MANIPULATING ORGANIC AMENDMENTS TO IMPROVE POTATO PRODUCTIVITY AND SOIL QUALITY

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Crop and Soil Sciences

2011

ABSTRACT

MANIPULATING ORGANIC AMENDMENTS TO IMPROVE POTATO PRODUCTIVITY AND SOIL QUALITY

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Organic amendments are well-known for increasing crop production and improving soil quality. This study was designed to examine organic amendment effects on potato systems in Montcalm County, Michigan. In the first chapter, I investigated the effects of poultry compost application and cover crops in different potato rotations on yield and soil quality by establishing a laboratory experiment on soils collected in 2006. In the second chapter, I organized a field experiment at the Montcalm Research Farm to examine the effects of poultry compost application rates and timing on potato yields and soil quality in 2009 and 2010. The result from the first study showed that compost applications at a low rate (5.6 Mg ha^{-1}) significantly increased potato yield in a potato-snap bean system both with and without rye cover and promoted soil microbial activity and soil characteristics. Additionally, clover cover crop significantly increased N in the light fraction as well as soil microbial activity in a potato-wheat system. In the second experiment, the compost applications were consistent across 2 years in increasing potato yield and also increasing soil pH, inorganic N, microbial biomass and enzyme activities. Scab incidence was negatively correlated to soil aggregate size > 1000 μm, net N mineralization, soil C&N, and cellobiohydrolase, glucosidase, and acid phosphatase activities. However, scab reduction was followed with high rates of compost application in the first year but not in second year. These results suggest that the combination of a low rate of compost with rye cover in potato-snap bean system will improve potato yields and soil quality.

Dedicated to my parents who inspired my thinking and encouraged me to overcome all the challenges

ACKNOWLEDGEMENTS

First, I would like to thank Dr. Stuart Grandy, my major advisor, for the opportunity to work on his project, his useful instructions, and for patience during editing and revising. Without his dedication and support, I would not have been able to finish this master's degree. I am also grateful to my committee members, Dr. Sieglinde Snapp and Dr. Jianjun Hao, for their guidance and support. I am thankful for 2 years of support from the project "Agricultural Scientific Technology (AST)", funded by collaboration between the Vietnam Ministry of Agricultural and Rural Development (MARD) and Asia Development Bank (ADB). Also, my thanks go out to the Potato Industry Commission for providing support for my project.

I also would like to thank Dr. Kyle Wickings for his kindness in guiding me through the soil analysis methods. Many thanks to Dr. Grandy's lab group, who helped me out with soil collection and lab work. I would like to thank Bruce Sackett and Dr. David Douches and his team for helping with potato harvesting at Montcalm Research Farm and potato grading at MSU. Thanks also to Bill Widdicombe for help with corn harvesting. I would like to thank David Weed and Steve Hamilton's lab for help using the TOC instrument. Thanks to Wei Wang and Juan Munoz for help with statistical analyses. Thanks to all other MSU's professors and friends for advanced information and idea exchange from classes. I would like to acknowledge Jesse Sadowsky for the useful discussions and sharing thoughts about research. I also would like to thank my friends at the Bower-Coop house where I lived. My gratitude also extends to Vietnamese friends from the Association of Vietnamese Scholars and Students (AVSS) at MSU for the good times after work during my stay in East Lansing. Lastly, I would like to thank my parents and sister for their love and support, and to friends and colleagues in Vietnam who encouraged me during my 3 years studying.

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CHAPTER 1

Integrating alternative potato cropping systems with manure additions to improve soil quality and yields

Abstract

The use of compost, cover crops and crop rotations has long been known as an effective tool for reducing environmental impact while also improving soil quality and increasing crop productivity. In this study, the effect of applying compost, an economical carbon input, at a low rate (5.6 Mg ha^{-1}) in combination with cover crop and crop rotation in a potato farm was evaluated as a strategy to increase potato yield and improve biological characteristics of sandy soil in Michigan. The trial, which was part of a long-term ecological research study, was a two-year rotation of potato with six different treatments; these included potato-snap bean and potato-wheat systems integrating with a rye or red clover cover crop and poultry compost application. The soils were collected after compost application but before potato planting in 2006, air-dried, and kept at room temperature and humidity until analysis. The results of a laboratory incubation experiment indicated that compost application, even at the low rate, had a significant impact on potato yield and soil microbial activity. Rye cover crop increased potato yield in 2005 but not in 2006. Scab incidence was negatively correlated to soil aggregate size > 1000 µm, net N mineralization, soil C & N, C in light fraction organic matter, cellobiohydrolase, β-1,4-glucosidase, and acid phosphatase. Both compost application and presence of a cover crop increased C and N mineralization. Red clover significantly increased microbial activity and N in the light fraction. The overall results suggested the use of a potato-bean rotation with a rye cover crop and compost application as an optimal system for Michigan potato growers.

1. Introduction

Michigan grows about 17,000 ha of potatoes (*Solanum tuberosum* L.) annually, more than any other vegetable crop (MDA, 2009). Michigan's potato industry faces many production and environmental challenges such as declining soil organic matter concentrations, depressed soil biological activity, and intense pressure from diseases such as stem canker, black scurf, and common scab (Hao *et al.*, 2009; Po *et al.*, 2009; Larkin *et al.*, 2010). These challenges are common to other potato-growing regions as well, where declines in soil structural stability, organic matter concentrations, productivity and severe disease problems have been frequently reported (Grandy *et al.*, 2002; Rees *et al.*, 2002; Carter *et al.*, 2003).

Organic matter applications (e.g. compost and manure) and crop rotation are known to promote soil microbial activity and increase plant productivity (Acosta-Martínez *et al.*, 2007; Larkin, 2008) and can alter the soil physical environment by promoting aggregation and reducing bulk density (Celik *et al.*, 2004; Hemmat *et al.*, 2010). Javier *et al.* (2007) suggested that measuring soil attributes such as these indicators will advance understanding of the relationships between management, soil properties, and plant disease. For example, soil enzymes that function as microbial catalysts for decomposing and transforming organic matter (Sinsabaugh *et al.*, 2008) were considered an indicator of microbial nutrient demand (Allison, 2005), and have been frequently correlated with total microbial activity (Sinsabaugh *et al.*, 2002; Caldwell, 2005). Bonanomi *et al.* (2010) found that disease suppression often increased during decomposition and suggested that this may be related to microbial activity during organic matter decomposition. Lozano *et al.* (2009) also suggested that compost decomposition may stimulate competitive interactions that suppress disease.

Potato common scab, caused by multiple species of *Streptomyces*, with *S. scabies* being dominant, is a common tuber disease of potatoes worldwide (Wanner, 2004; Loria *et al.*, 2006). *Stretomyces scabies* can have a significant impact on marketable yield by causing corky lesions on the tuber surface (Hao *et al.*, 2009; Wanner and Haynes, 2009) and is a long-term production challenge because the pathogen can survive in the soil and plant debris for more than 10 years (Conn and Lazarovits, 1999). These species can survive in the soil even under extreme environments such as high temperature and a wide range of moisture conditions, and can produce a phytotoxin, thaxtomin, which inhibits biosynthesis of cellulose (Wach *et al.*, 2005; Loria *et al.*, 2008). To date, many studies seeking controls for common scab in potato systems have been focused on cultural practices such as changing soil pH or using crop rotation; however, these methods are not effective in preventing the high crop losses observed in many regions (Loria *et al.*, 2006). Breeding scab-resistant potato varieties could prove effective but so far has not been achieved.

Recently, producers in Michigan and elsewhere have begun experimenting with crop rotations and organic amendments such as compost and manure to improve soil biological activity (Snapp *et al.*, 2007), and recent research points to possible links between soil management, biological activity, disease suppression, and crop yield (Bailey and Lazarovits, 2003; Larkin and Honeycutt, 2006; Larkin, 2008). For example, Conn and Lazarovits (1999) found that the use of chicken and swine manure resulted in a significant decline in potato common scab. Larkin (2008) observed that using crop rotation with biological amendments and compost application can decrease soilborne disease and increase potato yields. Carter *et al* (2003) found that potato crops rotated with red clover significantly reduced common scab infection compared to other cover crops such as ryegrass and barley. Griffin *et al* (2009) also

observed that rotating potatoes with cover crops such as red clover and ryegrass affected soil-borne disease: red clover in particular suppressed both *Rhizoctonia* and common scab in potato. Crop rotation may also be beneficial for improving soil structure, increasing organic matter, and providing resilience to potato cropping systems (Carter *et al.*, 2009), in contrast to continuous cropping with a single host plant, which can deplete soil resources and lead to problems with soil-borne pathogens (Janvier *et al.*, 2007).

There remain many challenges to using organic amendments and crop rotations to improve soil quality, increase yield and suppress disease. Firstly, the effects of organic amendments on plant diseases are often inconsistent. Organic matters with the same inputs sometimes suppress pathogens and reduce plant disease, but other times have the opposite effect (Bonanomi *et al.*, 2010). Furthermore, using compost and crop rotations can be expensive, time-consuming, and labor-intensive. One way to minimize the expense of organic amendments is to use very low application rates; however, many studies to date have used very high rates that are not economical for most growers (Grandy *et al.*, 1998; García-Gil *et al.*, 2000; Abbasi *et al.*, 2002; Hargreaves *et al.*, 2008). To reduce the cost associated with organic matter additions, Snapp *et al.* (2003) recommended combining compost use with cover crops. In Michigan, potato growers are widely interested in using organic amendments to enhance soil biology and have determined that application rates below ~5.6 Mg ha^{-1} are economical. My overall objective was to determine the effect of low rates of compost amendment in combination with different crop rotations and cover crops on soil biological processes and potato yields and quality.

2. Materials and methods

2.1. Site description and experimental design

The field experiment took place in a sandy loam soil at the Montcalm Potato Research Farm, Montcalm County, Michigan, USA (Longitude: 85° 10' 32", Latitude 43° 21' 12"). My study occurred during the second phase of a long-term research project begun in 2001. The research was divided into two phases with Phase 1 started in 2001 and Phase 2 was started in 2002. The main cropping systems were two-year rotations alternating one year of potato with one year of snap bean or wheat. These systems were integrated with rye and red clover winter cover crops and compost resulting in six different treatment systems relevant to our region (Table 1.1). The first treatment was potato with bare soil for winter in the first year followed by snap bean with bare soil for winter in the second year. The second treatment was potato with rye cover for winter in the first year then snap bean with rye cover for the second year. The third treatment was potato with bare soil for winter in the first year and snap bean with bare soil for winter in the second year and compost application before potato planting. The forth treatment was potato with rye cover in the first year and snap bean with rye cover in the second year and compost application before potato planting. The fifth treatment was potato with wheat cover for winter in the first year and wheat with rye cover for winter in the second year. The last treatment was potato with wheat cover for winter in the first year and wheat with red clover for winter cover in the second year. All the treatments were established in a randomized complete block design with four replications, a design which allows for the examination of the effects of compost and cover cropping, and their interaction, in a widely used rotation (potato-bean) with extensive external inputs and low soil organic matter concentrations. The design also permits a comparison of the potato-bean rotation to an alternative rotation (potato-wheat). This alternative rotation is used by some Michigan potato growers and replaces snap beans with a crop that enriches the soil with more residual C that has a higher C:N ratio and lower turnover time than

beans. The compost consisted of decomposed poultry manure (C: 50%, N: 4%, P_2O_5: 3%, K_2O: 2%, and Ca: 8%) and was applied on 16 May 2006, before potato planting at a rate of 5.6 Mg ha^{-1}. The C:N ratio of the compost was 12, the lignin content in compost was 4.2%, and the cellulose was 22.1%.

Snowden cultivar potato tubers were cut into pieces of approximately 56 g each and planted on 1 June 2006 at a space of 30.5 cm within row and 86 cm between rows. Each plots was rectangular, measured 5.5 by 16.7 m and contained six rows of potatoes (Nyiraneza and Snapp, 2007; Po *et al.*, 2009). Additional urea fertilizer was applied multiple to soils at planting, hilling, and tuberization to maintain available N at 224 kg ha^{-1} for all the treatments. Thus, N credits were calculated based on the amount of available N in compost and decomposed N from cover crops (Nyiraneza and Snapp, 2007; Po *et al.*, 2009). For instance, decomposed N from rye was about 11 kg N ha^{-1}, from red clover was about 30 kg N ha^{-1} and from compost was about 45 kg N ha^{-1}. Therefore, the inorganic N amounts added were 224 kg N ha^{-1} for potato-bean; 213 kg N ha^{-1} for potato-bean with rye and potato-wheat with rye; 179 kg N ha^{-1} for potato-bean with compost; 168 kg N ha^{-1} for potato-bean with rye and compost; and 194 kg N ha^{-1} for potato-wheat with clover. Potassium (K_2O) was added at a rate of 201 kg ha^{-1} before planting and an additional 38 kg P ha^{-1} was added at planting as starter fertilizer (P_2O_5).

Soil samples were collected at 0-20 cm depth just before potato planting on 1 June 2006. All the soils were air dried at room temperature. Potato plants were killed on 14 Sept 2006 using Matrix^{TM} (Rimsulfuron) at 0.98 L ha^{-1} (0.25 L ha^{-1} a.i.) and Poast^{TM} (Sethoxydim) at 1.23 L

ha^{-1} (0.55 L ha^{-1} a.i.) and harvested on 15 Oct 2006 using a one-row harvester. Potatoes were harvested from two 1.5 m middle sections of each row in each plot to determine tuber yield, in the same areas that were designated earlier in the season and used to conduct plant population counts. Specific gravity (weight-in-air/weight-in-water method) was determined on harvested tubers. Tubers were graded based on USDA market classes: U.S #1 diameter > 5.1 cm; size Bs diameter < 5.1 cm; tubers with external physiological deformities were placed in a defect category.

Potato scab was assessed using previously published protocols used at our experimental site (Snapp *et al.*, 2007). According to this method, the presence or absence of scab incidence was assessed on all tubers from one harvested row. If the tubers had visible scab that covered more than 50 % of the tuber (which would reduce marketability), the weight of those severely infected potatoes was divided by the total weight of all harvested tubers, allowing the percentage of severe scab incidence to be expressed by weight.

The potato yield and scab incidence from phase one of the rotation in 2005 was also collected to compare with the potato yield and scab incidence in 2006. In 2005, poultry compost was applied on 17 May 2005 and potatoes were planted on 25 May 2005. Potato vine desiccant was applied on 30 Aug 2005 and potato was harvested on 20 Sept 2005. Temperature and rainfall in 2005 and 2006 for the studied area were collected from the Entrican Station website at http://enviroweather.msu.edu.

2.2. Aggregate stability

Water stable aggregates were determined by wet sieving (Robertson *et al.*, 1999; Grandy *et al.*, 2007b) through three different sieves, 1000 µm, 250 µm, and 53 µm resulting in four

aggregates size classes: < 53 µm, 53 - 250 µm, 250 - 1000 µm, and > 1000 µm. Aggregates were wetted before sieving by placing 30 g of air-dried soil on a 125 mm paper filter paper (Whatman #1) in a Petri dish. Filter paper and soil were gradually wetted with about 30 mL H_2O using a pipette. Samples then were covered with parafilm to eliminate evaporation and kept at room temperature for 24 h to permit capillary wetting of the soil. After wetting, soil was first placed on a 1000 µm sieve in water for 3 min before the sieve was slowly moved up and down 3 cm 15 times for 1 min. All the soil that passed through the 1000 µm sieve was carefully transferred to the 250 µm sieve and sieved again. The same procedure was repeated with the 53 µm sieve. The soil remaining in each sieve was collected, dried at 60 ^{o}C and weighed.

Sand contents were determined by dispersing the soil in each aggregate size class with 0.5 % sodium hexametaphosphate on a shaker table for 24 h at 200 rpm. The samples were then sieved to pass through a 53 µm sieve. The sand was collected, dried and weighed and the sand free aggregate mass was calculated as follows: (aggregate - sand)/ (total soil - sand)*100.

2.3. Soil pH

Soil pH was determined in water by using a 1:2 w/v ratio according to Robertson *et al* (1999). Briefly, 15 g of soil was weighed and mixed with 30 mL DI H_2O. The slurry was stirred for 1 min and settled for 30 min before measuring pH using a probe (SevenEasy pH Mettler Toledo, Switzerland).

2.4. Soil C and N

Light fraction soil organic matter (LF) was determined by using density separation methods (Robertson *et al.*, 1999; Grandy *et al.*, 2007a). Twenty grams of air dried soil were weighed into a 50 mL centrifuge tube with 45 mL of sodium polytungstate (NaPT) at a density of 1.7 g/cm^3. The samples were capped and shaken for 30 min on a shaker table at 200 rpm before centrifuging for 20 min at 5000 rpm. LF was aspirated from the surface of the samples using a vaccum pump and subsequently rinsed with deionized water (approximately 400 mL) and dried at 60^{o}C for 48 h. Total C and N in both soil and LF were determined by combustion in an elemental analyzer (Elemental Combustion System – Costech Instruments).

2.5. C and N turnover

A laboratory incubation experiment was designed to determine potential soil respiration rates, N mineralization rates, and associated enzyme activities. Twenty grams of soil were placed into 60 mL serum vials and moistened to 60 % water holding capacity with soil moisture contents determined and monitored gravimetrically throughout the experiment. Water was periodically added to individual vials to maintain a constant moisture content. Vials were capped with a rubber septum and incubated in the dark at 25^{o}C. Two identical sets of vials were established for all the samples. One set was used to determine CO_2 flux and, at the end of the experiment, enzyme activity. The other set was destructively sampled after 30 d for determination of enzyme activity and N mineralization rates. Every 2-3 d for 145 d, all vials were opened for ~30 min to release accumulated CO_2. CO_2 flux (μg CO_2-C/g soil/day) was determined by taking a 1 mL sample of headspace three times over 60 min (0, 30 and 60 min) and measuring CO_2 on an infrared gas analyzer (LICOR-820). N mineralization rates were

determined by measuring the difference in soil NH_4^+ and NO_3^- concentrations at the beginning of the incubation and after 30 d (Robertson *et al.*, 1999). Inorganic N was extracted by shaking 10 g of soil in 50 mL of KCl 1M for 30 min and then determined colorimetrically using an autoanalyzer (Lachat Instruments, Milwaukee, WI).

2.6. Determination of enzyme activity

The activity of five extracellular soil enzymes was examined after 30 and 157 d using previously described methods (Grandy *et al.*, 2007a; Saiya-Cork *et al.*, 2002): β-1,4-N-acetyl glucosaminidase (NAG), cellobiohydrolase (CBH), β-1,4-glucosidase (BG), acid phosphatase (PHOS), and phenol oxidase (PHENOX). One gram of soil was homogenized in 125 mL sodium acetate 50 mM buffer at pH = 6 (to reflect the average pH of all the soil samples). The suspension was continually stirred and 200 µL aliquots were transferred by pipette into the appropriate column of a 96-well microplate. Buffer and different substrates were added appropriately following the method described in Saiya-Cork *et al* (2002) and Grandy *et al* (2007) prior to incubation in the dark at 15 °C before analysis in a fluorometer. NAG, BG, CBH, and PHOS were analyzed fluorometrically (Fluoroskan Ascent, Thermo Scientific, Hudson, NH), while PHENOX was analyzed using colorimetric methods in a spectrophotometer (Multiskan Ascent, Thermo Scientific, Hudson, NH).

2.7. Statistical analysis

Statistical analysis was performed using a randomized complete block design one way analysis of variance (ANOVA) in a mixed model using SAS (Version 9.2, SAS Institute, 2008). Assumptions of normality were analyzed by PROC UNIVARIATE and equality of variance of

residuals was checked by Levene's test. Log transformation was applied if necessary to meet the assumptions of normality and equality of variance for the response variables. Comparison between treatment means was determined by using Fisher's protected LSD at $p < 0.05$ where treatment was the fixed factor and block was the random factor. The relationships between variables were performed by Pearson's correlation coefficient (r) matrices using the SAS model at $p < 0.05$.

3. Results

3.1. Soil characteristics

Compost application significantly increased soil pH from 6.10 in potato-bean treatment to 6.43 in potato-bean with compost and 6.51 in potato-bean with compost and rye cover crop (Figure 1.1). The soil pH in the potato-bean with rye cover was 6.20, which was not different from the pH in the potato-bean. There was no difference in soil pH among potato-wheat with rye cover, potato-wheat with red clover cover and potato-bean treatments.

Compost applications and cover crop use did not influence the proportion of sand-free aggregates between treatments. Sand-free aggregates in the 1000-4000 μm size class ($\mu = 21.2$ %) were dominant in all treatments, followed by the 250-1000 μm size class ($\mu = 5.9$ %) and the 53-250 μm ($\mu = 2.3$ %) size class.

There were no significant effects of organic management on total soil C and N. The total soil C ranged from 6.9 - 10.0 g C kg^{-1} soil and total soil N ranged from 0.59 - 0.88 g N kg^{-1} soil (Table 1.2). The concentration of C in the LF (Light Fraction) in potato-wheat with clover systems was significantly lower than in potato-bean, potato-bean with compost, and potato-bean with compost and rye cover crop. In contrast, the concentration of N in LF in potato-wheat with

rye was lower than in potato-bean with compost. There was no difference among ecosystems in the amount of LF C in the soil but the LF N in potato-wheat with clover cover crop soils was significantly higher than in the remaining systems, which did not differ from each other ($p < 0.05$). In contrast, there was no difference in the ratio of LF N to total soil N among treatments but there were significant differences in the ratio of LF C to total soil C (Table 1.2); this ratio was higher in potato-wheat with clover cover ($p < 0.05$) than in the other treatments, which were not different from each other. There was no difference in soil C:N ratio (ranging from 10.6 to 13.3) and LF C:N ratio (ranging from 21.0 to 24.4) among systems.

Net N mineralization potential in potato-bean with compost, potato-bean with rye cover and compost, potato-bean with rye cover, and potato-wheat with clover cover were significantly higher than in potato-bean treatment but were not significantly different from each other. The net N mineralization in the potato-bean with rye cover and compost was double that in the potato-bean treatment. Only the potato-wheat with rye cover was not different from potato-bean treatment (Figure 1.2).

Carbon mineralization rates differed among treatments (Figure 1.3). The respiration rates in the potato-bean with compost were significantly higher than in the potato-bean at both 0-30 d and 0-145 d. Similarly, the respiration rate in potato-wheat with clover cover crop system was significant higher than in the potato-wheat with rye system ($p < 0.05$). The potato-bean with rye cover was not different from potato-bean with rye cover and compost addition in both periods. The rates of CO_2 production for both periods were highly related to each other ($r = 0.94$). The C mineralized after 145 d in the treatment with compost application was approximately 20 % of total soil C; in other treatments mineralized C composed 9 to 15 % of total soil C.

There were no treatment effects on soil enzyme activities at 30 d and 157 d of incubation, although there was an overall trend ($p < 0.1$) towards higher activity at 30 d (Table 1.3). There was also a trend ($p < 0.1$) of higher NAG (chitinase) activity in compost treatments than in treatments without compost, and higher activity in the potato-wheat rotation with clover cover than in the potato-wheat rotation with rye cover crop. BG activity was 49 - 88 nmol h^{-1} g^{-1} dried soil and 45 - 80 nmol h^{-1} g^{-1} dried soil at 30 d and at 157 d, respectively. Similarly, CBH ranged from 11 - 24 and 8 - 22 nmol h^{-1} g^{-1} dried soil and PHOS ranged 150 - 349 and 102 - 167 nmol h^{-1} g^{-1} dried soil in 30 d and 157 d, respectively.

