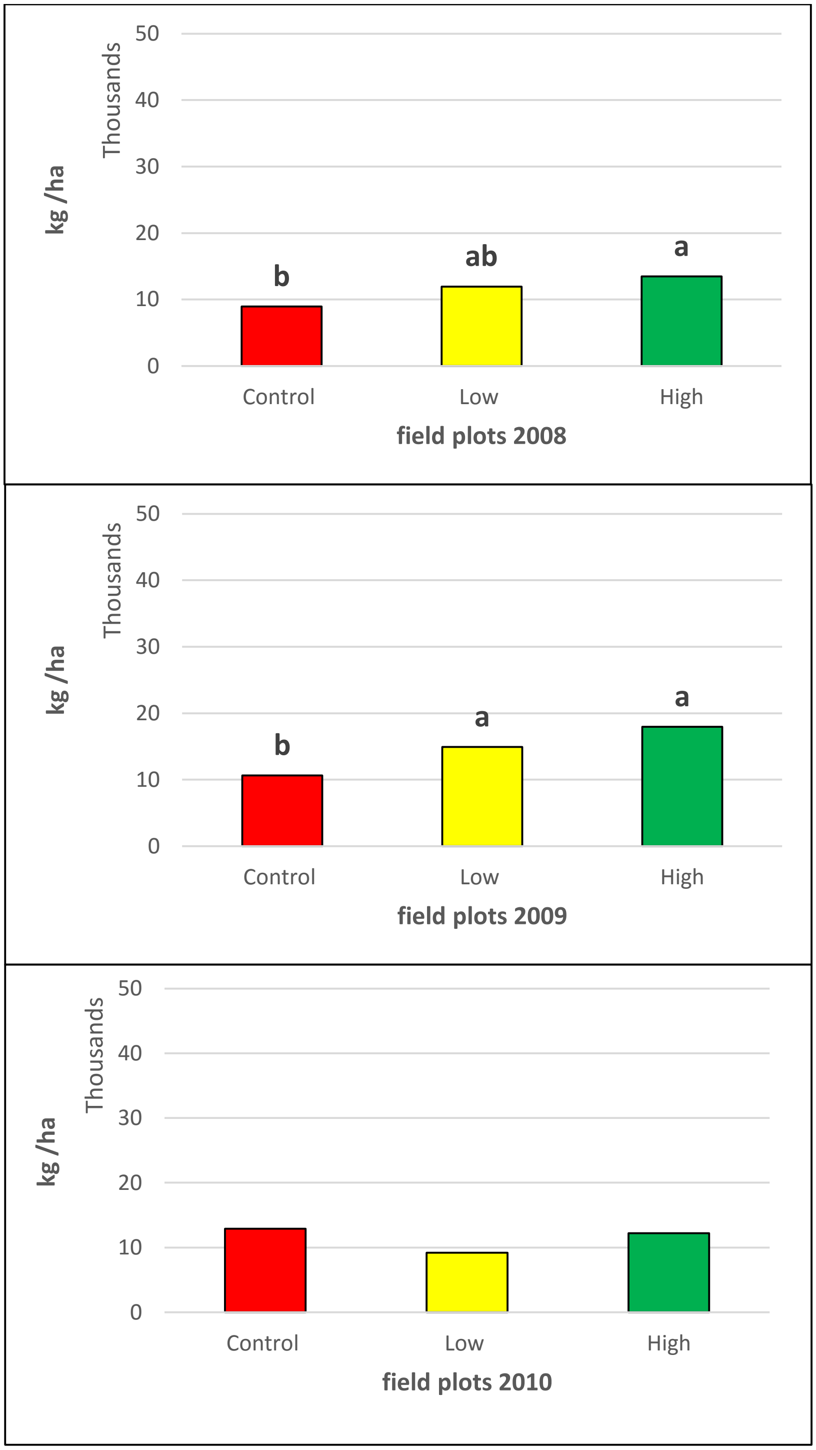

Figure 1-6: Tomato marketable yield in kg.ha^{-1} for 2008, 2009, and 2010 in field plots at different fertility treatment levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

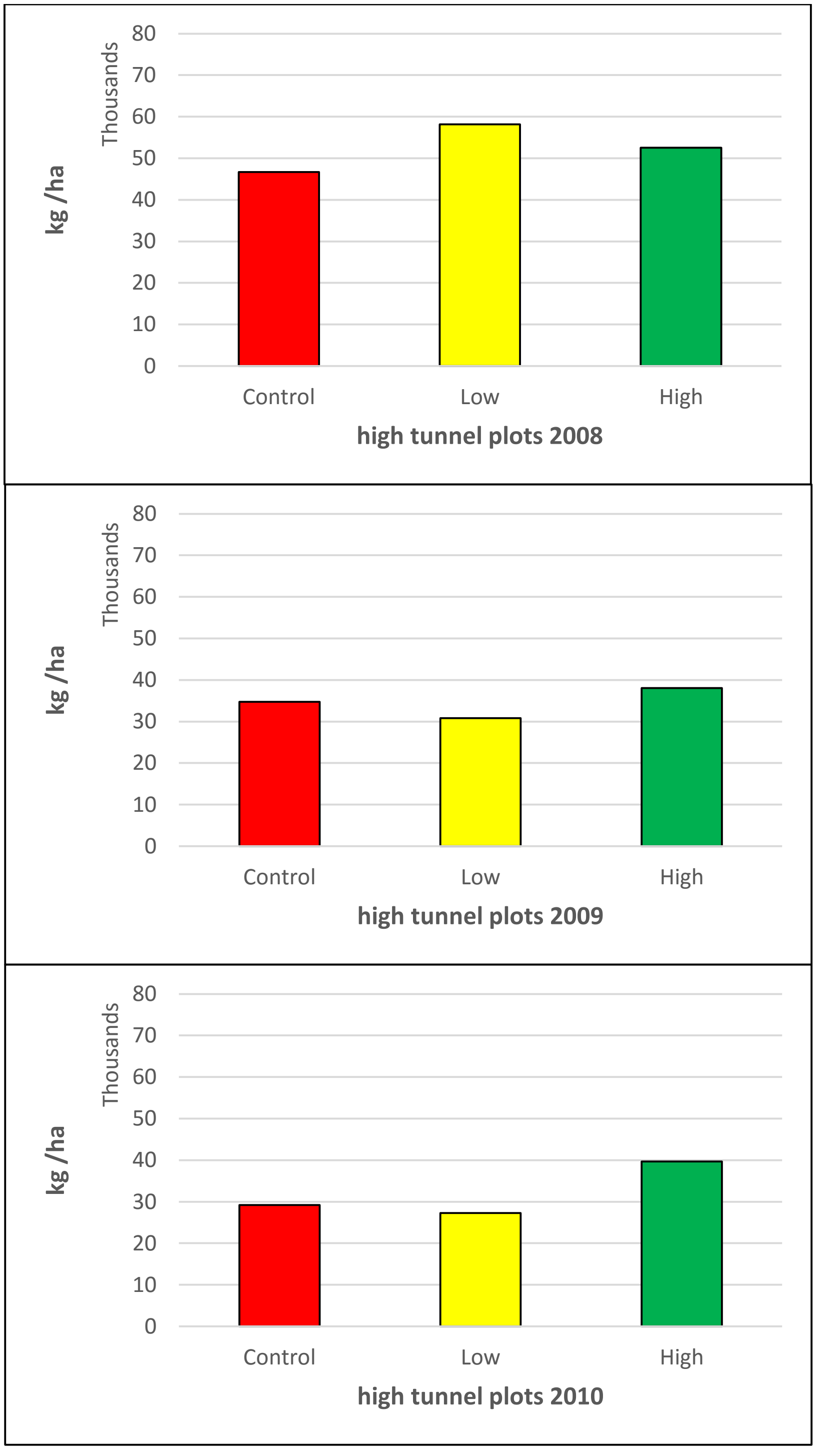

Figure 1-7: Tomato marketable yield in kg.ha^{-1} for 2008, 2009, and 2010 in high tunnel plots at different fertility treatment levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "

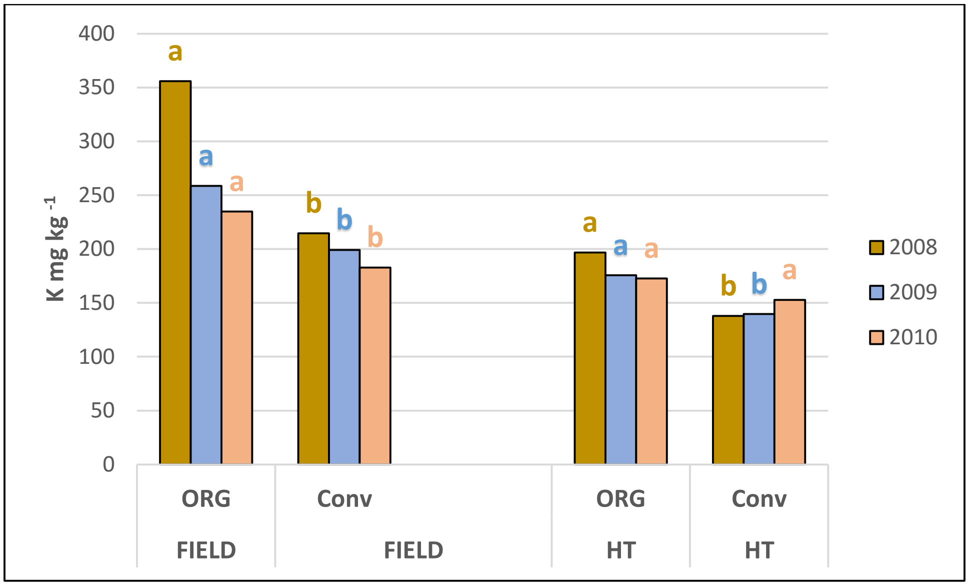

Figure 1-8: Extractable potassium (ammonium-acetate) concentration in mg kg $^{-1}$ in organic (ORG) versus conventional (Conv) managed systems for both field and high tunnel (HT) soil annual analysis in 2008, 2009 and 2010. "Means sharing the same letter within the same color are not significantly different from each other (Tukey's HSD, P<0.05)"

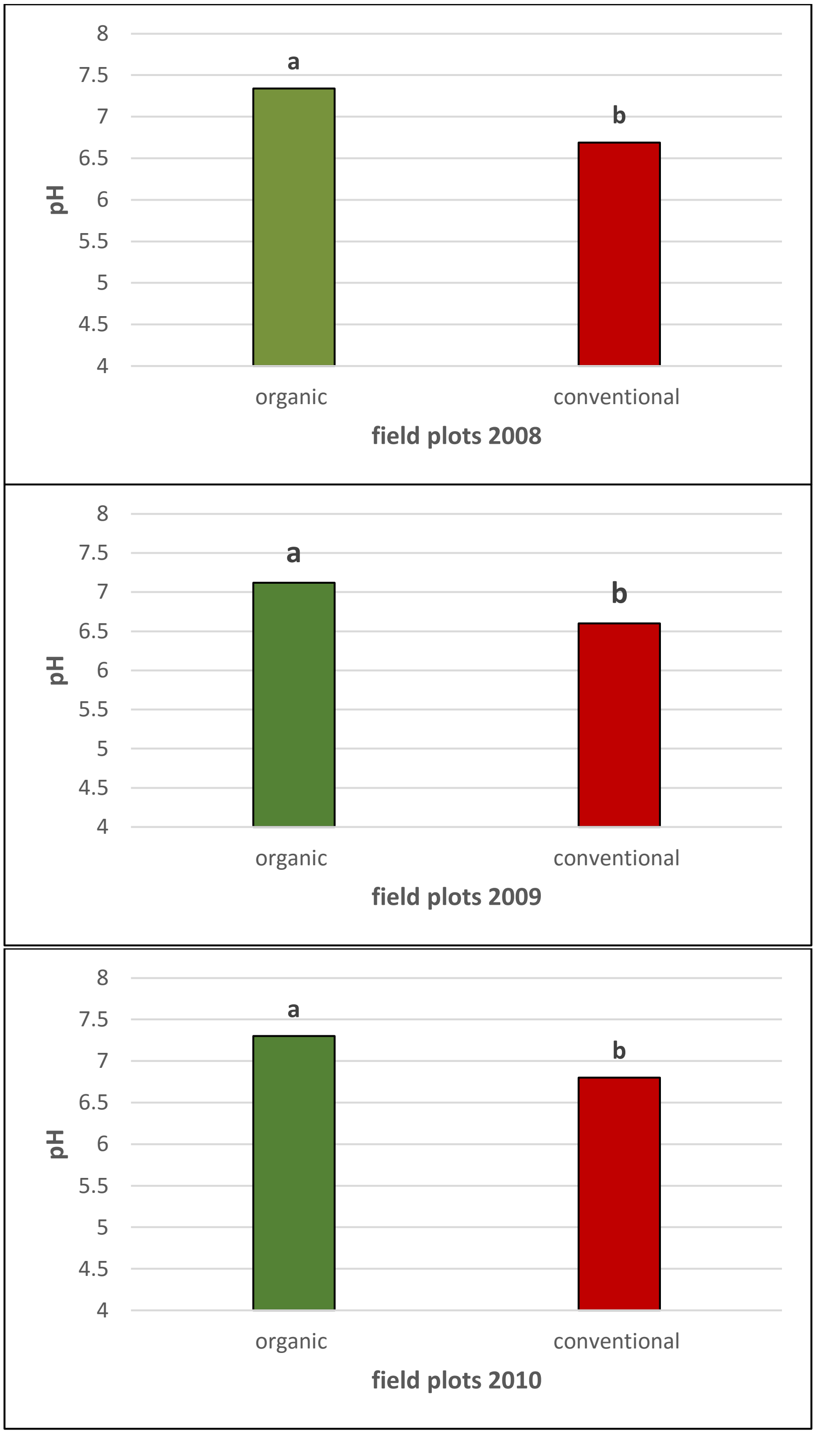

Figure 1-9: pH value for the annual soil analysis (0-15) cm for organic and conventional management systems in 2008, 2009, and 2010 in field plots for tomato crop. Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

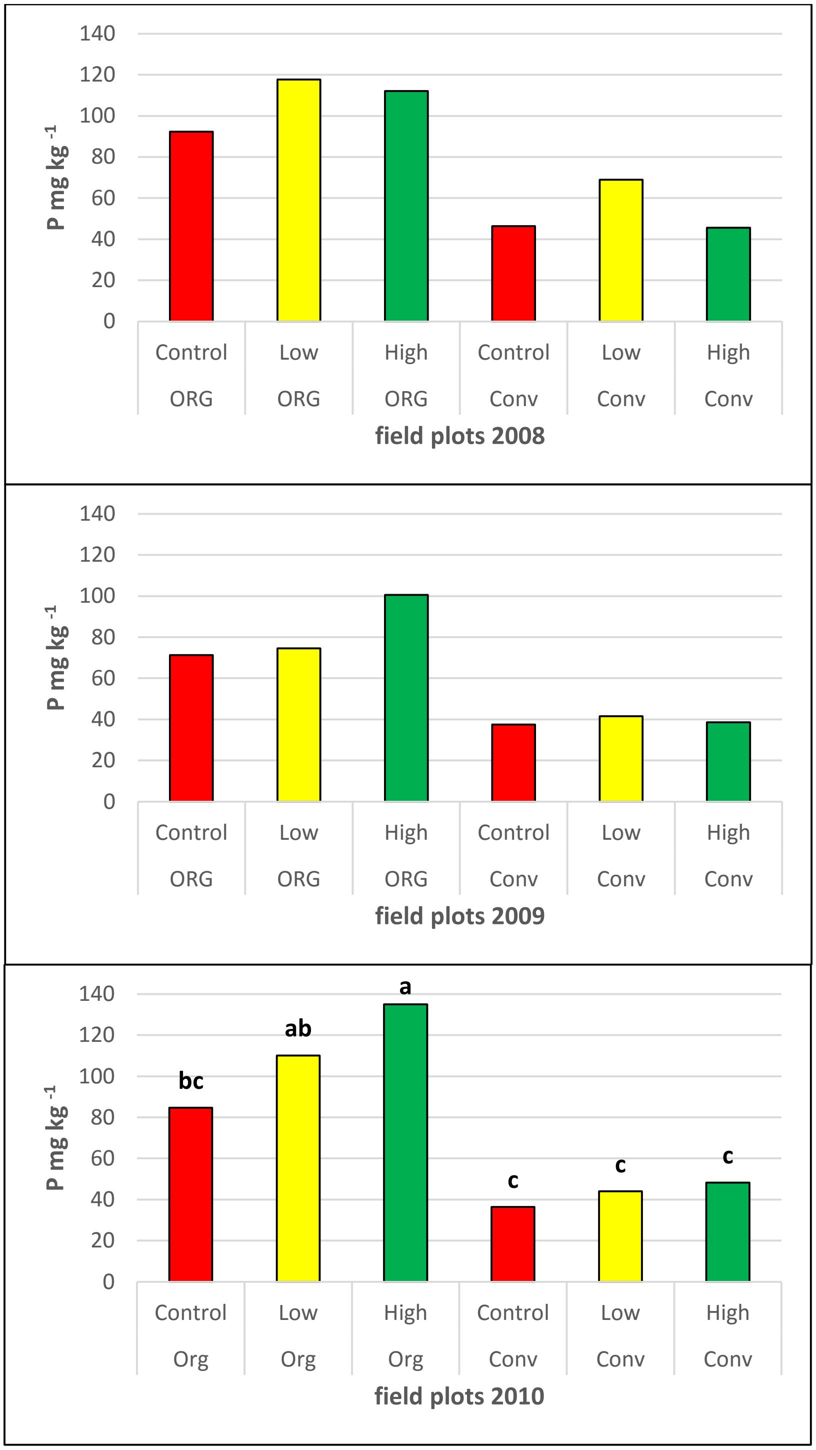

Figure 1-10: Phosphorus values in mg kg^{-1} for the annual soil analysis (0-15) cm for organic and conventional management systems in 2008, 2009 ,and 2010 in field plots for tomato crop at different fertility treatment levels; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

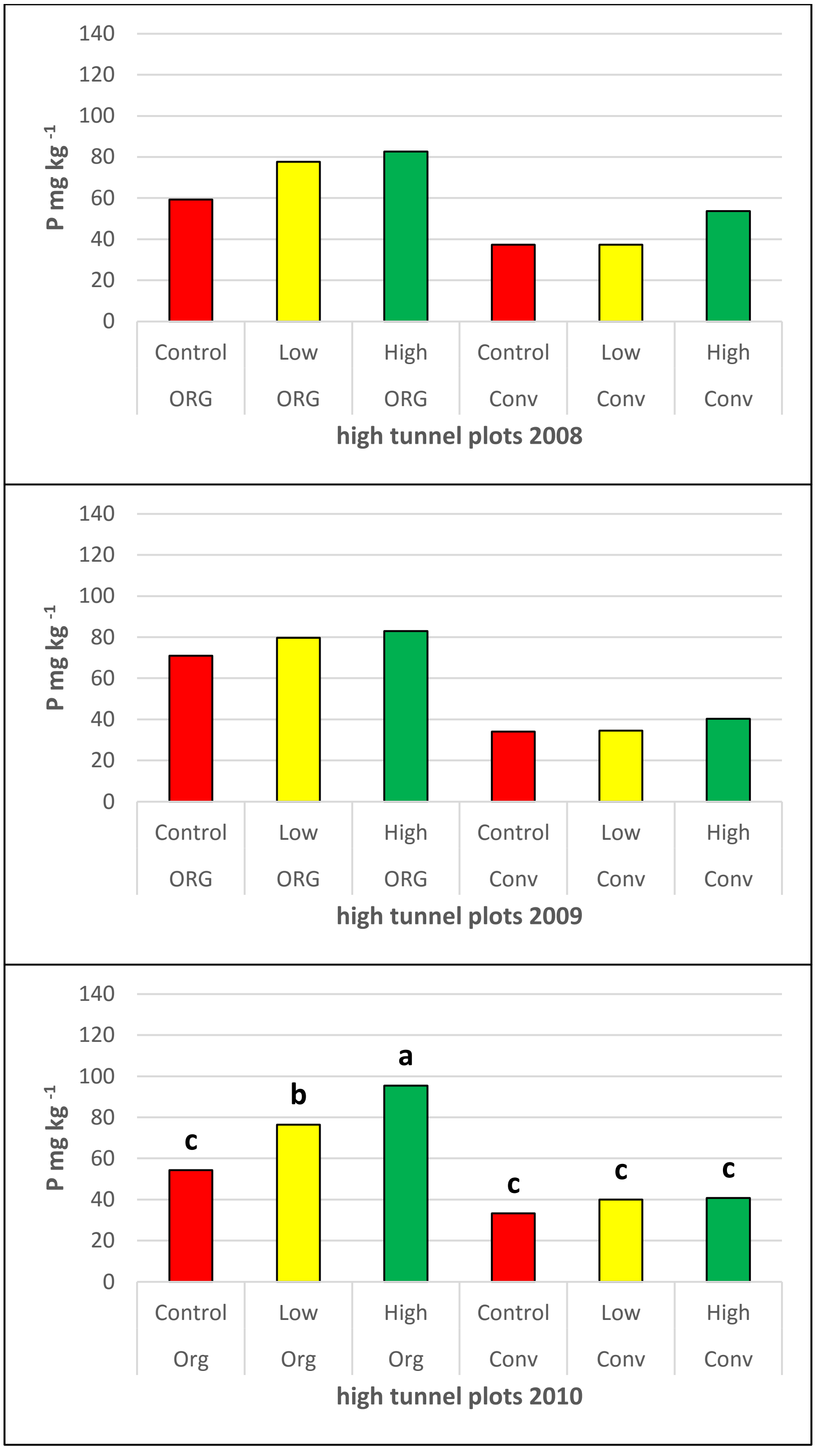

Figure 1-11: Phosphorus values in mg kg $^{-1}$ for annual soil analysis (0-15) cm for organic and conventional management systems in 2008 , 2009 , and 2010 in high tunnel plots for tomato crop at different fertility treatment levels; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

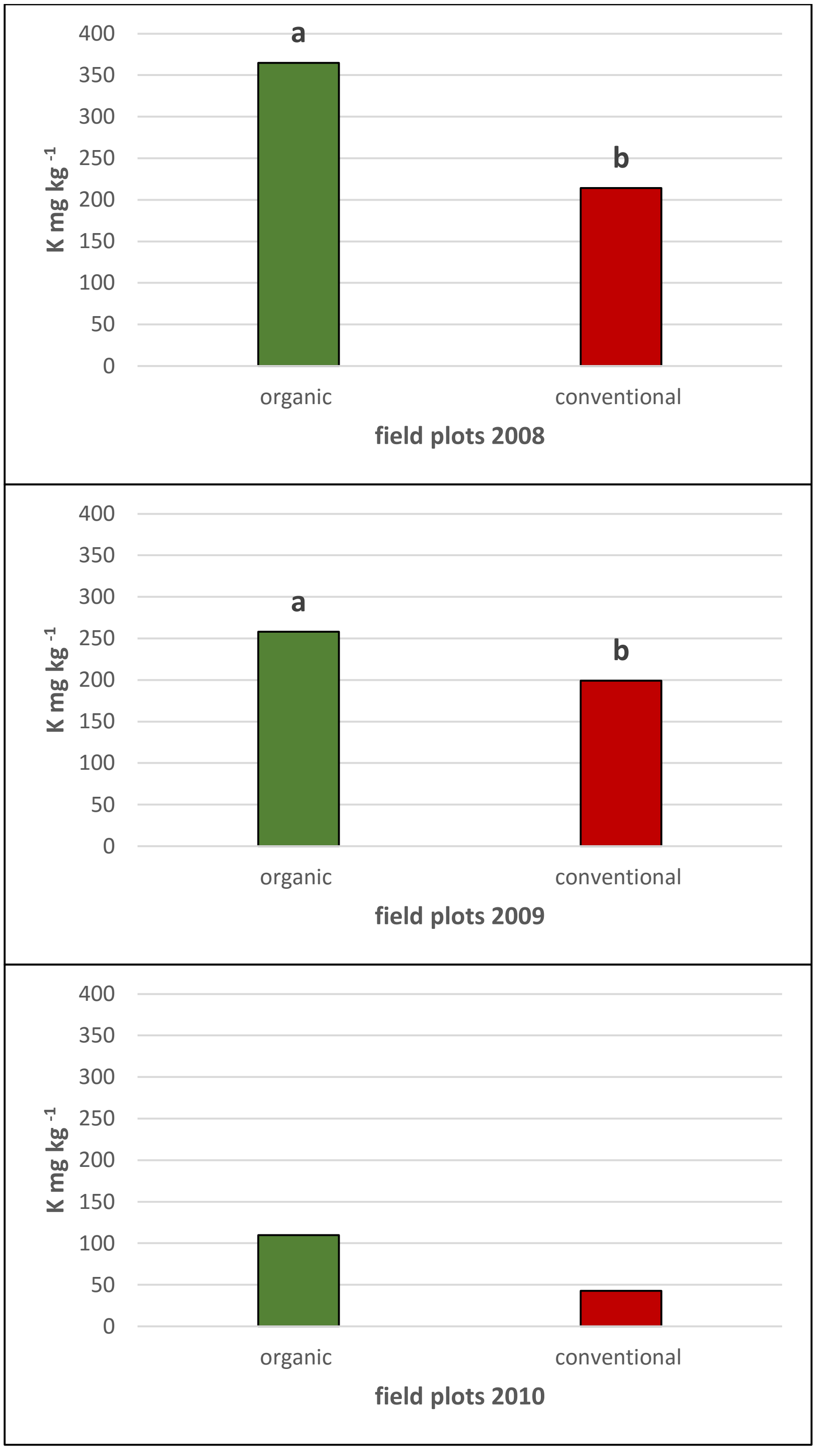

Figure 1-12: Potassium values in mg kg $^{-1}$ for annual soil analysis (0-15) cm for organic and conventional management systems in 2008, 2009, and in 2010 in field plots for tomato crop "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

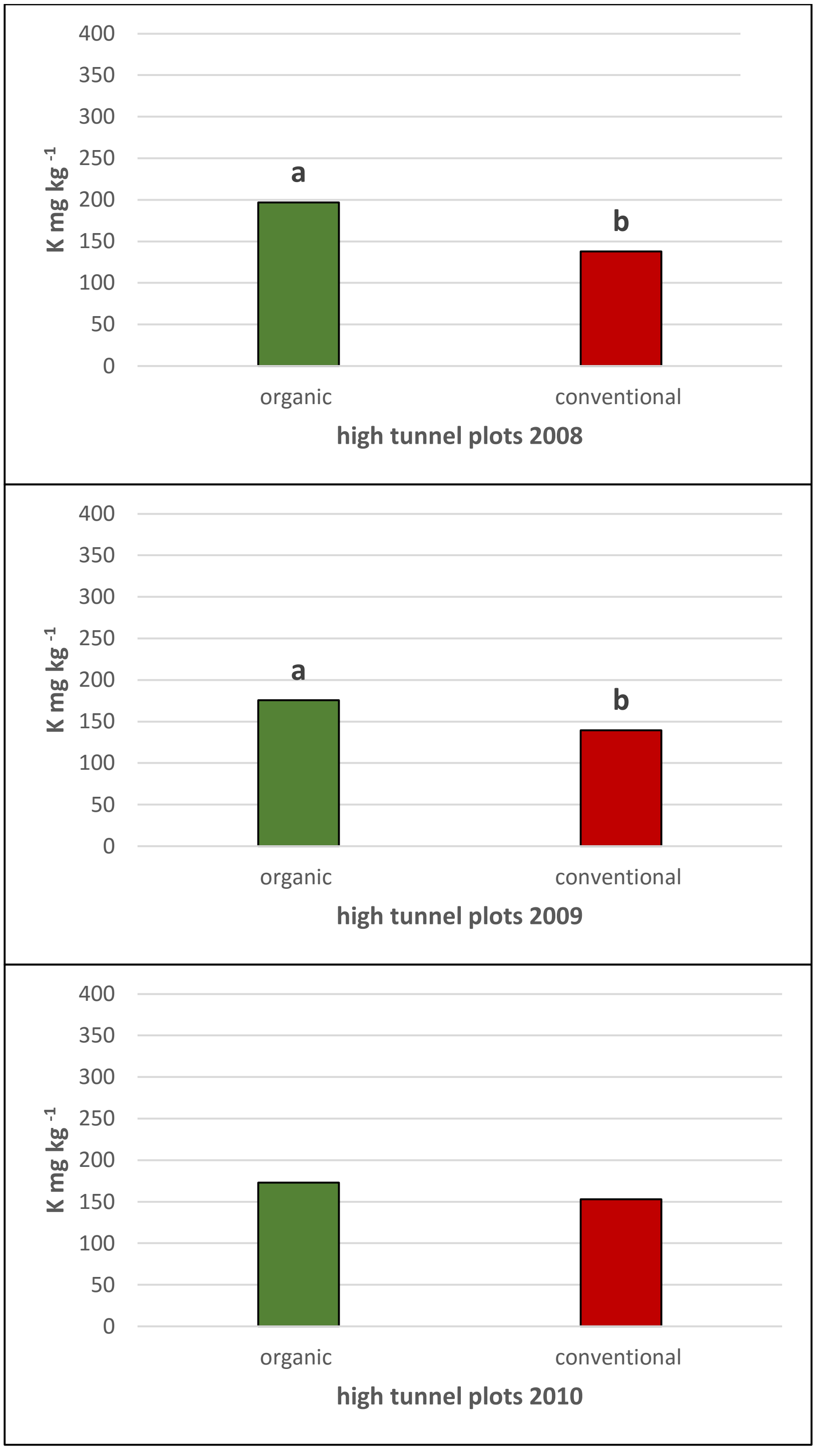

Figure 1-13: Potassium values in mg kg $^{-1}$ for annual soil analysis (0-15) cm for organic and conventional management systems in 2008, 2009, and in 2010 in high tunnel plots for tomato. "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

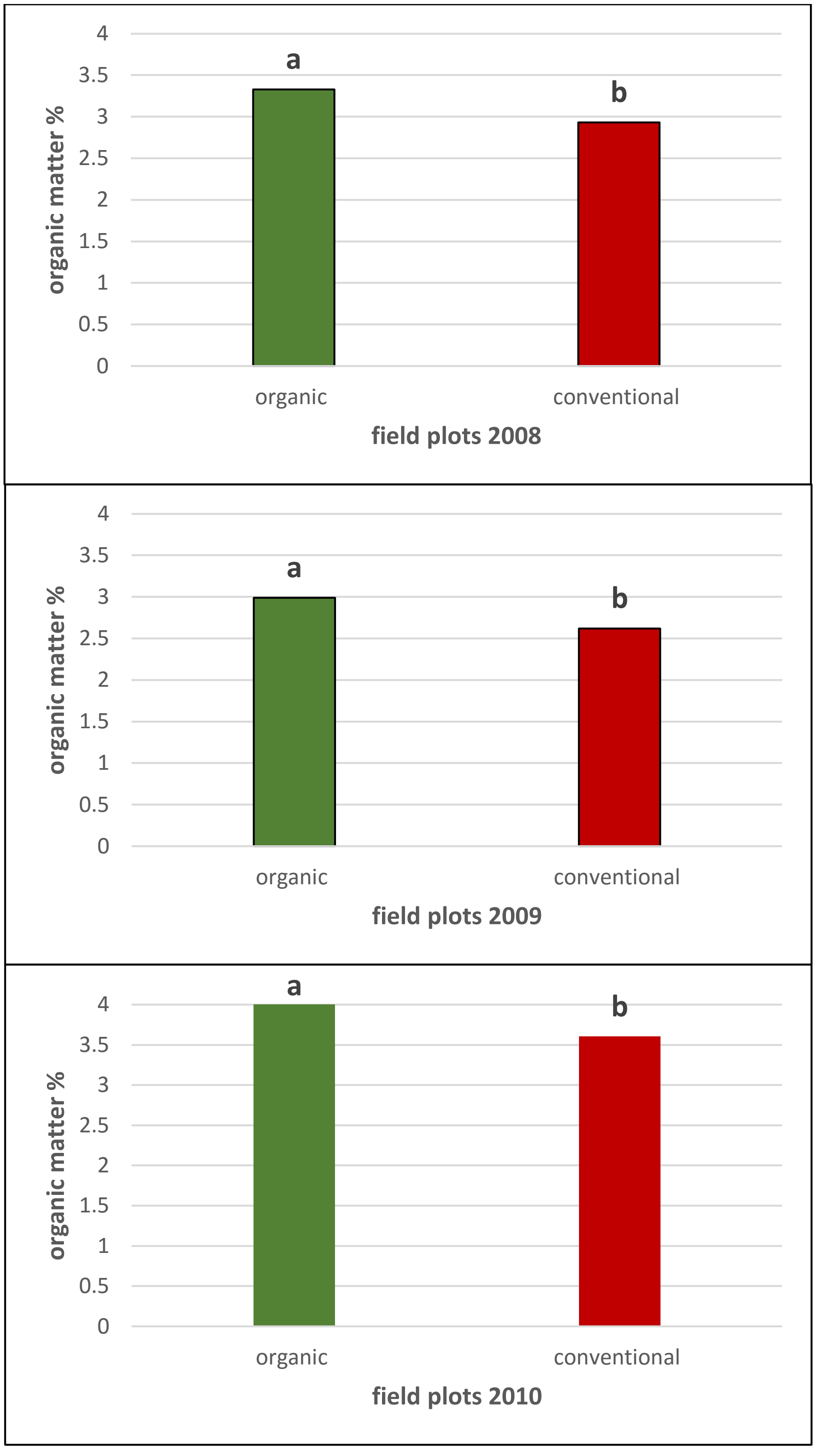

Figure 1-14: Percentage of organic matter for annual soil analysis (0-15) cm for organic and conventional management systems in 2008, 2009, and 2010 in field plots for tomato crop "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

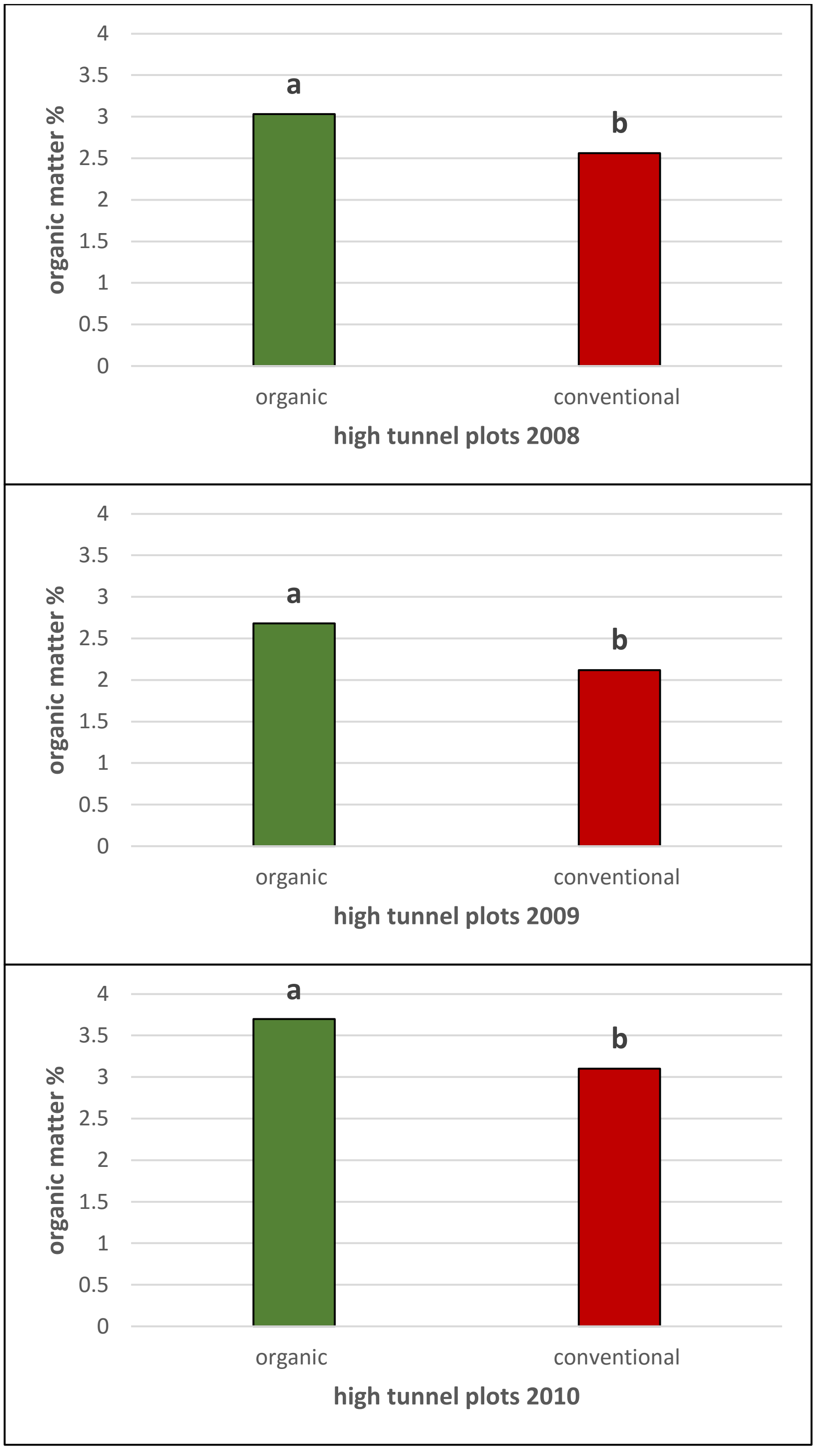

Figure 1-15: Percentage of organic matter for annual soil analysis (0-15) cm for organic and conventional management systems in 2008, 2009, and 2010 in high tunnel plots for tomato crop "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

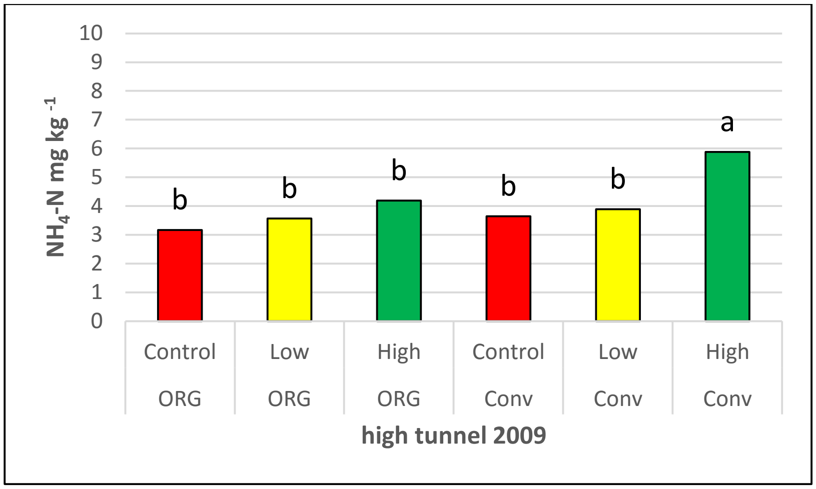

Figure 1-16: Ammonium nitrogen values in mg. kg $^{-1}$ for annual soil analysis (0-15) cm for organic & conventional management systems in 2009, in high tunnel plots for tomato crop at different fertility treatment levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

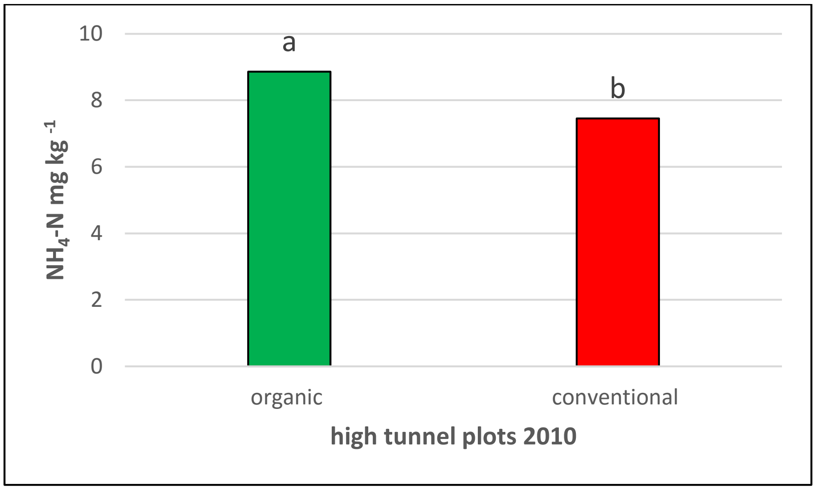

Figure 1-17: Ammonium nitrogen values in mg. kg $^{-1}$ for annual soil analysis (0-15) cm for organic and conventional management systems in 2010 in high tunnel plots for tomato crop. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

Table 1-1: Compost composition (dry weight) prepared from poultry manure for 2008, 2009 and 2010

	2008	**2009**	**2010**
Rate of compost applied	**4,016 kg/ha**	**3,954 kg/ha**	**3,954 kg/ha**
	%	%	%
Nitrogen			
Total Nitrogen	0.56	0.4	0.6
Organic Nitrogen	0.51	0.35	0.55
Ammonium Nitrogen	0.004	0.03	0.03
Nitrate-Nitrogen	0.05	0.09	0.01
Major & Secondary Nutrients			
Phosphorus as P2O5	0.96	0.69	0.7
Potassium as K2O	0.46	0.47	0.3
Sulfur	0.58	0.34	8
Calcium	2.9	4.3	5.6
Magnesium as MgO	0.41	0.27	0.3
Sodium	0.03	0.04	1
Micronutrients	**Mg kg $^{-1}$**	**Mg kg $^{-1}$**	**Mg kg $^{-1}$**
Zinc	81	72	74
Iron	9700	11002	5153
Manganese	554	509	317
Copper	49	47	43
Other Properties			
Moisture as received %	25.9	27.2	40.7
pH	.	6.2	6.6

Table 1-2: Dates for seeding, fertilizer application before and after planting, plant transplant of tomato crop and soluble fertilizer added to high fertility treatments in 2008, 2009, and 2010

	Tomato 2008					
seed sown	21-Mar					
pre-plant application	30-Apr					
seedlings fertilized	15-Apr	30-Apr	5-May			
seedling planted	5-May					
soluble fertilizer added	12-Jun	16-Jun	26-Jun	2-Jul	9-Jul	16-Jul
	Tomato 2009					
seed sown	31-Mar					
pre-plant application	15-May					
seedlings fertilized	8-Apr	22-Apr	8-May			
seedling planted	16-May					
soluble fertilizer added	1-Jun	8-Jun	18-Jun	25-Jun	2-Jul	9-Jul
	Tomato 2010					
seed sown	30-Mar					
pre-plant application	21-May					
seedlings fertilized	13-Apr	22-Apr	9-May			
seedling planted	25-May					
soluble fertilizer added	7-Jun	15-Jun	22-Jun	30-Jun	6-Jul	13-Jul

Table 1-3: Annual soil analysis dates for tomato crop in 2008, 2009, and 2010

	2008	**2009**	**2010**
Annual complete soil analysis	10-Mar	17-Mar	14-Apr
analysis 1	18-Jun	19-May	11-Jun
analysis 2	2-Jul	6-Jun	12-Jul
analysis 3	24-Jul	2-Jul	6-Aug

Table 1-4: Weather history for Olathe, KS for the summer of 2008, 2009 and 2010. Maximum temperature (ºF), precipitation (inches) and growing degree days (base 50)*

2008	**max temperature ºF**	**precipitation (Inch)**	**GDD**
May	87	1.00	435
June	91	3.73	711
July	97	3.56	846
August	96	0.36	784
September	90	3.17	492
Cumulative		**11.82**	**3,268**
2009	**max temperature ºF**	**precipitation (Inch)**	**GDD**
May	91	0.92	453
June	97	1.7	752
July	91	1.16	737
August	96	1.98	708
September	87	1.16	489
Cumulative		**6.92**	**3,140**
2010	**max temperature ºF**	**precipitation (Inch)**	**GDD**
May	87	1.04	421
June	93	3.34	806
July	94	2.22	914
August	102	0.00	934
September	89	2.64	580
Cumulative		**9.24**	**3,655**

*(Weather history, 2008-2010)

Table 1-5: Tomato marketable yield for 2008, 2009 and 2010 in kg per hectare at different fertility treatment levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer). "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

	Tomato yield kg.ha^{-1}						
	Field				**High tunnel**		
	2008	**2009**	**2010**		**2008**	**2009**	**2010**
Organic	11473.6	15770.2	10985.4		57417.0^{a}	38229.2	32077.4
Conventional	11424.8	13280.1	11864.2		47505.8^{b}	30759.1	32028.5
p-value	**0.9868**	**0.0706**	**0.8634**		**0.0163**	**0.2385**	**0.9943**
Control	8934.8^{b}	10643.6^{b}	12889.5		46724.6	34762.7	29196.8
Low	11961.9^{ab}	14940.1^{b}	9178.9		58149.4	30807.9	27292.6
High	13475.4^{a}	17967.2^{a}	12206.0		52534.6	38082.7	39693.9
p-value	**0.0147**	**0.0016**	**0.1539**		**0.0627**	**0.0762**	**0.0702**
Org. Control	9813.6	12352.5	12059.5		48848.4^{b}	36422.7	25925.5
Org. Low	12108.4	15623.7	8007.1		70101.5^{a}	38619.8	28269.1
Org. High	12498.9	19285.5	12987.2		53364.6^{b}	39596.3	42037.5
Conv. control	8056.0	8934.8	13719.5		44576.3b	32858.6	32516.8
Conv. Low	11815.4	14256.6	10350.7		46236.3^{b}	22849.6	26316.1
Conv. High	14403.1	16649.0	11473.6		51753.4^{b}	36520.4	37301.5
p-value	**0.3520**	**0.7906**	**0.5465**		**0.0479**	**0.0833**	**0.5043**

Table 1-6: Percentage of tomato yield (grade # 1) for conventional and organic management at different fertility treatment levels; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) in 2008, 2009 and 2010 for field and high tunnel plots. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

	2008		2009		2010	
	organic	**conventional**	**organic**	**conventional**	**organic**	**conventional**
	Field					
control	74.7^{a}	55.5^{b}	78.9^{a}	54.6^{b}	80.3^{a}	59.8^{b}
low	76.8^{a}	61.9^{b}	75.1^{a}	61.6^{b}	78.5^{a}	61.1^{b}
high	78.1^{a}	57.6^{b}	80.8^{a}	64.5^{b}	85.1^{a}	55.3^{b}
	High tunnel					
control	80.1^{a}	64.6^{b}	89.1^{a}	60.9^{b}	75.4^{a}	60.1^{ab}
low	75.9^{a}	63.4^{ab}	79.7^{a}	64.1^{b}	79.4^{a}	53.9^{b}
high	77.8^{a}	71.7^{a}	86.3^{a}	61.5^{b}	76.6^{a}	64.1^{ab}

Table 1-7: Statistic analysis for extractable potassium in 2008, 2009 and 2010 for annual soil analysis. Means of simple effect (management) with resulting p-value. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

	Field				**High Tunnel**		
	2008	**2009**	**2010**		**2008**	**2009**	**2010**
Organic	321.33^{a}	258.78^{a}	234.78^{a}		216.11^{a}	175.56^{a}	172.78^{a}
Conventional	209.56^{b}	199.22^{b}	182.78^{b}		150.11^{b}	139.56^{b}	152.89^{a}
p-value	**0.0001**	**0.0407**	**0.0538**		**0.0003**	**0.0007**	**0.123**

Table 1-8: Soil annual analysis for pH and resulting p-value for tomato crop grown under field and high tunnels plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer), and interaction between management and fertility, for 2008, 2009 and 2010

	Field pH		
	2008	**2009**	**2010**
Management	0.0001	0.0116	0.0087
Fertility	0.0878	0.2792	0.3725
Management*fertility	0.9747	0.9132	0.0264
	High tunnel pH		
	2008	**2009**	**2010**
Management	0.076	0.4474	0.2155
Fertility	0.3645	0.1398	0.0862
Management *fertility	0.3083	0.1796	0.7813

Table 1-9: Soil annual statistical analysis for phosphorous (P) and resulting p-value for tomato crop grown under field and high tunnels plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility, for 2008, 2009 and 2010

	Field P		
	2008	**2009**	**2010**
Management	0.0663	0.0964	0.0307
Fertility	0.1271	0.0543	0.0340
Management *fertility	0.5900	0.0461	0.1936
	High tunnel P		
	2008	**2009**	**2010**
Management	0.0612	0.1148	0.0147
Fertility	0.0987	0.4206	0.0060
Management *fertility	0.5332	0.8108	0.0408

Table 1-10: Soil potassium (K) mean values in mg.kg^{-1}and resulting p-value for tomato crop grown under field and high tunnels plots. Management (organic or conventional), for 2008, 2009 and 2010 "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

	Field K		
	2008	**2009**	**2010**
Organic	365.00^{a}	258.78^{a}	234.78^{a}
Conventional	214.67^{b}	199.22^{b}	182.78^{a}
p-value	0.0001	0.0407	0.0531
	High tunnel K		
	2008	**2009**	**2010**
Organic	196.89^{a}	175.56^{a}	172.78^{a}
Conventional	137.78^{b}	139.56^{b}	152.89^{a}
p-value	0.0003	0.0007	0.1230

Table 1-11: Soil organic matter percentage (OM) mean values and resulting p-value for tomato crop grown under field and high tunnels plots. Management (organic or conventional), for 2008, 2009 and 2010. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

	Field OM		
	2008	**2009**	**2010**
Organic	3.33^{a}	2.99^{a}	4.03^{a}
Conventional	2.93^{b}	2.62^{a}	3.57^{b}
Management p-value	0.0266	0.0736	0.0335
	High tunnel OM		
	2008	**2009**	**2010**
Organic	3.03^{a}	2.68^{a}	3.66^{a}
Conventional	2.55^{b}	2.11^{b}	3.08^{b}
Management p-value	0.0001	0.0002	0.0004

Table 1-12: Soil annual statistical analysis for ammonium- nitrogen (NH_4-N) and resulting p-value for tomato crop grown under field and high tunnels plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility, for 2008, 2009 and 2010

	Field NH_4-N		
	2008	**2009**	**2010**
Management	0.8453	0.0126	0.9147
Fertility	0.2341	0.6573	0.6259
Management *fertility	0.6839	0.0767	0.9871
	High tunnel NH_4-N		
	2008	**2009**	**2010**
Management	0.6839	0.0485	0.0186
Fertility	0.1175	0.0147	0.6009
Management *fertility	0.7122	0.3267	0.3393

Table 1-13: Soil annual statistical analysis for nitrate- nitrogen (NO_3-N) and resulting p-value for tomato crop grown under field and high tunnels plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility, for 2008, 2009 and 2010

	Field NO_3-N		
	2008	**2009**	**2010**
Management	0.1227	0.0572	0.0115
Fertility	0.7025	0.4085	0.0181
Management *fertility	0.3698	0.4851	0.0813
	High tunnel NO_3-N		
	2008	**2009**	**2010**
Management	0.7468	0.0925	0.2161
Fertility	0.7425	0.0456	0.2643
Management *fertility	0.5006	0.0650	0.1409

Table 1-14: Soil statistical analysis for ammonium-nitrogen (NH_4-N) and resulting p-value during the growing season for tomato crop grown under field plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer), and interaction between management and fertility, for 2008, 2009 and 2010 at first flowering, fruit set and fruit development stages

	First flowering	Fruit set	Fruit development
2008	**NH_4-N**	**NH_4-N**	**NH_4-N**
Management	0.5350	0.1469	0.5523
Fertility	0.9782	0.8056	0.4035
Management *fertility	0.8099	0.0805	0.0776
2009	**NH_4-N**	**NH_4-N**	**NH_4-N**
Management	0.0773	0.0622	0.3971
Fertility	0.6223	0.8774	0.7933
Management *fertility	0.5552	0.9125	0.9132
2010	**NH_4-N**	**NH_4-N**	**NH_4-N**
Management	0.6556	0.3116	0.0011
Fertility	0.3825	0.2366	0.1189
Management *fertility	0.3840	0.0921	0.7171

Table 1-15: Soil statistical analysis for ammonium-nitrogen (NH_4-N) and resulting p-value during growing season for tomato crop grown under high tunnel plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer), and interaction between management and fertility, for 2008, 2009 and 2010 at first flowering, fruit set and fruit development stages

2008	First flowering	Fruit set	Fruit development
	NH_4-N	NH_4-N	NH_4-N
Management	0.0351	0.863	0.2018
Fertility	0.05711	0.1435	0.1467
Management *fertility	0.9120	0.2391	0.7776
2009	NH_4-N	NH_4-N	NH_4-N
Management	0.9804	0.1684	0.0844
Fertility	0.4042	0.8201	0.6691
Management *fertility	0.6444	0.9606	0.1119
2010	NH_4-N	NH_4-N	NH_4-N
Management	0.192	0.1682	0.0634
Fertility	0.050	0.1405	0.4501
Management *fertility	0.1966	0.7864	0.0065

Table 1-16: Soil statistical analysis for nitrate-nitrogen (NO_3-N) and resulting p-value during growing season for tomato crop grown under field plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility, for 2008, 2009 and 2010 at first flowering, fruit set and fruit development stages

2008	First flowering	Fruit set	Fruit development
	NO_3-N	NO_3-N	NO_3-N
Management	0.7199	0.4676	0.7850
Fertility	0.2003	0.4992	0.3020
Management *fertility	0.6489	0.5714	0.9663
2009	NO_3-N	NO_3-N	NO_3-N
Management	0.0002	0.1945	0.3107
Fertility	0.0001	0.1224	0.0755
Management *fertility	0.0640	0.9391	0.9060
2010	NO_3-N	NO_3-N	NO_3-N
Management	0.5632	0.5426	0.0001
Fertility	0.3299	0.1817	0.1783
Management *fertility	0.8479	0.5418	0.5517

Table 1-17: Soil statistical analysis for nitrate-nitrogen (NO_3-N) and resulting p-value during growing season for tomato crop grown under high tunnel plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility, for 2008, 2009 and 2010 at first flowering, fruit set and fruit development stages

2008	**First flowering**	**Fruit set**	**Fruit development**
	NO_3-N	**NO_3-N**	**NO_3-N**
Management	0.5299	0.9008	0.9497
Fertility	0.0350	0.1621	0.2608
Management *fertility	0.9382	0.9652	0.9431
2009	**NO_3-N**	**NO_3-N**	**NO_3-N**
Management	0.1798	0.1049	0.8957
Fertility	0.0016	0.0071	0.0003
control	5.5^{b}	5.5^{b}	3.5^{c}
low	8.3^{ab}	8.5^{ab}	5.9^{b}
high	11.9^{a}	11.8^{a}	8.2^{a}
Management *fertility	0.1651	0.8719	0.0522
2010	**NO_3-N**	**NO_3-N**	**NO_3-N**
Management	0.8751	0.3263	0.8096
Fertility	0.2927	0.6204	0.5252
Management *fertility	0.2472	0.4528	0.4230