3.2. Potato yield and common scab incidence

Both the total yield (41.2 Mg ha^{-1}) and yield of US No.1 (37.4 Mg ha^{-1}) in potato-bean with rye and compost application was significantly higher than the other treatments in 2005 (Figure 1.4). Yields in potato-bean with compost were not different from potato yields in potato-bean with rye cover crop but both of them were still higher than yields in the potato-bean system. Potato yields in potato-wheat with rye and potato-wheat with clover were lower than the potato-bean system and did not significantly differ from each other.

The total yields and yields of US No.1-rated potatoes were higher in 2006 in the compost treatments than in potato-bean treatment (Figure 1.4). The total yield in potato-bean with compost was 33.6 Mg ha^{-1} and in potato-bean with compost and rye cover was 34.2 Mg ha^{-1}, which were almost double the yield of potato-bean system (18.2 Mg ha^{-1}). The rye cover crop did not influence potato yield in potato-bean systems. Potato-wheat with rye cover and potato-

wheat with clover cover crop did not differ from potato-bean. There was no difference in yields of potatoes of size B among treatments.

The treatment effect of scab incidence was not significant among the systems in both years, ranging from 70.0 to 90.2 % in 2005 and from 35.2 to 74.2 % in 2006 (Figure 1.5).

4. Discussion

4.1. The effect of organic amendments on potato yield and quality

The total potato yield and yield of size US No.1 demonstrated that relatively small applications of poultry manure compost (5.6 Mg ha^{-1}) can increase potato productivity. Compost application increased the yield of size US No.1 in potato-bean system by 20% in 2005 and 100% in 2006, and potato-bean with rye system by 25% in 2005 and 110% in 2006. The yields in 2006 were higher than previously reported for the potato-bean system. Po *et al.* (2009) reported comparable yields in potato-bean system of 29.3, 22.7, 31.4, and 25.6 Mg ha^{-1} in 2001, 2002, 2003, and 2004, respectively. They reported the highest yields in the potato-wheat with clover system and in the potato-bean with rye and hairy vetch system in 2003; these systems yielded about 40 % more than the potato-bean system. In contrast, the present study found that yields in potato-wheat with rye and potato-wheat with clover were either lower than (in 2005) or not different from (in 2006) potato-bean.

Compost application significantly increased potato yields in both 2005 and 2006. However, potato yields in all of the treatments in 2006 were lower than in 2005. Potato yields are affected by a wide range of biophysical factors including climate, soil physical and chemical characteristics, moisture, insects, and diseases. The higher yield in 2005 may be explained by the higher temperature that year relative to 2006 (Table 1.6). Additionally, the rainfall and number

of rainy days in 2006 was higher than in 2005; high soil water content can limit the availability of soil nutrients to plants which could account for the decreased potato yields observed in this year.

Cover crops influenced potato yield in 2005: the yield was higher with the presence of rye in potato-bean and potato-bean with compost systems. The difference between potato yields in 2005 and in 2006 suggested influences of other factors on potato yield. Po *et al* (2009) did not find any effect of rye cover in the potato-bean system from 2001 to 2004 and suggested that this may be because of differences in environmental conditions. The warmer temperature in 2005 may have provided better conditions for rye cover decomposition and the recovery of cover-crop derived N.

There was no scab reduction among the organic amendment treatments in both 2005 and 2006. Similar to previous studies (Hao et al, 2009), there was no correlation between common scab and potato yields, indicating that common scab did not affect potato yields. However, scab incidence in 2006 was lower than in 2005. Compost and cover crop can impact soilborne disease by altering soil microbial communities as a consequence of changing soil physical and chemical properties (Sarrantonio and Gallandt, 2003; Larkin et al., 2010). However, results have been mixed and organic amendments sometimes reduce certain diseases but increase others (Bailey and Lazarovits, 2003). Similar to the difference in potato yield, the difference of scab incidence between the two years may be explained by the difference of climate condition between the two years. The rainfall in 2006 was higher and more regular than in 2005 (Table 1.6), which may have increased the decomposition rate and microbial activity and reduced the *S. scabies* population.

4.2. The effect of organic amendments on soil biological processes

Compost application and cover crops are very important sources of soil C and N in potato systems. The compost in this study provided about 224 kg N ha^{-1} for the system and about 2.8 Mg C ha^{-1} C substrate for soil microbes. C mineralization rate has been used to indicate the potential turnover of organic matter and C sequestration (Wright *et al.*, 2008). Microbial activity, as approximated by respiration rate was higher when compost and clover cover crop were used in the potato systems (Figure 1.3). The C loss from mineralization after 157 d in the compost treatments was very high at 20% of total soil C; in the potato-wheat with clover system it was intermediate at 12%, and was lowest in the potato-wheat with rye system at 9%. These results are similar to those of Fortuna *et al* (2003) who found losses in total organic soil C of about 10% in 1994 and 8% in 1998. The soil was sampled before potato planting but after compost application; the addition of this new compost likely contributed greatly to the labile C pool. Rye cover crops also seemed to increase the labile C pool, as similar amounts of CO_2 were released in potato-bean with rye and potato-bean with rye and compost systems. Similar amounts of CO_2 were released in potato-bean and potato-wheat with rye cover systems; however, the potato-wheat with rye system released less CO_2 than potato-wheat with clover, suggesting that legume cover crops stimulate soil microbial activity much more than bare soil, or rye or wheat cover.

The use of rotations with cover crop and compost management also increases total soil N and minimizes the loss of N leaching (Fortuna *et al.*, 2003) because it enhances the amount and quality of residue input (Po *et al.*, 2009; Larkin, 2010). The net N mineralization is an important indicator of soil quality and is frequently positively related to organic matter decomposition processes (Bardgett, 2005). The net N mineralization in potato-bean system was lower than in all

other systems except potato-wheat with rye (Figure 1.2) indicating that N turnover can be increased by the use of compost as well as by the use of rye in a potato-bean system and clover in a potato-wheat system. This may be explained by the phenomenon that cropping systems with diverse residue inputs often have higher net N mineralization rates. For example, Sanchez *et al* (2001) demonstrated that N mineralization in a corn-corn-soybean-wheat rotation with red clover interseeded into wheat and corn and dairy manure application mineralized 70% more N than corn monoculture receiving only inorganic fertilizers. Our results indicated that the potato-bean with rye and compost mineralized almost 100% more N than potato-bean systems after 30 d.

The red clover cover crop also significantly increased N in the light fraction to two times that of potato-wheat with rye cover. Although rye cover crops capture NO_3^- during the winter and recycle it for the next crop season (Shrestha and Ladha, 2002), legumes often provide more N and support microbial activity that can significantly increase yield (Po *et al.*, 2009). Residues from legume cover crops typically have a lower C:N ratio (~14:1) and more soluble compounds than the residue from rye cover, which has a higher lignin concentration (Sanchez *et al.*, 2001; Bardgett, 2005). I did not find any influence of legume cover crop on soil C:N ratio and LF C:N ratio but legumes did influence the proportion of LF C relative to total C (Table 1.2), indicating a significant impact of legumes on the labile forms of C and N in soils.

Organic amendments provide carbon compounds as energy sources for microbial metabolism (Joergensen et al., 2010) and can change the mode of interaction among soil microbial communities (Yin *et al.*, 2011). In turn, microbial communities produce extracellular enzymes that play a very important role in organic matter decomposition processes (Wallenstein and Weintraub, 2008); some extracellular enzyme activities such as BG, PHOS, and NAG are reported to be positively correlated with plant disease suppression (Bonanomi *et al.*, 2010).

Laudicina *et al* (2010) demonstrated that enzyme activities were significantly increased by compost addition. In my study, enzyme activities were positively correlated to one another, but they were not affected by organic amendments. All the enzyme activities in this study were also correlated with net N mineralization and all except PHOS were associated with CO_2 respiration.

The ratio of C:N-degrading enzymes can provide a fundamental understanding of microbial community response to changing nutrient resources (Caldwell, 2005), and can help describe microbial investment into resource allocation. Thus, changes in enzyme potentials and their ratios in response to C and nutrient additions can be used as indicators of changes in resource allocation strategies of the microbial biomass. For example, Sinsabaugh *et al* (2008) calculated the activity ratio ln(BG):ln(LAP+NAG):ln(PHOS) as the convergence of C:N:P acquisition potentials. Similarly, I calculated the ratio of (BG+CBH):NAG:PHOS as an indicator of C:N:P acquisition potential and found that the ratio was 6:1:11. The higher ratios NAG:PHOS, BG:PHOS, and CBH:PHOS at 157 d in the potato-bean with rye and compost (Table 1.4) than in other treatments indicated a change in microbial investment into C and P containing enzymes later in the incubation. The difference of these enzyme ratios after a long-term incubation indicated the potential response of soil microbial community to different organic compound structures.

4.3. Relationship of soil biological processes to potato yield

Soil quality is an important predictor of crop yield because it provides an integrated view of different soil characteristics (Stine and Weil, 2002; Snapp and Morrone, 2008). The potato yield, in general, was higher in compost treatments and positively correlated to soil pH. However, with the exception of a negative correlation to PHOS, it was not correlated to other

soil characteristics and enzyme activities (Table 1.5). Potatoes grow well in soil with a wide range of pH but most of the potato production in United States is grown in alkaline soil (Thornton *et al.*, 2006). This suggests that the high potato yield in our study was associated with high soil pH resulting from compost application.

5. Conclusion

In the present study, we found that a low rate of compost application significantly increased potato yield. Clover cover crop significantly increased N in the light fraction and promoted soil microbial activity but resulted in the same potato yield in 2006 as rye cover crop. However, rye cover had a significant impact on potato yield in 2005. Potato yield was highly correlated to soil pH but in a small range. Both compost and cover crop applications significantly increased C and N mineralization in the soil. Scab incidence was not reduced in the presence of compost and cover crop and was not correlated to potato yield and pH in a small range. Scab incidence was negatively correlated to soil aggregate size > 1000 µm, net N mineralization, soil C andN, cellobiohydrolase, glucosidase, and acid phosphatase.

Table 1.1. Cropping system description.

Treatment	Cropping systems*	Compost addition**
PB	**Potato**-bare, **Snap bean**-bare	-
PBR	**Potato**-rye, **Snap bean**-Rye	-
PBCom	**Potato**-bare, **Snap bean**-bare	Poultry compost
PBRCom	**Potato**-rye, **Snap bean**-rye	Poultry compost
PWR	**Potato**-wheat, **Wheat**-rye	-
PWCl	**Potato**-wheat, **Wheat**-red clover	-

* These systems were 2 years rotation started in 2002. Soil samples were taken in 2006, before potato planting. Main crops are presented in bold font.
** The compost was added every other year before potato planting.

Table 1.2. C, N pools and C/N ratio in the research systems *

Treatment**	Soil C	Soil N	LF C	LF N	LF C	LF N
	g kg^{-1} soil		g kg^{-1} LF		g kg^{-1} soil	
PB	6.87 (2.3)	0.59 (0.27)	357 (5.6)a	15.9 (1.4)ab	1.19 (0.27)	0.053 (0.01)b
PBR	8.39 (2.9)	0.72 (0.20)	343 (14.5)ab	16.0 (1.9)ab	1.62 (0.56)	0.070 (0.018)b
PBCom	7.65 (1.7)	0.78 (0.20)	361 (26.9)a	17.3 (1.6)a	1.51 (0.15)	0.072 (0.005)b
PBRCom	8.15 (2.5)	0.68 (0.21)	360 (20.4)a	15.7 (3.1)ab	1.66 (0.54)	0.066 (0.015)b
PWR	8.30 (0.8)	0.63 (0.01)	341 (28.0)ab	14.0 (0.8)b	1.41 (0.20)	0.059 (0.01)b
PWCl	10.1 (2.6)	0.88 (0.20)	327 (16.8)b	15.1 (2.2)ab	2.58 (0.20)	0.126 (0.007)a

Treatment	LF C:soil C	LF N:soil N	Soil C:N	LF C:N
	%			
PB	18.5 (1.78)b	11.1 (2.32)	12.8 (1.3)	22.6 (1.6)
PBR	19.1 (1.32)b	9.9 (0.62)	11.2 (0.7)	21.8 (3.7)
PBCom	20.9 (1.86)b	10.7 (2.20)	10.6 (1.8)	21.0 (1.5)
PBRCom	20.0 (1.87)b	11.1 (1.97)	12.5 (0.9)	23.6 (4.9)
PWR	17.0 (1.67)b	9.3 (1.49)	13.3 (1.3)	24.4 (1.9)
PWCl	28.6 (4.04)a	15.9 (2.44)	11.3 (0.6)	22.1 (4.1)

* Means with the same letters were not significantly different from each other (Mean ± SE, $p < 0.05$).

**See Table 1.1 for detail of treatment abbreviations. LF: Light fraction

Table 1.3. Enzyme activities* associated with different cropping system management practices

Treatment**	NAG	BG	CBH	PHOS
At 30 d				
PB	8.5 (2.2)	48.8 (19.0)	16.2 (6.2)	148.9 (64.3)
PBR	16.7 (2.4)	69.8 (12.1)	18.9 (4.3)	213.3 (62.9)
PBCom	12.7 (2.7)	61.6 (14.6)	19.5 (6.2)	171.3 (73.1)
PBRCom	17.2 (4.0)	75.0 (16.9)	23.6 (7.4)	169.2(61.0)
PWR	13.2 (1.6)	50.5 (3.3)	10.9 (0.8)	153.9 (16.6)
PWCl	23.5 (6.7)	88.3 (26.7)	21.1 (7.2)	287.9 (86.6)
At 157 d				
PB	8.2 (1.8)	45.4 (15.4)	7.9 (3.7)	113.6 (39.7)
PBR	9.9 (1.2)	48.2 (5.4)	10.9 (1.6)	119.3 (33.1)
PBCom	10.8 (2.9)	56.4 (15.1)	12.1 (5.0)	102.1 (25.6)
PBRCom	15.9 (3.3)	79.7 (20.1)	21.4 (6.2)	119.2 (60.1)
PWR	10.8 (0.9)	45.6 (2.6)	9.9 (0.8)	106.9 (9.8)
PWCl	18.5 (3.4)	76.8 (20.8)	22.0 (9.6)	166.9 (41.1)

* Mean ± SE, nmol h^{-1} g^{-1}

**See Table 1.1 for detail of treatment abbreviations. NAG: β-1,4-N-acetyl glucosaminidase; BG: β-1,4-glucosidase, CBH: cellobiohydrolase, PHOS: acid phosphatase.

Table 1.4. Enzyme* ratio in the potato systems

Treatment*	CBH/NAG	BG/NAG	NAG/PHOS	BG/PHOS	CBH/PHOS	CBH/BG
At 30 d						
PB	1.82 (0.24)a	5.49 (0.79)	0.06 (0.01)	0.34 (0.02)	0.11 (0.01)	0.33 (0.01)a
PBR	1.14 (0.21)bc	4.26 (0.58)	0.09 (0.02)	0.36 (0.03)	0.09 (0.01)	0.26 (0.02)abc
PBCom	1.45 (0.17)ab	4.82 (0.12)	0.09 (0.01)	0.43 (0.05)	0.13 (0.02)	0.30 (0.04)ab
PBRCom	1.31 (0.19)abc	4.59 (0.53)	0.10 (0.03)	0.44 (0.08)	0.12 (0.02)	0.29 (0.04)abc
PWR	0.86 (0.09)c	3.91 (0.28)	0.09 (0.01)	0.34 (0.03)	0.07 (0.01)	0.22 (0.02)c
PWCl	0.90 (0.17)c	3.78 (0.36)	0.08 (0.01)	0.31 (0.03)	0.07 (0.01)	0.23 (0.02)bc
At 157 d						
PB	0.87 (0.21)	5.28 (0.60)	0.08 (0.01)b	0.40 (0.03)b	0.06 (0.01)b	0.16 (0.02)b
PBR	1.08 (0.08)	4.86 (0.17)	0.1 (0.02)b	0.47 (0.08)b	0.11 (0.02)b	0.22 (0.01)ab
PBCom	1.02 (0.12)	5.22 (0.05)	0.1 (0.003)b	0.55 (0.01)b	0.11 (0.01)b	0.20 (0.02)ab
PBRCom	1.31 (0.16)	4.93 (0.39)	0.20 (0.05)a	0.91 (0.18)a	0.23 (0.04)a	0.26 (0.01)a
PWR	0.94 (0.11)	4.34 (0.48)	0.10 (0.01)b	0.44 (0.04)b	0.09 (0.01)b	0.22 (0.01)ab
PWCl	1.06 (0.24)	4.00 (0.36)	0.12 (0.01)b	0.45 (0.02)b	0.12 (0.02)b	0.26 (0.04)a

* See Table 1.1 and 1.3 for treatment and enzyme abbreviations. Means with the same letters were not significantly different from each other ($p < 0.05$).

Table 1.5. Pearson's correlation coefficient (r)* between total potato yield, scab incidence, CO_2 respiration of 145 d, enzyme activity at 157 d and other soil characteristics.

	Yield	Scab	pH	Large	Med	Small	Net N	Soil N	Soil C	LF C	LF N	CO_2	NAG	CBH	BG
Scab	0.14														
pH	**0.65**	0.02													
Large	-0.29	**-0.50**	-0.28												
Med	-0.12	0.06	-0.19	-0.35											
Small	-0.05	-0.35	0.23	0.06	0.16										
Net N	0.04	-0.38	0.15	**0.66**	0.02	**0.44**									
Soil N	-0.33	**-0.50**	-0.20	**0.84**	-0.11	0.39	**0.76**								
Soil C	-0.34	**-0.61**	-0.32	**0.87**	0.01	0.38	**0.74**	**0.92**							
LF C	-0.31	-0.40	-0.37	**0.70**	0.11	0.34	**0.72**	**0.79**	**0.83**						
LF N	-0.33	-0.24	-0.38	**0.62**	0.05	0.16	**0.64**	**0.66**	**0.67**	**0.94**					
CO_2	0.27	-0.26	**0.54**	0.39	-0.27	0.36	**0.75**	**0.56**	0.40	0.40	0.36				
NAG	-0.19	-0.31	-0.04	**0.74**	-0.09	0.10	**0.73**	**0.69**	**0.70**	**0.68**	**0.67**	**0.45**			
CBH	-0.10	**-0.55**	0.08	**0.81**	-0.08	0.34	**0.84**	**0.82**	**0.83**	**0.67**	**0.55**	**0.56**	**0.88**		
BG	-0.16	**-0.48**	0.02	**0.84**	-0.09	0.29	**0.84**	**0.84**	**0.83**	**0.71**	**0.61**	**0.55**	**0.91**	**0.99**	
PHOS	**-0.42**	**-0.58**	-0.31	**0.90**	-0.02	0.31	**0.76**	**0.93**	**0.96**	**0.83**	**0.71**	0.40	**0.78**	**0.88**	**0.90**

* Bold letters indicate $p < 0.05$. Abbreviations: Large: aggregate size 1000-4000 µm, Med: size 250 - 1000 µm, Small: size 53 - 250 µm. See Table 1.3 for enzyme abbreviations.

Table 1.6. Temperature and precipitation in the research site in 2005 and 2006.

Growing season*	Average daily temperature °C	Total rainfall mm	Number of rainy days
2005	18.9	337.6	48
2006	17.7	422.7	67

* The climate data was collected from http://enviroweather.msu.edu for the potato growing season (15 May to 15 Oct) in 2005 and in 2006.

Table 1.7. Overall ANOVA of the soil characteristics

Soil characteristics	Overall F value	p value
pH	**8.59**	**0.0007**
Net N mineralization *	1.46	0.2648
Total soil N*	0.44	0.8144
Total soil C*	0.30	0.9040
Soil C:N	0.91	0.5029
Light fraction N, mg/kg soil	**4.80**	**0.0092**
Light fraction C, mg/kg soil	1.67	0.2076
LF C/ soil C, %	**4.37**	**0.0131**
LF N/ soil N, %	1.68	0.2049
CO2_30day*	**4.86**	**0.0088**
CO2_145 days*	**5.91**	**0.0039**
Light fraction	2.69	0.0661
Aggregate > 1000µm	0.38	0.8532
Aggregate 250 – 1000µm	0.59	0.7059
Aggregate 53 - 250µm	0.85	0.5347
NAG 30d, activity g^{-1} soil	2.08	0.1290
CBH 30d, activity g^{-1} soil	0.59	0.7082
BG 30d, activity g^{-1} soil	0.79	0.5767
PHOS 30d, activity g^{-1} soil	0.67	0.6553
NAG 157d, activity g^{-1} soil	2.42	0.0882
CBH 157d, activity g^{-1} soil *	1.69	0.2006
BG 157d, activity g^{-1} soil	1.10	0.4026
PHOS 157d, activity g^{-1} soil	0.40	0.8430
(CBH+BG):NAG 30d	**3.77**	**0.0225**
(CBH+BG):NAG 157d	1.07	0.4178
(CBH+BG):PHOS 30d	**3.19**	**0.0427**
(CBH+BG):PHOS 157d	**8.26**	**0.0008**
NAG:PHOS 30d	1.21	0.3566
NAG:PHOS 157d	**4.10**	**0.0167**

** values are log-transformed*

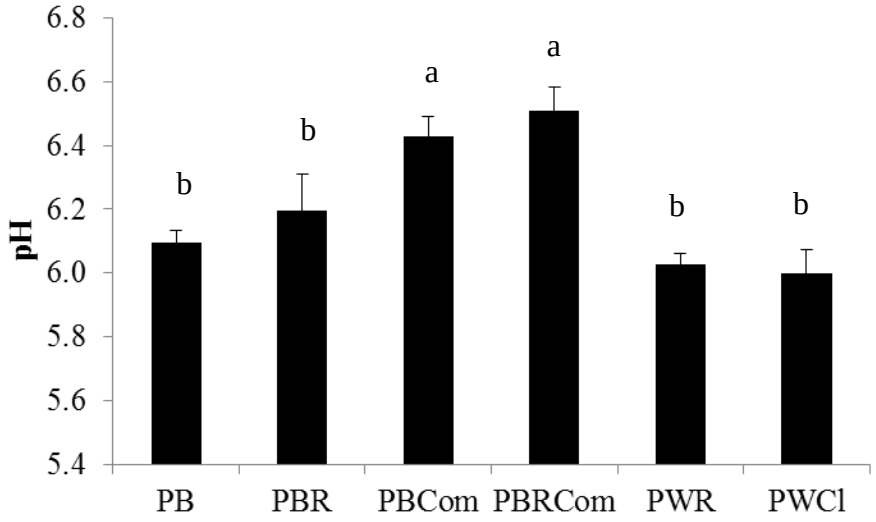

Figure 1.1. Soil pH in the potato systems (Mean ± SE). Means with the same letter were not significantly different ($p < 0.05$). Abbreviations of treatments were shown in Table 1.1

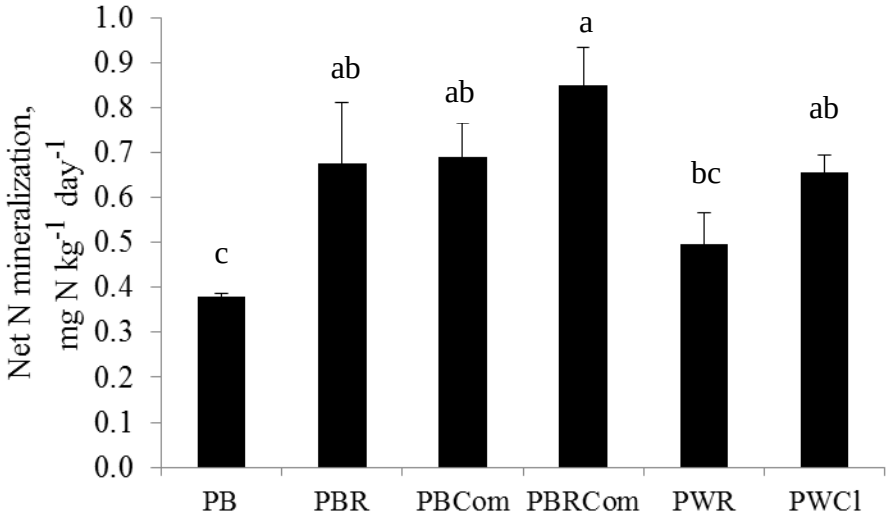

Figure 1.2. Net N mineralization in the potato systems (Mean ± SE, mg N kg^{-1} day^{-1}). Means with the same letter were not significantly different ($p < 0.05$). See Table 1.1 for description of treatment abbreviations.