Table 1-18: Statistical analysis for petiole sap in mg. kg^{-1} and the resulting p-value for tomato crop grown under field plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and the interaction between management and fertility for 2008, 2009 and 2010 at, flowering and fruit set and fruit development stages

		Field								
		2008			**2009**			**2010**		
		flowering	**fruit set**	**fruit dev.**	**flowering**	**fruit set**	**fruit dev.**	**flowering**	**fruit set**	**fruit dev.**
management	**Organic**	681.9	1677.5	892.45^{a}	466.7	720.0	656.7	4188.9^{b}	741.1	833.3
	Conventional	1608.9	530.6	448.27^{b}	1905.6	856.7	731.1	4466.7^{a}	966.7	772.2
	p-value	**0.1864**	**0.2258**	**0.0042**	**0.0756**	**0.2654**	**0.1863**	**0.0195**	**0.1541**	**0.4862**
fertility	**Control**	644.1	710.0	591.3	563.3^{b}	646.7	670.0	4033.3^{b}	875.0	630.0^{b}
	Low	1340.7	1183.1	624.1	883.3^{b}	870.0	758.3	4300^{b}	846.7	695.0^{b}
	High	1450.8	1419.2	795.6	2081.7^{a}	878.3	653.3	4650^{a}	840.0	1083.0^{a}
	p-value	**0.0627**	**0.1573**	**0.3471**	**0.0008**	**0.1618**	**0.2610**	**0.0014**	**0.9788**	**0.0029**
management* fertility	**Org. Control**	717.5	851.0	671.3	406.7^{b}	630.3	663.3	4000.0	700.0	543.33^{b}
	Org. Low	595.7	1862.2	889.9	336.7^{b}	846.7	700.0	4466.7	863.3	623.3^{b}
	Org. High	732.5	2319.4	1116.1	596.6^{b}	1120.0	606.7	4866.7	660.0	1333.3^{a}
	Conv. control	570.6	569.0	511.4	720.0^{b}	603.3	676.7	4000.0	1050.0	716.7^{b}
	Conv. Low	2085.8	503.9	358.3	1430.0^{b}	846.7	816.7	4133.3	816.7	766.7^{b}
	Conv. High	2169.2	518.9	475.2	3566.7^{a}	1120.0	700.0	4433.3	1033.3	833.3^{b}
	p-value	**0.0500**	**0.0499**	**0.2890**	**0.0022**	**0.1570**	**0.7135**	**0.3557**	**0.4491**	**0.0124**

Table 1-19: Statistical analysis for petiole sap (mg. kg^{-1}) and the resulting p-value for tomato crop grown under high tunnel plots. Management (organic or conventional), fertility control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and the interaction between management and fertility for 2008, 2009 and 2010 at, flowering and fruit set and fruit development stages

		High tunnel								
		2008			2009			2010		
		flowering	fruit set	fruit dev.	flowering	fruit set	fruit dev.	flowering	fruit set	fruit dev.
management	**Organic**	3609.8	3125.5	374.7	3422.2	1677.8^{b}	911.1	4522.2	1700.0^{b}	1088.9
	Conventional	3498.6	2825.5	450.0	2911.1	2700^{a}	7072.2	4555.6	2533.3^{a}	1100.0
	p-value	**0.8007**	**0.5261**	**0.5241**	**0.1792**	**0.0037**	**0.0986**	**0.9002**	**0.0004**	**0.8784**
fertility	**Control**	3437.4	3220.5	441.2	3166.7	1650.0^{b}	991.7	4283.3	1733.3^{b}	650.0^{c}
	Low	3554.2	3120.3	360.3	3400.0	2183.3^{ab}	991.6	4566.7	2066.7^{ab}	1050.0^{b}
	High	3670.9	2561.3	435.5	2933.3	2733.3^{a}	991.7	4766.7	2550.0^{a}	1583.3^{a}
	p-value	**0.5749**	**0.4365**	**0.4720**	**0.4031**	**0.0288**	**0.9547**	**0.3462**	**0.0079**	**0.0001**
management* fertility	**Org. Control**	3704.4	2703.2	437.4	3833.3	1266.7	1166.6^{a}	4300.0	1466.7	733.3
	Org. Low	3437.4	3620.9	298.3	3300.0	1866.7	783.3^{b}	4533.3	1733.3	1033.3
	Org. High	3704.4	3003.5	388.4	3133.3	1900.0	183.3^{b}	4733.3	1900.0	1500.0
	Conv. control	3170.4	3737.7	444.9	2500.0	2033.3	816.7^{b}	4266.7	2000.0	566.7
	Conv. Low	3671.0	2619.7	422.4	3500.0	2500.0	1200.0^{a}	4800.0	3200.0	1066.7
	Conv. High	3654.3	2119.2	482.7	2733.3	3566.7	1200.0^{a}	4600.0	2400.0	1666.7
	p-value	**0.2509**	**0.1472**	**0.7013**	**0.1234**	**0.3077**	**0.0004**	**0.9838**	**0.1995**	**0.2039**

Table 1-20: Published petiole sap NO_3-N (ppm) sufficiency ranges for tomato at selected growth stages*

Crop	Growth Stages	Fresh Sap
Tomato	vegetative	1000-1500
	flowering	600-800
	fruit set	400-600
	fruit development	200-400

*(Hotchmuth, 1994)

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Chapter 2 - Comparing organic and conventional fertilizers on yield and soil nutrient status of pac choi grown in field and under high tunnel systems

Introduction

Chinese cabbage (*Brassica rapa*) is a member of the Cruciferae family whose progenitor species is Brassica campestris. Not native to North America, it is believed to have evolved in the Mediterranean area and probably developed from selections of oil seed (Yang et al., 2001). It was introduced to China more than 2000 years ago but was not introduced to the United States until the late nineteenth century. Currently, it is grown throughout the year in California, Florida, and Hawaii, and in the spring and fall seasons in most other states. There are two main types of Chinese cabbage: the heading type (*Brassica rapa* L. subsp. pekinensis) and the non-heading type (*Brassica rapa* L. subsp. chinensis). Pac choi is the non-heading type and is characterized by dark green leaves and light petioles. The cabbages form loose upright heads with dark green leaves and thick, crisp, white or pale green ribs. It's a cool season crop that prefers moist, well drained, fertile soil high in organic matter, and uniform conditions in partial shade or sunlight. The ideal temperature during growth is 15-20°C, and while best grown in spring and autumn, it can be grown all year round. Most varieties are day-length sensitive, which means they will flower (bolt) as days lengthen. Thus, susceptibility to bolting after transplanting is determined by photoperiod and temperature during the growing season (Tindall, 1983). Kalisz and Cebula, (2006) noted that Chinese cabbage seedlings should be acclimated before they are transplanted so the plants can more successfully withstand adverse weather conditions of the spring season.

Therefore, short-term exposure of plants to lower temperatures prior to transplanting is one of the hardening techniques used.

Of the varieties available, ‘Mei Qing’ is bolt resistant and tolerant of a wide range of temperature characteristics. Pac choi should also be grown with protection from the wind, as the young plants can bruise easily. Also, the ideal soil pH is 6.0-7.5, as pac choi is sensitive to acid conditions. Finally, growers plant pac choi in high tunnels in the early spring and early fall

High tunnels can be used for winter production of a wide variety of leafy greens and herbs. “Leafy greens” is a broad term that includes vegetables such as lettuce, spinach, and leaf crops in the Brassica family, so pac choi is a good choice for this sort of production system. Such crops can be established by direct seeding although transplanting is the most common method. It takes anywhere from 30 days to 50 days until harvest, depending on the cultivar. High tunnel production of leafy greens can also enable producers to market products at higher prices before the start of a traditional local season that is field based. Consumption of pac choi is increasing in the United States as USDA statistics of vegetables and melons in 2014 indicated that domestic rail, trucks and air shipment of Chinese cabbage and pac choi was 65 tons compared to 30 tons in 2002 (U.S. Department of Agriculture, Agriculture Marketing Services, 2013).

Many researchers have shown that growing leafy greens under high tunnels could improve the yield and reduce disease damage. For example, one study compared high tunnel and field organic production systems for season extension and adverse climate protection for lettuce yield and quality in three different climates: hot and humid, hot and dry, and cool and humid. Wallace et al., (2012) found that high tunnel production systems offer greater control of environments suitable for lettuce production, especially in climates that are hot and humid and hot and dry, where later planted field systems may be more susceptible to temperature swings that affect lettuce quality.

Zhao and Carey (2009a) investigated the microclimate and production of eight leaf lettuce cultivars in high tunnels and field using unshaded and shaded tunnels. They found that lettuce grown in high tunnels covered by shade cloth had a lower bolting rate but decreased yield relative to field yield.

Mid-summer pac choi production would not be recommended for high tunnels or open fields based on the results of (Powell et al., 2013), who studied the yield and disease incidence in lettuce in field and high tunnel organic production for three years. Total yield was greater in high tunnels in the first two years but not in the third one. Romaine types had significantly greater incidence of gray mold and lettuce drop in high tunnel than in open field, while the leafy type had reduced incidence of gray mold and lettuce drop in high tunnel than in the open field.

Clearly, environment affects the release of nutrients from the soil and the availability of nitrate. In particular, cool soil limits the rate of nitrification via microbial transformation (Jarvis, 1996) while warm soil from spring to summer changes the response of leafy greens to ammonium as compared to their response to nitrate fertilizer (Maynard and Barker, 1979). Consequently, over-wintered spinach fertilized with ammonium had less N in leaves than spinach harvested in late spring or fall (Peavy and Greig, 1972). Air temperature and light also affect N uptake by leafy greens. Field grown lettuce did not accumulate N when air temperature was less than 13^{o}C, regardless of the form of N fertilizer (Gardner and Pew, 1974). Meanwhile, under controlled conditions, low temperature or high light lowered the concentration of nitrate in spinach leaves and increased the response to N application rate (Cantliffe, 1972a; Cantliffe et al., 1997). Furthermore, the effect of temperature on the uptake of nitrate and ammonium forms of nitrogen in lettuce was examined by (Macduff et al., 1987) at soil temperatures of 8, 13, and 23^{o}C, and they found that nitrogen absorption rates increased linearly as root, air and soil temperatures increased. Nitrate uptake was generally favored over ammonium uptake; but at higher temperatures, ammonium uptake was greater than nitrate uptake.

Pew et al., (1983) compared the effectiveness of ammonium sulfate, ammonium nitrate, calcium nitrate, and urea fertilizers on lettuce under winter conditions and found no differences in yield, quality, head size, and total N accumulation amongst the N sources. Air temperature, however, played an important role. When temperatures dropped below 55^{o}F (13^{o}C) for over 7 days, N uptake decreased dramatically for all forms of N fertilizer. Likely, this is because nitrification is fastest when soil temperatures drop below 50^{o}F (10^{o}C). Warm soil temperatures also maximize N mineralization rates. Thus, N requirements for cool-season crops are typically higher than for swarm-season crops.

Pac choi is a cool-season crop and, with other cool-season crops such as broccoli, lettuce, and cabbage, is considered to be a heavy user of nitrogen (Thompson, 2008). Thus, nitrogen fertilizer recommendations for cool season vegetables range from 156 to 312 kg N/ ha) (Guillard, 2004). For pac choi specifically, the recommendation is 33.6 to 56 kg N /ha pre-planting and 112 to 168 kg N / ha during the growing season (Hartz, 2007). In part, these recommendations are because all the major cool season vegetables are shallowly rooted with most roots in the top 5-10 cm of the soil. Although some N uptake occurs below that level, growers' management practices should target adequate N in the top foot and minimizing the movement of NO_3-N out of that zone.

Hartz (2006) reported that 125-143 kg N /ha of nitrogen gave the same yield in lettuce as did 215 kg N/ ha, which was the grower's typical practice. He also reported similar results with broccoli applying a total of 180 kg N/ ha in comparison with 280 kg N /ha, which represented the grower’s practice. Additionally, an experiment at the University of California by (Letey et al., 1983) tested four nitrogen fertilizer rates and two application methods on broccoli. The N fertilizer treatments consisted of 80, 145, 170, and 270 kg /ha). One third of the fertilizer was applied pre-plant, and the rest was either injected into the irrigation water or side-dressed in two applications. Letey et al., concluded that a consistent increase in shoot growth and head weight was observed as the N fertilizer application increased from 80 to 270 kg /ha.

Nitrogen fertilizer amount and timing clearly are crucial for the growth of pac choi warranting application rates determined by a soil test so as to limit N losses, especially from leaching. The timing of the N application should be determined by the growth stage of the plant. Later in the season, following pre-plant soil testing, sampling of plant tissue can help determine if fertilizer is needed and how much. To do this, petioles are usually taken from the youngest fully expanded leaf at specific growth stages (Hartz and Hochmuth, 1996). The leaf blade is removed, and the petiole is analyzed for nitrate. Petioles are targeted because they have higher nutrient contents than the blades where nitrogen is rapidly converted to proteins or other metabolites.

Hill (1991) reported increased fresh market head weight of pac choi by increasing N up to 178.5 lb/ac (200 Kg/ha). Meanwhile, increasing N from 0-60 lb/ac (0- 68 kg/ha) increased Chinese cabbage dry matter, while 50 lb N/ac (56 kg N/ha) produced 95% of the dry matter achievable with 200 lb N/ac (224 kg N/ha) (Guillard and Allinson, 1988).

Organic fertilizer has demonstrably beneficial effects on organic matter, which affects physical, chemical, and biological properties of soil (Rosen, 2007). Maintaining or increasing soil organic matter levels can improve aggregation of soil particles, which in turn results in better drainage, infiltration, and tilth. Also, organic matter acts as a slow release form of crop nutrients. The amount of organic matter is affected by tillage practices, crop rotation, amount of green manure, manure or compost, and inputs of organic residue. Liu et al., (2003) studied the effect of organic and inorganic nutrient solution on the growth and quality of pac choi, and their results showed that the yield for the winter experiment was 25.5% higher using organic fertilizer than with the inorganic fertilizer, but no yield differences were found in the spring season experiment. In a study to evaluate the value of fertilizer type on growth and composition of salad greens, fertilizers had little effect on growth rate, but specific leaf area was greater for plants with organic fertilizer. For lettuce, leaf concentration of N, P, K and Ca were raised by 10 to 20% with organic as opposed to nitrate-based fertilizer. However, for other salad greens, organic fertilizer lowered Ca in spinach and K in kale (Gent, 2002). In a study conducted by (Evanylo et al., 2008) to evaluate the effect of compost application in an organic vegetable cropping system, soil organic carbon, total nitrogen and available phosphorous increased 60%, 68%, and 225% respectively, with a high rate of compost application compared to control and low rate compost application.

A number of recent studies have compared the effects of conventional and organic production systems on health aspects and nutritional quality of pac choi (Talavera-Bianchi, 2010; Zhao et al., 2009b). For instance, a study to evaluate the influences of protected environment and organic fertilization on the antioxidant capacity and phenolic acids of leafy greens showed that pac choi in high tunnels had significantly lower oxygen radical absorbance capacity relative to field grown plants. While organic fertilizer increased the antioxidant capacity (Zhao et al., 2007) and phenolic acids (Zhao et al., 2009b) of pac choi compared with results for conventional treatment, both field and organic production significantly lowered the yield of pac choi.

However, adding compost to leafy vegetable production can improve the quality by increasing sugars and organic acids as well as improving the fertility and growth of plants in leafy greens (Tavarini et al., 2011).

Since pac choi prefers high fertility soil for maximum yield, nitrogen application by farmers often exceeds crop needs. This excess nitrogen is prone to leaching, thereby increasing the risk for groundwater contamination and adding extra cost on the farmer. Clearly, understanding nitrogen behavior in the soil is essential for maximizing nitrogen fertilizer use efficiency and, ultimately, yield and profitability and to minimize the risk of environmental damage.

As documented in the introduction, literature on the effect of nitrogen sources and rates for pac choi is minimal. Therefore a primary goal of this study is to evaluate the effect of types of nitrogen fertilizers and their rates on soil and tissue nutrient levels of pac choi in different management systems. Specifically, the objectives of this study were as follows: 1) Study the response of pac choi yield to organic compared to inorganic fertilizer under two different environmental conditions (high tunnels and field), 2) Determine pac choi yield under different nitrogen rates, and 3) Compare the effects of management practice (organic and inorganic fertilizer) on soil chemical properties and nutrient content of pac choi.

Materials and Methods

Trials were conducted on experimental plots to compare crops grown under organic and conventional production systems in high tunnels and field plots. The soil was a Kennebec silt loam that filled six 9.8 m x 6.1 m high tunnels with 1.5m sidewalls (Stuppy, North Kansas City, MO) and six adjacent 9.8 m x 6.1 m field plots. High tunnels were covered with single layer 6-mil (0.153mm) K-50 polyethylene (Klerk's Plastic Product Manufacturing, Inc., Richburg, SC).

Each system contained six plots that had been established in 2002 and arranged in a randomized complete block design with three replications. The treatment factor at establishment was fertilizer source with one plot per replication being managed with organic amendments and the other with conventional amendments. Organic plots were managed in compliance with USDA National Organic Program standards and were inspected and certified in 2003, 2006, 2007, 2008, and 2009.

For this study, which began in 2007, each high tunnel or field plot was subdivided into three 3.2x 6.1 m plots to which one of three fertilizer levels were assigned (control, low, and high) following a Latin square design to account for the gradient effect of light in the high-tunnels (Figure 2-1). Fertilizers rates were determined based on soil analysis at the beginning of the study in 2007 as were recommendations for vegetable crops in Kansas (Marr et al., 1998) with compost applied to organic plots and synthetic fertilizer applied to conventional plots. Compost application rates were based on the assumption that 50% of the nitrogen from compost would be available to plants during the growing season, while 100% would be available from conventional fertilizers (Warman and Havard, 1997). Low and high fertility treatments were given equal amounts of compost or synthetic fertilizer at the beginning of the growing season, and high fertility treatments received additional fertilization during the growing season.

Two crops were grown in these plots: pac choi and tomato. The crops were grown in one half of each field or in high tunnel plots with a rotation between pac choi and tomato each year to meet organic certification criteria (Figure 2-2). In our experimental system, a spring and a fall crop of pac choi was grown each year (2008 and 2009), while a single crop of tomato was grown in the summer. Between the spring and fall pac choi crops, plots were seeded with a summer cover crop of buckwheat (Fagopyrum sagittatum) (Albert Lea Seed, Albert Lea, MN, U.S.A.) at a rate of 134 kg/hectare (120 lb/acre). In the late fall (Oct 29, 2008 and Oct 28, 2009), all plots were seeded with a cover crop of winter rye (Secale cereale) (Albert Lea Seed, Albert Lea, MN, U.S.A.) at a rate of 229 kg /hectare.

Control plots received no supplemental fertilizer while low treatments received pre-plant fertilizer amendment one time per year in the spring. Jack's Peat-Lite 20N:4.4P:16.6K J. R. Peters, Inc., (Allentown, MO) at a rate of 98 kg N /hectare was applied to conventional plots, and a poultry-source compost (Microleverage 0.6N: 0.4P: 4.4K, Hughesville, MO.) at a rate of 197 kg N /hectare was applied to organic plots. Starting at planting, high fertility treatments plots received additional soluble fertilizer at a rate of 7.24 kg N /ha three times during each pac choi growing season and six times during tomato growing season. Organic plots received fish hydrolyzate 2.23N- 4.35P_2O_5- 0.3K_2O (Neptune's Harvest, Gloucester, MA.), and the conventional plots received 11.2Kg/ hectare KNO_3 and 11.2 kg/ hectare $Ca(NO_3)_2$. This rate was calculated to apply calcium equivalent to that in the fish hydrolyzate (Figure 2-3).

Pac choi seeds were started in a greenhouse in 13x 26 in flats using organic commercial media (Sunshine Mix Special blend E6340; SunGro Horticulture, Bellevue, WA) supplemented with MicroLeverage compost. All seedlings were supplemented with fish hydrolyzate 2.23N- 4.35P2O5- 0.3K2O (Neptune's Harvest, Gloucester, MA.) at a rate of 60 ml/4L three times until transplanted. Dates for seeds sowed, seedling fertilized, compost added, seedling transplanted, soluble fertilizer added, and harvesting time are presented in (Table 2-1). Pac choi seedlings were transplanted to high tunnel or field plots (3x3.2 m) on plots with drip irrigation and plastic mulch. Each fertility treatment had three rows with 20 plants/ row. The outer row was a border row allowed us to avoid inter-plot interference. Plant samples were chosen prior to final harvest using a random number generator (Figure 2-4).

Tissue sampling protocol and analysis

Leaf samples were taken once the plants were two weeks old. In spring 2008, pac choi, samples were taken on April 14 and 28, which was 14 and 27 days after planting, respectively. In fall 2008, pac choi samples were taken on September 20 and Oct 6, which was 15 and 31 days after planting. In spring 2009, pac choi samples were taken on April 21 and May 5, which was 11 and 25 days after planting. In fall 2009, pac choi samples were taken on Sept 19 and 30, which was 11 and 22 days after planting (Table 2-2). Three plants from each plot from each fertility level were collected. The youngest fully expanded leaf was collected from each sampled plant, and the blades were separated from the petioles. Petioles were chopped and pressed with a garlic press to extract fresh tissue sap, which was analyzed immediately to determine $NO_{3-}N$ with a handheld ion-specific electrode (Cardy nitrate $NO3^-$ meter, Horiba, Ltd., Kyoto, Japan) (Hochmuth, 1994b; Hochmuth, 1994c). The meter was calibrated before analysis and after every 10 measurements with a standard of 2,000 mg L^{-1} NO_3, and slope was adjusted with a 150 mg L^{-1} NO_3 solution. A few drops of the petiole sap were placed on a sampling sheet, and the reading was recorded after the value had stabilized. Meter readings were in units of mg.L^{-1} NO_3 (Hartz et al., 2007; Schulbach et al., 2007).

Soil sampling protocol and analysis

Soil tests were performed by Kansas State University (KSU) soil and nutritional analyses service lab in KSU Department of Agronomy. Initial soil samples were taken annually for baseline analysis prior to treatments and before the planting of pac choi. In addition, soil samples were taken twice during each pac choi growing season to assess relative differences in soil nutrient content due to the treatments (Table 2-3). Six cores from each plot were taken with a soil probe at two soil measurement depths (0-15) and (15-30) cm for annual analysis and at one depth

(0-15) cm during the growing season. The six cores of soil were mixed together, and a composite sample was placed in a sterile polypropylene bag, transported to the laboratory, and stored at 4°C. Soil samples were passed through a sieve of 2-mm screen diameter and oven dried at 60°C for 48 hours. After drying, soil samples were ground to fine powder, analyzed for (pH), measured with a 1:1 slurry method (Skalar SP50 Robotic Analyzer. Skalar Inc. Buford, GA 30518), subjected to a Bray-1 Phosphorus (P) test using a HCL- ammonium fluoride extraction (Lachat Quickchem 8000), tested for Potassium (K) using an Inductively Coupled Plasma (ICP) Spectrometer, (Model 3110 Flame Atomic Absorption, Spectrometer from Perkin Elmer Corp., Norwalk, CT), analyzed for organic matter (O.M) using the Wakleley-Black method (Model PC 910 Fiber Optic Spectrophotometer from Brinkmann Instruments, Inc., Westbury, NY.), and analyzed for ammonium (NH4-N) and nitrate (NO_3-N) on a (Rapid Flow Analyzer, Model RFA-300, from Alpkem Corporation, Clackamas, OR 97015) (Dahnike, 1975).

Pac choi harvest

All plots were harvested at (a five foot section) in one picking at the same day (one day for each environment system-high tunnel or field). The number of plants in each plot was counted before they were boxed and transported to lab space in an air conditioned building where they were weighed.

Statistical analysis

Data from the two environments (field and high tunnel) were analyzed similarly but independently. The data was analyzed for baseline levels using a non-repeated measures (one-time analysis) ANOVA (Proc GLIMMEX, SAS 9.3; SAS Institute, Cary, NC). The data for each growing season was analyzed as repeated measures in a split plot factorial ANOVA (Proc GLIMMIX, SAS 9.4; SAS Institute, Cary, NC). Means for significant effects and their interactions were compared using Tukey’s honestly significant different test when P< 0.05 (Proc LSMEANS, SAS, 9.3; SAS Institute).

Results

Crop yield

While high tunnel and field plots were planted and harvested simultaneously, the high tunnel plots received more heat units during the approximately five weeks of growth. Other stresses on the field plots such as direct sun, more wind, and rain could also explain the yield difference. However, due to the experimental plot layout, statistical comparisons could not be made. Statistical analysis for yield data is presented is in (Table 2-4) for both field and high tunnel plots in 2008 and 2009 growing seasons.

MGT didn’t have a significant effect on pac choi yield in the high tunnel plots in any growing season, while in the field, MGT had significant effect on pac choi yield in fall 2008 where organic MGT offered significantly higher yield than did conventional and in spring 2009 where conventional MGT offered significantly higher yield than did organic.

Fertility (FRT) had a significant effect on pac choi yield for all four seasons in field plots (Figure 2-5). Moreover, significant interaction between MGT and FRT in field plots was observed in spring seasons of 2008 and 2009 ($P= 0.0004, 0.0029$) respectively, where the low fertility rate for conventional was significantly higher than for organic management and the high fertility rate for conventional was significantly higher than for organic management system (Figure 2-6).

Although no significant differences occurred between organic low fertility treatment (compost application) and control (cover crop) treatments, conventional plots with low fertility treatments showed no significant yield differences than high fertility. This might be due to the slow rate of N mineralization from compost during spring time as this process varied with weather such as rainfall and temperature (Palm, 2001; Vanlauwe, 2005).

For high tunnel plots FRT showed significant differences in all seasons except fall of 2008 (Figure 2-7). Organic and conventional systems showed similar trend in spring where low fertility treatments (pre-plant application of compost or synthetic fertilizer) had significantly higher yield than did control, and no significant differences occurred between low and high treatments. In fall growing seasons, no significant differences registered between high and low fertility treatment or between low fertility treatment and control.

Annual soil analysis

Soil pH was in the normal range both in field and in high tunnel. Clearly, MGT had a significant effect on pH in 2009 both in field plots *($P< .0001$)* where pH for organic was higher than for the conventional system (Figure 2-8) However, FRT had a significant effect on pH in 2009 high tunnel (Figure 2-9). Additionally, interaction between MGT and FRT was significant for high tunnel plots in 2009 *($P= 0.0398$)* where organic control had a significantly higher pH than conventional control.

Meanwhile, FRT effect on soil P levels was significant in 2009 field plots ($P=0.03$) where low treatment was significantly higher than control (Figure 2-10). Although organic MGT showed higher levels of soil P than did conventional both in field and high tunnel plots, MGT effect was only significant in high tunnel plots in 2008 ($P=0.0019$) and 2009 ($P=0.0005$) (Figure 2-11).

Next, MGT showed a significant effect on K levels in 2008 and 2009 field plots ($P=0.0169$, $P=0.0056$) respectively (Figure 2-12) and in 2008 high tunnel plots ($P=0.0048$) (Figure 2-13) where organic had higher K levels than the conventional MGT system. However, no significant FRT or interaction effects were found in 2008 or 2009 in either field or high tunnel K soil levels.