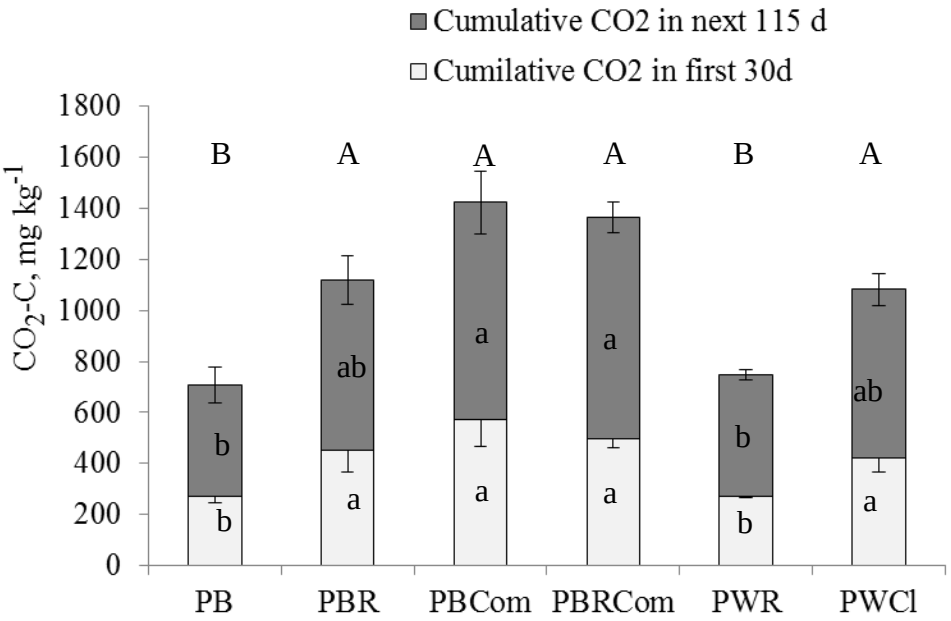

Figure 1.3. Cumulative CO_2-C (Mean ± SE, $p < 0.05$) produced in the first 30 days of incubation and after an additional 115 days. Means for the same time period with the same letter were not significantly different ($p < 0.05$). The upper case letters indicate the differences of total cumulative CO_2-C over the 145 d incubation. Treatment abbreviations were given in Table 1.1.

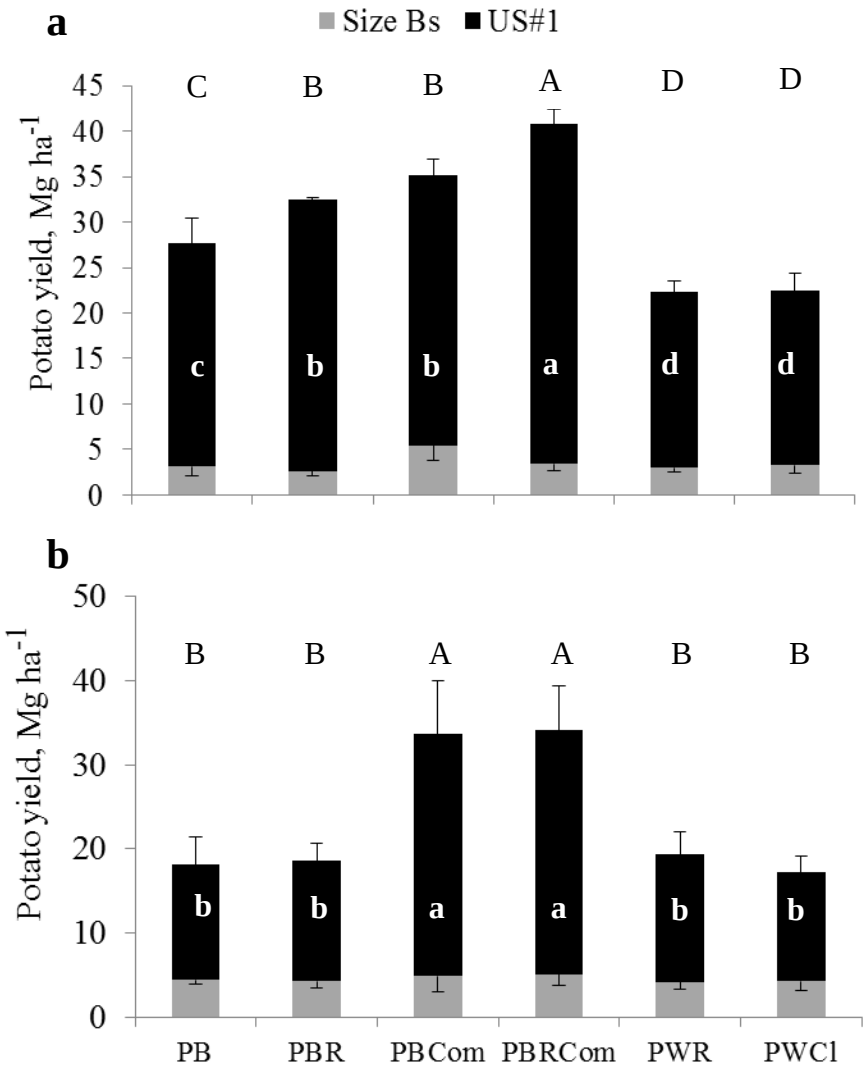

Figure 1.4. Potato yield in 2005 (a) and in 2006 (b) (Mean ± SE, $p < 0.05$). Size Bs: tuber diameter < 5.1 cm; US No.1: tuber diameter > 5.1 cm. Means for the same tuber size with the same letters were not significantly different ($p < 0.05$). Upper case letters indicated differences among treatments in total yield. Abbreviations of treatments were shown in Table 1.1.

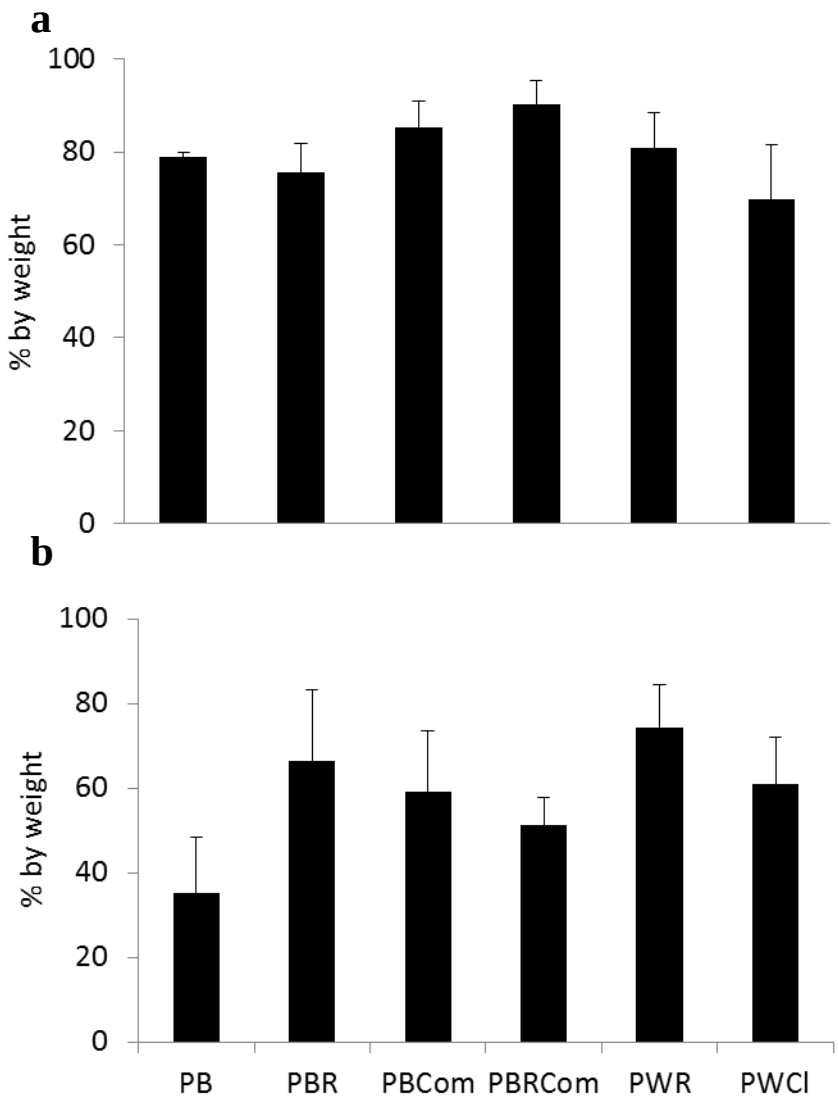

Figure 1.5. Potato scab in 2005 (a) and 2006 (b) in the potato systems. Abbreviations of treatments were shown in Table 1.1

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CHAPTER 2

Effect of application rates and timing of poultry compost amendment on potato and soil quality

Abstract

Compost amendment is an efficient method to improve soil biological characteristics, reduce environmental impacts and decrease cost of crop production. However, few studies have been undertaken to optimize the contribution of compost in order to achieve maximal crop yield and income. In this study, I examined the effect of poultry compost amendment rate and timing on soil biological characteristics and potato yield. Thus, I set up a field experiment in Montcalm Research Farm, Michigan with five treatments and five replicates in randomized complete block design. The experiment was designed with two phases. In the first phase, potato was planted in 2009 and corn planted in 2010; in the second phase, potato was planted in 2010. Soil samples were collected multiple times during growing seasons to examine soil biological characteristics. The result showed that both the application rates and timing of compost amendment influenced potato and corn yield and soil characteristics such as soil organic matter, water holding capacity, inorganic N, microbial biomass and enzyme activity. The higher rates of poultry compost application increased potato yield consistently in both 2009 and 2010. However, scab incidence was reduced following the increase of compost amendment in 2009 but not in 2010, when there was a lower scab incidence across all treatments. The common scab incidence was negatively correlated to soil characteristics in 2009 but not in 2010. I also found that poultry compost amendment at high rates significantly increased soil pH, inorganic N, microbial biomass and enzyme activities in both phases 2009 and 2010. However, while a high rate of compost

increases C sequestration, it tends to be less economical for farmers. The application of 1.7 ton C ha^{-1} per year was recommended to improve soil quality and maintain high crop yield.

1. Introduction

Limited availability of land and economic pressure has lead to an alteration of growing practices in the Michigan Potato Industry. Growers are using more fertilizers and other inputs in an effort to increase potato productivity (Sharifi *et al.*, 2009). However, uptake of N from these inputs is limited since potato root systems are very fibrous and shallow and Michigan potatoes are often grown in sandy soil with high leaching potential (Peralta and Stockle, 2002). Indigenous soil N sources derived from the turnover of soil organic matter and crop residues are generally not adequate to support optimum potato production, especially in the sandy soils typically used for MI potato production (Zebarth *et al.*, 2005). Therefore, potato growers tend to use high rates of N fertilizers to ensure an adequate supply (Prunty and Greenland, 1997). However, the increasing use of N fertilizers has raised concerns over N losses to the environment (Zielke and Christenson, 1986; Bardgett, 2005; Xu *et al.*, 2010). In potato cropping systems, nitrate leaching and nitrous oxide emissions (Zebarth *et al.*, 2005) have been reported. For example, Honisch *et al* (2002) reported a correlation of nitrate leached in wells and river water with potato cultivation. Munoz-Arboleda *et al* (2008) also demonstrated that fertilization at potato planting significantly increased nitrate content in ground water. The recommended N rates for sandy potato soils varies from 135 to 200 kg N ha^{-1} (Ziadi et *al.*, 2011) and N recovery in potato systems has been reported to range from 30 to 70 % (Zvomuya *et al.*, 2003).

Potatoes can be grown in a wide range of soil conditions (Thornton *et al.*, 2008). However, soil is only considered suitable for crop growth if it is able to maintain biological

diversity and a high capacity for nutrient cycling (Van Bruggen and Semenov, 2000; Nelson *et al.*, 2009). Recently, intensive cropping systems with two-year rotations of high-value crops are becoming more popular in the Great Lakes area (Sharifi *et al.*, 2009; Larkin *et al.*, 2011). These potato rotations are generally characterized by intensive tillage with low crop-residue inputs (Grandy *et al.*, 2002). This two-year rotation may significantly reduce soilborne diseases and produce higher-quality potatoes than continuous potato systems (Specht and Leach, 1987; Honeycutt *et al.*, 1996).

Soil texture is a key factor for potato management because it determines water availability and infiltration rates, which directly affect potato root systems and growth. Inadequate water availability in the soil can increase common scab infection while excessive water can reduce tuber yield and quality, facilitate the leaching of nutrients out of the root zone, and increase disease incidence (Powelson and Rowe, 2008). Potatoes have very fine and branching root systems that are susceptible to soil compaction and tillage. In Michigan, potatoes are grown in soils that have relatively low cation exchange capacity, low water holding capacity, high infiltration rates and high nutrient-leaching potential (Stark and Westermann, 2008).

The use of fresh manure has been reported to increase the incidence of common scab on potato tubers (Bailey and Lazarovits, 2003) but these results are variable and opposite results have been reported (Conn and Lazarovits, 1999). Both compost and manure amendment improve soil physical properties such as soil organic matter and water holding capacity, and increase plant productivity (Christensen and Johnston, 1997; Van Herk *et al.*, 2004; Munoz *et al.*, 2008) and may reduce plant soilborne disease (Bailey and Lazarovits 2003; Bonanomi *et al.*, 2010). Termorshuizen *et al* (2006) studied 120 bioassays including 18 composts and 7 pathosystems and found that 54 % of the treatments resulted in significant disease suppression, 43 % had no

effect on disease and 3 % resulted in increasing disease. Using compost can also provide more organic matter and biomass for the soil than other soil amendment methods such as crop rotation (Grandy *et al.*, 2002; Collins *et al.*, 2006), and a recent metanalysis with 120 comparisons indicates that the use of compost or manure amendments increases microbial biomass C by an average of 38% (Kallenbach and Grandy, in review).

Organic amendments have been studied widely as a strategy to reduce diseases and improve crop productivity and soil quality. For example, in a study in potato cropping systems, Porter *et al* (1999) reported that organic amendments in combination with irrigation improved both yield and soil properties. One way that organic amendments may increase yields is by suppressing disease. The mechanism of disease suppression is not well known but may include competition between beneficial organisms and pathogens for resources, production of antibiotics or toxic substances, enzyme activity or hyperparasitism, and the induction of systemically-acquired resistance in host plants (Hoitink *et al.*, 1997; Kinkel, 2008).

In the first chapter of this thesis, I found that compost application greatly improved soil quality and potato yield. In that research, I found that a low rate of poultry manure compost application in combination with rye cover crop and different rotation potato-wheat with red clover increased potato yields and soil microbial activity. In order to develop better predictions about the optimum rate of manure application, in this study I applied multiple rates of poultry compost to the potato system and also examined the effect of application frequency. The overall objective of this study was to examine the effect of compost rates and timing on soil biological characteristics and potato quality.

2. Materials and methods

2.1. Experimental site

The experiment was carried out at the Michigan State University Potato Research Farm, in Montcalm County, Michigan (43° 21' 13" N and 85° 10' 33" W). The experimental design was a randomized complete block with 5 treatments and 5 replicates (Figure 2.1). Experimental plots were rectangles of 3.5 m in width and 7.6 m in length. The experiment was set up for two phases. The first phase started with potato planted in 2009 and then corn planting in 2010. The second phase started with potato planting in 2010, which was the final year of the study.

Phase 1: Poultry compost (N: 4 %, P_2O_5: 3 %, K_2O: 2 %, and Ca: 8 %) supplied from Herbruck Poultry Ranch (MI 48881), one of the primary suppliers to the Michigan potato industry, was applied on 20 May 2009 before potato planting. The five rates of poultry compost were 0, 1.7, 3.4, 6.8, and13.6 ton C ha^{-1}. Only the treatment that received 1.7 ton C ha^{-1} in 2009 received the same amount in 2010. This allowed me to compare this treatment to the one that received 3.4 ton C ha^{-1} in 2009 but none in 2010 in order to examine the effect of timing of poultry compost on crop productivity and soil quality.

Snowden potato was planted on 22 May 2009. Urea was applied three times to provide and balance nitrogen in all the systems. At planting, urea was applied on all plots at a rate of 16 kg N ha^{-1}. The second urea application occurred on 24 Jun 2009 at a rate of 67 kg N ha^{-1} for control (Ctrl), T1 and T2; and 30 kg N ha^{-1} for T3 (abbreviations of treatments were given in Table 2.1). Urea was applied a third time on 9 Jul 2009 at a rate of 67 kg N ha^{-1} for Ctrl and 33 kg N ha^{-1} for T1. Potato tubers were harvested on 15 Oct 2009. Rye was used as a winter cover crop in all treatments and received urea applied at a rate of 35 kg N ha^{-1} at planting.

For the second year in the same plots, compost was applied at 1.7 ton ha^{-1} to T1 only on 23 Apr 2010. Then corn (Great Lakes 404163VT3) was planted on 10 May 2010 for all the plots with NPK fertilizer applied on the same day at a rate of (22 - 11 - 11) kg (N-P_2O_5-K_2O) ha^{-1}. Urea was applied again on 5 Jul 2010 at 76 kg N ha^{-1} for T1, and 110 kg N ha^{-1} for Ctrl, T2, T3, and T4.

Phase 2: Poultry compost was applied on 27 Apr 2010 with the same rates in the first year/Phase 1 (Table 2.1). Snowden potato was planted on 20 May 2010 and NPK fertilizer was applied at a rate of (67-24-42) kg (N-P_2O_5-K_2O) ha^{-1}. Urea was applied again at 67 kg N ha^{-1} for Ctrl, T1, T2 and 30 kg N ha^{-1} for T3 on 21 Jun 2010 to balance N for all the treatments. Potato tubers were harvested on 19 Oct 2010.

In Phase 1 of our experiment, there were a total of 12 sampling times in 2009 (potato) and three sampling times in 2010 (corn). In Phase 2, soil samples were taken four times over the potato growing season in 2010. Soil samples were taken to a depth of 15 cm with a 2-cm diameter corer. Twelve replicate samples were taken within each plot. Each of the twelve samples was taken at a distance of ~15 cm from a plant in order to capture soil biological and nutrient cycling processes occurring in the vicinity of the root zone. The twelve samples were combined to form a composite sample representative of the entire plot. Soil samples were immediately put into a cooler in the field until they were brought to the lab and put in a refrigerator at 4 ^{o}C. All the soil samples were homogenized by passing through a 2 mm or 4 mm sieve depending on the soil moisture status before analysis. All soil biological analyses were

carried out within one week from sampling date in the following order: enzyme activity first, then microbial biomass, then inorganic N, and finally soil pH.

2.2. Analytical methods

Potato yield and scab incidence assessment

Potatoes in Phase 1 plots were harvested on 15 Oct 2009 and in Phase 2 plots on 19 Oct 2010. Potatoes in non-plots (NP), which did not receive compost or fertilizers (Figure 2.1), were also harvested as a reference for comparing potato yield with no management. Potato plants were killed about one month before harvest using Reglone Desiccant at 2.3 L ha^{-1}. The middle 2 rows of each plot were harvested using a one-row potato harvester (Jerry Johnston of Vestaburg Michigan) to determine tuber yield and assess common scab incidence. Tubers were graded and weighed according to USDA market classes: oversize > 8.3 cm; A = 5.1 - 8.3 cm; B < 5.1 cm. US No.1 is sum of oversize and A potatoes.

Common scab incidence was assessed based on potato surface damage (Driscoll *et al.*, 2009). According to this method, potato common scab was rated at the same time potatoes were graded. The scab incidence was assessed on a scale of 0 to 5 where 0 was no common scab infection, 3 was intermediate infection with the scab lesions covering 25 to 50 % of the surface area and pitted lesions of one cm depth covering less than 5 % of the surface area, and 5 was the most severe, with lesions covering more than 50 % of surface area, pitted lesions of more than 1cm depth covering more than 25 % of the surface area.

Corn in Phase 1 was harvested from the two middle rows of each plot on 2 Nov 2010 using a one-row corn harvester (John Deere). I also harvested corn in the NP plots in all the blocks.

Soil pH and moisture

Soil pH was determined in water with a soil:water ratio of 1:2 w/v according to Robertson *et al* (1999). Briefly, 15 g of soil was weighed and mixed with 30 mL DI H_2O. The slurry was stirred for one minute and allowed to settle for 30 min before measuring pH using a pH meter (SevenEasy pH Mettler Toledo, Switzerland). Gravimetric soil moisture content was determined after drying field-moist soil in a 65 ^{o}C oven for about 48 hours.

Inorganic nitrogen

Ten grams of fresh soil were weighed into a 125 mL flask and then nitrate- and ammonium-extracted in 50 mL of 1M KCl for 30 min on a shaker table. The solution was filtered through 125 mm filter paper (Whatman #1) and stored at 4 ^{o}C. The nitrate and ammonium analyses were carried out within one month after extraction. Nitrate nitrogen (NO_3^--N) concentration in the extracted solution was determined using a modification of the method described by Doane and Horwath (2003). This assay uses vanadium to reduce NO_3^- to NO_2^-, which reacts with sulfanilamide and N-1-naphthyl-ethylenediamine dihydrochloride to form a pink color that is analyzed by a spectrophotometer. Briefly, the sample solution and KNO_3 standard solution were pipetted into 96 well clear microplates (Fisher Scientific, USA). Concentration and volume of samples and standard were adjusted appropriately to the NO_3^--N concentration in each set of samples. Twenty samples with four analytical replicates each were run on each plate. Eight standard samples ranging from 0 to 10 ppm were loaded into each plate

with two replicates per standard. The saturated vanadium solution was prepared by mixing 1 g $VaCL_3$ with 150 mL of 1M HCl. The working assay solution consisted of 25 mL of saturated vanadium solution, 200 mL H_2O, 1.65 mL of 2 % w/v sulfanilamide in 1 M HCl, and 1.65 mL of 0.2 % w/v N-(1-naphthyl)-ethylenediamine dihydrochloride in DI water. The bottle head spaces were purged with N_2 gas for 30 sec and capped quickly to minimize vanadium oxidization. Vanadium assay solution was added to the sample solution using a multichannel pipettor. The samples were incubated at room temperature for 8 - 10 h before measuring nitrate concentration by a spectrophotometer at λ = 540 nm (Multiskan Ascent, Thermo Scientific, Hudson, NH).