Next, organic matter concentration was significantly different between organic and conventional MGT systems in 2008 and 2009 in both field (Figure 2-14) and high tunnel (Figure 2-15) plots, respectively, where organic had higher OM concentration than did conventional MGT systems Also, a significant FRT effect on OM percent was noted in field plots in 2009 ($P=0.01$) where low fertility treatments had a significant higher OM (3.0%) than control (2.72%).

Finally, annual soil analysis for NH_4-N in field and high tunnel plots, indicated no significant effect of MGT or FRT in 2008 and 2009 (Table 2-5). FRT effect was significant for NO_3-N levels in field plots only in both 2008 and 2009 (Figure 2-16). However, high tunnel NO_3-N levels didn’t registered a significant effect of MGT or FRT for either 2008 or 2009 (Table 2-6).

Analysis of soil and tissue nitrogen levels during the growing seasons:

Statistical analysis for NH_4-N concentration mean values are presented in (Table 2-7) for 2008 and (Table 2-8) for 2009 growing seasons. MGT had a no significant effect on NH_4-N in 2008 except for mid-season analysis in the spring, while FRT had a significant effect on NH_4-N at midseason and pre-harvest analysis for both spring and fall of 2008 in both field (Figure 2-17) and high tunnel (Figure 2-18). Meanwhile MGT had a significant effect on NH_4-N at mid-season analysis for both spring and fall 2009 in both field and high tunnel (Figure 2-19) plots. Significant interaction between MGT and FRT was registered for spring 2008 at the field plots and fall 2009 at the high tunnel plots.

NO_3-N concentration levels for field plots during the growing seasons are presented in (Table 2-9). MGT was significant for mid-season analysis of NO_3-N in both spring and fall in 2008 and 2009 but not for pre-harvest analysis in any growing season. FRT was also significant for mid-season analysis of NO_3-N in both spring and fall seasons of 2008 and 2009 and for pre-harvest analysis in fall 2008. Next, NO_3-N concentration levels for high tunnel during the growing seasons are presented in (Table 2-10). MGT had significant effect on NO_3-N for mid-season analyses during fall 2008 and for pre-harvest analysis in spring 2008, 2009, and fall 2009, while FRT effect was significant for mid-season analysis in spring 2008 and fall 2008 and 2009. However, FRT effect for pre-harvest analysis was only significant in spring 2008 and fall 2009.

Petiole sap concentration levels for field plots during the growing seasons are presented in (Table 2-10). MGT had no significant effect on petiole sap nitrate in any growing season whereas FRT had a significant effect on petiole sap nitrate mid-season analysis in spring 2008 and fall 2008 and 2009. Meanwhile, pre-harvest analysis of petiole sap nitrate was significant in fall 2008 and spring 2009, Significant interaction effect occurred on petiole sap nitrate in fall 2009. (Table 2-17)

Finally, petiole sap nitrate analyses for high tunnel during the growing seasons are presented in (Table 2-11)). FRT effect was significant in both mid-season and pre-harvest analyses in fall 2008, and spring 2009 while MGT had no significant effect on petiole sap nitrate in any growing season.

Discussion and Conclusion

The impact of high tunnel versus field production on the yield of many economically important vegetable crops has been well studied. While some investigations report increased vegetable yield in high tunnels (O'Connell et al., 2012; Waterer, 2003), others have reported similar or reduced levels of productivity (Rogers and Wszelaki, 2012). Statistical analysis of both environments (high tunnel and field) was performed separately in this study due to the limitation of the experimental design and layout, observation for high tunnel production was higher than field. These results agree with those of other studies where the highest marketable yield of lettuce was obtained from the high tunnel, and it exceeded that from field by 110% (Libik and Siwek, 1993).

Additionally, yield was significantly different between high and low FRT treatments in the field organic MGT system and significantly different between low fertility rate and control in the conventional field. Meanwhile, in high tunnel plots, FRT treatment differences were significant between low (pre-application of compost or synthetic fertilizer) and control (cover crop) in the spring growing season, yet no differences between low and high fertility (liquid fertilizer) treatments occurred. This demonstrates that cover crop with pre-plant amendments can meet the crop fertility needs in high tunnels (organic and conventional management) and in conventional field plots. Likely, additional liquid fertilizer is needed in the organic field plots to obtain this maximum yield due to the slow mineralization of organic fertilizers (compost) during the spring seasons. Next, the only source of nitrogen in control plots is through the decomposition of cover crop residue during the growing season. While incorporating buckwheat into the control treatments does add to the soil organic N reserves by recycling nitrogen that was taken up, this does not always increase N availability and yield of succeeding crops (Kuo et al., 1996). In addition, incorporation of cover crops can also lead to net N immobilization, which could affect successive crop growth and yield negatively. Specifically, high C:N ratio and low N concentration in residues of crops such as buckwheat can cause net N immobilization in the soil (Quemada and Cabrera, 1995). Therefore, in this study, treatments without pre-plant applications could have been affected by decreased N availability during their initial growth stages due to N-immobilization or lower N mineralization, and since pac choi has a relatively short growth period (five weeks), fresh yield was significantly decreased.

Yield in organic did not differ from that in the conventional system for high tunnel plots in any growing season, confirming that the organic amendments (compost and fish hydrolysate) mineralize more quickly in warmer soil and can be used effectively to meet fertility needs. These results are in accordance with results of other studies that have reported similar yield from composted animal manure and inorganic fertilizer amendments in high tunnel plots (Reeve and Drost, 2012).

MGT effect was also significant on OM in 2008 and 2009, which supports direct impact of soil organic matter on soil productivity that has been observed in many studies (Bauer and Black, 1994; Larney et al., 2000). These studies suggest that increasing soil organic matter will increase the productivity of soil leading to greater yields due to increased cation exchange capacity, increased water retention, and increased microbial activity (Havlin et al., 1990).

Maynard et al., (2014) compared the yield of seven crops with a yearly application of composted animal manure to yield from plots fertilized with NPK fertilizer for three consecutive years. Yield of all vegetable crops increased as the rate of compost increased. In addition to yield, compost has other beneficial effects on soil property including water retention, cation exchange capacity, soil structure, and soil organic matter (Giusquiani et al., 1995; Ouédraogo et al., 2001; Rivero et al., 2004).

Specific to yield, Guertal, (2000) examined the effectiveness of pre-plant application of synthetic nitrogen fertilizer compared to split application of soluble fertilizer on green bell pepper where yield was maximized at 100% pre-plant application of nitrogen source. Similar results were found in a study conducted by (Bakker et al., 2009) where 187 kg N/ha applied as a pre-plant were assumed to optimize broccoli yield, and eliminating the starter application was assumed to significantly lower the yield. Additionally, in an experiment to study the effect of N fertilizer source on lettuce yield, (Premuzic et al., 2002) found no significant difference between organic and inorganic fertilizers with respect to yield, but both were significantly higher than control.

In a long term study, incorporating compost was better than applying inorganic fertilizer and dairy manure for building soil nutrient levels, providing residual nutrients, reducing nutrient losses to ground and surface waters, and promoting higher soil C and N content (Hepperly et al., 2009). In that field trial, conventional treatments had higher yield than organic in spring seasons. This might be because conventional treatments had pre-plant application of synthetic fertilizer that was readily available to the plants while mineralization rate of compost in the organic treatments could have been decreased by soil temperature and moisture content. Van Kessel and Reeve, (2002) reported that mineralization is slower in soils that are cold or dry.

In our study, soil chemical analysis levels were within acceptable ranges for both organic and conventional systems at different fertility rates (Marr et al., 1998). This is important because soil pH is a major driver of many chemical and biological properties in soil. Fluctuations in soil pH can alter the availability of macro and micro nutrients and can also affect the composition and function of soil microbial communities. Also, in the absence of rainfall leaching events in high tunnels, irrigation water potentially can raise soil pH in areas like the Midwest where groundwater can be alkaline. In our study, soil pH in high tunnel plots was not different from that in field plots, but FRT effect and interaction between MGT system and FRT were significant. Specifically, high tunnel pH in 2009 was lower with conventional treatment (synthetic fertilizer) than with organic treatment (compost). This is not surprising as reduced soil pH as a result of inorganic fertilization has long been understood (Fox and Hoffman, 1981).

Soil P was significantly impacted by the MGT system where the high tunnel organic system contained more available P than did the field organic system. Bray-1 P which represents P readily available to plants, was greater in low fertility treatments (compost and cover crop) and high fertility treatments than in control (cover crop), which indicates the potential of P accumulating with organic fertilizers in high tunnels. Our finding is consistent with those of other studies that have shown excessive P in soil receiving poultry litter amendments (Mikkelsen, 2000; Reeve and Drost, 2012). In the Mikkelsen, Reeve and Drost studies, the available soil P in cover crop treatments was significantly lower than of that of pre-plant amendments in 2009. Moreover, P mineralization can be problematic in high tunnel systems where soil moisture saturation is more limited than in field systems as a result of limited exposure to rainfall. Therefore, high tunnel growers should perform routine soil nutrient analyses to monitor P levels to meet crop nutrient needs and limit negative environmental impact associated with P accumulation. Growers also can incorporate buckwheat in their crop rotation as a P scavenger (Pritchett, 2011).

Although K levels were within acceptable ranges for all treatments in both systems, soil testing indicated that high tunnels previously fertilized and managed conventionally were lower in P than were organic treatments. This suggests that K levels in conventional high tunnel plots should be monitored.

Annual analysis of soil inorganic nitrogen indicated no differences between organic and conventional MGT except for NH_4-N in 2008, but the fertility effect was significant for several sampling dates in field plots but not for high tunnel plots. However, precipitation recorded for

April 2009 (80 mm) indicated a dryer month in this region than for April 2008 (130 mm) (Figure 2-20), which can have an adverse effect on N mineralization. Qi et al., (2011) evaluated moisture effect on soil C and N mineralization, and results indicated that C and N mineralization rate, potential mineralization, and potential rate of initial C mineralization all increased as the soil moisture rose, which can significantly influence plant growth. Other studies indicated that soil C and N mineralization was regulated by several environmental factors such as temperature, moisture, and oxygen content in the soil (Wang et al., 2006; Xu et al., 2007).

In our study, April 2008 had a recorded 30° F (-1°C) low temperature with only five days of temperatures ranging 30-35°F compared to a 25°F (-4°C) low in April 2009 with 10 days of temperatures ranging 25-25°F (Weather History, 2008). De Neve et al., (2003) studied the changes in the composition of the soil solution following mineralization of N at six different temperatures and found that N mineralization rate increased fourfold as the temperature increased to 30°C.

In general, NO_3-N concentration was highest at the earliest stage sampled and then declined with later crop samplings suggesting crop uptake was keeping up with the available N from mineralization or liquid fertilizer. Similar results were reported from field studies with spring wheat (Boatwright and Haas, 1961) and winter wheat (Fowler et al., 1990; Gregory et al., 1979) where the concentration of nutrients within the whole plant generally decreased throughout growth.

The increase in yield in field plots with high fertility treatments from liquid fertilizers in organic managed plots of the four growing seasons and conventional managed plots in fall 2009 could be explained by chemical properties of soil. For example, fish hydrolysate and NPK fertilizers contain high concentrations of available N, which can be taken up by plants directly and quickly. Since Pac choi has a high demand for N over a short period of time, growers must ensure adequate N supply during the crop growth stage. Fortunately, Blatt, (1991); Emino and Warman, (2004) confirmed the ability of fish fertilizer to produce larger plants despite lower NPK values due to its complex composition. Increases in yield could also be a result of N effect on photosynthesis, dry matter partitioning, and the amount of assimilates that are produced by the plant (Dordas and Sioulas, 2008). In another study, Sady et al., (1994) reported that by increasing the N level from 0 kg Nha^{-1}, lettuce yield increased, but no significant differences were observed between 100, 150 and 200 kg Nha^{-1}. Apparently, the form of organic N fertilizers incorporated in the soil and the amount of inorganic N availability influences the N uptake in the plant. Next, a study conducted by Tosun and Ustun (2004) found that N type significantly influenced lettuce plant diameter and the number of total marketable leaves. The fish treatment, which contains higher inorganic N than other organic fertilizer, recorded significantly higher yield than the compost treatment alone, and this was comparable to performance with conventional NPK fertilizer.

Regarding petiole sap nitrate concentration, this decreases as the crop matures according to several studies evaluating, many crops (MacKerron et al., 1995; Parks et al., 2012).The decrease is usually slower for plants given higher rates of nitrogen fertilizer (Gardner, 1989) or when a previous crop supplies significant amounts of nitrogen (Porter and Sisson, 1991). Crop uptake and leaching might be the reason for this decrease (Stockdale et al., 1997). However, the nitrate concentration in petioles decreases during the season even when supplemental nitrogen fertilizer is given every seven to ten days (Davies et al., 1987; Huett, 1988; Huett and White, 1992). For example, Davies et al., (1987) found an increase in nitrate reductase activity during the first part of the growing season, up to 88 days after planting. The decrease in petiole nitrate is not always uniform in time, and nitrate concentration can be higher or lower from week to week (MacKerron et al., 1995). Also, the rate at which nitrate concentration decreases can vary from year to year (Wang and Li, 2004). The differences may be due to the changes in nitrogen supply resulting from root development, different rates of mineralization of soil nitrogen, variation in soil moisture (MacKerron et al., 1995), or other environmental conditions that influence nitrate uptake or assimilation (Breimer, 1982). Ultimately, decreasing nitrate concentration in petioles over time has been taken into account by some authors in developing guidelines for acceptable sap nitrate concentration (Altamimi, 2013; Gardner and Jones, 1975; Gardner and Pew, 1974; Kubota et al., 1996; Kubota et al., 1997). The critical concentrations given by (Altamimi, 2013) for pac choi are 800-1200 ppm (field crop), 800-1100 ppm (high tunnel crop), and 1500-2000 ppm (greenhouse crop) during mid-season, and 500-800 ppm (field crop), 500-700 ppm (high tunnel crop), and 800-1000 ppm (greenhouse crop) at pre-harvest (Table 2-13). Given these ranges, the petiole sap nitrate concentration was within range for all fertility treatments except control.

Petiole sap nitrate concentrations in high fertility treatments were significantly higher than low fertility treatments, which doesn’t agree with yield results for high tunnel plots as no significant differences occurred between high and low fertility treatments. This anomaly could be due to luxury uptake beyond the crop’s needs. Logically, if the plots were over fertilized, nitrate concentration in the petioles would be higher than necessary for maximum yield. This suggests that soil testing prior to planting is a key element for successful nutrient management, especially for N fertilizers that pose a risk for groundwater contamination. Clearly, available nutrients should be used before any fertilizer is applied, and pre-plant soil sampling can determine whether soil nitrate concentrations are sufficient for crop establishment.

The portable cardy meter proved useful to determine NO_3 levels in sap tissue. By knowing when and how much N fertilizer to apply, a farmer can avoid excessive nutrient application, thereby reducing the potential for environmental damage, as well as lowering production costs.

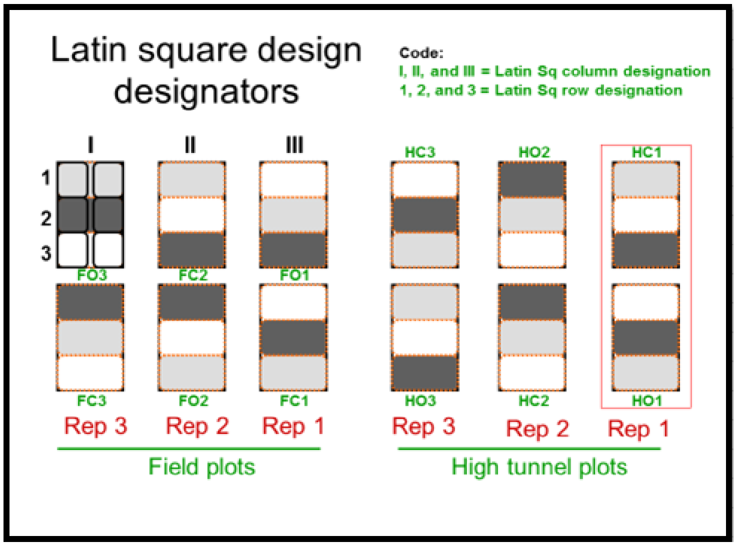


Figure 2-1: Latin square design for the high tunnel (HT) or field (F) plots in Olathe, KS with the organic (O) or conventional (C) management systems at the three fertility treatment levels control, low, and high

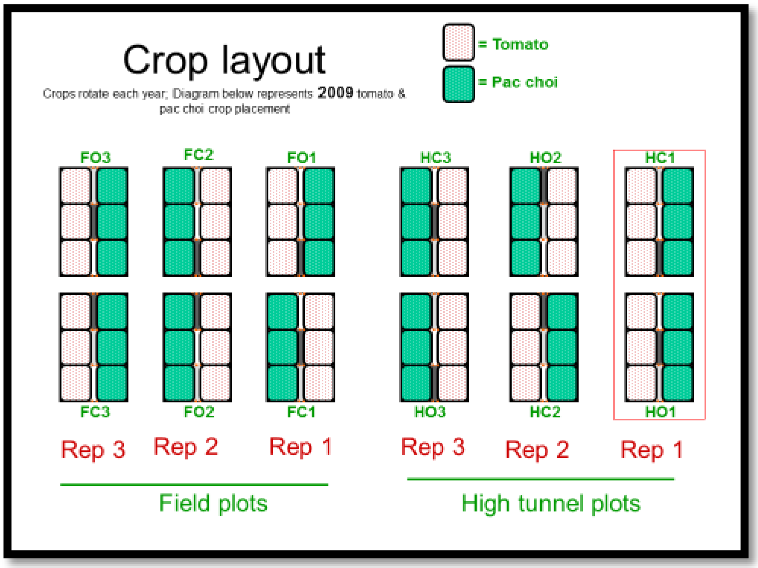


Figure 2-2: Crops (tomato and pac choi) rotate each year with cover crop in between seasons to meet organic certification

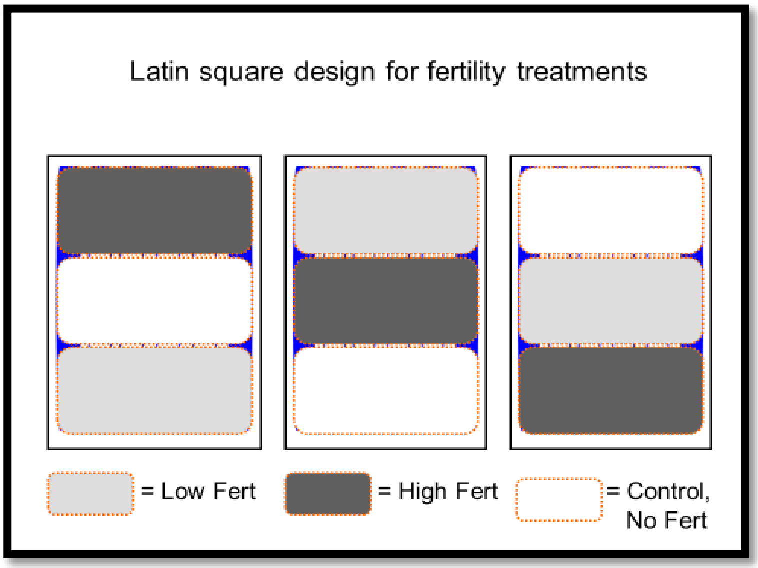


Figure 2-3: Fertility treatments. Control: cover crop, Low: cover crop plus pre-plant fertilizer amendment, High: cover crop plus pre-pant fertilizer amendment plus liquid fertilizer during the growing season

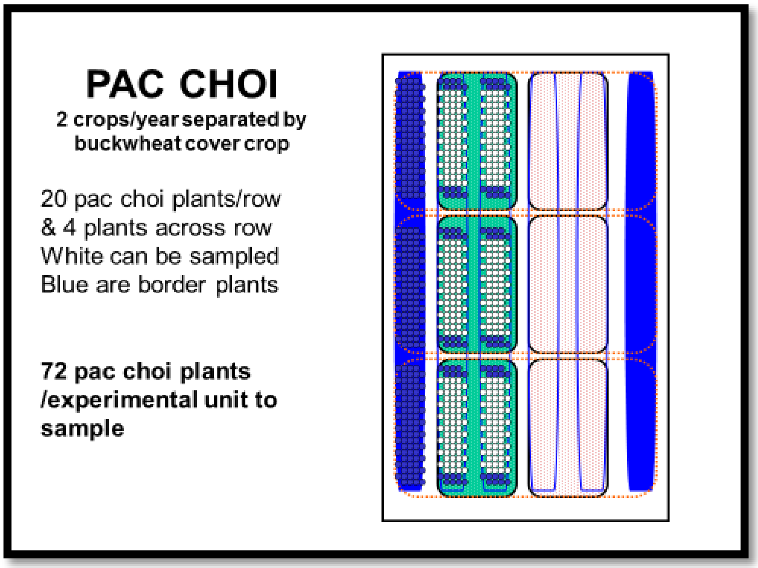


Figure 2-4: Pac choi layout in high tunnel or field plots. Sampling for data analysis is from the 72 pac choi plants in the two inner rows avoiding the border plants (buffer)

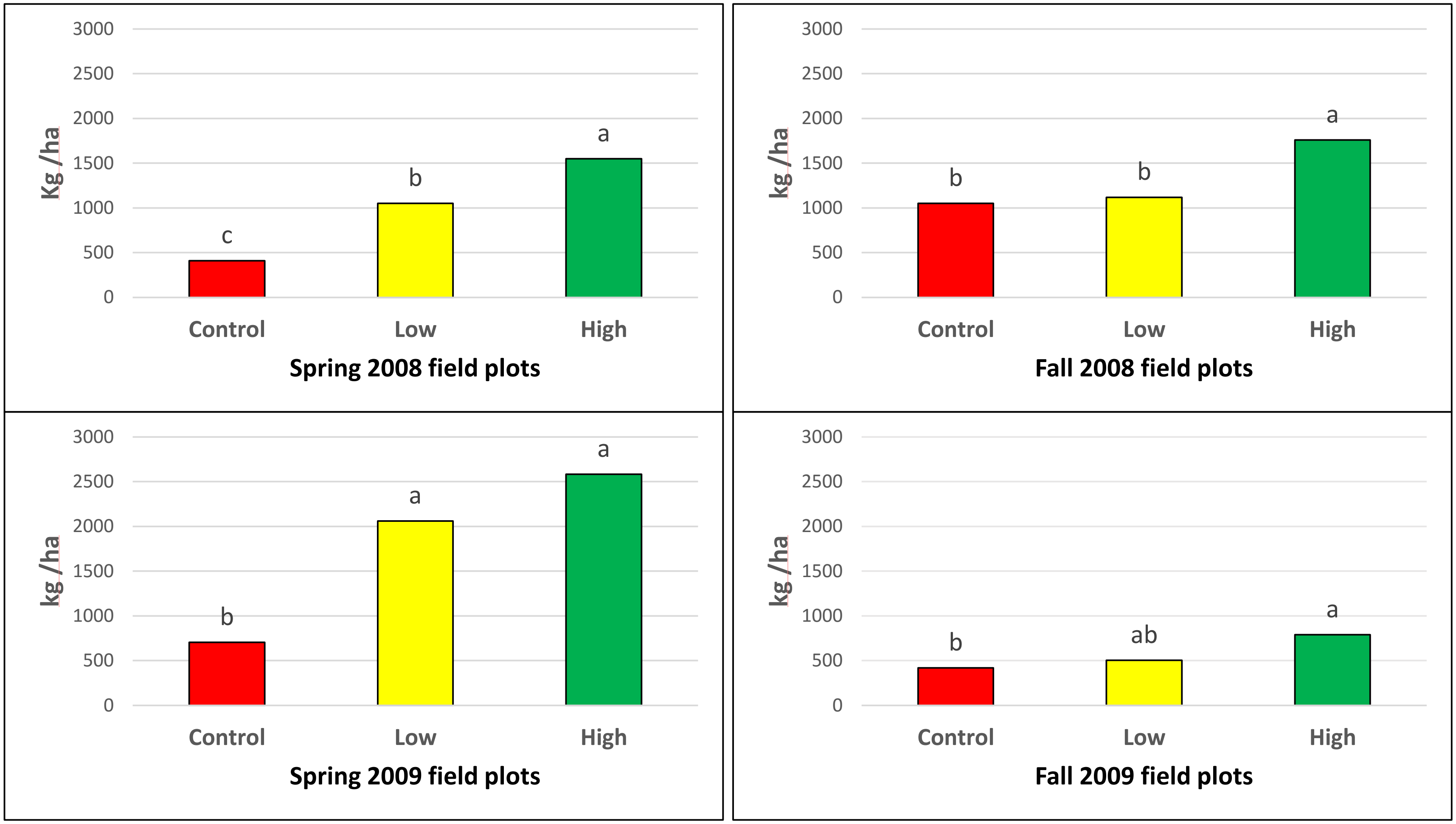


Figure 2-5: Pac choi yield data in kg. ha $^{-1}$ for field plots in spring and fall 2008 and 2009 at different fertility treatment levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