Ammonium (NH_4^+-N) was measured by modifying the method described by Sinsabaugh *et al* (2000). The principle of this assay is to use salicylate and cyanurate to react with ammonium, forming a green color which is measured on a spectrophotometer. The samples and standard solutions were prepared as in the NO_3^--N assay. Salicilate solution was prepared by dissolving one packet of Ammonia Salicilate Reagent Powder Pillows in 5 mL DI H_2O and 40 µL was pipetted into each well using a multichannel pipettor. Following this, 40 µL cyanurate solution was added to each well. The samples were incubated in room temperature for 30 min before determining the NH_4^+-N concentration in a microplate spectrophotometer (Multiskan Ascent, Thermo Scientific, Hudson, NH) at λ = 630 nm.

Microbial biomass C and N

Microbial biomass C and N were measured according to the fumigation/extraction method (Brookes *et al.*, 1985; Beck *et al.,* 1997; Robertson *et al.*, 1999). Fifteen g of soil was

weighed into a 50 mL beaker and brought to 50 % water-holding capacity before placing into a desiccator. Another beaker containing 50 mL of ethanol-free chloroform and boiling chips were placed in the middle of the desiccator. The dessicator was lined with wet paper towels to maintain humidity. Air in the desiccator was evacuated until the chloroform boiled. The chloroform was maintained at boil for 3 min and then vented. The procedure was repeated 3 times, omitting venting after the final sequence. Samples were subsequently kept in the dark at room temperature to fumigate for 24 h. Chloroform was removed from dessicators, the air was released, and a vacuum was applied six times to completely remove residual chloroform. After vaccuming, the soil samples were transferred to a 125 mL flask and extracted with 60 mL of 0.5M K_2SO_4. The sample solutions were shaken on a shaker table at 200 rpm for 1 h and filtered (Whatman #5, 125 mm). A subset of non-fumigated control samples were weighed into 125 mL flasks and extracted. The extracts were stored at -20^{o}C before analyzing for total dissolved organic C and total N with a TOC analyzer **(**Shimadzu, model TOC-V_{CPH} with a TNM-1 nitrogen module attached). Microbial biomass C (MBC) was calculated as EC/kEC where EC is the chloroform labile C pool, determined as the difference between fumigated and non-fumigated samples, and kEC is a soil-specific value estimated as 0.45 (Beck *et al.*, 1997). Microbial biomass N (MBN) was calculated using the same approach but with a value of 0.54 (Brookes *et al.*, 1985).

Enzyme activity

The enzyme assay followed previously-described protocols (Saiya-Cork *et al.*, 2002; Grandy *et al.*, 2007). Enzyme activities were determined within 24-48 h after soil sampling. One g of soil and 125 mL of 50 mM sodium acetate buffer were combined in a 140 mL plastic bottle .

The pH of sodium acetate buffer was adjusted to the average soil pH of all the samples (6.5) using HCl 0.1M. The solution was homogenized for 30 sec and assays were run using 96-well microplates. Black plates (Greiner Bio-one) were used for hydrolytic enzyme and clear plates (Fisher Scientific) for phenol oxidase. The first three columns contained control and standard samples, the next three sets of three columns (4, 5, 6; 7, 8, 9; and 10, 11, 12) were used for three other soil samples. The amount of 200 µL of soil slurry were added to each well of one column of another black plate as a control. The molarity of standards and substrates for each appropriate enzyme is shown in Table 2.3. For hydrolytic enzymes, 250 µL buffer solution was added to column 1 and 200 µL to columns 2 and 3; for oxidative enxymes, 250 µL was added to column 1 and 200 µL to column 2. For the enzymes β-1,4-glucosidase (BG), β-1,4-N-acetyl-glucosaminidase (NAG), and acid phosphatase (PHOS), 50 µL of 4-methylumbelliferone (MUB) was pipetted into columns 2, 4, 7 and 10 in all plates; for the enzyme tyrosine amino peptidase (TAP), 50 µL of 7-amino-4-methylcoumarin (MC) was added to the same columns. For hydrolytic enzymes, 50 µL of each substrate was pipetted into columns 3, 5, 6, 8, 9, 11, 12 for each plate. For phenol oxidase (PHENOX), 50 µL buffer was added to columns 4, 7, 10 and 50 µL L-3,4-dihydroxyphenylalanine (L-DOPA) to columns 2, 5, 6, 8, 9, 11, 12. After adding the substrate, all the plates were incubated in a 15^{o}C incubator. BG and PHOS were incubated for about 1.5-2 h, NAG for about 2-2.5 h, TAP for about 5-6 h, and PHENOX for about 24 h. After incubation, 10 µL NaOH 1M was added to each well across all the columns to stop the reaction of the hydrolytic enzymes. The hydrolytic enzyme activities were measured by a fluorometric analyzer (Fluoroskan Ascent, Thermo Scientific, Hudson, NH) and PHENOX was measured using colorimetric methods in a spectrophotometer (Multiskan Ascent, Thermo Scientific, Hudson, NH).

Statistical analysis

Statistical analyses of amendment effects were carried out with a repeated measure analysis of variance (ANOVA) using Proc mixed in SAS (SAS version 9.2, SAS Institute 2008). A one-way ANOVA was also used to examine seasonal averages for each data set. Assumptions of normality and equal variance of residuals were examined by Proc univariate in SAS and log transformations were used if necessary to meet these assumptions. The best fit model was chosen based on the AIC values for the unequal variance structure models. Where ANOVA indicated significant differences, Fisher's protected LSD ($\alpha = 0.05$) was used to separate treatment means. Pearson's correlation coefficients were calculated to examine relationships among parameters. Principal component analysis (PCA) was used to visualize the linear integrated relationship among potato yield, common scab and other soil characteristics with compost treatment.

3. Result

3.1. Potato systems

Potato yield and common scab incidence

Compost application had a significant effect on potato productivity. Both the total potato yield and potato yield of grade US No.1 in T3 (6.8 ton C ha^{-1}) and T4 (13.6 ton C ha^{-1}) in 2009 were significantly higher than in Ctrl (Figure 2.2). The total potato yield and US No.1 yield in T1 (1.7 ton C ha^{-1}) and T2 (3.4 ton C ha^{-1}) were not different from in Ctrl. The potato yield of these sizes in all the compost treatments and Ctrl were significantly higher than in the NP (non-plot) treatment, which produced the highest amount of size B potato yield. In 2010, the total potato yield and US No.1 yield in all the compost treatments were significantly higher than in Ctrl and

in NP. T4 produced the highest total potato yield in all the systems. T3 and T4 also produced more overweight potatoes than other treatments. The potato yields in Ctrl and NP were similar in 2010. There was no difference in B grade potato yield between any of the systems in 2010.

In 2009, the incidence of common scab in the Ctrl treatment did not differ from that of T1 and T2, but was significantly higher than that of T3 and T4 (Figure 2.3). Scab incidence in T4 was significantly lower than in T1 and T2. The scab incidence in the NP treatment did not differ from the scab incidence in Ctrl treatment, but was significantly higher than that of all the compost treatments. In 2010, the scab incidence was generally lower than in 2009 and there were no differences between treatments. The scab incidence in 2009 was negatively correlated to soil moisture, pH, inorganic N, MBN, and TAP; in 2010, the scab incidence was not correlated with any soil characteristics.

Soil pH

In 2009, the seasonal average of soil pH in all the compost treatments were significantly higher than in Ctrl (Figure 2.4). The higher rate of compost in T3 and T4 also significantly raised pH compared to other treatments throughout the growing season (Table 2.4). In 2010, the average soil pH over the growing season in T1 was similar to the soil pH in the Ctrl treatment but the soil pH of all the remaining compost treatments was significantly higher than in Ctrl. The soil pH in T3 and T4 was significantly higher than the soil pH in T2 but they were not different from each other. In all treatments, the soil pH generally decreased in the middle of the season and increased by the end of the season (Table 2.4).

Inorganic nitrogen

The seasonal average of NO_3^--N concentration in potato soil in 2009 was not different between Ctrl and T1, in which compost was applied at the rate of 1.7 ton C ha^{-1} (Figure 2.5). However, at higher rates of compost application in T2, T3, and T4, NO_3^--N contents were significantly higher than in Ctrl. NO_3^--N in T4 was higher than in T2 and T3, which did not differ from one another. No treatment effect on NO_3^--N was found on the first sampling date, 2 June 2009, or the last sampling date, 26 Nov 2009 (Table 2.5). At all the other measurement dates, the treatment effect was significant and in almost all of these days, the higher compost applications increased the NO_3^--N content in the soil. The NO_3^--N content in first sampling date, which was 2 weeks after composting, was similar in all the treatments (μ=34.2 mg NO_3^--N kg^{-1} soil). Relative to the first sampling date, the NO_3^--N on the second sampling date (18 Jun 2009) was reduced about 6 times in Ctrl and T1 and 4 times in T2 but increased 1.5 times in T3 and nearly maintained in T4 (Table 2.5). All the treatments peaked on 16 Jul 2009 and then declined over time until the end of the season, when the mean of all the treatments was 3.7 mg NO_3^--N kg^{-1} soil.

In 2010, the compost applications in T2, T3 and T4 significantly increased NO_3^--N (Figure 2.5). There was no difference between the seasonal average of NO_3^--N in T1 and Ctrl but the seasonal averages of NO_3^--N in T2, T3, and T4 were significantly higher than in Ctrl. Treatment effects were significant at $p < 0.0001$ at all dates over the growing season except on 5

July ($p < 0.0001$). On 12 Aug, all the compost treatments increased NO_3^--N in the soil and the next day, only T2, T3, and T4 had that effect.

The lowest NH_4^+-N content was in Ctrl treatment and the highest content was in T4 treatment, which was about 4-fold higher than in Ctrl (Figure 2.6). The NH_4^+-N contents in all the compost treatments were significantly higher than in the Ctrl treatment. On the first sampling day in 2009 (Table 2.5), the lowest NH_4^+-N concentration was in Ctrl (20.3 mg NH_4^+-N kg^{-1}) and the highest value was in T4 (150.9 mg NH_4^+-N kg^{-1}). Only NH_4-N in T1 was not different from that in Ctrl. On the second sampling day, 18 June 2009, the NH_4^+-N content in Ctrl and T1 was similar to the first sampling date but the NH_4^+-N contents in T2, T3, and T4 treatments were significantly lower than on the first sampling day. On 16 July 2009, the NH_4^+-N contents were notably lower than earlier sampling dates (Table 2.5). NH_4^+-N remained low after 16 July.

The average NH_4^+-N contents across all treatments in 2010 were different from the average NH_4^+-N contents in 2009. In 2010, the NH_4^+-N content in T4 was higher than in the remaining treatments, which did not differ from one another. NH_4^+-N contents were not consistent across dates (Table 2.6). Similar to 2009, NH_4^+-N concentrations in 2010 declined in July.

Microbial biomass

There were significant differences in microbial biomass between treatments when data were averaged over the growing season (Figure 2.7). MBC in T2, T3, and T4 was higher than in Ctrl while MBC in T1 was similar to MBC in Ctrl. All five measurements of MBC in 2009 showed a significant treatment effect (Table 2.7). In 2010, the seasonal averages of MBC in T1 and Ctrl did not differ and were lower than the other treatments (Figure 2.7). Only three measurements were taken in 2010 but each of these exhibited a strong treatment effect ($p < 0.0001$) and showed that higher amendment application rates generally increased MBC (Table 2.7). T4 always had the highest MBC on all dates sampled.

The seasonal average of MBN in 2009 was different among the treatments (Figure 2.7). MBN in T2, T3, and T4 were significantly higher than in Ctrl. MBN in T3 and T4 did not differ, and was about a fold higher than MBN in Ctrl. MBN in T1 was similar to MBN in Ctrl. There was variation amongst dates in treatment effects on MBN. For example, on the first and the last dates, MBN in T4 was not different from in Ctrl (Table 2.8) but at three other dates MBN was higher in T4. In 2010, the seasonal average of MBN was positively related to amendment application rate (Figure 2.7). The MBN values of T1 and T2 did not differ from one another, or from Ctrl on 12 Aug 2010; however, on the next measurement, 14 Sep 2010, MBN in all the compost treatments were higher than in Ctrl (Table 2.8).

Enzyme activities

In 2009, average BG activities in T2 and T4 were significantly higher than in Ctrl (Figure 2.8). The BG activities in the potato soils in 2009 were inconsistent across the dates (Table 2.9). For example, on 16 Jul 2009, BG in T2 and T4 were higher than in Ctrl and in T1. At the next measurement on 29 Jul 2009, only BG in T2 was higher than in Ctrl. In 2010, the seasonal

average of BG activity in T4 was higher than BG activity in T1, T2, and T3 but similar to that of Ctrl (Figure 2.9). The compost application rate did not affect BG activity in the potato soil in 2010 at the 2 first dates, but on 12 Aug 2010 and 14 Sep 2010, BG in T4 was not different from Ctrl but was higher than the 3 other compost treatments.

The seasonal average of NAG activity was significantly affected by compost application rates (Figure 2.8). NAG activities in T2, T3 and T4 were significantly higher than in Ctrl and were higher in T2 and T4 than in T1 and T3. On 2 Jun 2009, compost treatment had a strong effect on NAG activity in the potato systems (Table 2.10). NAG activity in T4 was three times higher than in Ctrl. The compost rates showed strong effects again on 13 Aug 2009 when NAG activity in all the compost treatments was higher than in Ctrl. There was a treatment effect on only one of the four last measurement dates, 13 Oct 2009: NAG in T2 and T4 were higher than in Ctrl. Seasonal mean NAG activities in 2010 were similar to those in 2009 (Figure 2.9). All of the dates had similar results in that NAG activities in T3 and T4 were higher than in Ctrl and typically those in T1 and T2 were similar to those in Ctrl, except on 1 June 2010.

Average PHOS activity in T2 was higher than in all the remaining treatments in 2009 (Figure 2.8). PHOS content in T2 was 111.0 nmol h^{-1} g^{-1}, almost two times higher than in Ctrl and T3. The differences of PHOS content between treatments were not consistent across the dates (Table 2.11). Average annual PHOS activities in 2010 were not different among treatments (Figure 2.9). However, on 1 Jun 2010, PHOS activity in T1 was higher than in Ctrl, and on 5 Jul, PHOS activity in T3 was significantly lower than in all the remaining treatments. There was no treatment effect in the two final measurements.

The seasonal averages of TAP activities in all the compost treatments were significantly higher than in the Ctrl (Figure 2.8), and TAP activity in T2, T3, and T4 was higher than in T1.

There was no treatment effect on TAP activity in the first two measurements (Table 2.12). The mean of TAP activity in all treatments on 18 Jun 2009 was about 12 nmol h^{-1} g^{-1} soil and was reduced by about half on 1 Jul 2009. On 16 Jul, 13 Aug 2009, 24 Aug 2009, and 13 Oct 2009 TAP activities in the compost treatments were significantly higher than in Ctrl. In 2010 as in 2009, TAP activities were higher in all compost treatments than in Ctrl (Figure 2.9). Compost effects were apparent at all the dates except the first (Table 2.12).

In 2009, average PHENOX activities in Ctrl and T1 were higher than in T3, and higher in T4 than in T2 and T3 (Figure 2.10). On 2 Jun 2009 (Table 2.13), PHENOX activity in Ctrl was significantly higher than in the compost treatments. There was no subsequent treatment effect until 13 Aug 2009, when PHENOX activity in Ctrl was similar to T1 but higher than T2 and T3. In 2010, average PHENOX activity in Ctrl was higher than in T1, T2, and T3 (Figure 2.10). The treatment effect was significant only on 14 Sep 2010 (Table 2.13).

Principal components analysis

Principal component analysis of all the variables in 2009 showed that the treatments receiving compost strongly separated from the Ctrl. This was based on soil biological and chemical metrics, which were higher in the organically amended treatments, high scab incidence in the Ctrl treatment (Figure 2.11). In 2010, soil biological characteristics distinguished T4 from the other treatments. Pearson's correlation coefficients between variables for all the plots also indicated that potato yield in 2009 was negatively correlated to common scab and positively correlated to pH, microbial biomass C&N, and TAP enzyme activity (Table 2.15). The potato yield in 2010 was positively correlated to pH, NO_3^--N, microbial biomass C&N, and NAG and

TAP enzyme activities, and negatively correlated to PHENOX enzyme activity; there was no correlation with common scab.

3.2. Corn systems

Corn yield

Although the compost application was made in 2009, it still influenced corn yield in 2010 (Figure 2.12). The corn yield was highest in T4 (14.1 Mg ha^{-1}) and lowest in Ctrl (11.8 Mg ha^{-1}). Corn yield was higher than Ctrl in all treatments except T3 and all of those were significantly higher than in NP. Corn yield in T1 was not different from T2, T3 and T4, and the yield in T4 was significantly higher than in T2 and T3. Corn yield was significantly correlated to soil moisture, and microbial biomass C and N and negatively correlated to ammonium (Table 2.20).

Soil properties

The poultry compost applied in 2009 still had a significant effect on soil pH in 2010. Averaged over the growing season, the soil pH in Ctrl was 6.31, significantly lower than in all compost treatments (Table 2.16). Averaged over the growing season, NO_3^--N in T1 was significantly higher than in the other treatments (Table 2.17). There was no difference between NO_3^--N in T3 and T4 but they were significantly higher than NO_3^--N in T2, which was not different from the NO_3^--N content in Ctrl treatment. On average, the NH_4^+-N contents in Ctrl and T3 were higher than the NH_4^+-N contents in the remaining treatments (Table 2.17). In contrast with NO_3^--N, no any effect of compost application on NH_4^+-N was observed in the first

measurement on 24 May 2010; however, by the end of the season, the treatments with the higher rate of compost (T3 and T4) had higher NH_4^+-N in the soil.

Microbial biomass

The MBC in corn soil was significantly affected by the poultry compost applied a year before. The seasonal average of MBC in each of the compost treatments was higher than in Ctrl (Table 2.18). On 24 May 2010, MBC in T2, T3, and T4 was similar and higher than in Ctrl, which did not differ from T1. On 19 Jul 2010, the amount of MBC in T1 was significantly increased from 51.2 to 136.8 mg kg^{-1} while the amount of MBC in T2, T3 and T4 remained about the same as on 24 May 2010. By the end of the season, although MBC in all the treatments had decreased, levels in compost treatments were higher than in the control. For MBN, the seasonal averages in all compost treatments were also higher than in Ctrl. This trend was the same for all dates except 24 May 2010, on which MBN level in T1 was similar to Ctrl. Similarly to the results for MBC, MBN in the soil did not increase with additional compost in the T1 treatment.

Enzyme activities

There were no treatment main effects or treatment by time interactions for BG or NAG (Table 2.21). Averaged over the season, TAP activity in T1, T2 and T4 was not different from Ctrl which was higher than in T3 (Table 2.19). In the first measurement, the TAP content in Ctrl was significantly higher than any of the compost treatments; on the next sample date the TAP contents in Ctrl and T3 were similar, and were lower than T1, T2, and T4. There was no treatment effect on TAP activity at the end of the season. The seasonal average of PHOS content

in T3 was lower than in Ctrl, T1 and T2. PHOS activity in T2 did not differ from T1, and was higher than in T3 and T4. PHENOX was measured only once in the beginning of the season and did not show any treatment effect (Table 2.19).

3.3. Environmental conditions

The daily average temperature was collected near the research site from 20 April to 20 Oct in 2009 and 2010. The temperature in 2010 was significantly higher than in 2009 ($p < 0.05$), especially during 20 May to 20 July (Figure 2.13).

Total precipitation (Figure 2.14) during the growing season in 2009 (445 mm) was higher than in 2010 (373 mm). However, the higher rainfall in 2009 was driven by a few large precipitation events; in fact, the median rainfall in 2009 (3.0mm) was lower than median rainfall in 2010 (4.6 mm) and the numbers of rainy days was the same for both years (65 days). In both years, fields were irrigated six times; however more water was applied in 2010 leading to a higher amount of irrigation water used that year (Table 2.22).

Compost application significantly affected soil moisture in the potato system in 2009 but not in 2010 (Figure 2.15). In 2009, the soil moisture in T2 and T4 was higher than in Ctrl. In the corn soil in 2010, the moisture content in T4 was significantly higher than the other treatments, which were similar to each other (Figure 2.16).

4. Discussion

4.1. Effect of poultry compost application rates on potato quality

The fundamental challenge of potato cultivation is to maximize yield and reduce diseases below economic thresholds, and to maintain high soil quality. In this study, poultry compost

application significantly increased potato yield. Higher rates of compost produced higher potato yields and especially increased the number of US No.1 tubers. A net benefit analysis estimated that a minimum yield increase of 3 Mg ha^{-1} in US No. 1 tubers would be necessary to support farmer adoption of organic inputs among Michigan potato producers (Labarta *et al.*, 2002). Snapp *et al* (2003) stated that poultry compost applied with a reduced fertilizer rate could significantly increase potato yield from 3.4 to 6.8 Mg ha^{-1}. This result demonstrated that compost at a rate of 1.7, 3.4, 6.8, and 13.4 Mg C ha^{-1} increased the yield of US No.1 potatoes by 1.99, 1.44, 6.96, and 5.79 Mg ha^{-1} in 2009 and by 5.08, 6.25, 7.77, and 10.2 Mg ha^{-1} in 2010, respectively. This increased yield is possibly explained by the increase in leaf area index when compost is added (Larkin *et al.*, 2011). Moreover, the combination of inorganic fertilizers with compost application may have maximized N use efficiency (Sikora and Enkiri, 2000; Nyiraneza and Snapp, 2007). For instance, Carter *et al* (2004) found that the compost in combination with N application could maximize the potato yield to 39 Mg ha^{-1}.

Environmental conditions such as temperature and soil moisture can be the factors that affect potato yield. For example, in a study adding compost to potato systems in sandy soil in Prince Edward Island, Carter (2007) found that the increase of soil organic C was associated with an increase of soil moisture content and water-holding capacity, and resulted in higher potato yields. Because the Ctrl system did not receive compost and therefore had lower water-holding capacity, a short period of water deficit could reduce potato yields and quality (Gregory and Simmonds, 1992; Carter, 2007). Irrigation in combination with a more regular rainfall in 2010 and higher temperatures, likely account for the overall higher yields in 2010 than in 2009.

Environmental changes associated with poultry compost may have also influenced common scab. For example, Larkin *et al* (2011) found that common scab in potato systems with irrigation was increased by 10 to 50% compared to systems without irrigation. Other studies have found the opposite result: irrigation tended to reduce common scab (Lapwood, 1973; Davis *et al.*, 1976). Many studies on common scab suppression have focused on cultural controls and resistant cultivars (Loria *et al.*, 2006) but few have focused on using compost application. I found that compost amendment substantially changed the soil environment and soil biological activity by increasing soil water holding capacity, tuber yield, and microbial activity. Potato responses to amendments may also depend upon the chemical characteristics of the amendment. Saison *et al* (2006) stated that the effect of compost amendment on soilborne disease was mostly affected by the characteristics of the compost used. My results indicated that the rates of compost application significantly changed the soil microbial biomass and certain types of enzyme activities in the soil. This could explain the reduction of common scab in 2009; however, the difference in common scab between 2009 and 2010 is more likely due to different environmental conditions such as temperature or rainfall.

4.2. Management of poultry compost application rates and timing on corn yield

High rates of compost application could increase yields and improve environmental conditions but are not considered economical by potato growers (Evanylo *et al.*, 2008). Researchers need to determine the lower rate that preserves efficacy, and how frequently compost should be applied. The compost application in this study occurred once but in some instances there were still effects on the corn yield in the next year. In 2010, the additional application of 1.7 ton C ha^{-1} in T1, which provided the same amount of compost in T2 after two

years (but with a different frequency of application), increased corn yield to equal that of T2. Crop yield may not benefit from low rates of compost in a short tern but may be increased by the accrual of nutrients supplied by multiple applications of compost (Evanylo *et al.*, 2008). The plots treated with poultry compost preserved more of the inorganic N that was applied, thereby increasing N availability for corn growth (Munoz *et al.*, 2008; Bowden *et al.*, 2010). Smiciklas *et al* (2008) suggested that the optimal compost application rates for the corn-soybean systems were about 22.4 to 44.8 Mg ha^{-1} but that rate may not be economical and may result in excessive P-loading. Our result also indicated that there was no difference of corn yield between T1 (3.4 Mg C ha^{-1} in total) and T4 (13.4 Mg C ha^{-1}). This suggested that timing of compost application should be considered to minimize costs for growers.

4.3. Effect of poultry compost application rates on soil quality management

Management to maintain and improve soil quality is very important and is a difficult task in potato systems. High rates of poultry compost application in this study significantly enhanced soil biological characteristics and nutrient availability. This occurred because the poultry compost increased soil organic matter, which in turn increased water holding capacity, particulate organic matter C and N, nutrient levels and biomass (Grandy *et al.*, 2002; Larkin *et al.*, 2011). Thus, it provided N-bearing compounds and organic matter that promoted soil biological processes (Grandy *et al.*, 2009). The acquisition of nutrients by microbes from soil organic matter has often been determined by the availability of nutrients in the soil (Caldwell, 2005; Moorhead and Sinsabaugh, 2006). Grandy *et al* (2009) indicated that BG, NAG and L-leucine aminopeptidase (LAP) were highly correlated to the abundance of N-bearing compounds. This was also similar to our result that BG, NAG, and TAP were tied to substrate availability

from poultry compost in potato systems. Microbial biomass and inorganic N also increased following compost application. There was no correlation between PHOS and MBC, N, or inorganic N, probably because PHOS can be produced by a wide range of taxa in both acid- and alkaline-active forms (Sinsabaugh *et al.*, 2008).

Sufficient N management is essential to maximize crop production; meanwhile, excessive fertilization will increase the costs of production and the risks of NO_3^--N leaching and NH_3 volatilization. Compost application increases soil organic matter and microbial biomass, and therefore helps to reduce N loss from leaching and runoff and increase N recovery. Although N was balanced in all the systems, inorganic N contents in the treatments receiving higher rates of compost were nevertheless significantly higher than in the Ctrl treatment during the growing seasons. The management of combining compost with N fertilizers was reported to improve soil physical and chemical properties and provide environmental benefits (Evanylo *et al.*, 2008). Nyiraneza and Snapp (2007) also demonstrated that using a combination of poultry compost and N fertilizer increased N availability in potato systems. The sole use of inorganic N can reduce MBC in the soil (Peacock *et al.*, 2001, Lupwayi *et al.*, 2005) while the integration of fertilizers with organic application usually increases MBN and has negligible or no effect on MBC (Limon-Ortega *et al.*, 2009).

4.4. Effect of timing of poultry compost application on soil quality management

Carter *et al* (2004) stated that an annual compost application rate of 2-3 Mg C ha^{-1} was the minimum amount needed to maintain soil organic matter levels in potato systems in sandy loam soil for a rotation cycle. In another study of potato rotations in the same area (Angers *et al.*, 1999), the systems with C input higher than 2.4 Mg C ha^{-1} yr^{-1} were found to have the capacity

of maintaining organic matter levels in the soil. In this study, the rate of 1.7 Mg C ha^{-1} applied in the first year was probably not high enough to have an effect. For example, seasonal averages of MBC and MBN in T1 were not different from T2 in the potato system in 2009; however, in the corn system in 2010, they were significantly lower in T1 than in T2. This could be explained by the disturbance of the compost addition in T1 on soil microbial community in 2010. Hadas and Portnoy (1997) demonstrated that only 9 % of the total organic N was mineralized from compost decomposition after 33 weeks. Examining NO_3^--N contents in these systems, I found that though there was no difference in 2009, in 2010 the seasonal average of NO_3^--N in T1 was significantly increased to a level higher than in T4. This can be explained by the N recovery capability of poultry compost addition in increasing the high corn yield in T1.

Compost mineralization processes are greatly affected by N content in compost, C/N ratio, soil texture, pH and climate. Some studies have found that only a portion of N inputs were mineralized in the first year following application (Scherer *et al.*, 1996; Brandt *et al.*, 1999). However, other studies also demonstrated that little to no N availability remained in the second year due to nutrient loss during composting (Mahimairaja *et al.*, 1995; Warman and Cooper, 2000; Muñoz *et al.*, 2008). Therefore, in the long-term use of compost application, integrating N supply with the residual N mineralized from compost in the following years is a very important component of managing soil quality and improving crop production.

5. Conclusion

This study was conducted to examine the effect of poultry compost amendment in terms of application rates and timing on plant yields and soil quality. Regardless of application rate and

timing, compost amendment increased potato and corn yield and soil characteristics such as soil organic matter, water holding capacity, inorganic N, microbial biomass and enzyme activity. In chapter 1, compost application at a low and economical rate (5.6 Mg ha^{-1}) combined with rye cover crop significantly increased potato yield and soil microbial activity. In this study, higher rates of poultry compost application resulted in increased potato yields in both 2009 and 2010. However, the effect of compost application on scab incidence was not consistent: there was a treatment effect in 2009 but not in 2010, when there was an overall reduction of scab. The common scab incidence was also found to be negatively correlated with soil characteristics in 2009 but not in 2010.

In examining the effect of high rates of compost application on soil quality, I also found that poultry compost significantly increased soil pH, inorganic N, microbial biomass and enzyme activities in both phases 2009 and 2010. These effects of compost application carried over to the second year in corn soil. However, although applying compost at a high rate increases C sequestration, it tends to be less economical for farmers. Therefore, dividing the poultry compost application into two smaller applications of 1.7 ton C ha^{-1} each year for two years was recommended in this study in order to improve soil quality and crop yield without burdening farmers financially.

Overall, poultry compost application greatly increased both potato and corn yields and improved soil biological characteristics. The optimal combination of application rates and timing of compost need to be further examined in order to determine the best long term management practices for using organic amendments to improve potato productivity.

Table 2.1. Poultry manure amendment rates for potato in 2009 and corn in 2010 in Phase 1.

Treatment	Rate of compost amendment in 2009, ton C ha^{-1} *	Rate of compost amendment in 2010, ton C ha^{-1}
Ctrl	0	0
T1	1.7	1.7
T2	3.4	0
T3	6.8	0
T4	13.6	0

* Manure application rate for Phase 2 in 2010 was repeated as in Phase 1 in 2009.

Table 2.2. Field operation dates of the two study phases.

Operations	Dates*	
	Phase 1	**Phase 2**
2009	**Potato**	
Compost application	20 May	-
Planting	22 May	-
Fertilizer application No.1	22 May	-
Fertilizer application No.2	24 June	-
Fertilizer application No.3	9 July	-
Vine kill for potato	18 September	-
Harvest	15 October	-
2010	**Corn**	**Potato**
Compost application	23 April	27 April
Planting	10 May	20 May
Fertilizer application No.1	10 May	20 May
Fertilizer application No.2	5 July	21 June
Vine kill for potato	-	17 September
Harvest	2 November	19 October

* Phase 1 began in 2009 and Phase 2 began in 2010. In 2009, soil samples were collected 12 times in Phase 1 every two weeks during the growing season. In 2010, soil samples were collected three times for Phase 1 and four times for Phase 2 over the growing season.

Table 2.3. Substrate/fluorescing agents and the molarity of each used in the enzyme assay

Substrate/ Fluorescing agent	Chemical formula	Enzyme	Molarity used (mM)
4-methylumbelliferone (MUB)	$C_{10}H_8O_3$		0.01
7-amino-4-methylcoumarin (MC)	$C_{10}H_9NO_2$		0.01
4-Methylumbelliferyl β-D-glucopyranoside	$C_{16}H_{18}O_8$	β-glucosidase	0.2
4-Methylumbelliferyl phosphate	$C_{10}H_9O_6P$	Acid phosphatase	0.2
4-Methylumbelliferyl N-acetyl-β-D-glucosaminide	$C_{18}H_{21}NO_8.H_2O$	β-1,4-D-acetyl glucosaminidase	0.2
L-Tyrosine 7-amido-4-methylcoumarin	$C_{19}H_{18}N_2O_4$	Tyrosine amino peptidase	0.1
L-3,4-dihydroxyphenylalanine	$C_9H_{11}NO_4$	Phenol oxidase	25

Table 2.4. Soil pH in the potato systems *

Phase 1 - potato 2009

Trt	29 Jul 2009	13 Aug 2009	9 Sep 2009	13 Oct 2009
Ctrl	5.69 (0.04)d	5.84 (0.07)c	5.90 (0.07)c	5.98 (0.04)c
T1	6.39 (0.06)b	5.82 (0.09)c	6.13 (0.03)b	6.55 (0.04)b
T2	6.02 (0.07)c	5.73 (0.10)c	6.19 (0.08)b	6.57 (0.11)b
T3	6.58 (0.06)b	6.32 (0.03)b	6.47 (0.10)a	6.95 (0.10)a
T4	6.89 (0.15)a	6.57 (0.07)a	6.64 (0.01)a	7.07 (0.08)a
p value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

Phase 2 - potato 2010

	1 Jun 2010	5 Jul 2010	14 Sep 2010
Ctrl	5.87 (0.17)b	5.32 (0.10)c	6.32 (0.14)b
T1	5.82 (0.15)b	5.45 (0.15)c	6.32 (0.13)b
T2	6.07 (0.16)b	5.83 (0.19)b	6.48 (0.23)b
T3	6.46 (0.09)a	6.11 (0.08)a	7.08 (0.09)a
T4	6.51 (0.16)a	6.05 (0.10)ab	7.05 (0.10)a
p value	< 0.0005	< 0.0001	< 0.0001

* Means (±SE) with different letters differ significantly ($p < 0.05$).

Table 2.5. Inorganic N in potato soil in 2009/Phase 1 *.

NO_3^--N

	2 Jun 2009	18 Jun 2009	1 Jul 2009	16 Jul 2009	29 Jul 2009	24 Aug 2009	9 Sep 2009	23 Sep 2009	13 Oct 2009	26 Nov 2009
Ctrl	30.0	5.78	5.05	38.2	17.2	5.58	10.9	15.7	1.91	3.15
	(5.56)	(0.80)b	(0.51)c	(5.93)b	(2.42)c	(0.44)b	(1.14)c	(1.71)b	(0.25)c	(0.17)
T1	36.0	5.72	8.42	38.3	20.5	6.07	12.2	16.4	2.36	3.20
	(5.17)	(0.43)b	(1.53)b	(5.62)b	(3.19)c	(0.54)b	(1.08)bc	(2.28)b	(0.30)c	(0.49)
T2	32.6	8.06	16.8	54.6	31.6	9.44	14.9	20.4	4.44	4.65
	(6.60)	(0.88)b	(1.55)a	(7.79)b	(3.33)ab	(1.74)a	(1.01)ab	(1.74)ab	(0.74)b	(0.61)
T3	32.8	53.3	23.3	48.2	24.9	7.69	8.80	17.9	6.08	3.57
	(4.14)	(12.4)a	(5.30)a	(10.6)b	(2.85)bc	(1.00)ab	(0.87)d	(1.48)b	(0.58)ab	(0.38)
T4	39.8	30.5	17.1	87.0	44.3	9.25	15.6	26.1	6.48	4.03
	(8.85)	(7.09)a	(1.44)a	(10.0)a	(8.89)a	(0.52)a	(1.69)a	(1.09)a	(0.73)a	(0.73)
p value	ns	< 0.0001	< 0.0001	0.0034	0.0036	0.0286	< 0.0001	0.0094	< 0.0001	ns

NH_4^+-N

	2 Jun 2009	18 Jun 2009	16 Jul 2009	29 Jul 2009	13 Aug 2009	24 Aug 2009	9 Sep 2009	23 Sep 2009	13 Oct 2009	26 Nov 2009
Ctrl	20.3	17.8	0.71	0.53	1.03	1.40	1.42	0.87	1.04	0.76
	(7.63)d	(4.99)c	(0.06)c	(0.09)d	(0.06)c	(0.07)b	(0.24)	(0.05)b	(0.11)bc	(0.14)
T1	48.9	46.1	1.69	0.62	1.27	1.52	1.31	1.04	0.88	0.79
	(10.6)cd	(11.4)ab	(0.11)b	(0.06)cd	(0.08)bc	(0.03)b	(0.18)	(0.05)b	(0.07)c	(0.10)
T2	70.3	18.1	1.77	0.76	1.73	1.78	1.22	0.69	1.05	0.68
	(20.1)bc	(3.87)c	(0.17)b	(0.08)bc	(0.22)b	(0.06)ab	(0.05)	(0.12)b	(0.10)bc	(0.03)
T3	102.1	36.9	1.38	0.93	1.78	1.95	1.28	1.39	1.30	1.03
	(14.89)b	(5.32)bc	(0.19)b	(0.03)b	(0.14)b	(0.14)a	(0.21)	(0.15)a	(0.08)ab	(0.08)
T4	150.9	59.2	2.35	1.82	2.64	2.15	1.37	1.67	1.58	0.80
	(10.6)a	(7.76)a	(0.11)a	(0.07)a	(0.29)a	(0.23)a	(0.11)	(0.20)a	(0.13)a	(0.08)
p value	0.0003	0.0154	0.0001	0.0001	0.0001	0.0013	ns	0.0002	0.0012	ns

* Mean±SE (mg N kg^{-1} soil) Means with the same letters did not differ significantly ($p < 0.05$). Abbreviation: ns – not significant.

Table 2.6. Inorganic N of potato 2010/Phase 2 *

NO_3^--N

	1 Jun 2010	5 Jul 2010	12 Aug 2010	14 Sep 2010
Ctrl	18.8 (2.40)d	26.2 (2.54)	4.50 (0.21)c	8.60 (1.40)c
T1	25.1 (1.57)cd	31.2 (1.84)	7.05 (0.74)b	13.3 (1.52)c
T2	34.2 (2.03)bc	31.5 (4.13)	7.74 (0.70)b	22.2 (2.76)b
T3	44.6 (5.23)b	30.2 (2.02)	7.08 (0.60)b	27.5 (2.40)a
T4	90.0 (7.29)a	35.7 (8.31)	13.0 (2.84)a	29.7 (3.38)a
p value	< 0.0001	ns	< 0.0001	< 0.0001

NH_4^+-N

	1 Jun 2010	5 Jul 2010	12 Aug 2010	14 Sep 2010
Ctrl	26.4 (4.03)bc	3.81 (0.41)a	1.04 (0.16)a	0.47 (0.06)ab
T1	25.3 (3.52)bc	4.05 (0.43)a	0.41 (0.03)b	0.33 (0.03)b
T2	23.4 (1.77)c	3.26 (1.12)a	0.52 (0.03)b	0.43 (0.05)ab
T3	34.4 (4.05)b	1.39 (0.21)b	0.49 (0.02)b	0.55 (0.09)a
T4	51.2 (3.49)a	1.08 (0.11)b	1.69 (0.46)a	0.70 (0.15)a
p value	0.0012	0.0027	0.0005	0.0417

* Mean±SE (mg N kg^{-1} soil). Means with the same letter did not significantly differ ($p < 0.05$).
Abbreviation: ns – not significant

Table 2.7. Microbial biomass C in the potato soil over the growing season 2009/Phase 1 and 2010/Phase 2 *

Potato 2009 – Phase 1					
	1 Jul 2009	29 Jul 2009	13 Aug 2009	9 Sep 2009	26 Nov 2009
Ctrl	45.1 (4.83)bc	155.5 (8.75)ab	134.3 (11.2)b	70.7 (10.6)c	103.6 (15.0)b
T1	37.8 (7.86)c	205.5 (23.0)a	139.5 (15.8)b	69.0 (20.0)c	110.1 (5.2)b
T2	32.8 (6.96)c	169.5 (33.9)ab	215.5 (18.0)a	84.9 (20.2)bc	132.5 (3.2)ab
T3	61.3 (8.67)b	203.7 (19.4)a	119.1 (18.9)b	134.0 (20.9)ab	141.8 (12.6)a
T4	128.4 (15.3)a	119.6 (12.3)b	206.9 (20.4)a	148.6 (24.1)a	55.7 (10.8)c
p value	< 0.0001	0.0275	0.0009	0.0150	< 0.0001
Potato 2010 – Phase 2					
	11 Jun 2010	12 Aug 2010	14 Sep 2010		
Ctrl	69.6 (4.52)d	79.6 (7.34)c	73.3 (5.64)c		
T1	67.3 (9.61)d	74.4 (7.82)c	76.9 (2.29)c		
T2	127.6 (6.98)c	95.0 (9.28)bc	83.8 (6.56)bc		
T3	155.2 (12.1)b	118.1 (13.1)b	95.4 (5.08)b		
T4	193.5 (9.92)a	176.9 (9.23)a	137.7 (10.1)a		
p value	< 0.0001	< 0.0001	< 0.0001		

* Mean ±SE (mg kg^{-1} soil). Means with different letters were significantly different at $p < 0.05$.

Table 2.8. Microbial biomass N in potato soil over the growing season 2009/Phase 1 and 2010/Phase 2*

Potato 2009 – Phase 1					
	1 Jul 2009	29 Jul 2009	13 Aug 2009	9 Sep 2009	26 Nov 2009
Ctrl	18.1 (3.63)bc	18.1 (1.56)b	19.3 (2.73)b	9.75 (1.29)c	16.6 (1.88)c
T1	11.9 (2.96)c	21.9 (3.81)b	28.3 (1.78)b	17.7 (3.85)bc	17.5 (1.10)bc
T2	25.9 (7.75)ab	24.7 (7.69)b	19.7 (2.04)b	16.9 (4.86)bc	21.7 (1.42)ab
T3	34.9 (4.38)a	37.2 (5.91)a	19.8 (5.29)b	35.0 (4.08)a	26.1 (1.88)a
T4	23.7 (3.89)ab	46.9 (5.97)a	46.2 (1.72)a	23.5 (4.73)ab	21.1 (3.40)abc
p value	0.0125	0.0030	0.0001	0.0082	0.0167
Potato 2010 – Phase 2					
	12 Aug 2010	14 Sep 2010			
Ctrl	12.8 (0.71)c	11.7 (0.98)d			
T1	16.7 (1.07)c	18.6 (0.72)bc			
T2	16.6 (1.13)bc	16.5 (2.27)c			
T3	20.8 (2.61)b	21.3 (1.88)b			
T4	32.2 (1.01)a	35.4 (1.01)a			
p value	< 0.0001	< 0.0001			

* Mean ±SE (mg kg^{-1} soil). Means with different letters were significantly different at $p < 0.05$.

Table 2.9. β-1,4-glucosidase activity of potato soil over the growing season 2009/Phase 1 and 2010/Phase 2 *

Potato 2009 – Phase 1

	2 Jun 2009	18 Jun 2009	1 Jul 2009	16 Jul 2009	29 Jul 2009	13 Aug 2009	24 Aug 2009	9 Sep 2009	23 Sep 2009	13 Oct 2009	26 Nov 2009
Ctrl	20.4	49.3	30.2	48.1	61.3	58.1	32.5c	45.3	36.0	35.4	22.8
	(2.55)c	(8.87)	(5.46)	(8.57)b	(7.24)b	(6.24)c	(3.99)	(4.42)ab	(3.51)c	(7.00)c	(1.97)b
T1	55.8	49.7	33.1	45.9	68.5	61.5	47.5b	38.7	34.0	46.4	21.4
	(5.44)b	(12.89)	(8.88)	(6.31)b	(9.88)b	(7.36)bc	(5.51)	(2.70)b	(5.79)c	(6.60)bc	(1.62)b
T2	74.3	60.4	37.9	80.2a	105.6	76.7	68.2	52.4	74.2	70.4	30.3
	(6.16)a	(9.01)	(6.20)	(12.4)	(13.5)a	(4.23)ab	(5.52)a	(7.41)a	(9.64)a	(11.9)a	(3.52)a
T3	75.3	43.9	20.3	51.1	52.54	66.2	62.9	48.7	55.4	39.4	18.6
	(7.37)a	(10.6)	(4.35)	(12.6)b	(5.92)b	(3.10)bc	(3.21)a	(1.80)ab	(4.58)b	(9.07)c	(0.63)b
T4	81.9	32.6	36.7	83.0	68.1	84.4	64.3	57.0	39.2c	69.7	30.5
	(7.51)a	(7.78)	(8.06)	(7.76)a	(9.87)b	(6.25)a	(3.74)a	(2.01)a	(3.10)	(5.35)ab	(1.85)a
p value	< 0.0001	ns	ns	0.0150	0.0136	0.0171	< 0.0001	0.0458	0.0002	0.0120	0.0010

Potato 2010 – Phase 2

	1 Jun 2010	5 Jul 2010	12 Aug 2010	14 Sep 2010
Ctrl	26.3 (0.62)	25.7 (1.41)	40.9 (2.88)ab	42.2 (1.84)ab
T1	28.5 (2.33)	25.8 (1.89)	33.8 (2.02)c	35.9 (3.30)bc
T2	30.9 (1.53)	29.5 (4.03)	35.2 (1.47)bc	33.6 (2.28)c
T3	29.3 (2.56)	24.7 (0.76)	35.4 (3.05)bc	34.9 (1.40)c
T4	28.1 (2.37)	31.0 (1.84)	44.1 (2.11)a	42.8 (2.18)a
p value	ns	ns	0.0047	0.0059

* Mean±SE (nmol h^{-1} g^{-1} soil). Means with different letters were significantly different ($p < 0.05$).

Table 2.10. β-1,4-N-acetyl glucosaminidase activity of potato soil over the growing season 2009/Phase 1 and 2010/Phase 2*

Potato 2009 – Phase 1

	2 Jun 2009	18 Jun 2009	1 Jul 2009	16 Jul 2009	29 Jul 2009	13 Aug 2009	24 Aug 2009	9 Sep 2009	23 Sep 2009	13 Oct 2009	26 Nov 2009
Ctrl	14.3	23.1	13.5	22.8	28.7	30.9	9.49	20.2	11.9	18.1	12.9
	(3.29)c	(2.58)	(1.47)	(2.09)bc	(2.46)b	(1.93)c	(2.01)c	(1.47)	(0.91)	(2.75)c	(0.80)
T1	27.5	30.6	17.8	20.2	31.4	39.6	11.0	23.5	11.1	23.1	13.1
	(2.72)b	(4.44)	(2.77)	(2.98)c	(3.61)b	(4.26)b	(1.46)bc	(3.25)	(1.31)	(4.42)bc	(1.12)
T2	34.1	36.3	23.1	38.5	49.0	40.4	16.0	23.5	11.9	32.1	14.1
	(4.66)ab	(2.72)	(4.19)	(6.25)a	(6.62)a	(2.09)b	(1.36)ab	(3.51)	(0.86)	(4.54)a	(0.72)
T3	36.7	20.8	14.0	27.2	32.0	40.6	19.3	23.7	11.8	18.6	11.9
	(2.79)ab	(1.63)	(2.92)	(7.45)abc	(3.61)b	(1.62)b	(0.95)a	(2.68)	(0.62)	(4.74)c	(1.62)
T4	42.2	35.6	18.5	35.2	36.9	58.7	17.2	31.6	13.1	28.6	15.6
	(2.76)a	(7.83)	(1.44)	(3.87)ab	(3.19)b	(2.08)a	(2.29)a	(5.22)	(1.67)	(1.61)ab	(1.98)
p value	< 0.0001	ns	ns	0.0389	0.0319	< 0.0001	0.0034	ns	ns	0.0400	ns

Potato 2010 – Phase 2

	1 Jun 2010	5 Jul 2010	12 Aug 2010	14 Sep 2010
Ctrl	8.6 (0.29)d	10.5 (0.90)c	15.7 (0.81)c	13.0 (0.80)c
T1	12.9 (1.33)bc	9.6 (0.67)c	15.3 (1.62)c	14.5 (0.84)c
T2	11.1 (1.00)cd	11.9 (1.03)bc	16.5 (1.76)bc	15.0 (1.05)c
T3	15.6 (1.17)b	15.0 (1.34)b	19.1 (1.91)b	22.1 (1.30)b
T4	23.0 (1.97)a	19.8 (2.72)a	30.3 (0.85)a	29.8 (2.94)a
p value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

* Mean±SE (nmol h^{-1} g^{-1} soil). Means with different letters were significantly different ($p < 0.05$).