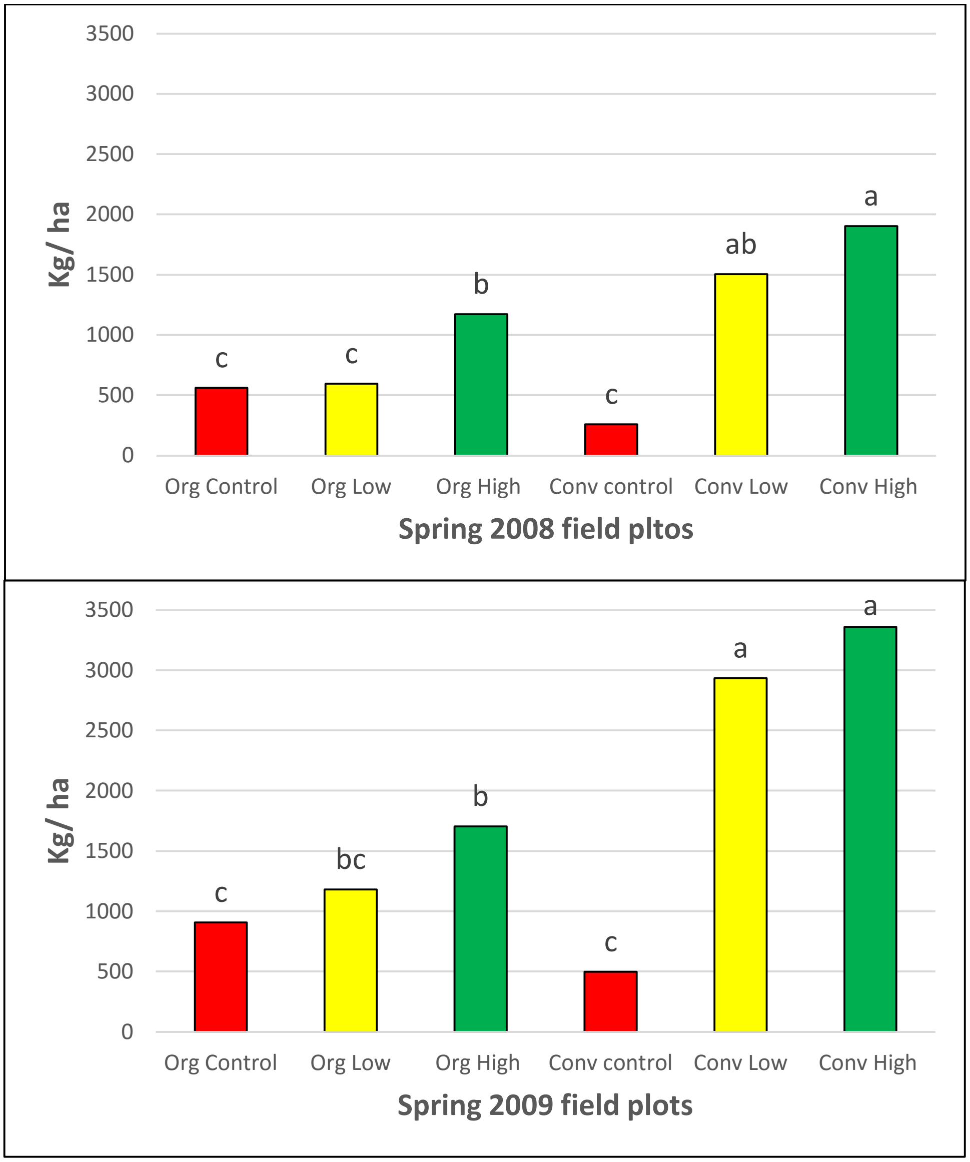
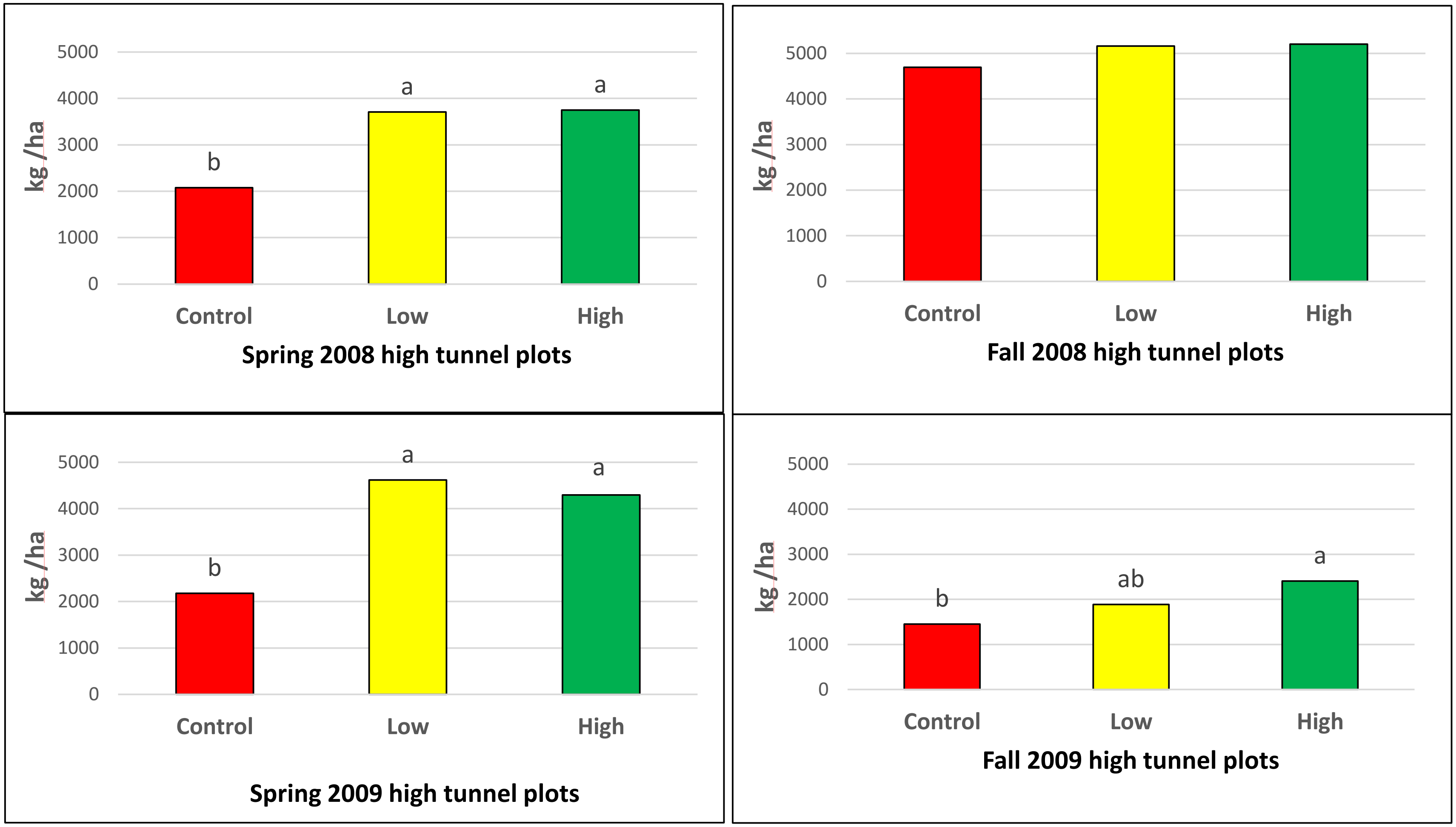


Figure 2-6: Pac choi yield data in kg. ha $^{-1}$ for field plots in spring 2008 and 2009 at different fertility treatment control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)



Spring 2008 high tunnel plots

Fall 2008 high tunnel plots

Spring 2009 high tunnel plots

Fall 2009 high tunnel plots

Figure 2-7: Pac choi yield data in kg. ha $^{-1}$ for high tunnel plots in spring and fall 2008 and 2009 at different fertility treatment levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

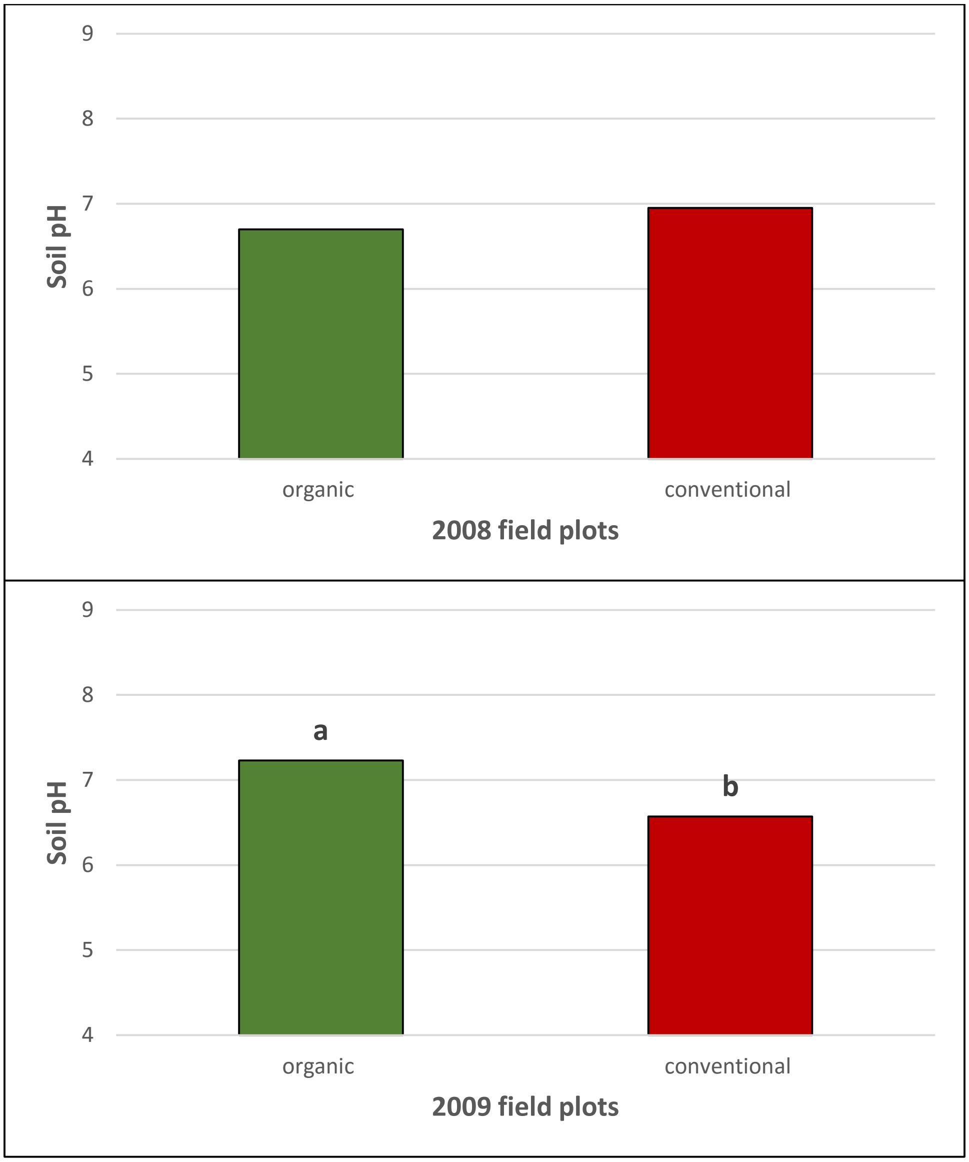


Figure 2-8: pH value for annual soil analysis (0-15) cm in 2008 and 2009 in field plots for pac choi grown with organic and conventional management systems "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

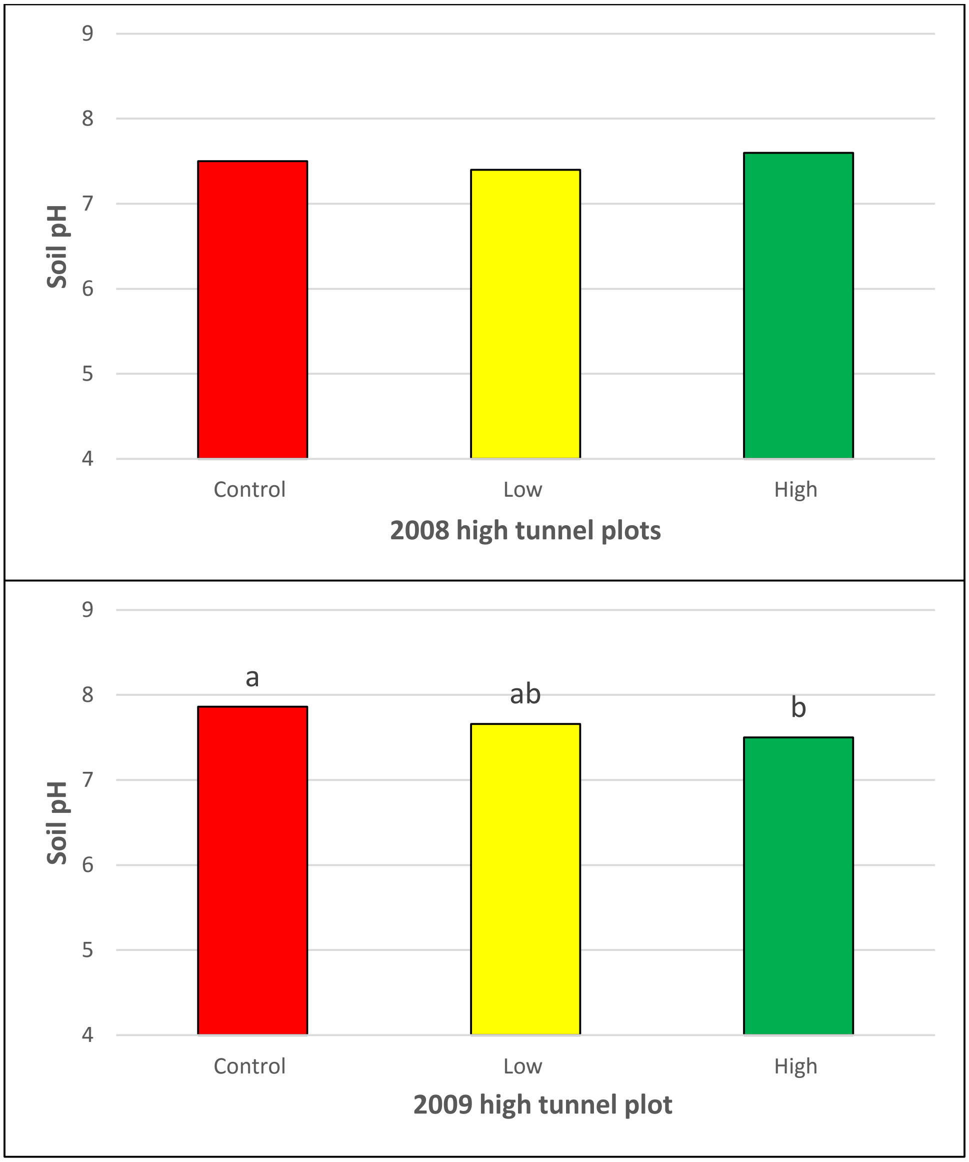


Figure 2-9: pH value for annual soil analysis (0-15) cm in 2008 and 2009 in high tunnel plots for pac choi crop at different fertility levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

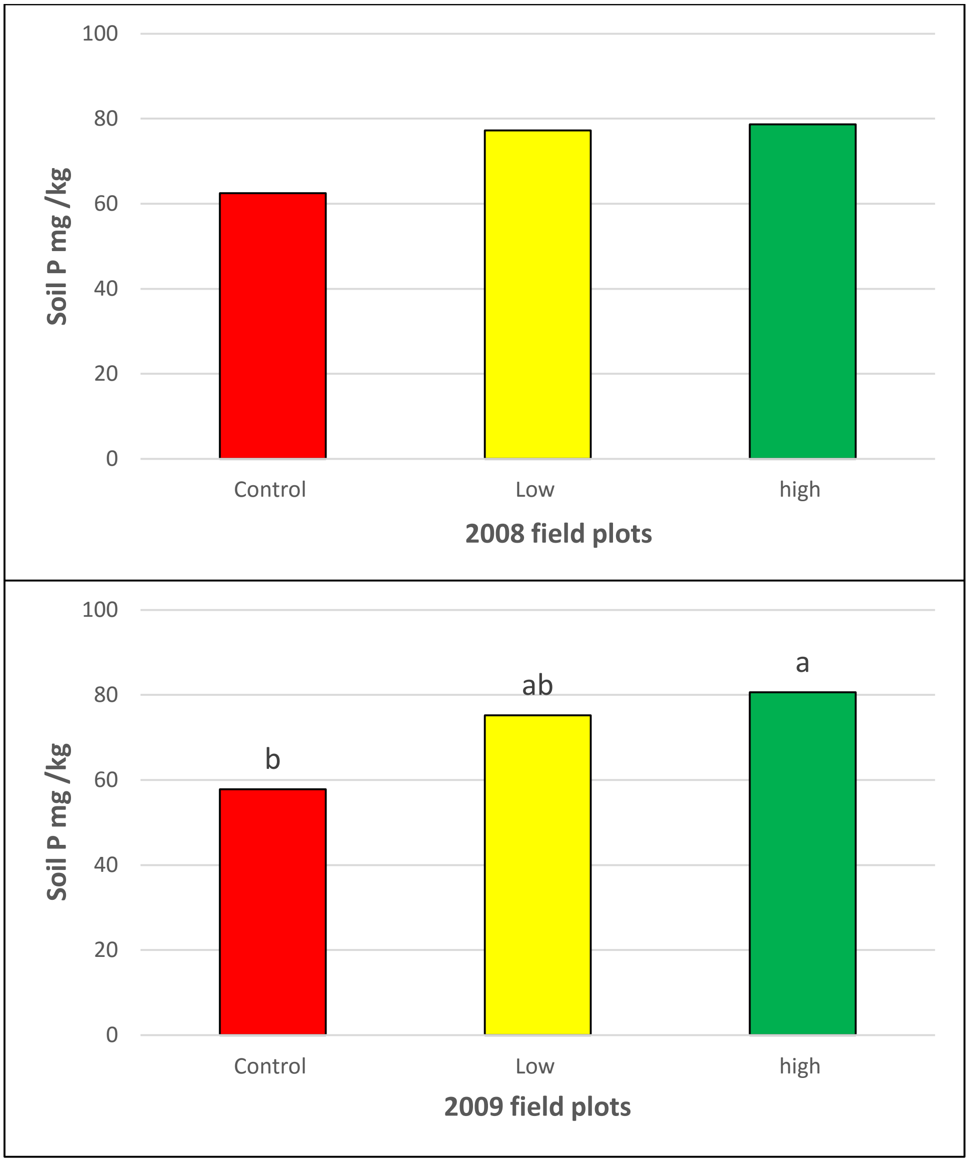


Figure 2-10: Phosphorus values in mg. Kg^{-1} for annual soil analysis (0-15) cm in 200) and 2009 in field plots for pac choi crop at different fertility levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

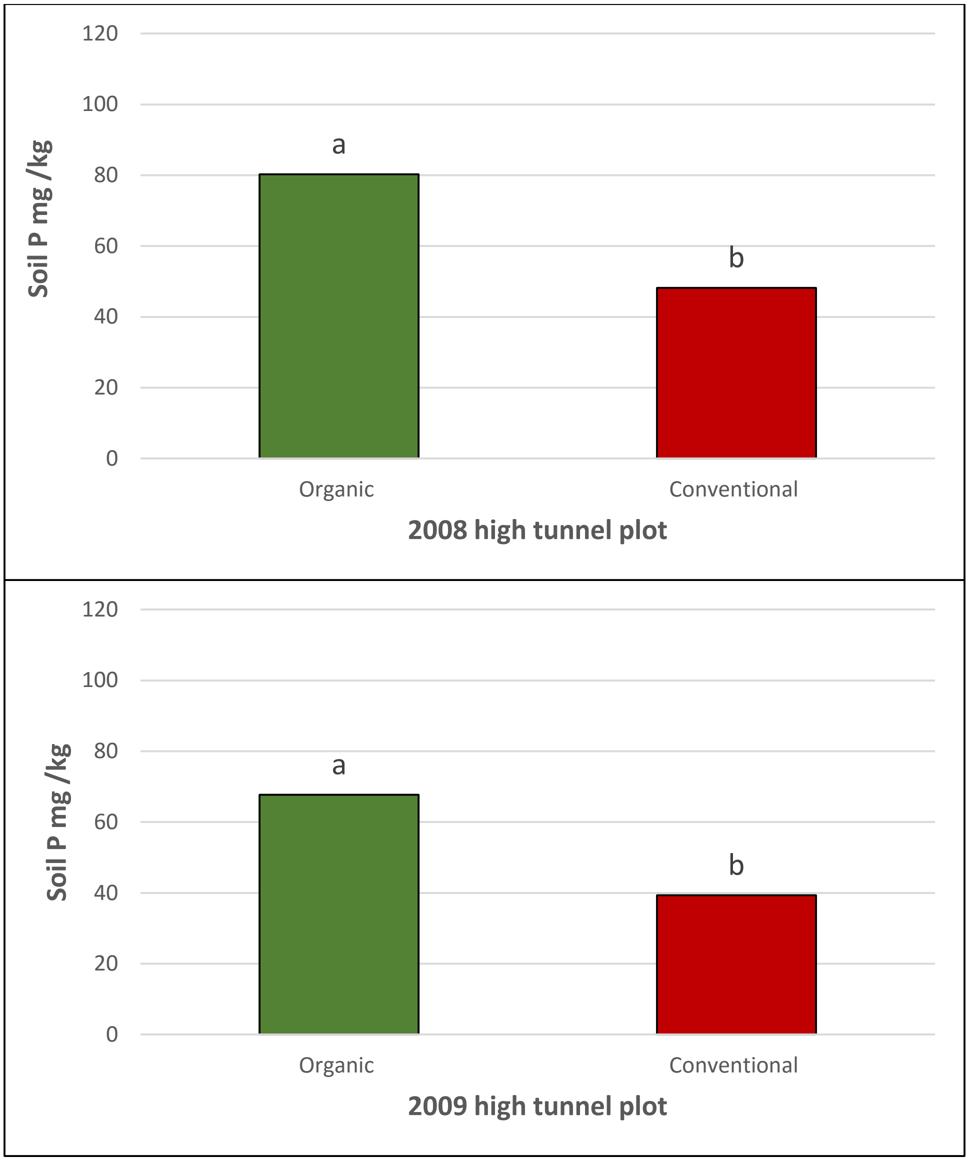


Figure 2-11: Phosphorus values in mg. Kg^{-1} for annual soil analysis (0-15) cm in 200) and 2009 in high tunnel plots for pac choi grown with organic or conventional management systems. "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

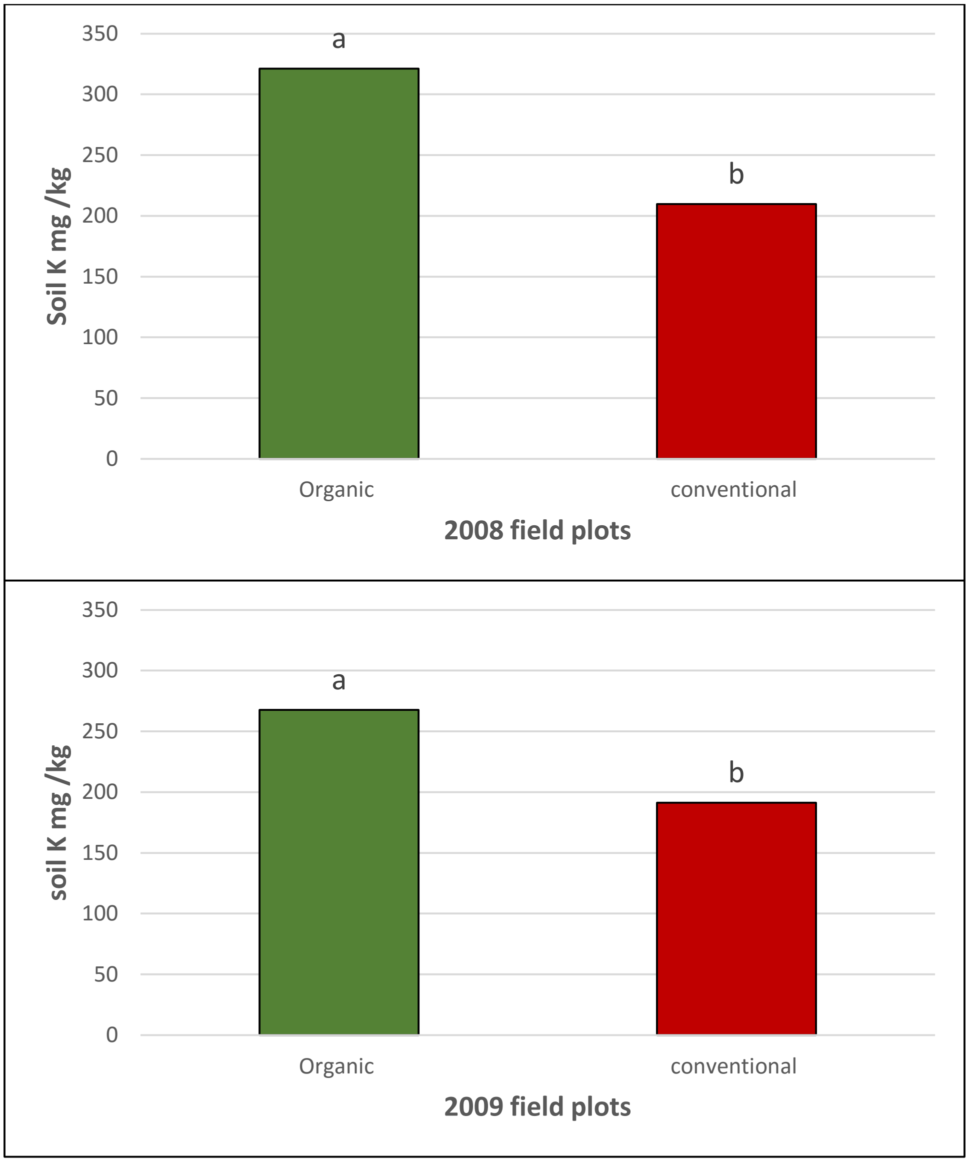


Figure 2-12: Potassium values in mg .kg $^{-1}$ for annual soil analysis (0-15) cm in 2008 and 2009 in field plots for pac choi grown with organic or conventional management systems. "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

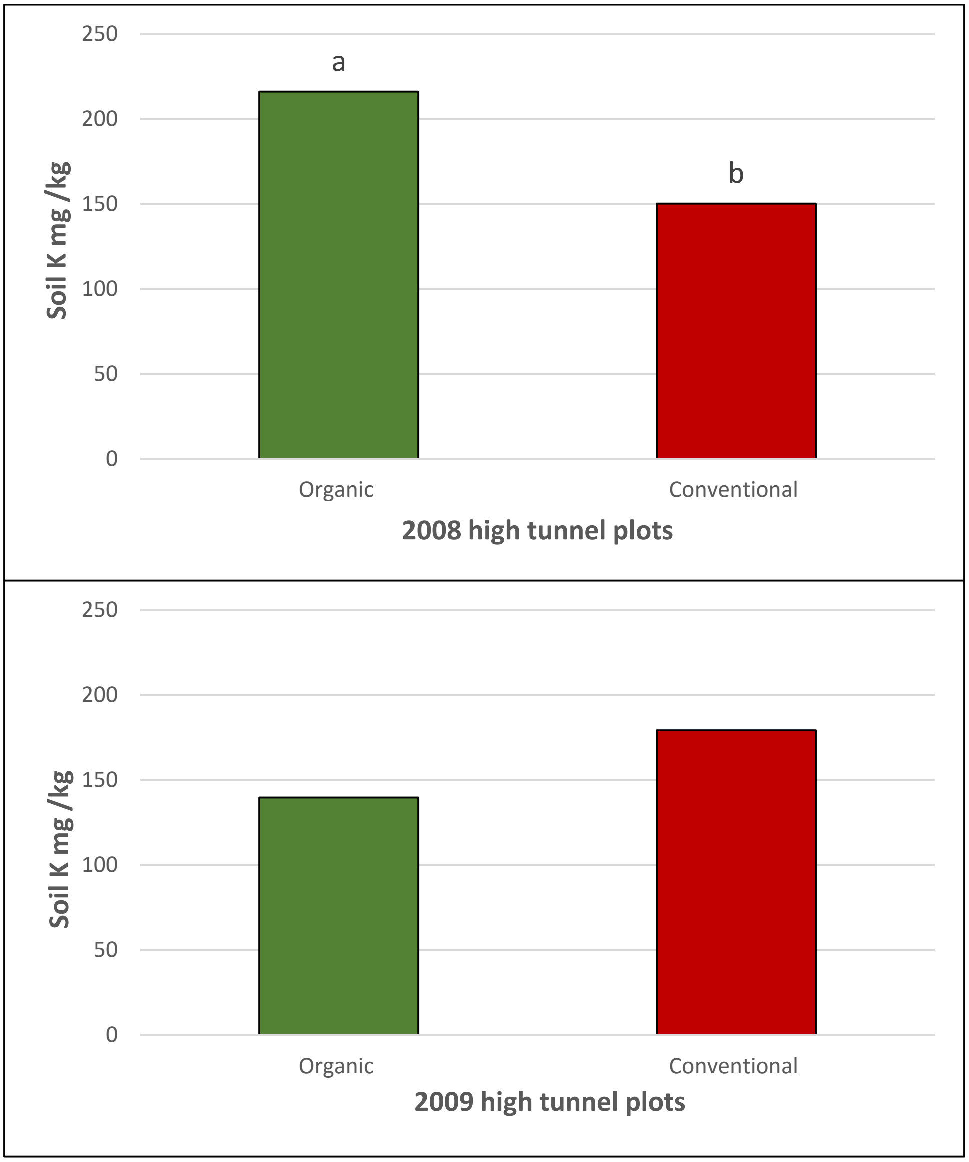


Figure 2-13 Potassium values in mg .kg $^{-1}$ for annual soil analysis (0-15) cm in 2008 and 2009 in high tunnel plots for pac choi grown with organic or conventional management systems. "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

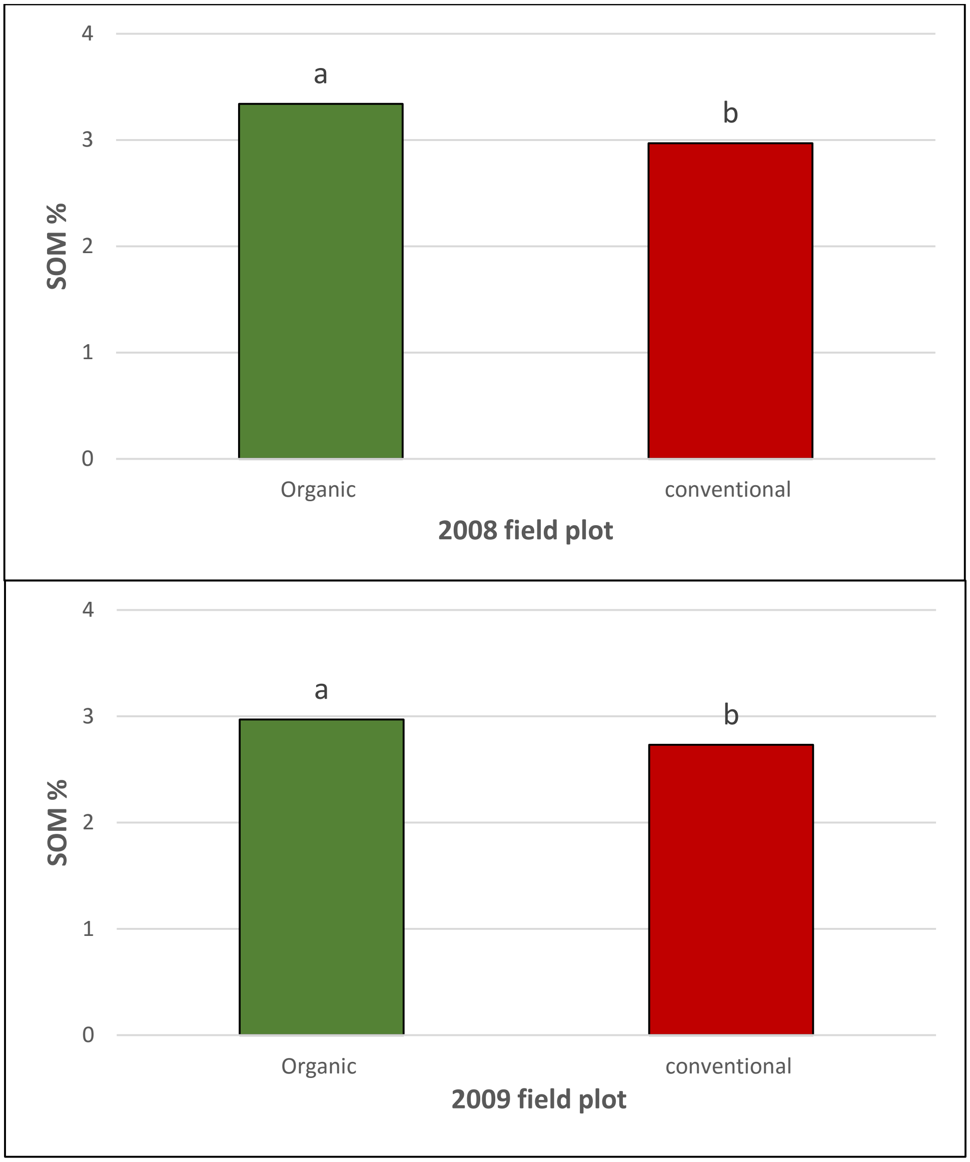


Figure 2-14: Soil organic matter percent SOM% for annual analysis in 2008 and 2009 in field plots for pac choi grown with organic or conventional management systems. "Means sharing the same letters are not significantly different from each other (Tukey's HSD, P<0.05)"

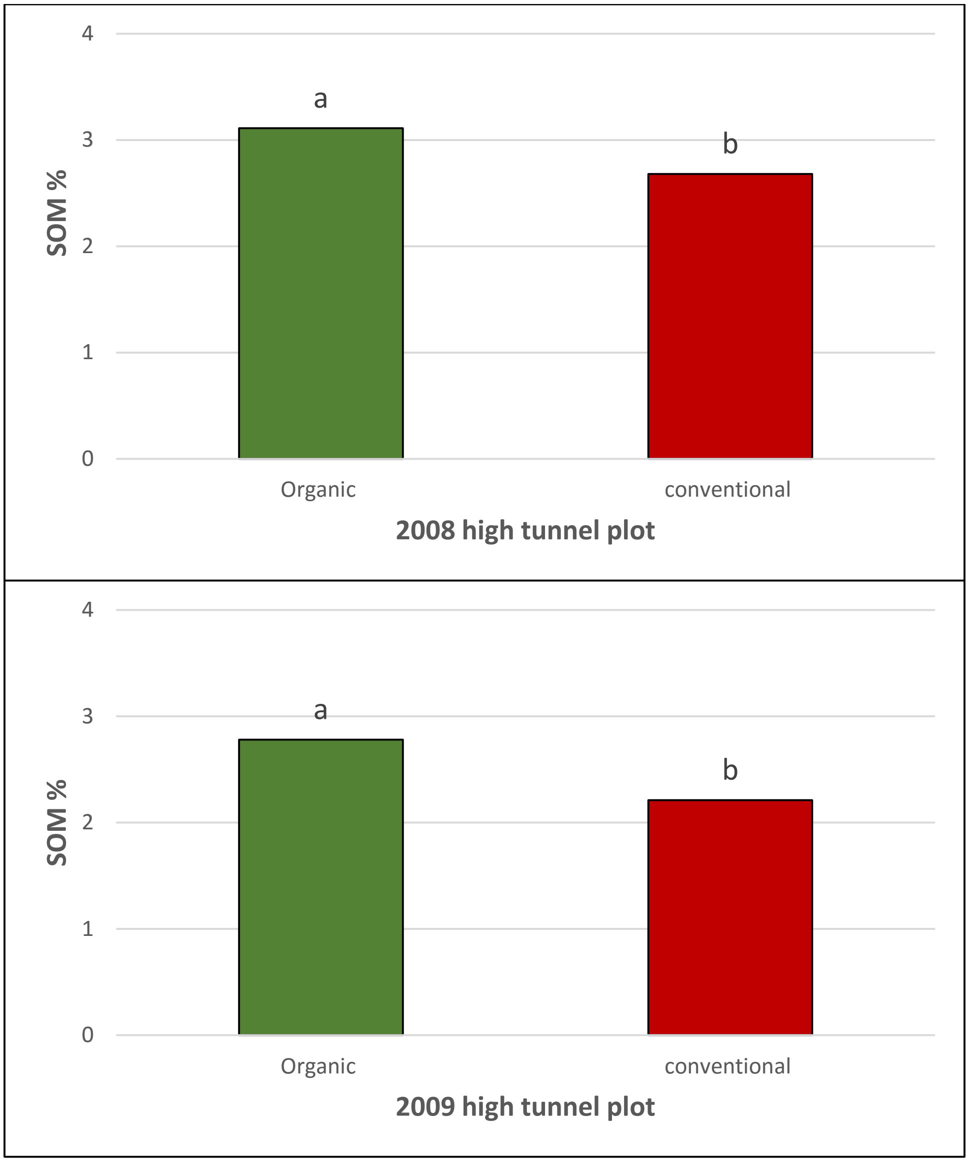


Figure 2-15: Soil organic matter percent SOM% for annual analysis in 2008 and 2009 in high tunnel plots for pac choi grown with organic or conventional management systems. "Means sharing the same letters are not significantly different from each other (Tukey's HSD, P<0.05)"

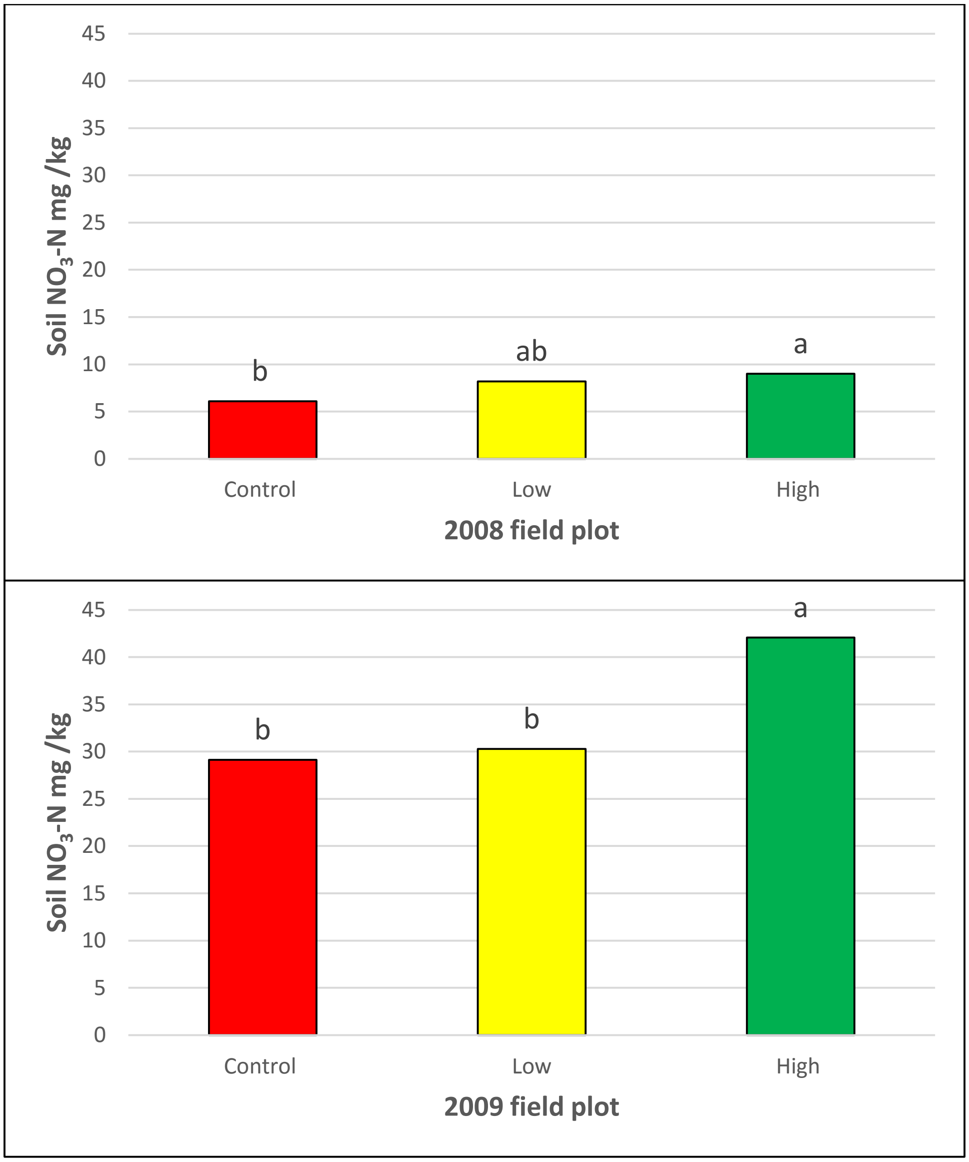


Figure 2-16: Nitrate nitrogen values (NO_3-N) n mg. kg $^{-1}$ for annual soil analysis (0-15) cm in 2008 and 2009 in field plots for pac choi crop at different fertility levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters are not significantly different from each other (Tukey's, $P<0.05$)"

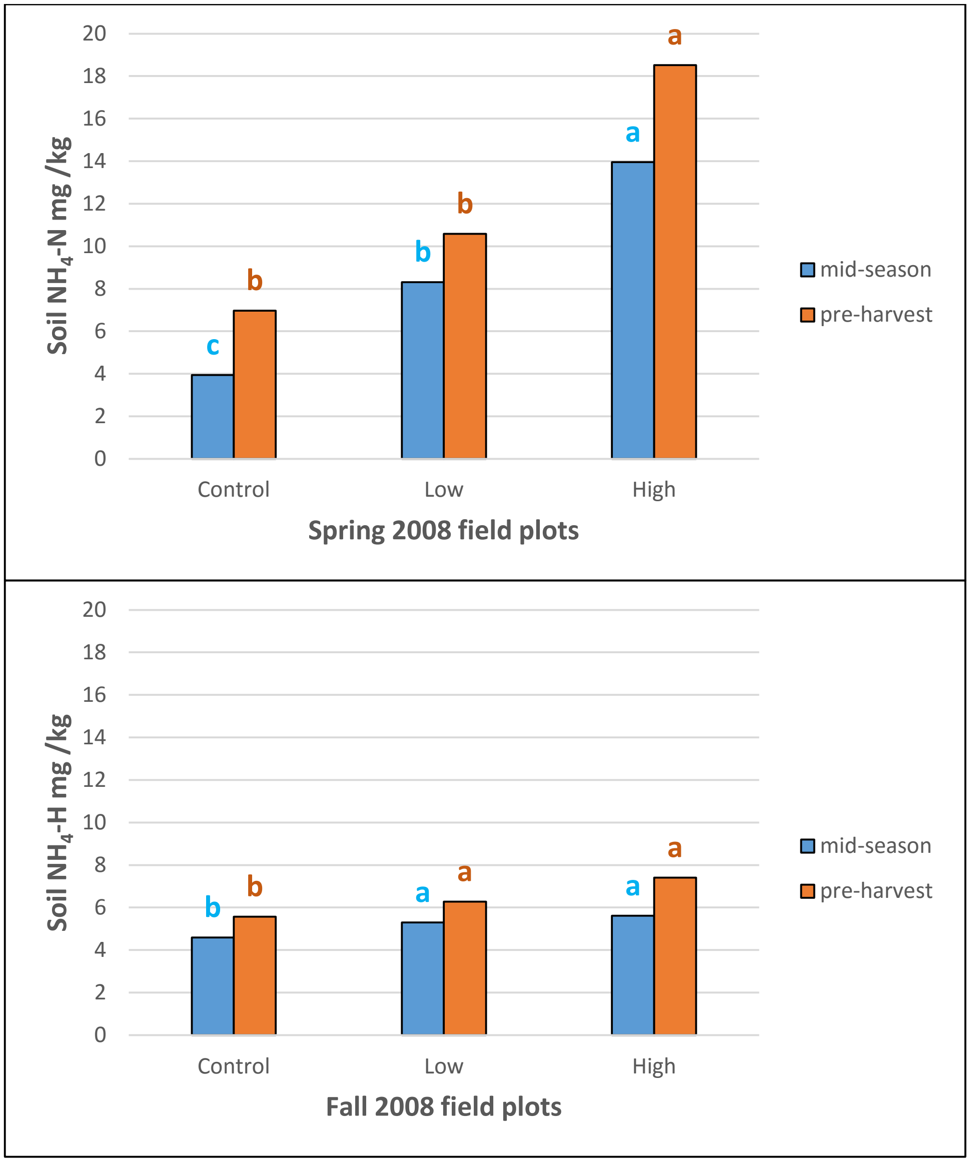


Figure 2-17: Ammonium nitrogen values in mg. kg^{-1} for soil analysis during pac choi growing stages in field plots (midseason and pre-harvest) for 2008 spring and fall at different fertility levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters within the same color are not significantly different from each other (Tukey's, P<0.05)"

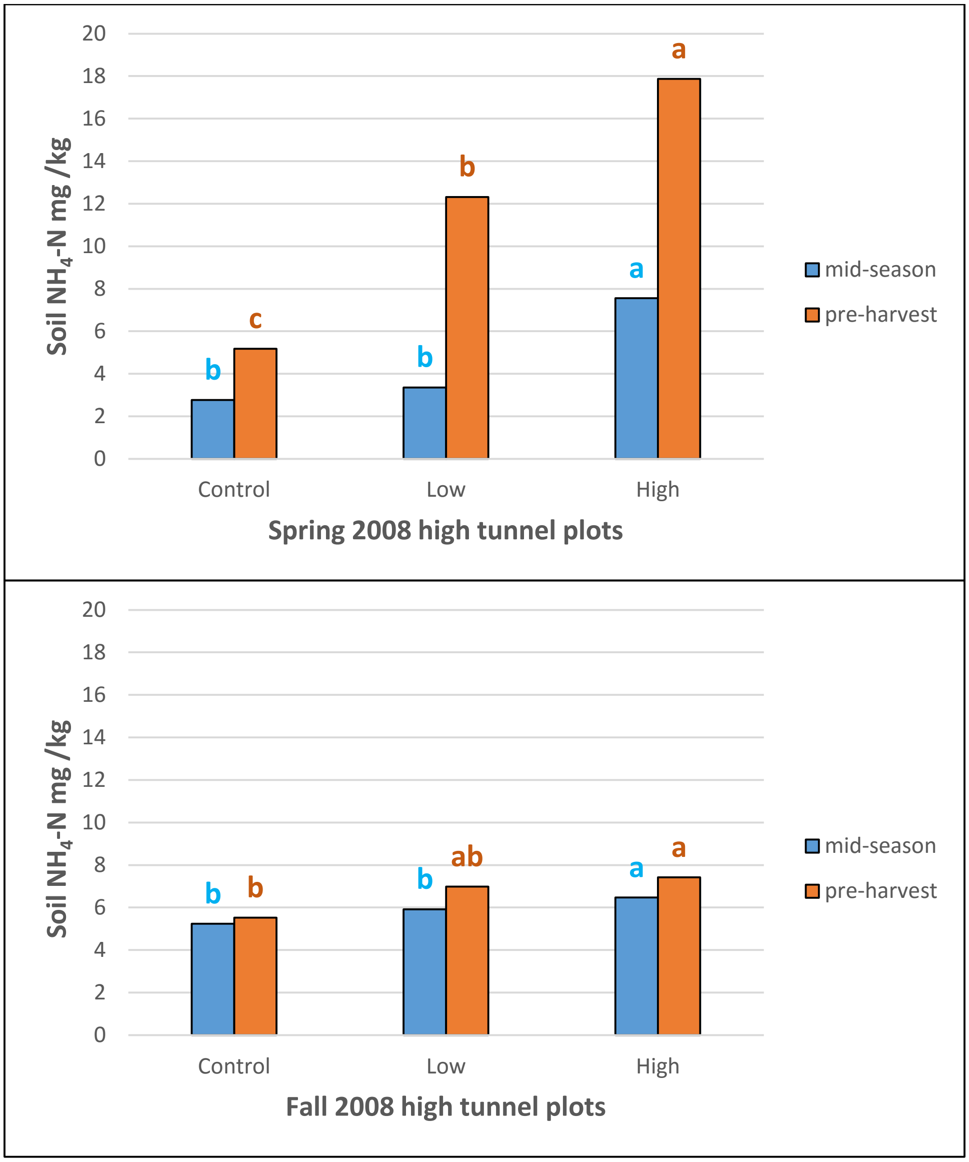


Figure 2-18: Ammonium nitrogen values in mg. kg^{-1} for soil analysis during pac choi growing stages in high tunnel plots (midseason and pre-harvest) for 2008 spring and fall at different fertility levels control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) "Means sharing the same letters within the same color are not significantly different from each other (Tukey's, $P<0.05$)"

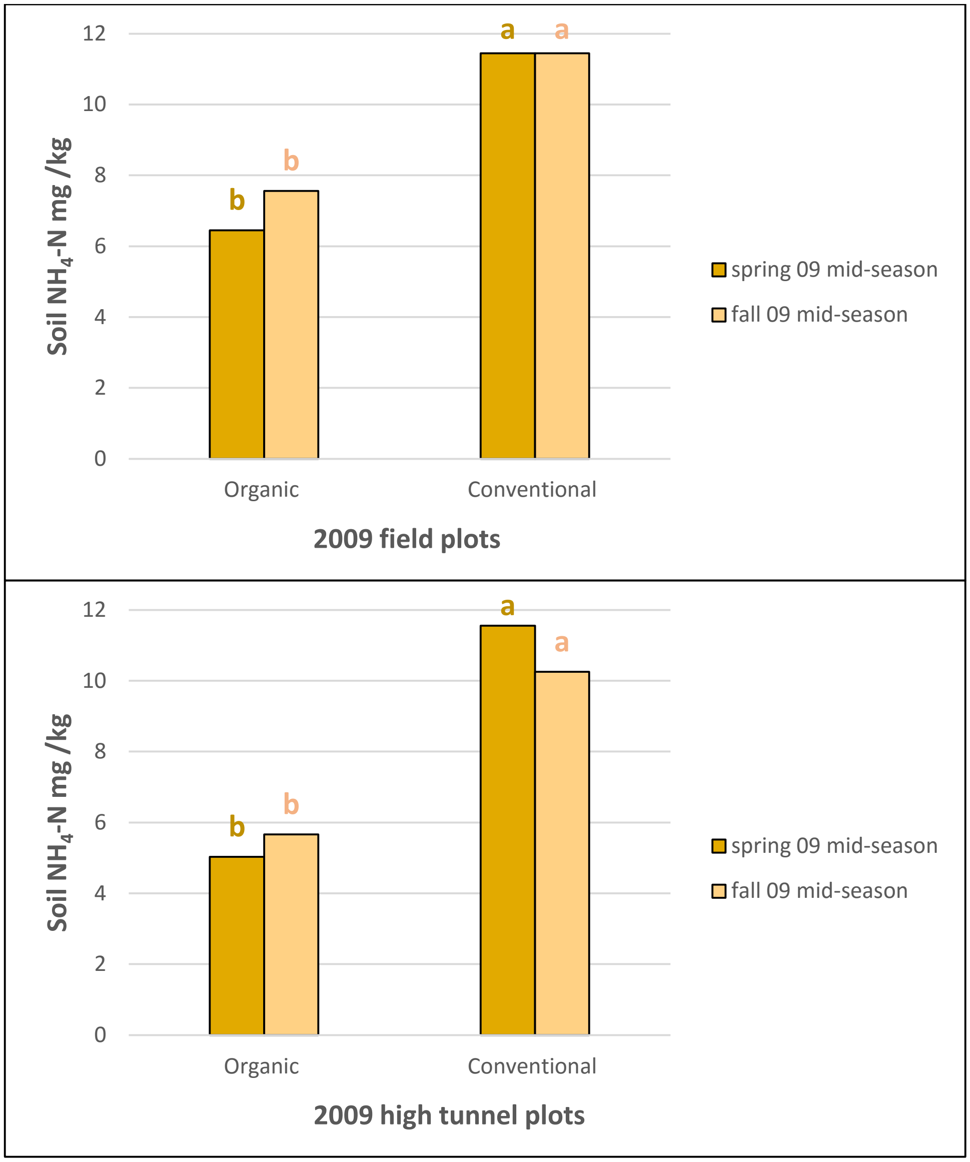


Figure 2-19: Ammonium nitrogen values for mid-season soil analysis in mg. kg^{-1} during pac choi growing stages in field and high tunnel plots for 2009 spring and fall at organic and conventional management systems. "Means sharing the same letters within the same color are not significantly different from each (Tukey's, P<0.05)"

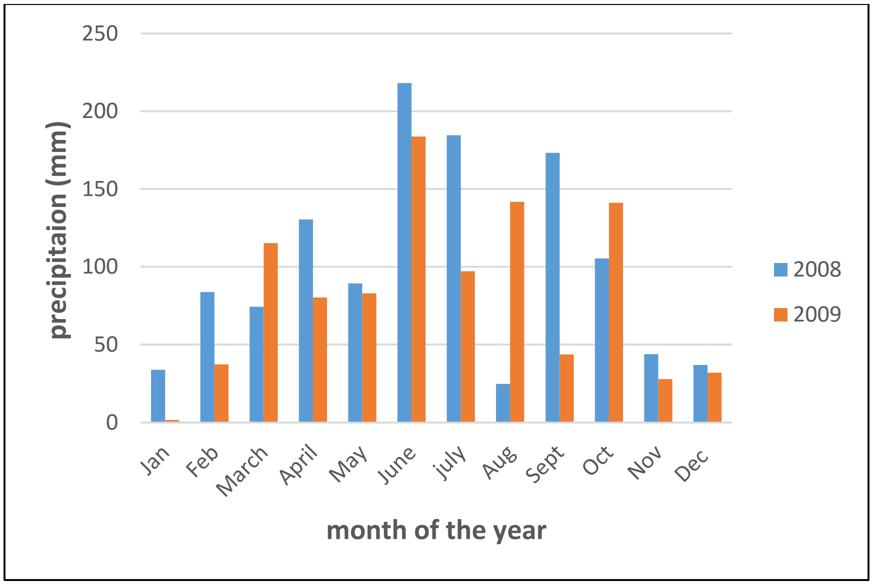


Figure 2-20: Average monthly precipitation (mm) in 2008 and 2009 at the research center in Olathe KS. Spring pac choi was grown in April and harvested in May. Fall pac choi was grown in September and harvested in October

Table 2-1: The dates of the activities and applications for 2008 and 2009 spring and fall pac choi

Activity	**pac choi spring 2008**			**pac choi fall 2008**		
seed sown	27-Feb			8-Aug		
seedlings fertilized	20-Mar	28-Mar	31-Mar	20-Aug	29-Aug	3-Sep
compost/ fertilizer pre-application	31-Mar			NA		
seedling transplanted	1-Apr			5-Sep		
liquid fertilizers supplement	1-Apr	17-Apr	24-Apr	9-Sep	18-Sep	26-Sep
harvesting	8-May			17-Oct		
Activity	**pac choi spring 2009**			**pac choi fall 2009**		
seed sown	3-Mar			3-Aug		
seedlings fertilized	26-Mar	3-Apr	9-Apr	10-Aug	20-Aug	29-Aug
compost/ fertilizer pre-application	25-Mar			NA		
seedling transplanted	10-Apr			8-Sep		
liquid fertilizers supplement	17-Apr	24-Apr	12-May	9-Sep	18-Sep	28-Sep
harvesting	21-May			21-Oct		

Table 2-2: Dates and days after planting (DAP) of petiole sap analysis for pac choi for 2008, and 2009 spring and fall seasons

2008	**2009**
14-April (*14 DAP*)	21-April (*11 DAP*)
28- April (*27 DAP*)	5-May (*25 DAP*)
20- Sept (*15 DAP*)	19-Sept (*11 DAP*)
6-Oct (*31 DAP*)	30- Sept (2*2 DAP*)

Table 2-3: Soil annual analysis dates for pac choi in 2008 and 2009 for spring and fall seasons

	2008		**2009**	
	spring	**fall**	**spring**	**fall**
Annual analysis	10-Mar		17-Mar	
analysis 1	15-Apr	15-Sep	21-Apr	18-Sep
analysis 2	29-Apr	29-Sep	5-May	30-Sep

Table 2-4: Statistical analysis for pac choi yield in kg. ha^{-1} for 2008 and 2009 spring and fall seasons at field and high tunnel plots for main effects, management; organic (org) and conventional (conv), fertility treatments; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for 2008 and 2009 growing seasons. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