Table 2.11. Acid phosphatase activity of potato soil over the growing season 2009/Phase 1 and 2010/Phase 2*

Potato 2009 – Phase 1

	18 Jun 2009	1 Jul 2009	16 Jul 2009	29 Jul 2009	13 Aug 2009	24 Aug 2009	9 Sep 2009	23 Sep 2009	13 Oct 2009	26 Nov 2009
Ctrl	72.6	50.4	93.6	68.8	92.7	63.1	48.9	49.7	23.1	12.1
	(7.38)a	(6.00)a	(7.94)	(6.02)b	(12.9)	(12.5)c	(11.0)c	(4.83)b	(7.05)c	(1.16)
T1	37.6	49.7	88.7	57.8	94.5	94.8	91.1	64.7	51.4	14.5
	(6.60)bc	(11.8)a	(14.2)	(10.3)b	(19.6)	(12.2)b	(7.62)ab	(9.15)b	(9.74)ab	(1.64)
T2	64.1	60.6	117	124	161	168	131	149	87.9	22.3
	(12.4)ab	(14.8)a	(20.3)	(14.7)a	(18.5)	(11.9)a	(11.2)a	(26.0)a	(12.4)a	(1.79)
T3	36.1	17.9	60.4	57.9	110	93.2	84.6	80.0	31.3	13.8
	(2.22)bc	(0.75)b	(12.8)	(10.2)b	(9.55)	(6.82)b	(5.16)b	(22.8)b	(6.43)bc	(2.91)
T4	34.5	57.2	88.9	46.9	130	120	91.8	54.3	50.1	18.2
	(10.4)c	(11.6)a	(18.1)	(10.7)b	(18.6)	(6.64)ab	(9.87)ab	(11.9)b	(8.03)ab	(3.97)
p value	0.0022	< 0.0001	ns	0.0007	ns	0.0023	0.0012	0.0003	< 0.0001	ns

Potato 2010 – Phase 2

	1 Jun 2010	5 Jul 2010	12 Aug 2010	14 Sep 2010
Ctrl	51.6 (6.97)bc	50.4 (5.83)a	166 (26.0)	138 (13.0)
T1	71.2 (6.04)a	53.4 (8.27)a	152 (21.1)	161 (24.7)
T2	67.6 (9.67)ab	67.4 (6.57)a	146 (24.7)	167 (28.7)
T3	65.8 (6.55)ab	20.3 (4.70)b	137 (16.6)	143 (25.9)
T4	41.1 (4.65)c	62.3 (7.23)a	172 (41.1)	187 (46.2)
p value	0.0047	0.0007	ns	ns

* Mean±SE (nmol h^{-1} g^{-1} soil). Means with different letters were significantly different ($p < 0.05$).

Table 2.12. Tyrosine amino peptidase activity of potato soil over the growing season 2009/Phase 1 and 2010/Phase 2 *

Potato 2009 – Phase 1

	18 Jun 2009	1 Jul 2009	16 Jul 2009	29 Jul 2009	13 Aug 2009	24 Aug 2009	9 Sep 2009	23 Sep 2009	13 Oct 2009	26 Nov 2009
Ctrl	11.1	5.79	2.50	10.4	10.5	5.36	12.0	2.98	5.07	3.09
	(1.93)	(1.14)	(0.18)c	(1.69)	(1.01)d	(0.78)d	(1.35)	(0.22)b	(1.32)b	(0.69)
T1	6.97	4.41	14.21	14.7	19.5	10.6	10.1	2.82	8.24	2.31
	(0.93)	(1.18)	(2.93)b	(2.62)	(1.07)c	(0.83)c	(0.99)	(0.14)b	(0.53)ab	(0.17)
T2	15.2	8.33	23.4	19.8	24.4	18.1	13.0	3.90	13.5	3.74
	(2.89)	(2.47)	(3.09)a	(4.32)	(0.94)b	(1.40)a	(2.10)	(0.47)ab	(2.50)a	(0.86)
T3	12.1	3.08	25.5	19.2	24.1	12.8	13.4	3.96	9.94	3.27
	(3.52)	(0.74)	(3.02)a	(3.41)	(1.40)b	(0.46)bc	(1.56)	(0.67)ab	(2.56)a	(0.24)
T4	14.5	7.70	23.4	20.3	33.8	15.1	14.9	5.23	15.0	3.76
	(4.11)	(1.64)	(2.84)a	(4.88)	(2.34)a	(1.28)ab	(1.03)	(0.63)a	(1.74)a	(0.46)
p value	ns	ns	< 0.0001	ns	< 0.0001	< 0.0001	ns	0.0111	0.0037	ns

Potato 2010 – Phase 2

	1 Jun 2010	5 Jul 2010	12 Aug 2010	14 Sep 2010
Ctrl	5.20 (0.67)	3.69 (0.32)d	10.7 (1.05)d	9.24 (0.63)c
T1	6.22 (0.50)	4.51 (0.47)cd	14.7 (0.66)c	10.6 (0.52)bc
T2	6.67 (1.15)	6.73 (1.44)ab	15.1 (1.11)c	9.83 (0.48)c
T3	8.27 (1.12)	5.50 (1.12)bc	20.1 (1.13)b	12.9 (1.28)b
T4	8.17 (0.67)	10.8 (0.77)a	26.4 (1.04)a	15.9 (0.98)a
p value	ns	0.0002	< 0.0001	< 0.0001

* Mean±SE (nmol h^{-1} g^{-1} soil). Means with different letters were significantly different ($p < 0.05$).

Table 2.13. Phenol oxidase activity of potato soil over the growing season 2009/Phase 1 and 2010/Phase 2*

Potato 2009 – Phase 1

	2 Jun 2009	18 Jun 2009	1 Jul 2009	29 Jul 2009	13 Aug 2009	24 Aug 2009	23 Sep 2009	26 Nov 2009
Ctrl	1.07 (0.11)a	0.59 (0.19)	0.76 (0.18)	1.30 (0.12)	1.27 (0.09)a	1.12 (0.11)	1.24 (0.11)b	0.82 (0.07)b
T1	0.45 (0.03)bc	0.66 (0.12)	0.77 (0.08)	1.23 (0.14)	1.15 (0.12)ab	0.89 (0.08)	1.66 (0.23)b	0.62 (0.13)b
T2	0.47 (0.07)b	0.84 (0.08)	0.75 (0.11)	1.26 (0.14)	0.92 (0.09)bc	0.89 (0.08)	0.82 (0.13)c	0.66 (0.14)bc
T3	0.19 (0.07)c	0.66 (0.09)	0.61 (0.16)	1.05 (0.29)	0.80 (0.06)c	0.85 (0.03)	0.92 (0.07)bc	0.28 (0.05)c
T4	0.47 (0.09)b	0.82 (0.09)	0.81 (0.17)	1.29 (0.08)	0.95 (0.02)abc	0.94 (0.05)	2.05 (0.06)a	1.71 (0.25)a
p value	< 0.0001	ns	ns	ns	0.0071	ns	< 0.0001	< 0.0001

Potato 2010 – Phase 2

	1 Jun 2010	5 Jul 2010	14 Sep 2010
Ctrl	0.50	0.32	0.80a
T1	0.36	0.32	0.46abc
T2	0.39	0.19	0.41bc
T3	0.23	0.46	0.38c
T4	0.42	0.30	0.62ab
p value	ns	ns	0.0191

* Mean±SE (µmol h^{-1} g^{-1} soil). Means with different letters were significantly different ($p < 0.05$).

Table 2.14. Overall repeated measures ANOVA of potato soil characteristics in both phases in 2009 and 2010.

Potato 2009 – Phase 1

	pH	NO_3^--N*	NH_4^+-N*	MBC	MBN*	BG	NAG*	PHOS*	TAP*	PHENOX
Trt	< 0.0001	< 0.0001	< 0.0001	0.0181	< 0.0001	0.0023	0.0006	0.0010	< 0.0001	0.0006
Date	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0035	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Trt*date	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

Potato 2010 – Phase 2

	pH	NO_3^--N*	NH_4^--N*	MBC	MBN*	BG	NAG*	PHOS	TAP	PHENOX
Trt	< 0.0001	< 0.0001	0.0054	< 0.0001	< 0.0001	0.0275	< 0.0001	0.0132	< 0.0001	0.1722
Date	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.6095	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0076
Trt*date	0.0114	< 0.0001	< 0.0001	< 0.0001	0.6324	0.0313	0.0402	0.0002	< 0.0001	0.2642

* Logarithmic transformation. Abbreviations: MBC: microbial biomass C, MBN, microbial biomass N, BG: β-1,4-glucosidase, NAG: β-1,4-N-acetyl glucosaminidase, PHOS: acid phosphatase, TAP: tyrosine amino peptidase, PHENOX: phenol oxidase.

Table 2.15. Pearson's correlation coefficients (r) between seasonal means of variables in potato soil in 2009/Phase 1 and 2010/Phase 2*

Potato 2009/Phase 1

	Total yield	Scab	W%	pH	NO_3^-	NH_4^+	MBC	MBN	BG	NAG	TAP	PHOS
Scab	**-0.56**											
W%	0.39	**-0.43**										
pH	**0.52**	**-0.51**	0.33									
NO_3^-	0.22	**-0.47**	**0.66**	**0.68**								
NH_4^+	0.26	**-0.48**	**0.42**	**0.87**	**0.82**							
MBC	**0.62**	-0.32	**0.48**	**0.64**	**0.42**	**0.48**						
MBN	**0.50**	**-0.59**	**0.51**	**0.78**	**0.74**	**0.70**	**0.57**					
BG	0.35	-0.17	**0.77**	0.28	**0.47**	0.32	**0.53**	0.29				
NAG	0.33	-0.39	**0.72**	**0.51**	**0.64**	**0.54**	**0.51**	**0.46**	**0.87**			
TAP	**0.45**	**-0.45**	**0.77**	**0.68**	**0.74**	**0.66**	**0.72**	**0.65**	**0.80**	**0.89**		
PHOS	-0.01	-0.11	**0.65**	-0.19	0.23	-0.05	0.13	0.03	**0.76**	**0.62**	**0.52**	
PHENOX	0.10	-0.28	0.16	0.01	-0.04	0.13	-0.06	0.12	-0.09	-0.06	-0.07	-0.11

Potato 2010/Phase 2

	Total Yield	Scab	W%	pH	NO_3^-	NH_4^+	MBC	MBN	BG	NAG	TAP	PHOS
Scab	0.14											
W	-0.17	-0.18										
pH	**0.54**	0.30	-0.03									
NO_3^-	**0.53**	-0.15	0.38	**0.46**								
NH_4^+	0.35	-0.12	0.19	0.32	**0.75**							
MBC	**0.53**	-0.01	0.34	**0.62**	**0.91**	**0.73**						
MBN	**0.61**	0.07	0.32	**0.61**	**0.82**	**0.69**	**0.91**					
BG	-0.03	0.04	0.36	0.24	0.35	0.38	**0.49**	**0.50**				
NAG	**0.46**	-0.04	**0.41**	**0.43**	**0.89**	**0.76**	**0.91**	**0.87**	**0.49**			
TAP	**0.53**	0.05	**0.42**	**0.62**	**0.85**	**0.66**	**0.92**	**0.91**	**0.42**	**0.89**		
PHOS	-0.22	-0.27	**0.52**	**-0.58**	0.31	0.21	0.19	0.10	0.16	0.37	0.19	
PHENOX	**-0.45**	0.13	0.11	-0.33	-0.08	0.16	-0.02	-0.02	0.31	0.05	-0.16	0.32

* The bold numbers indicate significance at $p < 0.05$. See Table 2.14 for abbreviations.

Table 2.16. Soil pH of corn soil 2010/Phase 1*.

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	6.34 (0.02)c	5.79 (0.15)c	6.81 (0.10)d	6.31 (0.08)c
T1	6.37 (0.07)c	6.14 (0.07)b	7.09 (0.12)bc	6.53 (0.07)b
T2	6.59 (0.09)b	6.19 (0.11)b	7.06 (0.07)cd	6.61 (0.07)b
T3	7.05 (0.06)a	6.40 (0.09)ab	7.34 (0.08)ab	6.93 (0.06)a
T4	6.93 (0.07)a	6.53 (0.10)a	7.46 (0.05)a	6.97 (0.05)a
p value	< 0.0001	0.0021	0.0005	< 0.0001

* Means with different letters are significantly different ($p < 0.05$).

Table 2.17. Inorganic N in corn soil 2010/Phase 1*.

NO_3^--N

Trt	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	4.56 (0.28)c	4.69 (0.47)bc	2.57 (0.22)c	3.92 (0.20)c
T1	11.8 (0.82)a	4.56 (0.42)bc	3.56 (0.50)ab	6.81 (0.44)a
T2	5.77 (0.58)bc	3.53 (0.45)c	3.40 (0.35)b	4.30 (0.18)c
T3	6.10 (0.95)b	6.74 (0.71)a	4.24 (0.46)ab	5.65 (0.54)b
T4	7.05 (0.34)b	6.05 (0.63)ab	4.44 (0.30)a	5.82 (0.17)b
p value	< 0.0001	0.0107	0.0076	< 0.0001

NH_4^+-N

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	0.64 (0.04)	4.88 (0.73)a	0.24 (0.02)b	1.93 (0.24)a
T1	0.70 (0.05)	1.69 (0.14)b	0.32 (0.05)ab	0.90 (0.05)b
T2	0.69 (0.03)	1.41 (0.09)b	0.24 (0.01)b	0.78 (0.03)b
T3	0.77 (0.02)	4.30 (0.51)a	0.39 (0.08)a	1.82 (0.17)a
T4	0.79 (0.06)	2.47 (0.93)b	0.38 (0.04)a	1.08 (0.27)b
p value	ns	0.0002	0.0362	< 0.0001

* Means with different letters are significantly different ($p < 0.05$).

Table 2.18. Microbial biomass in corn soil 2010/Phase 1*

Microbial biomass C

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	51.2 (9.3)b	91.9 (4.69)c	60.9 (3.99)d	68.0 (2.96)d
T1	51.2 (12.4)b	136.8 (8.28)ab	77.7 (4.98)bc	88.5 (3.51)c
T2	139.1 (16.1)a	140.9 (9.53)ab	86.5 (4.02)ab	122.2 (8.04)a
T3	123.8 (5.7)a	128.3 (7.04)b	73.1 (1.88)c	108.4 (4.00)b
T4	132.4 (10.1)a	157.4 (7.22)a	94.1 (5.12)a	127.9 (4.74)a
p value	< 0.0001	< 0.0001	0.0001	< 0.0001

Microbial biomass N

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	13.0 (0.71)b	17.4 (1.41)b	8.3 (0.62)d	13.5 (0.81)c
T1	12.6 (2.48)b	23.5 (1.34)a	12.1 (1.11)c	16.8 (1.43)b
T2	22.6 (2.47)a	25.3 (2.75)a	14.9 (0.67)ab	21.0 (1.19)a
T3	21.9 (2.80)a	24.3 (1.85)a	13.2 (0.38)bc	19.8 (0.87)ab
T4	27.1 (0.99)a	27.2 (1.82)a	16.2 (0.54)a	22.9 (0.96)a
p value	0.0012	0.0471	< 0.0001	0.0001

* Means with different letters are significantly different ($p < 0.05$).

Table 2.19. Enzyme activities* in corn soil, 2010/Phase 1.

β-1,4-glucosidase (BG), nmol h^{-1} g^{-1} soil

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	54.9 (6.38)	65.0 (4.78)	35.0 (3.38)	51.6 (4.80)
T1	49.8 (5.15)	61.9 (3.67)	34.7 (4.23)	48.8 (3.16)
T2	62.1 (6.78)	72.7 (3.62)	41.9 (1.81)	58.9 (3.62)
T3	50.7 (5.10)	60.0 (4.80)	38.7 (1.92)	49.8 (3.26)
T4	49.1 (6.93)	71.7 (5.31)	37.9 (2.70)	52.9 (2.87)
p value	ns	ns	ns	ns

β-1,4-N-acetyl glucosaminidase (NAG), nmol h^{-1} g^{-1} soil

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	22.6 (2.70)	24.5 (2.04)bc	13.8 (0.71)b	20.3 (1.62)
T1	21.2 (2.93)	29.1 (1.88)ab	14.3 (1.73)b	21.5 (1.26)
T2	22.1 (2.53)	29.9 (2.31)a	16.3 (1.29)ab	22.8 (1.38)
T3	15.8 (1.76)	22.5 (1.54)c	17.5 (0.73)a	18.6 (1.15)
T4	18.5 (3.31)	29.4 (2.39)ab	18.2 (1.31)a	22.0 (1.12)
p value	ns	0.0230	0.0146	ns

Tyrosine amino peptidase (TAP), nmol h^{-1} g^{-1} soil

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	17.6 (1.79)a	13.3 (0.95)c	10.1 (0.74)	13.7 (0.81)ab
T1	10.0 (0.86)bc	15.6 (0.88)b	10.9 (0.97)	12.2 (0.50)bc
T2	13.1 (1.32)b	18.3 (0.66)a	11.5 (0.20)	14.3 (0.45)a
T3	11.1 (1.32)bc	15.1 (0.57)bc	9.5 (0.43)	11.9 (0.59)c
T4	7.6 (1.11)c	17.0 (0.41)ab	12.7 (0.45)	12.4 (0.20)bc
p value	0.0001	0.0017	ns	0.0282

Acid phosphatase (PHOS), nmol h^{-1} g^{-1} soil

	24 May 2010	19 Jul 2010	29 Sep 2010	Average
Ctrl	124 (18.8)	167 (17.3)ab	122 (9.3)ab	138 (14.4)ab
T1	98 (12.6)	165 (14.4)ab	119 (10.6)abc	127 (7.5)ab
T2	127 (18.6)	189 (10.2)a	145 (8.9)a	154 (11.1)a
T3	83 (14.5)	92 (7.3)c	95 (7.4)c	90 (8.1)c
T4	87 (23.6)	141 (12.6)b	107 (8.0)bc	112 (11.7)bc
p value	ns	0.0004	0.0083	0.0077

Phenol oxidase (PHENOX), µmol h^{-1} g^{-1} soil

	24 May 2010
Ctrl	0.65 (0.08)
T1	0.49 (0.08)
T2	0.64 (0.10)
T3	0.35 (0.12)
T4	0.62 (0.13)
p value	ns

* Means with different letters are significantly different ($p < 0.05$).

Table 2.20. Pearson's correlation coefficients (r) between seasonal means of variables in corn soil, 2010 *.

	Corn yield	pH	W	NO_3	NH_4	MBC	MBN	BG	NAG	TAP	PHOS
pH	0.36										
W	**0.45**	0.37									
NO_3	0.36	0.24	0.32								
NH_4	**-0.53**	-0.13	-0.26	-0.14							
MBC	**0.51**	**0.68**	**0.53**	0.22	**-0.40**						
MBN	**0.54**	**0.70**	**0.62**	0.34	-0.34	**0.92**					
BG	0.05	-0.10	**0.52**	-0.04	-0.21	0.35	0.31				
NAG	0.32	-0.15	**0.49**	0.12	**-0.51**	0.32	0.31	**0.79**			
TAP	0.00	**-0.43**	0.28	-0.26	-0.09	0.09	0.09	**0.66**	**0.57**		
PHOS	0.01	**-0.65**	0.24	-0.11	-0.18	-0.04	-0.07	**0.67**	**0.61**	**0.79**	
PHENOX	-0.11	**-0.42**	-0.09	**-0.56**	0.03	-0.29	-0.36	0.17	0.15	0.39	0.33

* The bold numbers indicate significance at $p < 0.05$. See Table 2.14 for abbreviations.

Table 2.21. Overall repeated measures ANOVA of corn soil characteristics, 2010/Phase 1.

	pH	NO_3-N*	NH_4-N	MBC	MBN*	BG*	NAG	PHOS	TAP	PHENOX
Trt		0.0001	< 0.0001	< 0.0001	< 0.0001	0.3699	0.2127	0.0068	0.0327	-
Date		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	-
Trt*date		< 0.0001	0.0011	< 0.0001	0.6579	0.6503	0.0665	0.0125	< 0.0001	-

* Logarithmic transformation. See Table 2.14 for abbreviations.

Table 2.22. Irrigation water added to the research field during the growing seasons of 2009 and 2010.

Potato 2009/Phase 1	Irrigation, mm	Potato 2010/Phase 2	Irrigation, mm*
25 Jun 2009	19.1	1 Jul 2010	22.9
6 Jul 2009	20.3	7 Jul 2010	25.4
10 Jul 2009	20.3	21 Jul 2010	25.4
18 Jul 2009	25.4	29 Jul 2010	27.9
29 Jul 2009	25.4	4 Aug 2010	27.9
5 Aug 2009	25.4	19 Aug 2010	25.4
Total	**135.9**	**Total**	**154.9**

* The amount of irrigation water applied was the same for potato 2010/Phase 2 and corn 2010/Phase1.