	Field					**High tunnel**			
	Spring 2008	**Fall 2008**	**Spring 2009**	**Fall 2009**		**Spring 2008**	**Fall 2008**	**Spring 2009**	**Fall 2009**
Organic	781.2	1826.0^{a}	1264.5^{b}	505.3		3227.3	5107.0	3285.9	2021.3
Conventional	1220.6	790.9^{b}	2299.6^{a}	633.2		3124.7	4931.2	4106.1	1710.3
p-value	**0.1467**	**0.005^{7}**	**0.0008**	**0.2968**		**0.7963**	**0.6598**	**0.368**	**0.5565**
Control	410.1^{c}	1049.7^{b}	703.1^{b}	418.3^{b}		2075.0^{b}	4696.9	2177.6^{b}	1452.5^{b}
Low	1049.7^{b}	1118.1^{b}	2060.4^{a}	502.1^{ab}		3705.7^{a}	5160.7	4618.8^{a}	1884.6^{ab}
High	1547.7^{a}	1757.7^{a}	2582.8^{a}	788.5^{a}		3749.7^{a}	5204.6	4296.5^{a}	2407.0^{a}
p-value	**<.0001**	**0.0099**	**<.0001**	**0.0375**		**0.0004**	**0.5227**	**0.0055**	**0.0188**
Org Control	561.5^{c}	1611.2	908.1^{bc}	556.6		2099.4	5111.9	1977.4	1674.7
Org Low	595.7^{c}	1552.6	1181.5^{bc}	623.0		3886.4	5297.4	3901.0	2436.3
Org High	1171.8^{b}	2314.3	1704.0^{b}	720.6		3700.9	4921.5	3979.2	1957.8
Conv control	258.8^{c}	488.2	498.0^{c}	279.8		2050.6	4281.9	2377.7	1230.4
Conv Low	1503.8^{ab}	683.5	2934.3^{a}	380.8		3515.3	5028.9	4692.0	1816.3
Conv High	1904.1^{a}	1210.8	3461.6^{a}	854.4		3808.3	5487.8	5253.5	2084.8
p-value	**0.0004**	**0.7521**	**0.0029**	**0.2488**		**0.7095**	**0.3735**	**0.7563**	**0.7848**

Table 2-5: Soil annual statistical analysis for ammonium-nitrogen (NH_4-N) and the resulting p-value for pac choi crop. Addresses management; (organic or conventional), fertility tratments; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for 2008 and 2009

Field NH_4-N		
	2008	**2009**
Management	0.3373	0.6385
Fertility	0.3894	0.4959
Management*fertility	0.3883	0.9757
High tunnel NH_4-N		
	2008	**2009**
Management	0.3234	0.6246
Fertility	0.8268	0.5880
Management*fertility	0.2030	0.6570

Table 2-6: Soil annual statistical analysis for nitrate-nitrogen (NO_3-N) and resulting p-value for pac choi crop grown under field and high tunnel plots. Addresses management (organic or conventional), fertility treatments, control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for 2008 and 2009

Field NO_3-N		
	2008	**2009**
Management	0.9474	0.5571
Fertility	0.0352	0.0238
Management*fertility	0.0564	0.7306
High tunnel NO_3-N		
	2008	**2009**
Management	0.5091	0.7323
Fertility	0.6104	0.1225
Management*fertility	0.7050	0.8058

Table 2-7: Soil ammonium nitrogen NH_4-N mean values (mg. kg^{-1}) for main effects; management (organic and conventional), fertility treatments; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for pac choi grown in field and high tunnel plots in spring and fall 2008."Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

		Field					**High tunnel**			
		Spring 08		**Fall 08**			**Spring 08**		**Fall 08**	
		mid-season	**pre-harvest**	**mid-season**	**pre-harvest**		**mid-season**	**pre-harvest**	**mid-season**	**pre-harvest**
Management	**Organic**	4.36^{b}	11.3	5.4	7.2		4.1	12.5	6.34	6.8
	Conv.	13.11^{a}	12.8	4.9	5.6		5.0	11.1	5.41	6.5
	p-value	**0.0001**	**0.2124**	**0.1211**	**0.0881**		**0.2155**	**0.2958**	**0.0272**	**0.5969**
Fertility	**Control**	3.94^{c}	6.97^{b}	4.59^{b}	5.57^{b}		2.76^{b}	5.18^{c}	5.23^{b}	5.52^{b}
	Low	8.31^{b}	10.58^{b}	5.3^{a}	6.28^{ab}		3.36^{b}	12.32^{b}	5.92^{ab}	6.98^{ab}
	High	13.95^{a}	18.52^{a}	5.61^{a}	7.41^{a}		7.55^{a}	17.87^{a}	6.47^{a}	7.42^{a}
	p-value	**0.0001**	**0.0001**	**0.0287**	**0.0058**		**0.0001**	**0.0001**	**0.0532**	**0.0177**
Management * fertility	**Org Control**	2.6^{d}	6.45^{c}	4.25^{c}	5.9		2.9	5.5	5.65	4.94
	Org Low	3.3^{cd}	7.35^{c}	3.63^{ab}	7.3		2.3	12.0	6.37	7.58
	Org High	6.7^{c}	20.03^{a}	6.31^{a}	8.5		7.1	20.0	6.98	7.77
	Conv control	4.9^{cd}	7.5^{c}	4.92^{bc}	5.2		2.6	4.9	4.79	6.08
	Conv Low	13.26^{b}	13.81^{b}	4.97^{bc}	5.3		4.5	12.7	5.46	6.37
	Conv High	21.16^{a}	17.0^{ab}	4.92^{bc}	6.3		8.0	15.8	5.96	7.06
	p-value	**0.001**	**0.0169**	**0.0306**	**0.1856**		**0.2017**	**0.2877**	**0.9846**	**0.1512**

Table 2-8: Statistical analysis and the resulting p-value for soil NO_3-N during pac choi crop grown under field plots. Addresses management (MGT) (organic or conventional), fertility (FRT) treatments; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for 2008 and 2009 spring and fall crops. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

		mid-season	**pre-harvest**			**mid-season**	**pre-harvest**
Spring 08	**MGT**	0.0531	0.8975	**Spring 09**	**MGT**	0.0006	0.1061
	FRT	0.0001	0.0611		**FRT**	0.0001	0.9366
	MGT*FRT	0.0024	0.1979		**MGT*FRT**	0.0006	0.9006
Fall 08	**MGT**	0.0433	0.0729	**Fall 09**	**MGT**	0.0006	0.2634
	FRT	0.0002	0.0001		**FRT**	0.0001	0.3595
	MGT*FRT	0.0229	0.0006		**MGT*FRT**	0.0006	0.4993

Table 2-9: Statistical analysis and resulting p-value for soil NO_3-N during pac choi crop grown under high tunnel plots. Addresses management (MGT) (organic or conventional), fertility (FRT) treatments; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for 2008 and 2009 spring and fall crops. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

		mid-season	**pre-harvest**			**mid-season**	**pre-harvest**
Spring 08	**MGT**	0.4433	0.0134	**Spring 09**	**MGT**	0.7562	0.0314
	FRT	0.0001	0.0001		**FRT**	0.0856	0.2389
	MGT*FRT	0.2423	0.0178		**MGT*FRT**	0.2024	0.4405
Fall 08	**MGT**	0.0001	0.1285	**Fall 09**	**MGT**	0.2818	0.0054
	FRT	0.0001	0.0839		**FRT**	0.0001	0.0004
	MGT*FRT	0.0001	0.2009		**MGT*FRT**	0.5568	0.0099

Table 2-10: Statistical analysis and the resulting p-value for petiole sap nitrate NO_3^- during pac choi crop grown in field plots. Addresses management (MGT) (organic or conventional), fertility (FRT) tretments; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for 2008 and 2009 spring and fall crops. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

		mid-season	pre-harvest			mid-season	pre-harvest
Spring 08	**MGT**	0.1489	0.3622	**Spring 09**	**MGT**	0.6905	0.5870
	FRT	0.0165	0.3658		**FRT**	0.1403	0.0394
	MGT*FRT	0.1194	0.8659		**MGT*FRT**	0.6798	0.7184
Fall 08	**MGT**	0.5880	0.7831	**Fall 09**	**MGT**	0.6152	0.5435
	FRT	0.0007	0.0097		**FRT**	0.0128	0.5394
	MGT*FRT	0.9975	0.446		**MGT*FRT**	0.0116	0.637

Table 2-11: Statistical analysis and the resulting p-value for petiole sap nitrate NO_3^- during pac choi crop grown under high tunnel plots. Addresses management (MGT) (organic or conventional), fertility (FRT) treatments; control (cover crop), low (cover crop and pre-pant application), and high (cover crop, pre-plant application and soluble fertilizer) and interaction between management and fertility for 2008 and 2009 spring and fall crops. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

		mid-season	**pre-harvest**			**mid-season**	**pre-harvest**
Spring 08	**MGT**	0.6785	0.3771	**Spring 09**	**MGT**	0.6722	0.1494
	FRT	0.8066	0.2220		**FRT**	0.0157	0.0888
	MGT*FRT	0.9625	0.7841		**MGT*FRT**	0.5038	0.3815
Fall 08	**MGT**	0.2568	0.2871	**Fall 09**	**MGT**	0.8239	0.7197
	FRT	0.0047	0.0016		**FRT**	0.9797	0.2691
	MGT*FRT	0.4310	0.2922		**MGT*FRT**	0.2271	0.7305

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Chapter 3 - Estimation of soil N availability for tomato production in high tunnel vs field under organic and conventional management.

Introduction

Healthy plants normally contain higher concentrations of nitrogen N than any other mineral nutrient (Berry, 1982). This is because nitrogen is involved in the structure of amino acids, proteins, chlorophyll, nucleic acids, and many enzymes (Smith, 1997) and is essential for carbohydrate utilization (Havlin et al., 1990; Hills, 1983). Since N is a major component of so many essential plant compounds, it is not surprising that N is the most frequently deficient nutrient in crop production (Berry, 1982). Therefore, most non-legume cropping systems require additional fertilizer N for profitable yields (Havlin et al., 2005), and N fertilizers are regularly applied in large quantities especially to field crops (Jones et al., 1991). Clearly, where N supply is inadequate, yield potentials and maximum economic returns will not be realized. Conversely, excessive fertilization can result in unnecessary costs but also raise concern about the possible negative influence of N on the environment through N leaching, NO_3^- contamination of surface and groundwater and N_2O emissions into the atmosphere. To optimize agricultural production while minimizing the potentially negative effects of N fertilization on the environment, growers should match the supply of plant available N to crop demand by considering several factors

First, organic soil N consists of proteins, amino acids, amino sugars, and other complex N compounds (Havlin et al., 2005b). These organic N materials may comprise 95% or more of total soil N but are not immediately available to plant (Palm et al., 2001). To become plant available, organic N must be converted to inorganic N through the process of mineralization. Inorganic forms of soil N include ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_2O), nitric oxide (NO), and elemental N (N_2) (Schimel, 2004). Ammonium and nitrate are most important (Morra et al., 2010) since both forms are readily available for plant uptake.

Next, amino sugars occur as structural components of a broad group of substances (Stevenson, 1982). They have been identified in the cell walls of bacteria and fungi, and in insect exoskeletons and other animal tissues (Parsons et al., 1983). More recently, amino sugar N has been identified as a possible labile fraction of organic soil N that readily supplies plant available N through mineralization ((Mulvaney et al., 2001).

Furthermore, the supply of plant available N is derived mainly from residual mineral N, mineralization of organic soil N and incorporated crop residues, biological N_2 fixation, and applied organic and inorganic N sources (Cassman et al., 2002; Keeney, 1982). The relative contribution that each component makes to available N depends largely on the many management and environmental factors affecting N mineralization, namely immobilization, and losses of ammonium and nitrate from the soil (Havlin et al., 2005).

Residual mineral N refers to inorganic soil N arising from mineralization of organic N or application of fertilizer N that is not utilized by a crop in a given season but that carries over to the period of growth of the succeeding crop (Allison, 1973). The contribution of residual mineral N to the plant available pool can be substantial (Soper and Huang, 1963) and is influenced by numerous N-cycle processes including mineralization, immobilization, nitrification, denitrification, leaching, and plant uptake (Khan et al., 2001). Loss of N from agricultural systems not only negatively impacts crop productivity, but can also have detrimental impacts on the environment. One major pathway by which agricultural systems are susceptible to N loss is via $NO3^-$ leaching, which can negatively impact the health of humans (Townsend et al., 2003) and aquatic life (Rabalais et al., 1996), and is largely mediated during nitrification. Another major route of N loss in soils is via denitrification, by which gaseous forms of N are emitted from soil to the atmosphere. Nitrous oxide (N_2O) is an intermediate in the denitrification pathway, and is a potent greenhouse gas that has a global warming potential about 300 times greater than that of carbon dioxide (Lashof and Ahuja, 1990), and can help deplete stratospheric ozone (Ravishankara et al., 2009). As a result, nitrification and denitrification dynamics are critical in controlling N loss from agricultural soils, and thereby decreasing negative impacts on the environment.

Meanwhile, mineralization is the transformation of N from an organic state into the inorganic forms of NH_4^+ or NH_3^- (Myrold, 2008), a process facilitated by heterotrophic microorganisms in two separate reactions (Havlin et al., 2005). In the first reaction, termed aminization, proteins are degraded into amines, amino acids, and urea. The products of aminization are further decomposed to release NH_4^+ or NH_3 in a second reaction called ammonification.

As N mineralization proceeds, the process of N immobilization occurs simultaneously. Nitrogen immobilization is defined as the transformation of inorganic N compounds into an organic state (Myrold, 2008) and is basically the reverse of N mineralization (Havlin et al., 2005b) In this process, soil organisms assimilate inorganic N compounds and transform them into organic N constituents of their cells and tissues Myrold, 2008). Therefore, the amount of N available for crop production will be strongly influenced by the rate and balance of the two processes. Additionally, soil temperature and moisture are the major environmental factors that control N mineralization (Sierra, 1997) by influencing the survival and activity of soil microorganisms (Pulleman and Tietema, 1999). In general, the rate of microbial activity increases with increasing temperature (Stanford et al., 1973), with an optimum temperature between 25 and 35°C (Havlin et al., 2005) . Soil microbial activity is also related to previous temperature conditions. Thus, the temporary increase in microbial activity following the thawing of frozen soil can be attributed to the rapid decomposition of soluble organic materials released from microbial cells ruptured during freezing (DeLuca et al., 1992).This means the rate of N mineralization and the total amount of N mineralized may increase with freezing and thawing (DeLuca et al., 1992), which is not likely to happen in soil kept at a stable temperature.

Maximum aerobic microbial activity and N mineralization normally occurs between 50 and 70% of water-filled pore space (Hamza, 2005) whereas anaerobic conditions reduce the rate of mineralization (Havlin et al., 2005a) and may lead to an accumulation of NH_4 or NH_3 since the process of nitrification would be inhibited causing greater potential for NO_3^- loss through denitrification (Jenkinson, 1985). In such cases, drying and rewetting of soil may increase mineralization of carbon and N from biomass-derived substrate and other organic materials made available by the soil disruption (Van Gestel et al., 1993). Soil microbial activity is further influenced by the interaction between temperature and moisture. In general, N mineralization is more responsive to temperature when moisture content is favorable for the process (Sierra, 1997; Zak et al., 1999).

The need to account for mineralization of soil organic N in predicting fertilizer N requirements has long been recognized and many biological and chemical indices of soil N availability have been proposed (Bremner and Keeney, 1965; Campbell et al., 1994; Stanford and Smith, 1972; Walley et al., 2002). Researchers' objective is to develop an index that correlates highly with some previously established reliable biological measure of soil N availability such as N uptake, crop yield, or potentially mineralizable N (Stanford and Smith, 1972). Adoption of such an index for routine soil testing would also require a procedure that is rapid and precise (Haney et al., 2001). At present, most indices have proven inadequate because they do not measure the potential of the soil to mineralize N over the growing season or quantify soil N mineralization in response to weather conditions (Campbell et al., 1994).

Biological methods that estimate the amount of mineral N produced by incubation of soil under optimum conditions are generally regarded as the best indices of soil N availability since the agents responsible for the mineral N produced in the incubation are those that make soil organic N available to crops during the growing season (Bremner and Keeney, 1965). In general, most biological indices are based on short term incubations (7-25 days) under either aerobic or anaerobic conditions (Keeney and Nelson, 1982). Aerobic incubation techniques generally involve measuring the (NO_3 + NH_4)-N produced (Bremner and Keeney, 1965) but differ widely with respect to protocols for pretreatment and incubation of soil samples (Benbi and Richter, 2002; Bremner and Keeney, 1965). However, anaerobic procedures are simplified in that only NH_4-N production needs to be determined since no NO_3-N is produced (Bremner and Keeney, 1965). Regardless of the incubation method, comparisons of N availability in soils are difficult unless the techniques are rigorously standardized (Benbi and Richter, 2002; Bremner and Keeney, 1965).

Even with standardization, results of short term incubations do not necessarily reflect the potential, long term capacities of soils to supply N (Stanford and Smith, 1972). Responding to this issue, researchers developed a long term incubation method where soil is incubated for up to 30 weeks with the inorganic N removed at various times during the incubation (Keeney, 1982; Stanford and Smith, 1972).The N mineralization potential could then be estimated from the cumulative amounts of N mineralized based on the assumption that N mineralization follows first order kinetics (Campbell et al., 1994; Stanford, 1982). Despite the improvement in predicting soil N availability (Stanford, 1982), determining long term mineralization capacities of soils is generally not suited for routine soil testing because of the lengthy time periods required (Haney et al., 2001),

The development of the Illinois soil N test (ISNT) was stimulated by earlier reports that identified numerous sites throughout the north-central and northeastern USA where corn did not respond to N fertilization (Mulvaney et al., 2001). In many cases, excessive accumulations of NO_3^- were not predicted by soil testing for NO_3^- either before or after planting, and over-fertilization resulted (Mulvaney et al., 2001). The goal was to identify and measure a fraction of soil organic N that is directly related to fertilizer N responsiveness and design a simple soil test procedure suitable for routine soil analysis (Mulvaney et al., 2001). Previous studies regarding different forms of organic soil N had been based largely on identifying and estimating the N compounds released from soil by hydrolysis with hot mineral acids (Bremner and Keeney, 1965; Stevenson, 1982). The major fractions include total-N, NH_4-N, (NH_4 + amino sugar)-N, and amino acid-N. Amino sugar-N is understood as the difference between determinations of (NH4 + amino sugar)-N and NH_4-N (Bremner and Mulvaney, 1982; Stevenson, 1982).

Further research by Mulvaney and Khan (2001) indicated that conventional steam distillation analyses were not quantitative for either amino sugar-N or amino acid-N due in part to defects in steam distillation methodology. These defects were overcome by developing simple Mason jar diffusion methods that are accurate, specific, and reliable to fractionate N in soil hydrolysates. Using Mason jar diffusion methodology, the researchers then compared N distribution analyses of soil hydrolysates from composite soil samples (0-30 cm depth) collected in early spring from 18 sites throughout Illinois with differing N fertilizer responses by corn

(Mulvaney et al., 2001). Nonresponsive soils were found to have concentrations of amino sugar-N 33% to 1000% greater *(P* <0.001) than responsive soils, whereas no consistent difference was observed in the content of total hydrolyzable N, hydrolyzable NH_4-N, or amino acid-N. Based on amino sugar-N, all 18 soils were classified correctly as responsive or nonresponsive to N fertilization suggesting the soil amino sugar-N fraction is a key factor affecting the responsiveness of corn to N fertilization (Mulvaney et al., 2001). However, determining amino sugar-N in soil hydrolysates to detect sites that do not require N fertilization is complicated and time-consuming for routine soil analysis, so the ISNT was developed to estimate amino sugar-N by performing diffusion directly on the soil itself without the need for acid hydrolysis (Khan et al., 2001).

Based on a 30 cm soil sampling depth, a test value of 230 mg N kg-1 or higher indicates that corn will be nonresponsive to N fertilization in central or northern Illinois; this means nitrogen is available to be mineralized during the subsequent crop growing season, so additional fertilizer would not be required. Additionally, a critical value of 300 mg N kg-1 would be appropriate for samples collected from a 15 cm depth. Unfortunately, as designed, the ISNT does not recover NO_3-N to reduce soil test variability or eliminate the need for profile sampling (Khan et al., 2001). Since exchangeable NH_4-N is recovered along with amino sugar-N, the ISNT will not provide a reliable estimate of amino sugar-N for sites that have received a recent input of NH_4-N through application of ammoniacal fertilizer, manure (Khan et al., 2001), or compost (Klapwyk and Ketterings, 2006).

Since limited information is available for estimating soil N availability for tomato production using the Illinois Soil Nitrate Test (ISNT), the objective of this study is 1. To estimate the soil N availability for tomato in high tunnel and field conditions under organic and conventional systems using the ISNT, 2. To explore the relationship between N mineralization from incubation as potentially mineralized nitrogen (PMN) and the ISNT, 3. To determine the impact of long term fertility management practices of organic and conventional on soil amino sugar-N, and 4. To explore the relationship between ISNT and organic matter, total carbon, and total nitrogen.

Materials and Methods

This study was conducted on replicated experimental plots designed to compare crops grown under organic and conventional production systems in high tunnels and field systems at Kansas State University Research Center in Olathe, KS (USDA hardiness zone 5 to 5b) using a Kennebec silt loam. Six 9.8 x 6.1 square meter high tunnels with 1.5m sidewalls (Stuppy, North Kansas City, MO) and six adjacent 9.8 m x 6.1 m field plots were used for this study. High tunnels were covered with single layer 6-mil (0.153mm) K-50 polyethylene (Klerk's Plastic Product Manufacturing, Inc., Richburg, SC). Each system contained six plots, which had been established in 2002 and arranged in a randomized complete block design with three replications. The treatment factor at establishment was fertilizer source with one plot per replication being managed with organic amendments and the other with conventional amendments. Organic plots were managed in compliance with USDA National Organic Program standards, and were inspected and certified in 2003, 2006, 2007, and 2008.

In 2007, each high tunnel or field plot was subdivided into three 3.2x6.1 m^2 plots to which one of three fertilizer levels was assigned; control (only cover crop), low (cover crop in addition to pre-plant application) and high (cover crop, pre-pant application and soluble fertilizer) following a latin square design to account for the gradient effect of light in the high-tunnels. Fertilizer rates were determined based on soil analysis at the beginning of the study in

2007, and recommendations for vegetable crops in Kansas (Marr et al., 1998) with compost applied to organic plots and synthetic fertilizer applied to conventional plots. Compost application rates were based on the assumption that 50% of the nitrogen from compost would be available to plants during the growing season, while 100% would be available from conventional fertilizers (Warman and Havard, 1997). The organically managed plots were receiving composted cattle manure and alfalfa hay applied twice a year with fish emulsion fertigation several times during the growing seasons while conventional plots were receiving NPK 13-13-13 as a pre-plant application with calcium nitrate several times during the growing season. (Zhao, 2006; Knewtson, 2008). Thus, the presence of considerable soil reserves of essential plant nutrients from fertilization of previous crops most likely limited yield responses to FRT treatments in this study.

Low and high fertility plots were fertilized with equal amounts of compost or synthetic fertilizer at the beginning of the growing season, and high fertility plots received additional fertilization during the growing season by liquid application through the drip irrigation system.

Two crops were grown in this experiment: Pac choi (*Brassica rapa* L. *chinensis* 'Mei Qing Choi') (Johnny's Selected Seed, Albion, ME, U.S.A.) and tomato (*Lycopersicon esculentum* 'Bush Celebrity') (Totally Tomatoes, Randolph, WI, U.S.A.).The crops were grown in one half of each field or high tunnel plots (6.8 x3 m) with a rotation between pac choi and tomato crops each year to meet organic certification criteria. In this system, a spring and a fall crop of pac choi was grown each year, while a single crop of tomato was grown during the summer months. Between the spring and fall pac choi crops, the plots were seeded with a summer cover crop of buckwheat (*Fagopyrum sagittatum*) (Albert Lea Seed, Albert Lea, MN, U.S.A.) at a rate of 134 kg/ha. In the late fall, all plots were seeded with a cover crop of annual winter rye (*Secale cereale*) (Albert Lea Seed, Albert Lea, MN, U.S.A.) at a rate of 229 kg/ha.

In this study, two fertility treatments were used, control (no fertility added), and pre-plant fertility treatments (compost or synthetic fertilizer) in two production systems (field and high tunnel) n=24.

Jack's Peat-Lite 20N:4.4P:16.6K J. R. Peters, Inc., (Allentown, MO) at a rate of 98 kg N/ha was applied to conventional plots, and a mixed-source compost (Microleverage 0.6N: 0.4P: 4.4K, Hughesville, MO.) at a rate of 197 kg N/hectare was applied to organic plots.

In 2010, soil samples were collected in December at 0-15 cm depth from the plots where tomato was planted during the summer. Six soil cores were taken at random from plots in each fertility rate, then mixed together to form a bulk sample. The samples were stored in a walk-in cooler (2-5^{o}C) at Kansas state university, and then passed through a sieve with a mesh-screen (2mm). The samples were tested at Kansas State University's soil and nutritional analyses services lab in the Department of Agronomy for (pH), measured with a 1:1 slurry method (Skalar SP50 Robotic Analyzer. Skalar Inc. Buford, GA 30518), tested for Bray-1 Phosphorus (P) test using a HCL- ammonium fluoride extraction (Lachat Quickchem 8000), tested for Potassium (K) using ammonium acetate extraction on an Inductively Coupled Plasma (ICP) Spectrometer, (Model 3110 Flame Atomic Absorption, Spectrometer from Perkin Elmer Corp., Norwalk, CT), tested for organic matter (O.M) using the Wakleley-Black method (Model PC 910 Fiber Optic Spectrophotometer from Brinkmann Instruments, Inc., Westbury, NY.), tested for ammonium (NH_4-N) and nitrate (NO_3-N), analyzed of both nitrate and ammonia on a Rapid Flow Analyzer, Model RFA-300 (from Alpkem Corporation, Clackamas, OR 97015), and finally tested for total

N and total C using a combustion analyzer (LECO TruSpec CN, LECO Corporation, St. Joseph, MI, 2005) (Dahnike, 1975).

Prior to analysis, the remaining sample was divided into seven subsamples. The first set was dried, ground and sent to a commercial lab in Wisconsin (VH consulting Inc. Hudson, WI) to determine the concentration of (NH_4+ amino sugar)-N in ppm (mg kg^{-1}) using the ISNT. The second set of subsamples (24 different treatments) was used to determine the gravimetric soil water content (Black et al., 1965). The third set of subsamples was used to analyze the mineral nitrogen (NH_4-N) and nitrate (NO_3-N) at time “zero” (right before incubation) using the Rapid Flow Analyzer, Model RFA-300 (from Alpkem Corporation, Clackamas, OR 97015) at Kansas State University’s soil and nutritional analyses services lab in the Department of Agronomy. The rest of the subsamples were used for incubation under controlled laboratory conditions at Kansas State University under the following (Stanford and Smith, 1972) procedure: optimum temperature of 30^{o}C and soil moisture adjusted to 50-60% of water filled pore space. All incubated subsample flasks were covered with parafilm to allow air exchange but minimize moisture loss. Then, twenty four experimental units were destructively sampled on each of four sampling dates (week 1, week 2, week 4, and week 8)

Subsamples were removed at different times during incubation and leached with a 2 *M* KCl solution (149.1-g KC1/L distilled/deionized water). Cumulative mineralized labile organic N was used to calculate potentially mineralizableN (PMN) by assuming that the mineralization of labile organic N follows first order kinetics. Total inorganic N (NH_4-N and NO_3-N) was extracted by shaking 5 g soil in 25 mL of 2 *M* KCl solution at approximately 180 rpm for 1 hour and filtering soil and extracting solution through Whatman no. 2 filter paper. The extracts were then stored in sealed plastic scintillation vials at less than 4 ^{o}C prior to analysis. Ammonium-N and NO3- -N were determined in Kansas State University's soil and nutritional analyses services lab in the Department of Agronomy. Potential mineralization Nitrogen (PMN) was calculated as follows:

Net N mineralization = (NH_4-N Treatments + NO_3-N Treatments) – (NH_4-N t0 + NO3--N t0).

Data were analyzed using analysis of variance performed on soil measurements (PMN, ISNT, OM, TC, and TN). The main effects of management (MGT) system (organic vs. conventional), fertility (FRT) level treatments (control vs. pre-plant application), and their interactions were included in the model using SAS software (SAS 9.4; SAS Institute, Cary, NC) and the procedure PROC GLIMMIX. When significant treatment effects were identified, a mean separation test was carried out using LSMEANS procedure with Tukey adjustment at $P< 0.05$.

Data from the two production systems (field and high tunnel) were treated similarly but were analyzed independently due to the limitations of the plot design and layout. Regression, multiple regression, stepwise (R^2) regression analysis, and Pearson correlation coefficients were assessed on the variables in this experiment to determine if they correlated using PROC REG and PROC CORR of (SAS 9.4 Cary, NC).

Results and discussion

Illinois Soil Nitrate Test (ISNT):

MGT showed a highly significant effect on ISNT in the high tunnel plots *($p=0.008$),* while showing slightly differences on ISNT in field plots ($p= 0.076$) (Figure 3- 1). Overall, organic ISNT values (206.7 and 181.5) mg. kg^{-1} were greater than conventional values (182.9 and158.3) mg. kg^{-1} in both high tunnel and field respectively. Moreover, neither the high tunnel nor field plots showed a statistically significant effect for fertility (Table 3-1). The lack of detectable differences in fertility treatments is consistent with the findings of (Ruffo et al., 2005) where N fertilizer treatments didn’t have a significant effect on ISNT in any plots where samples were collected in the same year as N fertilization. Furthermore, Marriott and Wander (2006b) observed no difference in ISNT values between organic systems receiving composted manure and organic systems whose fertility was based solely on legumes.

MGT also showed significant effect on organic matter concentration where the organic system had higher OM (4.01 and 3.63) mg. kg $^{-1}$than did conventional (3.62 and 3.04 mg.kg^{-1}) in both field and in high tunnel respectively (Figure3-2). This agrees with a study conducted by (Schlegel, 1992) where composted manure increased soil organic matter with increasing compost application. FRT had no significant effect on OM concentration in both field and high tunnel (Table 3-2).

Total N (Figure3-3), and total C (Figure3-4) concentration also was significantly higher under organic MGT in both field and high tunnel plots as compared to conventional plots (Table 3-3). In support of this finding, the Marriott and Wander (2006a) research reported increased total N concentration in organic management compared to conventional. Also in support, Eghball and Power (1994) conclude adding manure or compost will generally increase soil organic matter and therefore should increase the potential of the soil to supply N. Eghball and Power (1999) estimated 8% N availability from compost in the first residual year after application while (Paul and Beauchamp, 1994) reported 2.9% N recovery in the first residual year and 5.5% in the second residual year. Overall, the statistical effect of FRT level was significant for total N and total C for both field and high tunnel as pre-plant compost application showed a higher total N and total C than control (cover crop).

When the ISNT was originally developed, a critical value of 225-235 mg kg^{-1} or higher based on the depth of soil samples collected indicated corn would be non-responsive to N fertilization (Hoeft et al., 2001; Khan et al., 2001; Mulvaney et al., 2006). If the ISNT estimates a labile fraction of soil N associated with organic matter, test values should be higher in surface samples. This was confirmed by Dolan et al (2006) and Khan et al (2001) who found the highest ISNT values were obtained from 0-15 cm soil samples and that a decrease occurs with greater depth. Based on results from (Khan et al., 2001), our ISNT values were below the proposed critical value (225 mg.kg^{-1})for both pre-plant fertility treatments (compost or synthetic application) and control (cover crop), which is associated with responsive sites that are low and need additional N taking into consideration that tomato N requirement is about half of that needed by corn.

Since the ISNT measures a labile fraction of organic N, then the test values should vary with time. Also, according to Mulvaney et al., (2006), the time of sampling has a significant effect on ISNT. In our study, the soil samples collected for ISNT were taken in December of 2010. In a study to compare the ISNT of soil samples before and after 8 weeks incubation, (Khan et al., 2001) found that ISNT consistently declined upon incubation. In a study conducted by Mulvaney et al (2006) to compare the ISNT of soil samples collected in late November and early April from five sites under continuous corn, ISNT was found to be 3.5% to 12.6% higher for spring sampling presumably owing to microbial decomposition of crop residues over winter. To conclude then, the potential risk of identifying a non-responsive soil as responsive on the basis of a lower ISNT value has led (Mulvaney et al., 2006) to recommend that sampling for the ISNT is best done in the fall. Therefore, in our study, if the ISNT had been performed earlier than December (for example, late fall), we may have observed a higher test value.

Soil incubation tests:

The lab incubation study evaluating potentially mineralizable nitrogen (PMN) indicated that MGT effect was significant in high tunnel ($P=0.008$) but not in the field (Figure 3-5), where the organic system had significantly higher PMN (22.5 mg.kg^{-1}) than the conventional (19.04 mg.kg^{-1}). Also, each MGT system showed no fertility effect on PMN where fertility treatments demonstrated very little fluctuation over the eight weeks of incubation (Table 3-4). This means that the effect of compost application from 2007-2010 was no different from the effect of the synthetic fertilizer, considering that the organic plots (both control and pre-plant fertility treatments) were under compost application since 2007. Ultimately, the incubation procedure for the organic soil amended with compost in high tunnel plots gave the highest PMN value (24.94 mg N kg$^{-1),}$ while the lowest value (11.54 mg N kg^{-1}) accrued to the conventional soil with control treatment (cover crop) in the field plots.

Overall, total N and total C were significantly affected by MGT and fertility with no significant interaction. In particular, OM, total C, and total N were significantly higher in organic systems in both field and high tunnel plots while total N was significantly higher in pre-plant fertility treatment than control in both environment systems. This can be attributed to greater C and N inputs via composted manure application over the years. Indeed, similar results have been reported from other studies of long term fertilization in cropland soils (Blair et al., 2006; Giacometti et al., 2013). Specifically, the amounts of N mineralized from the incubated soil samples increase with increasing organic matter. In our study, OM showed a strong correlation to PMN in field plots ($P=0.005$) (Table 3-5) but not in high tunnel plots (Table 3-6) while total C and total N showed a significant correlation with PMN ($P= 0.0004$ and $P=0.005$) in high tunnel plots, respectively. Both carbon and nitrogen dynamics are relevant to consider because C and N are the main determinants of OM decomposition rate (Grigatti et al., 2007).

Incubation tests are time consuming, labor intensive, and the results are often poorly reproducible because results depend on characteristics of the specific soil used for testing such as pH, soil texture, initial OM content, and nutrients content and because some factors are not easily standardized such as soil porosity and soil moisture content. Therefore, we tested for any correlation between the ISNT and PMN. Our study showed that ISNT strongly correlated to PMN in field plots ($P<0.0001$) with the Pearson regression analysis determined as $r^2= 0.88$ (Figure 3-6). Although correlation exists between ISNT and PMN in high tunnel plots ($P=0.039$), the Pearson regression analysis $r^2=0.35$ (Figure 3-7) was not strong enough to use as a practical means to predict the PMN. All correlation analysis *p*=values are presented in (Table 3-5) for field and (Table 3-6) for high tunnel plots.

In our study, the strong correlation between soil OM content and ISNT in field plots suggests that the ISNT measures a constant fraction of the soil organic nitrogen rather than the readily mineralizable nitrogen component. This was supported in a study by Klapwyk and Ketterings (2006) who found a strong relationship ($r^2=0.94$) between ISNT and soil OM. Klapwyk and Ketterings (2006) reported that the ISNT alone was not effective in explaining differences in corn yield response to added N; however, when the ISNT values were combined with soil OM measurements, the resulting model was able to separate nitrogen from responsive sites from that of unresponsive sites.

In a study conducted by Mulvaney et al (2006) to evaluate the consistency of the ISNT for predicting the need for N fertilization in corn, the test failure rate was 27%, which was due to various factors that decreased N availability or crop N uptake including the use of winter rye

(*Secale cereal* L.) cover crop and moisture stress during the growing season. In our study, winter rye was used every fall from 2007- 2010 as a cover crop between the two vegetable crops (tomato and pac choi), which apparently could have some undesirable characteristics including N immobilization following incorporation of non-leguminous residue (Holderbaum et al., 1990; Kuo et al., 1996; Wagger, 1989a; Wagger, 1989b).

Finally, the reason that field PMN values were higher than high tunnel values might be due to the fact that high tunnel plots were limited in irrigation between October and December prior to soil sampleing. This may be explained by maximum aerobic microbial activity and N mineralization normally occurring between 50% and 70% water filled pore space, which could lead to an accumulation of NH_4^+ or NH_3^- since the process of nitrification is inhibited, promoting greater potential for NO_3^- loss through denitrification (Myrold, 2008). However, drying and rewetting of soil may increase mineralization of carbon and N form biomass derived substrate and other organic materials made available by the soil disruption (Van Gestel, 1993). Soil microbial activity is further influenced by the interaction between moisture and temperature. In general, N mineralization is more responsive to temperature when moisture content is favorable for the process (Sierra, 1997).

Since these factors might have affected the ISNT results in our study, more studies are warranted before researchers can use the ISNT as a PMN predictor.

Conclusion

The results indicated that ISNT concentration values for all soil samples taken from field or high tunnel plots under organic or conventional systems with control and pre-plant fertility treatments were below the proposed value for corn crop suggested by (Khan, 2001). However, ISNT was found to correlate with PMN with the stronger correlation in field plots rather than in high tunnels plots. The results also showed that the ISNT strongly correlated with OM in the field plots. However, fertility effect was not significant for both ISNT and PMN for both field and high tunnel plots, which suggests that the long term compost application (2007-2010) didn’t have much effect on available nitrogen in the soil. On the other hand, fertility did show a significant effect on total C and total N in organic systems of both field and high tunnel plots, which could be attributed to greater C and N inputs from the composted manure. The no effect result for the conventional system could be related to the lower C input or N leaching in the field plots, so again, more studies are warranted before researchers can use the ISNT values as a predictor for PMN.

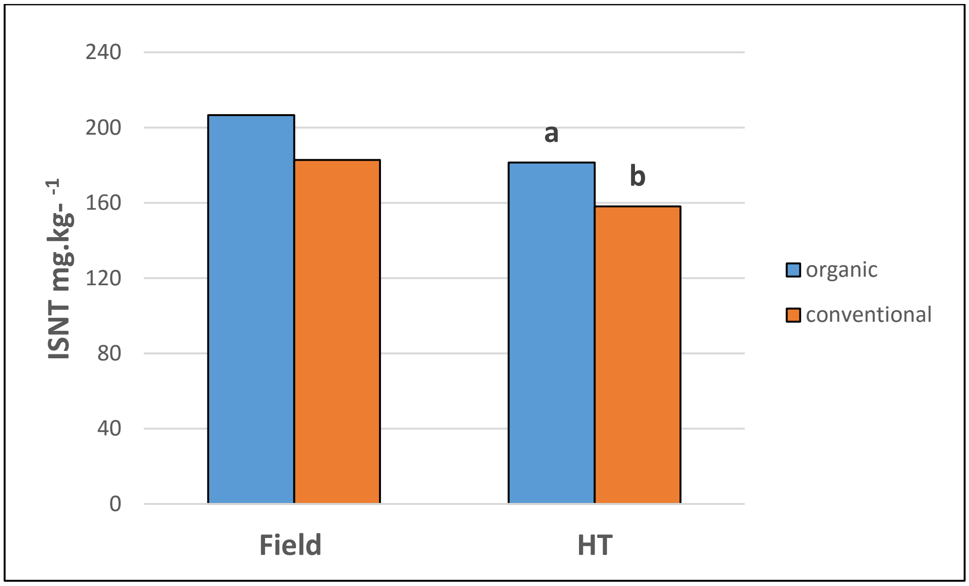

Figure 3-1: Illinois Soil Nitrate test (ISNT) for 2010 tomato plots in field and high tunnel (HT) plots in organic and conventional systems "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

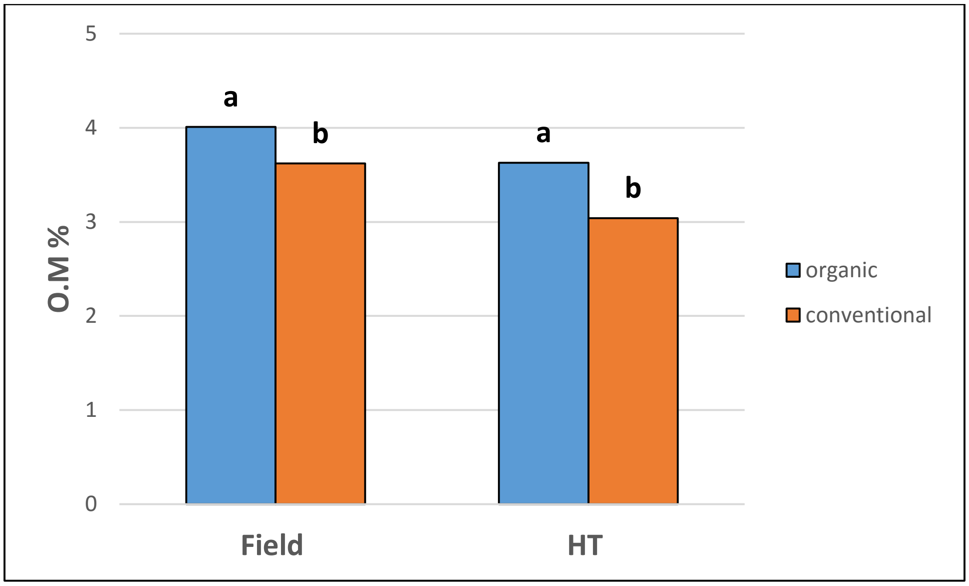

Figure 3-2: Percentage of organic matter for tomato soil in field and high tunnel (HT) plots for organic and conventional systems. "Means sharing the same letters are not significantly different from each other (Tukey's, P<0.05)"

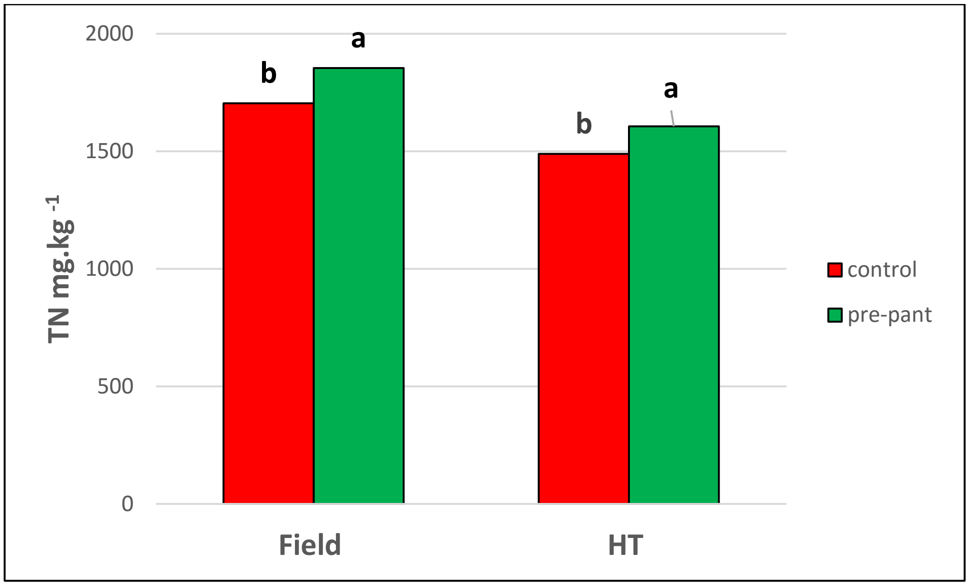

Figure 3-3: Total nitrogen (TN) mg. kg^{-1} for 2010 tomato plots in field and high tunnel plots at 2 different fertility rates (control and pre-plant application). "Means sharing the same letters are not significantly different from each other (Tukey's HSD, P<0.05)"

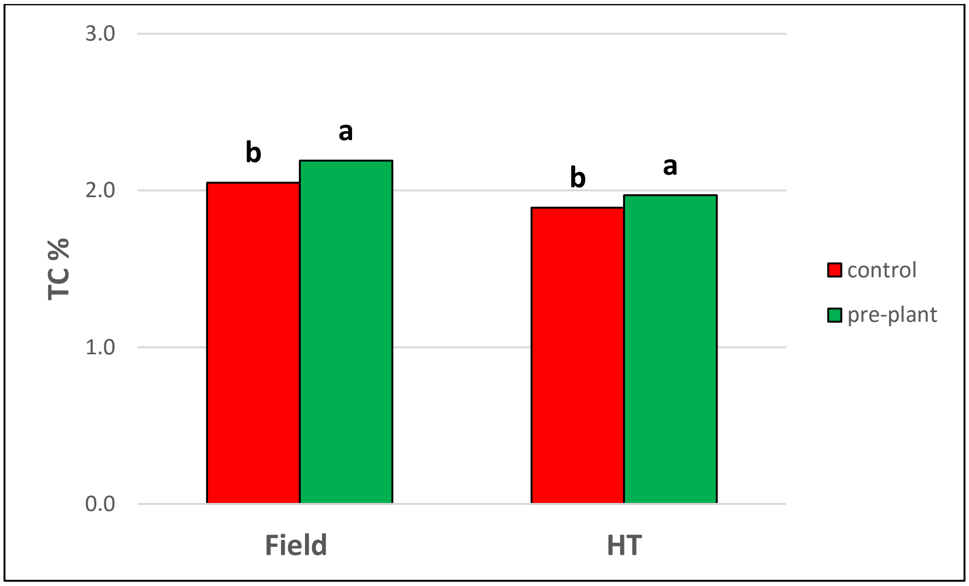

Figure 3-4: Percentage of total carbon (TC) mg. kg $^{-1}$ for 2010 tomato plots in field and high tunnel (HT) plots at 2 different fertility rates(control and pre-plant application). "Means sharing the same superscript are not significantly different from each other (Tukey's HSD, P<0.05)"

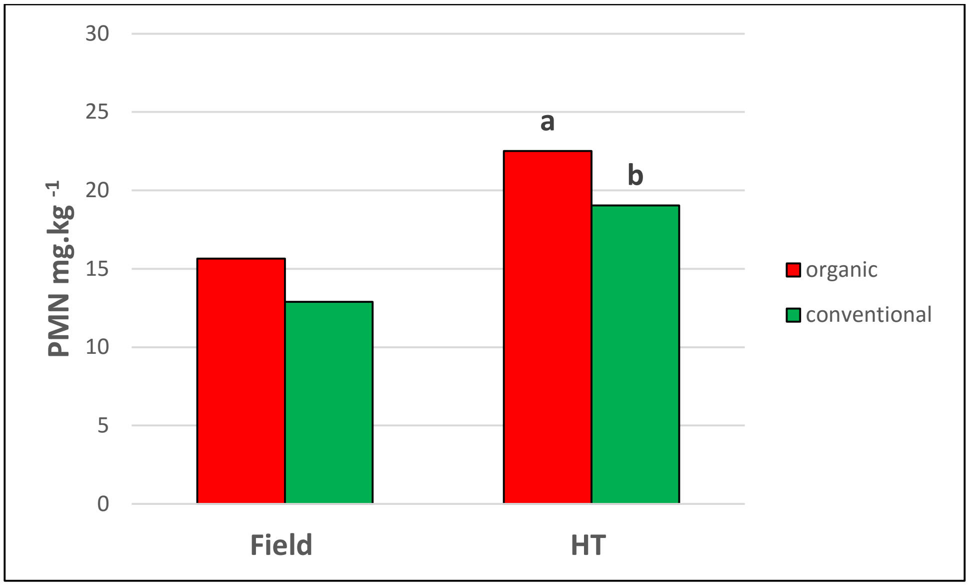

Figure 3-5: Potentially mineralizable nitrogen mg.kg $^{-1}$ for 2010 tomato plots in field and high tunnel (HT) plots at 2 different fertility rates (control and pre-plant application) "Means sharing the same superscript are not significantly different from each other (Tukey's HSD, P<0.05)"

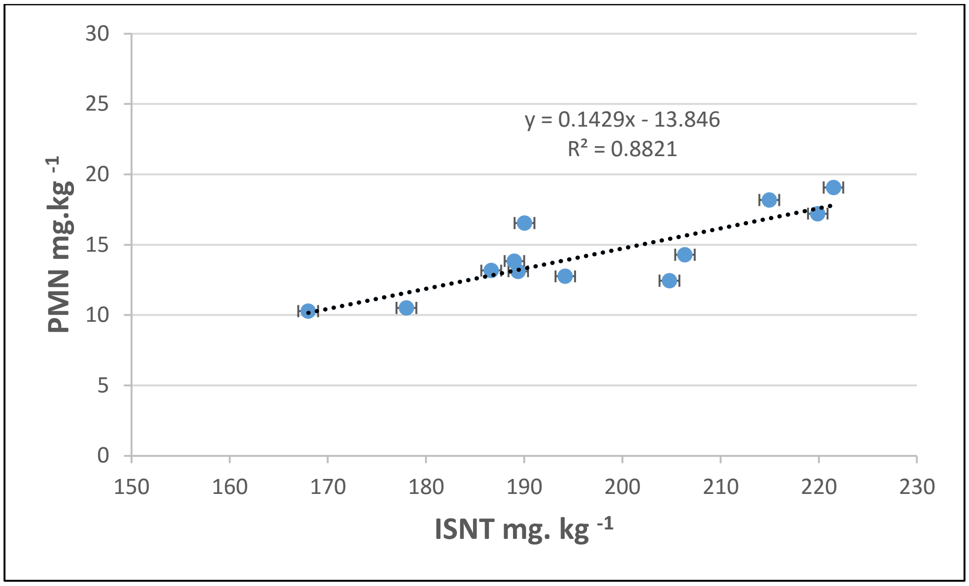

Figure 3-6: Pearson correlation analysis between Illinois Soil Nitrate Test (ISNT) and potentially mineralizable nitrogen (PMN) for tomato soil in field plots

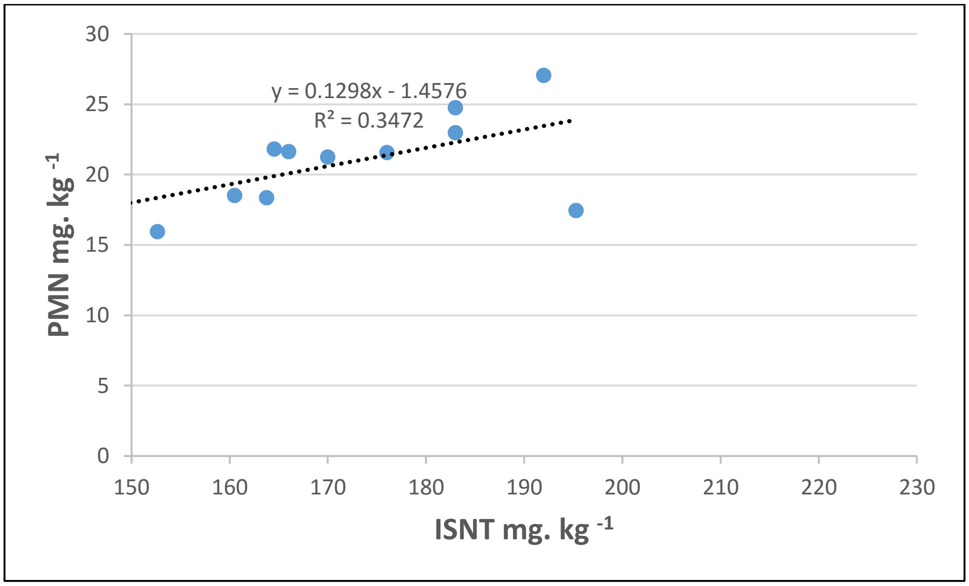

Figure 3-7: Pearson correlation analysis between Illinois Soil Nitrate test (ISNT) and potentially mineralizable nitrogen (PMN) for tomato soil in high tunnel plots

Table 3-1: Statistical analysis (p-values) for parameters; management (organic or conventional), fertility (control or pre-plant application) and their interaction using Illinois Soil Nitrate test (ISNT), for both field and high tunnel plots

	ISNT	
	Field	**High tunnel**
Management	0.0760	0.0080
Fertility	0.2540	0.4260
Management * fertility	0.7370	0.5250

Table 3-2: Statistical analysis (p-values) for parameters; management (organic or conventional), fertility (control or pre-plant application) and their interaction using organic matter (OM), for both field and high tunnel plots

	Organic matter (OM)	
	Field	**High tunnel**
Management	0.0290	0.0030
Fertility	0.4440	0.9730
Management * fertility	0.7780	0.6430

Table 3-3: Statistical analysis (p-values) for parameters; management (organic or conventional), fertility (control or pre-plant application) and their interaction using total nitrogen (N) and total carbon (C), for both field and high tunnel plots

	TN		**TC**	
	Field	**High tunnel**	**Field**	**High tunnel**
organic	1880.5^{a}	1737.7^{a}	2.24^{a}	2.08a
conventional	1677.2^{b}	1359.7^{b}	2.01^{b}	1.75^{b}
p-value	0.0030	0.0001	0.012	0.0002
Control	1703.8^{b}	1488.2b	2.05b	1.89^{b}
Pre-plant	1853.9^{a}	1606.5a	2.19a	1.97^{a}
p-value	0.0150	0.0350	0.0500	0.0350

Table 3-4: Statistical analysis (p-values) for parameter; management (organic or conventional), fertility (control or pre-plant application) and their interaction using potentially mineralizable nitrogen (PMN) for both field and high tunnel plots

	PMN	
	Field	**High tunnel**
Management	0.4010	0.0080
Fertility	0.5760	0.8690
Management *fertility	0.5520	0.1240

Table 3-5: Pearson correlation p values for field plots for potential mineralizable nitrogen (PMN), Illinois Soil Nitrate test (ISNT), organic matter (OM), total carbon (TC), and total nitrogen (TN)

	PMN	**ISNT**	**OM**	**TC**	**TN**
PMN		<.0001	0.0050	0.2360	0.2760
ISNT	<.0001		0.0050	0.3980	0.4020
OM	0.0050	0.0050		0.1320	0.1540
TC	0.2360	0.3980	0.130		<.0001
TN	0.2760	0.4020	0.1540	<.0001	

Table 3-6: Pearson correlation p values for high tunnel plots for potential mineralizable nitrogen (PMN), Illinois Soil Nitrate test (ISNT), organic matter (OM), total carbon (TC), and total nitrogen (TN)

	PMN	**ISNT**	**OM**	**TC**	**TN**
PMN		0.0390	0.2730	0.0004	0.0050
ISNT	0.0390		0.0780	0.0040	0.0020
OM	0.2730	0.0780		0.0150	0.0110
TC	0.0004	0.0040	0.0150		<.0001
TN	0.0050	0.0020	0.0110	<.0001	

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