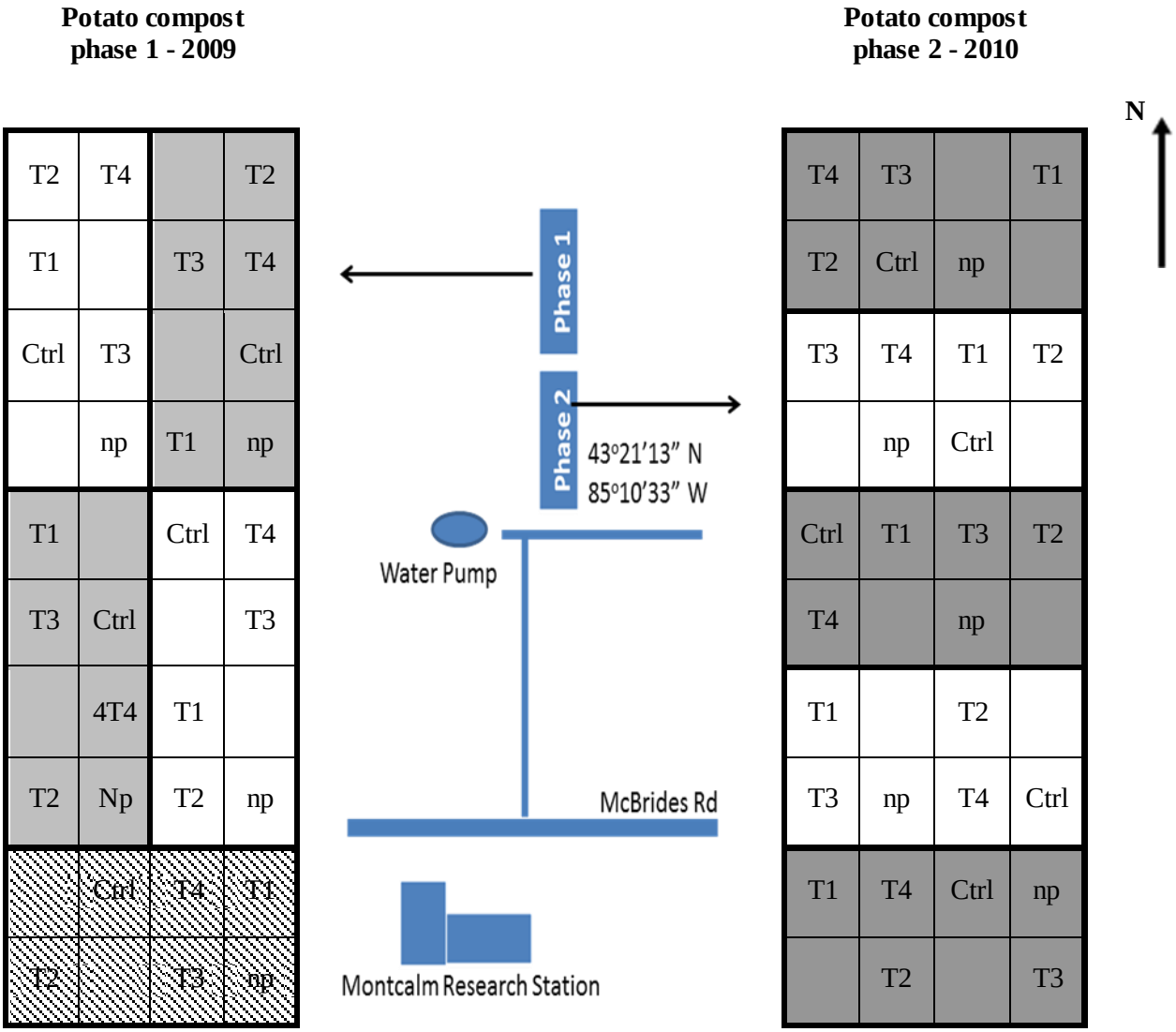

Figure 2.1. Experimental design and location. Phase 1 started in 2009 and Phase 2 started in 2010. The five treatments were laid out randomly with five blocks (indicated by bold squares) in a seven-treatments-experiment. Treatment abbreviations were shown in Table 1. Np: non treated plot (no fertilizers and no compost added). The empty plots were the treatments that were not used in this study.

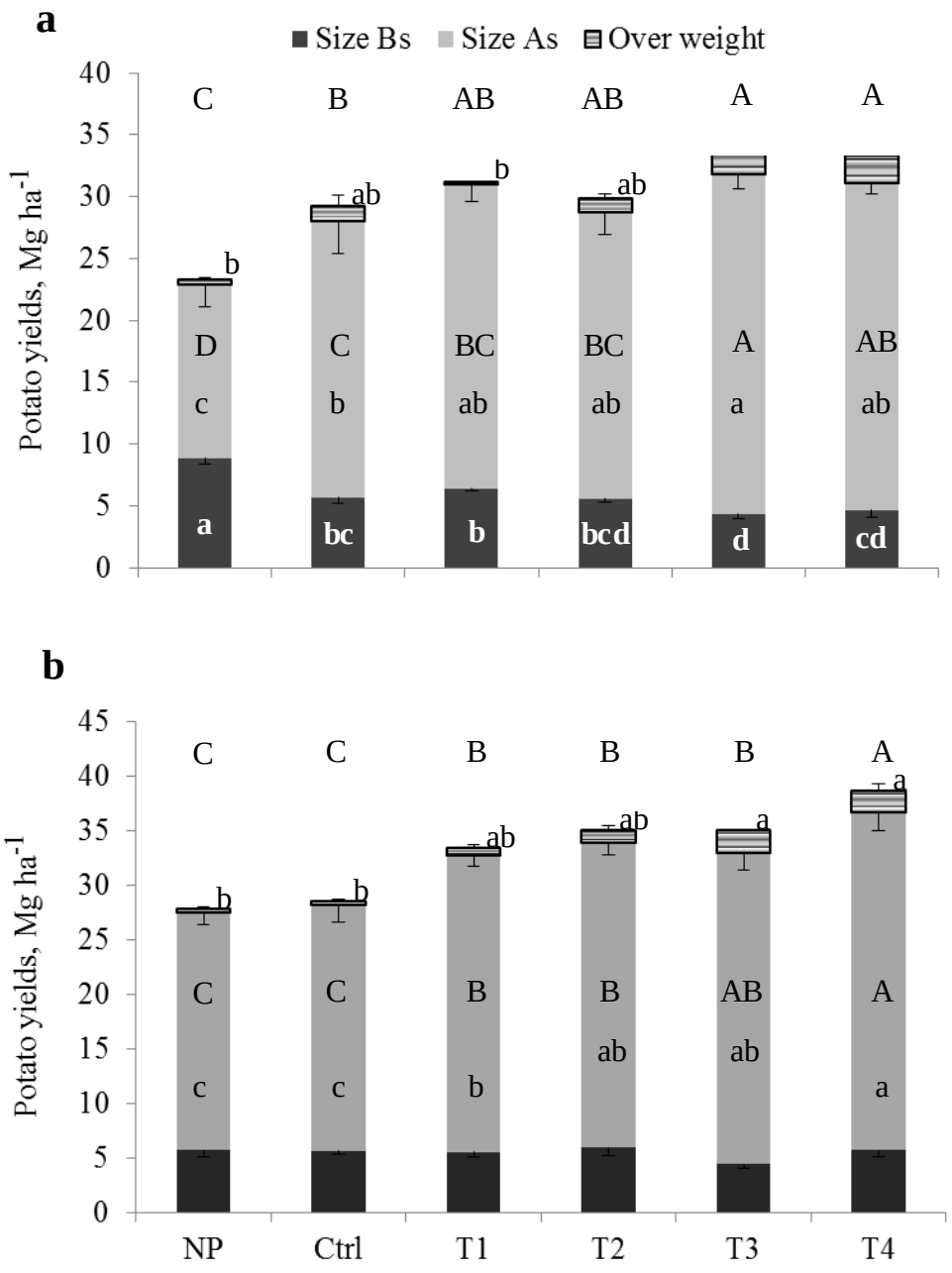

Figure 2.2. Potato yield in 2009 (a) and 2010(b) in Montcalm Research Farm. Potato size Bs: < 5 cm diameter; size As: 5 - 8.3 cm diameter; over weight: > 8.3 cm diameter. T1 – T4: compost treatments. NP: non treated plot - no compost, no fertilizers added in the growing season. Means for the same tuber size with the same letter are not significantly different ($p < 0.05$). The first row of uppercase letters indicate differences among treatments in total potato yields. The second row of uppercase letters show differences among treatments in potato yields of size US No.1.

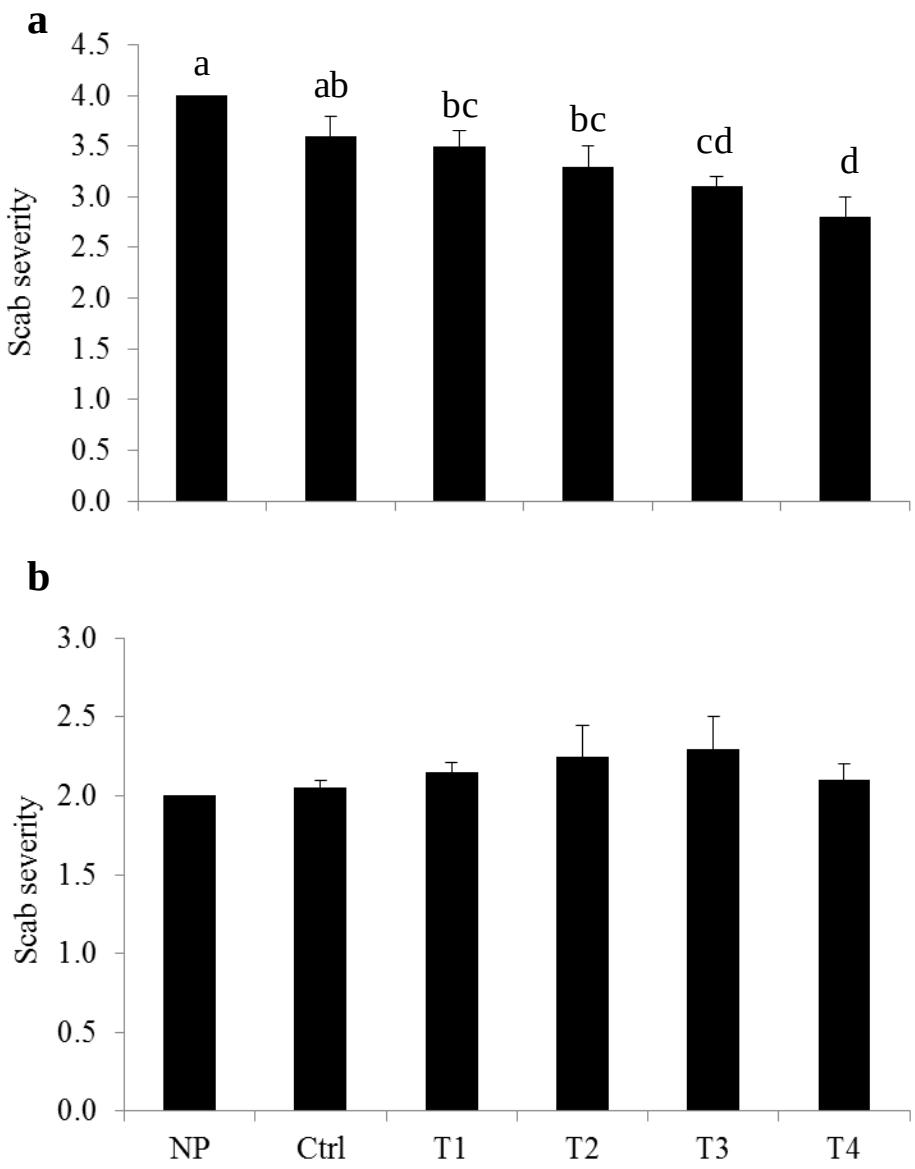

Figure 2.3. Common scab severity in potato (mean±SE, $p < 0.05$). (a) Scab incidence in 2009 and (b) Scab incidence in 2010. The disease was assessed after harvesting by rating from 0 to 5 where 0 is no infection; 1 is low infection; 3 is intermediate; and 5 is severe infection.

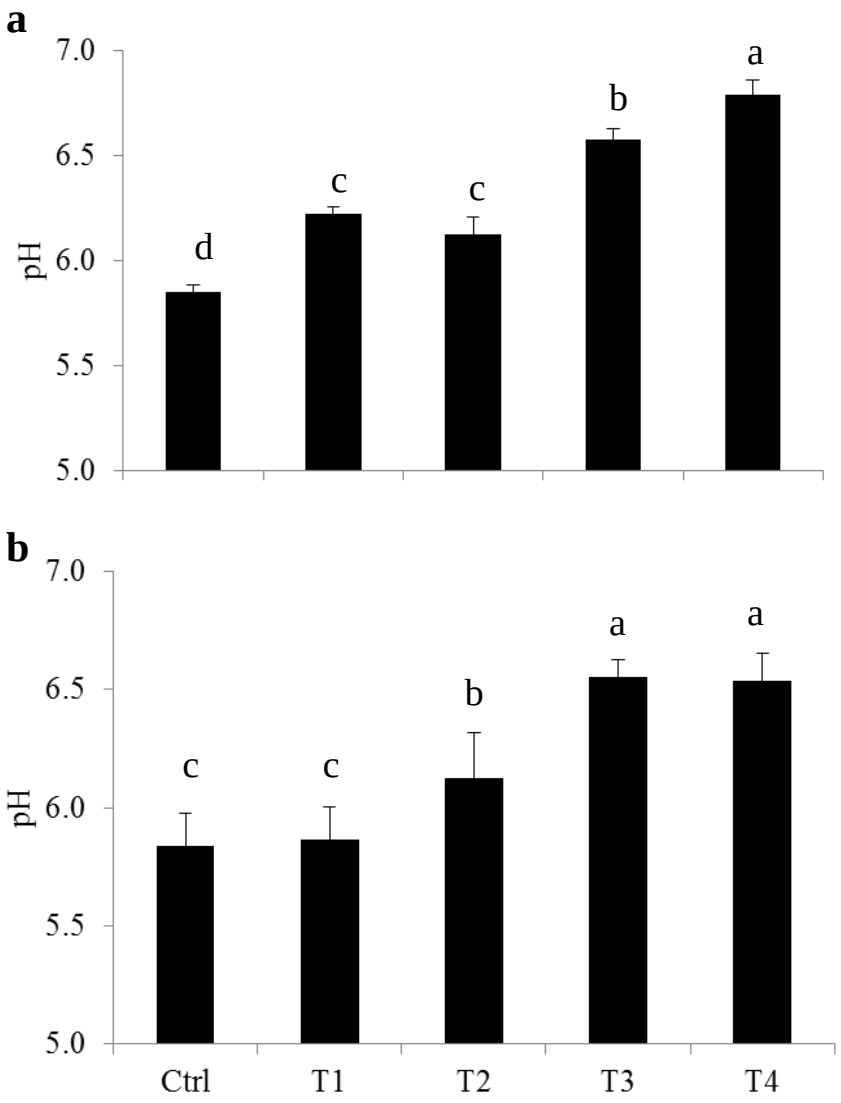

Figure 2.4. Average soil pH. (a) pH in 2009 and (b) pH in 2010 (Mean±SE). Means with different letters are significantly different ($p < 0.05$).

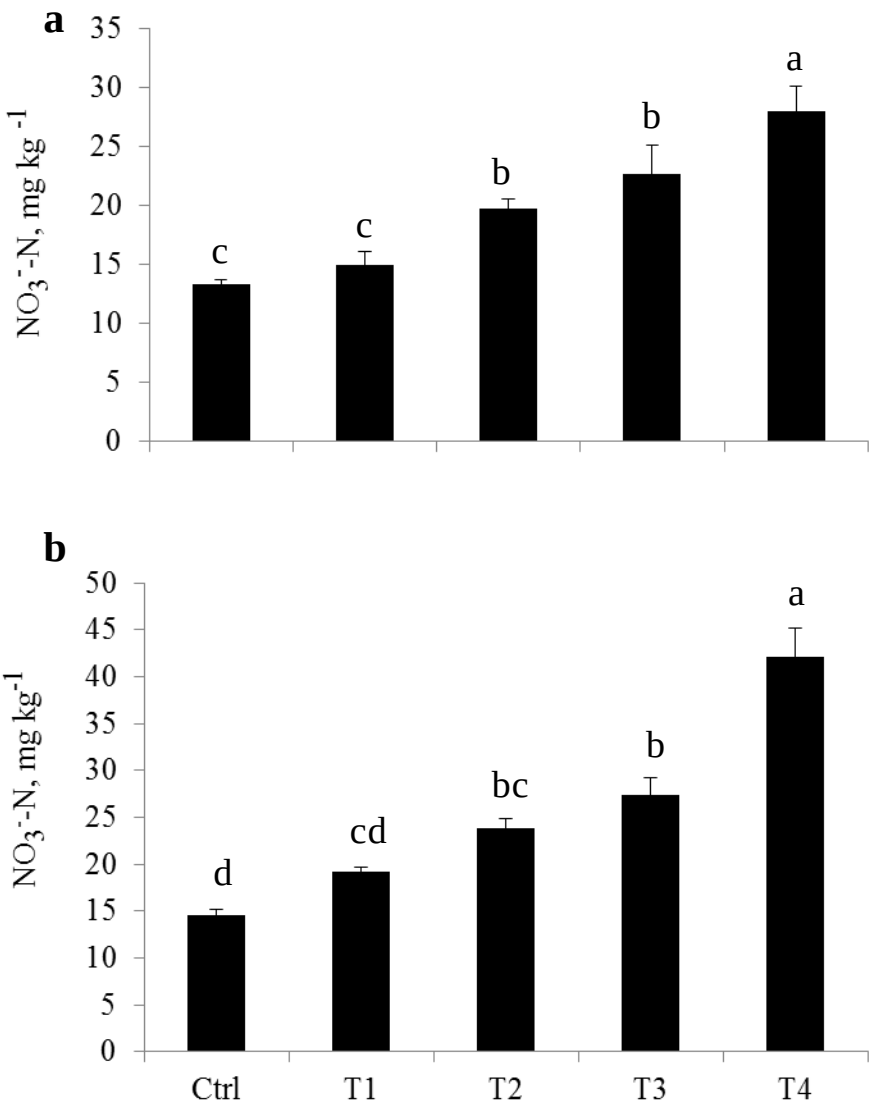

Figure 2.5. Average NO_3^--N of potato soil in 2009 (a) and 2010 (b). Mean±SE (mg NO_3^--N kg^{-1} soil). Means with different letters are significantly different ($p < 0.05$).

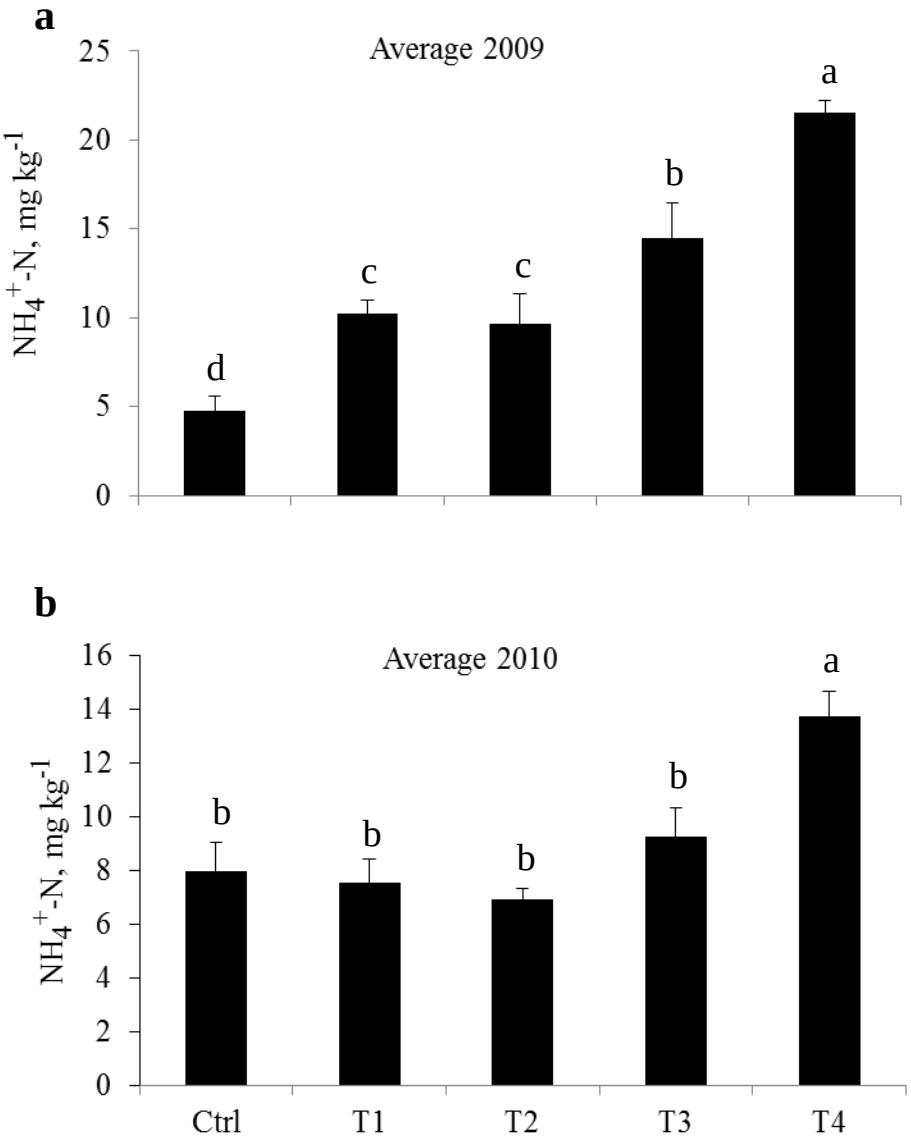

Figure 2.6. Average of NH_4^+-N in potato soil 2009 (a) and 2010 (b) (Mean±SE, mg NH_4^+-N kg^{-1} soil). Means with different letters are significantly different ($p < 0.05$).

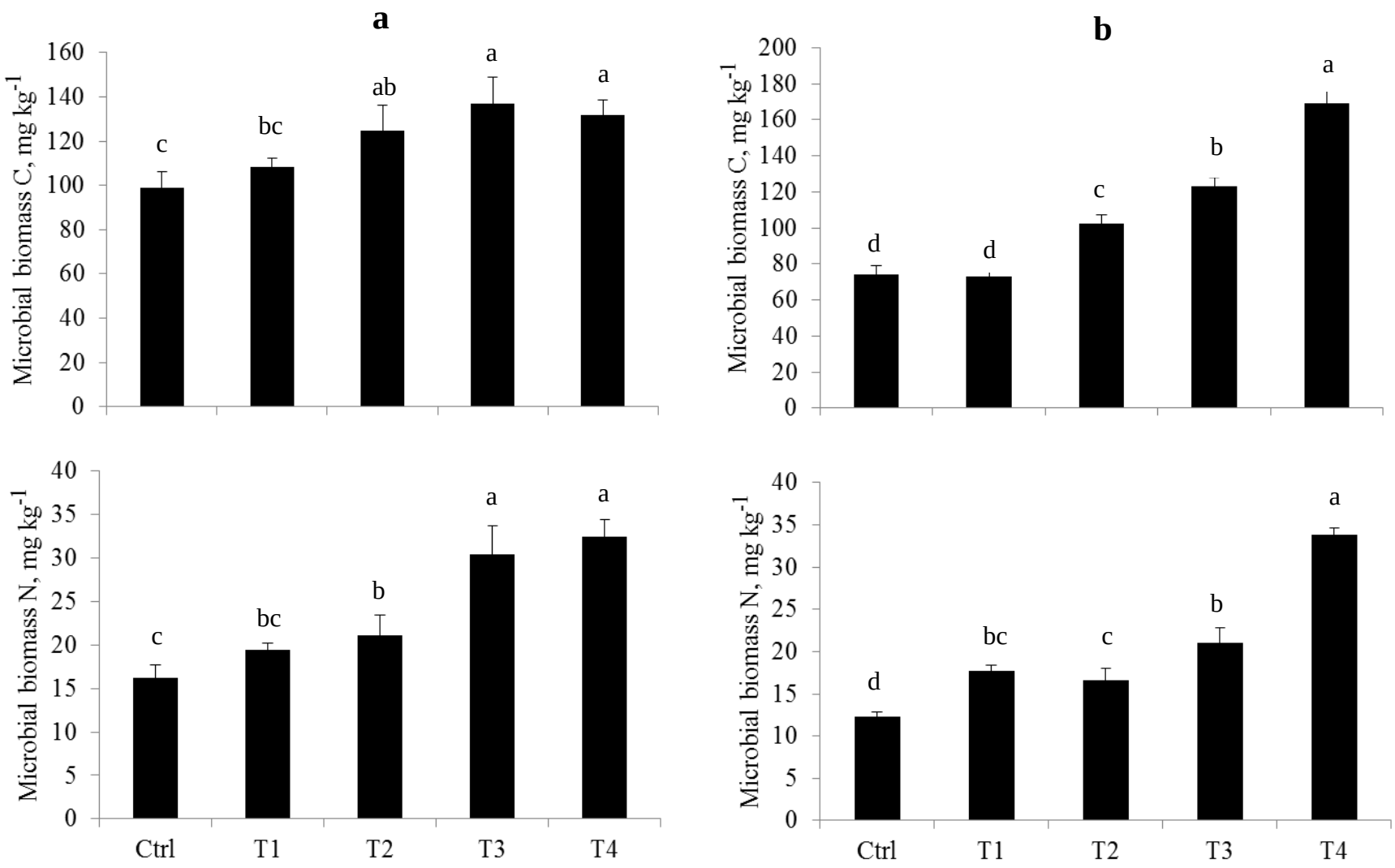

Figure 2.7. Seasonal average of microbial biomasses in potato soil in 2009 (a) and 2010 (b) (Mean±SE, mg kg^{-1} soil). Means with different letters are significantlt different ($p < 0.05$).

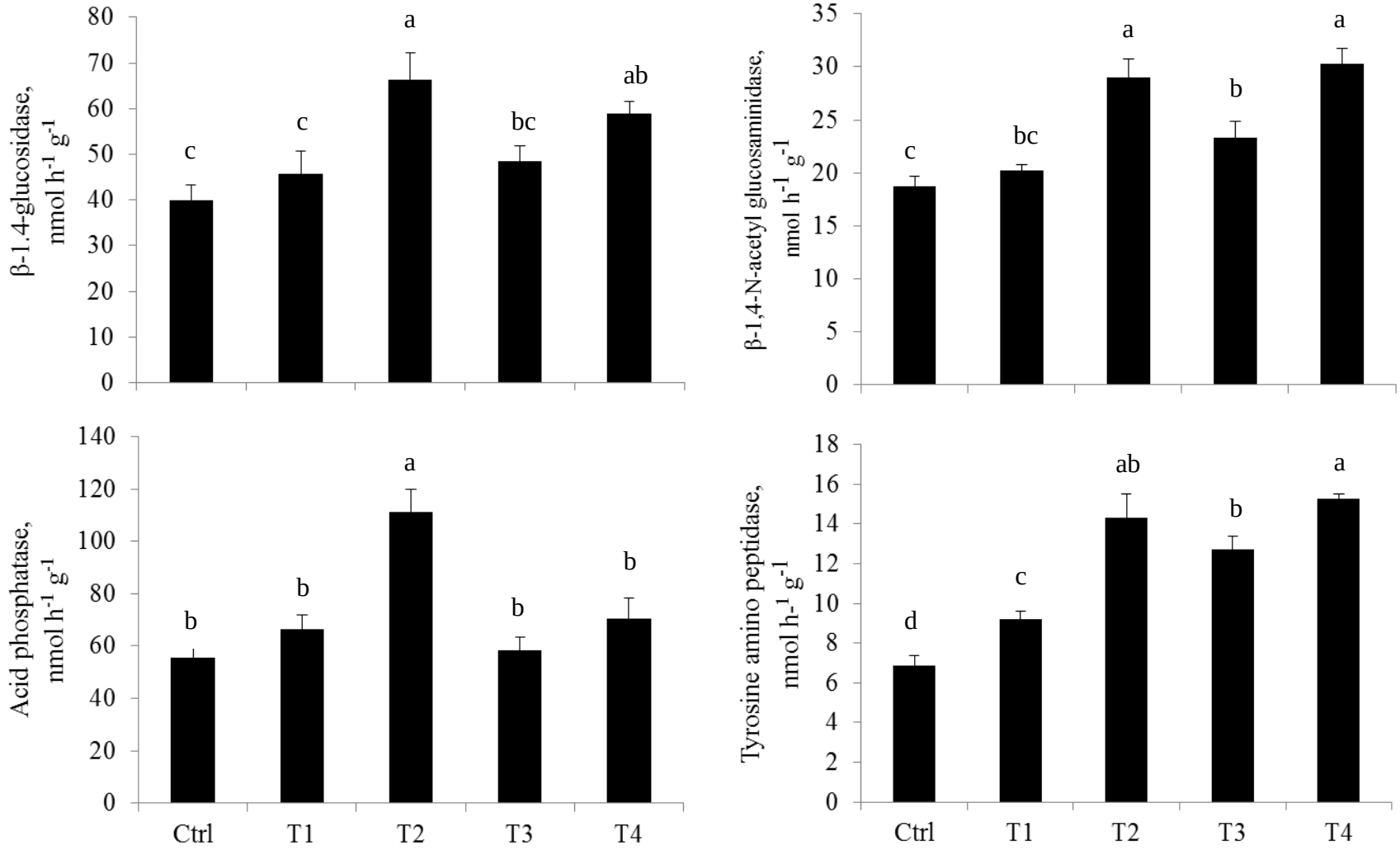

Figure 2.8. Seasonal average of hydrolytic enzyme activities in potato systems in 2009 (Mean±SE, nmol h^{-1} g^{-1} soil). Means with different letters are significantly different ($p < 0.05$).

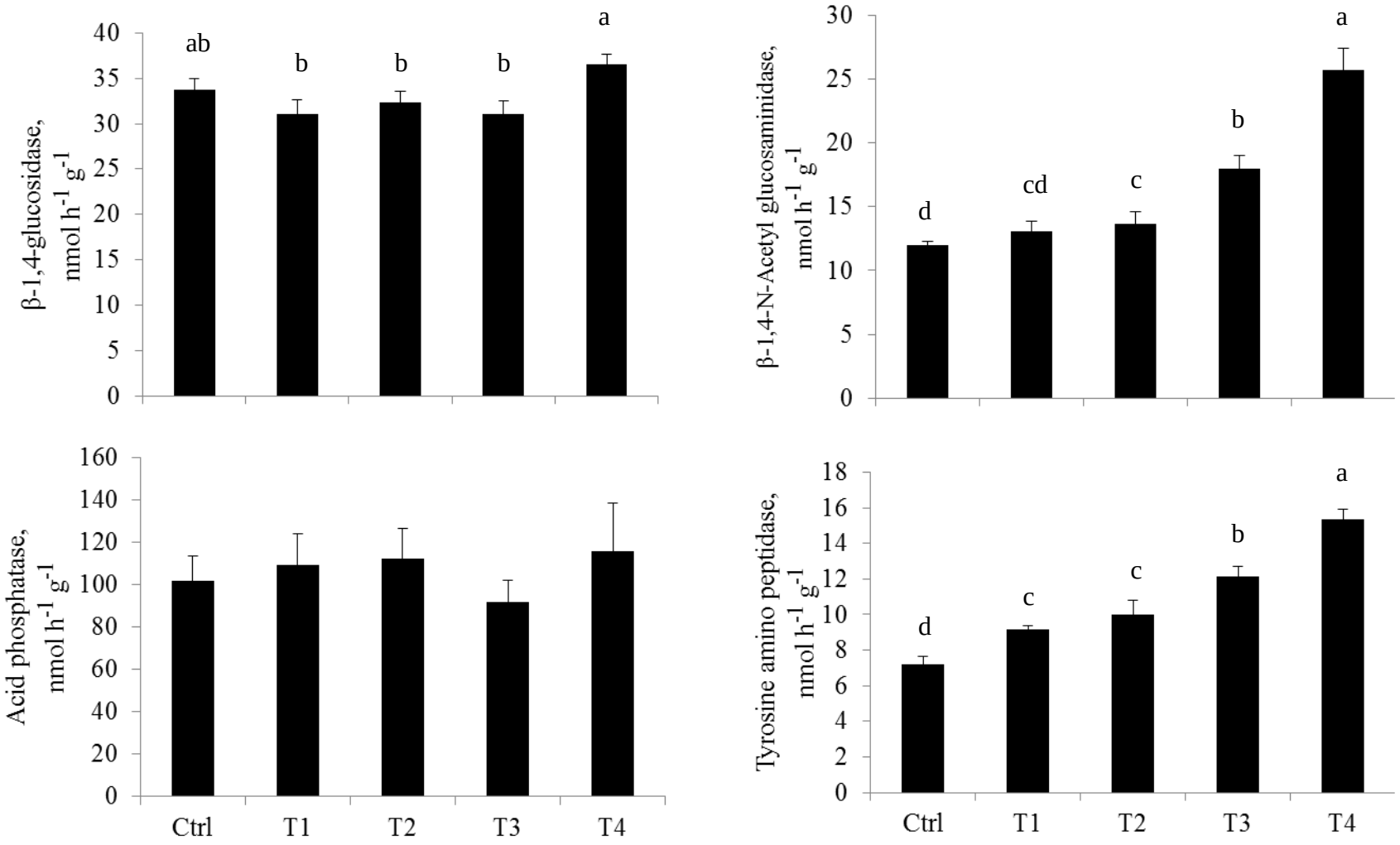

Figure 2.9. Hydrolytic enzyme activity in the potato systems in 2010 (Mean±SE, nmol h^{-1} g^{-1} soil). Means with different letters are significantly different ($p < 0.05$).

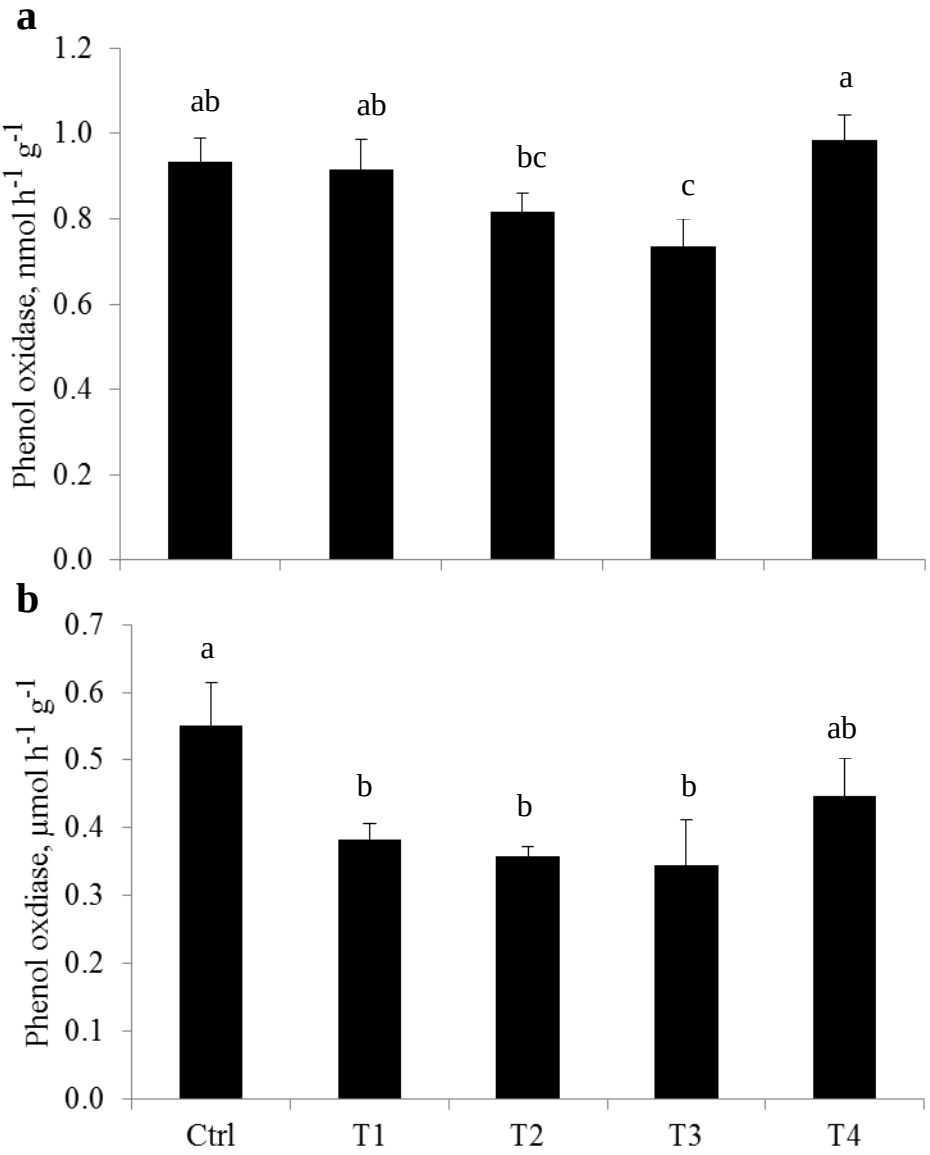

Figure 2.10. Phenol oxidase in the potato soil in 2009 (a) and 2010 (b) (Mean±SE, µmol h^{-1} g^{-1}). Means with different letters are significantly different ($p < 0.05$).

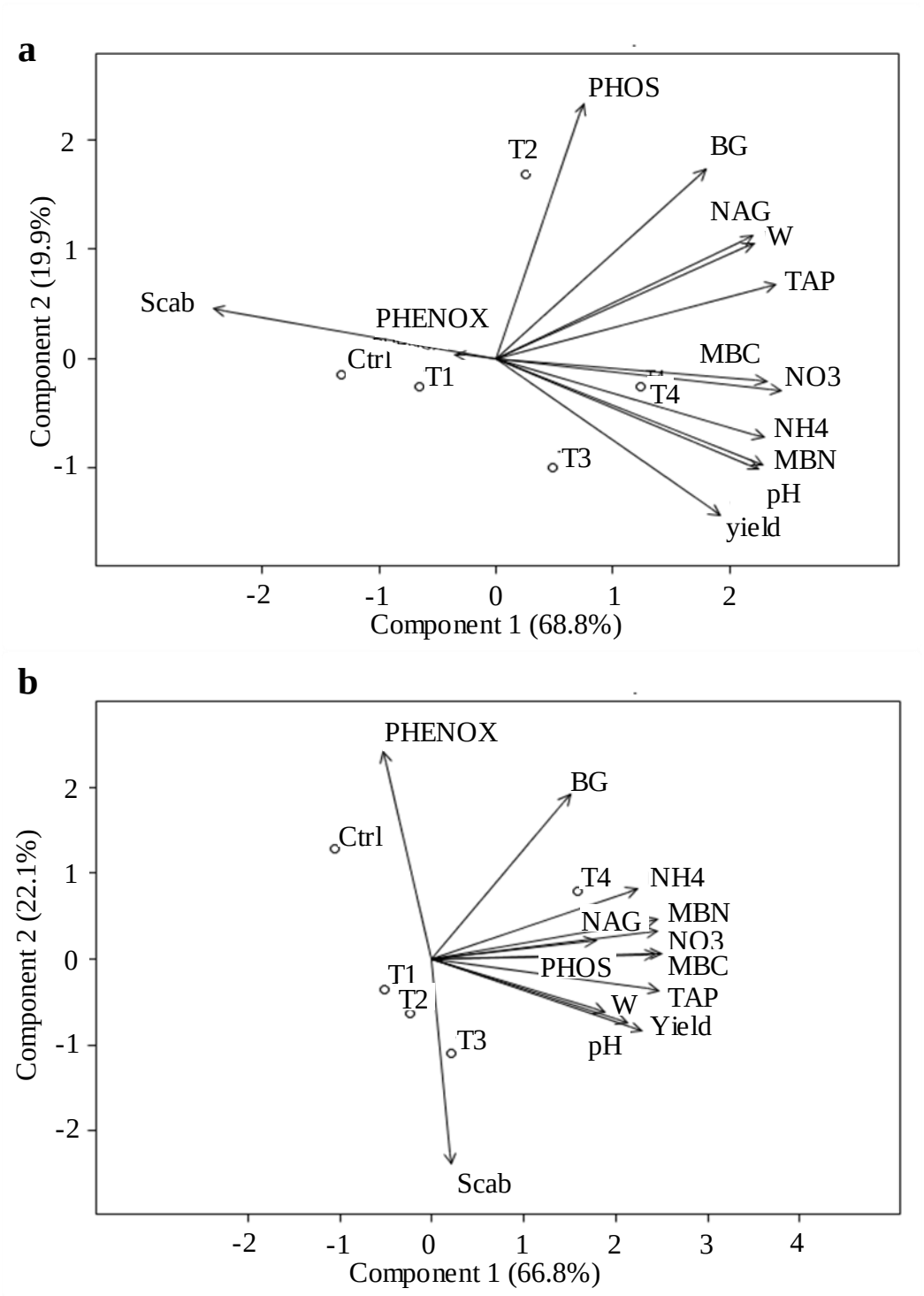

Figure 2.11. Principal component analysis for potato quality and soil characteristics in potato systems in 2009 (a) and 2010 (b). Circles with numbers indicate different sites and arrows indicate soil characteristics. Data used for the simulation were the average of variables over growing seasons. See Table 2.14 for abbreviations.

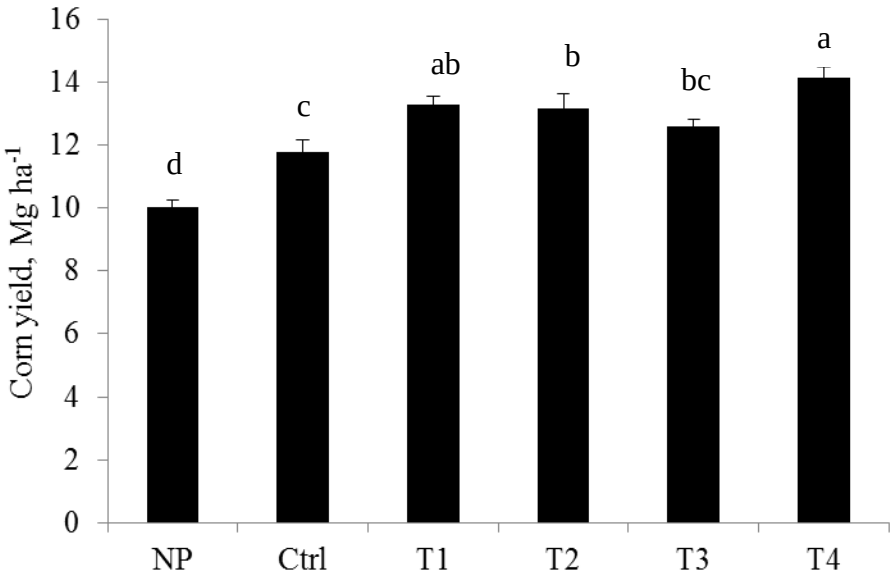

Figure 2.12. Corn yield in 2010/Phase 1, in which poultry compost was added in 2009 (Mean±SE, 10^3 kg ha^{-1}). Additional compost was added to T1 in 2010. NP: non treated plot - no compost, no fertilizers added. Means with different letters are significantly different ($p < 0.05$).

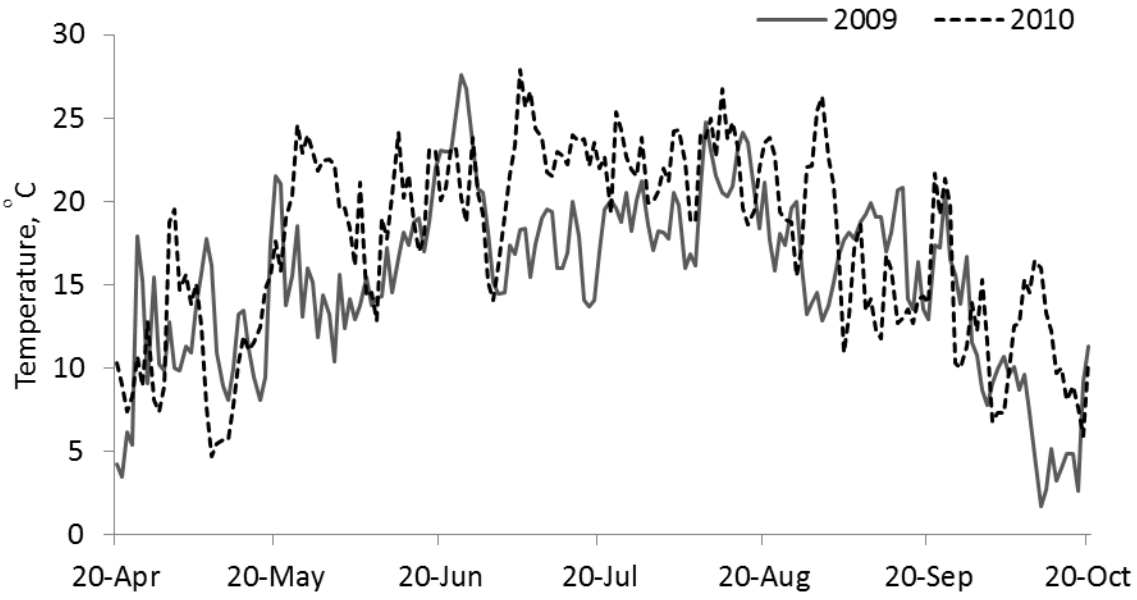

Figure 2.13. Daily average temperature at Montcalm Research Farm in 2009 and 2010. Data were collected at Entrican Station, Michigan about 1.5 km east of the research field. The average of 6 months from 20 Apr to 20 Oct in 2009 was 15.4 °C and in 2010 was 17.5 °C (Source: http://enviroweather.msu.edu).

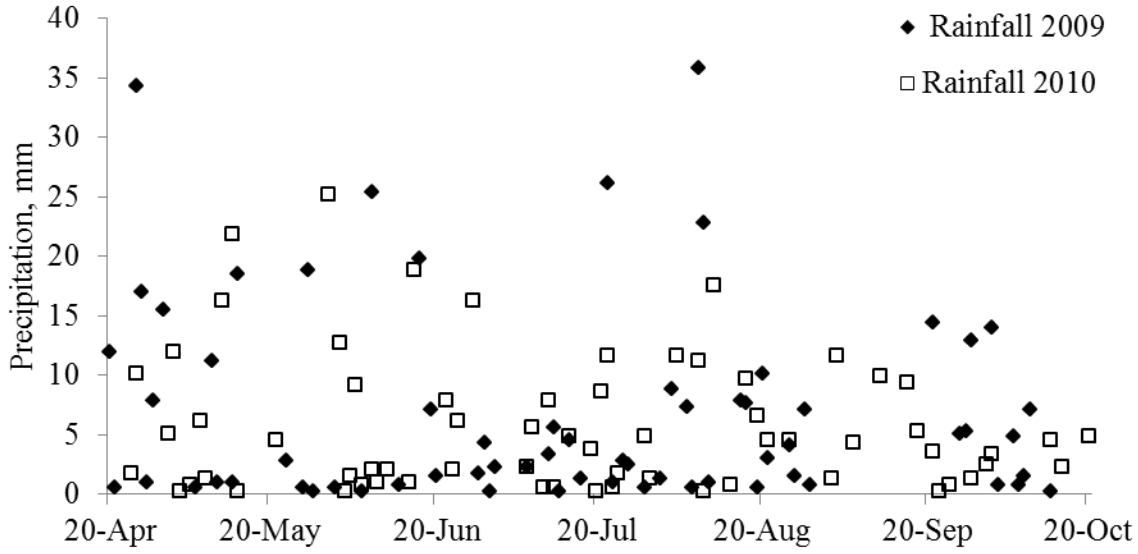

Figure 2.14. Daily rainfall at Montcalm Research Farm in 2009 and 2010. Data were collected at Entrican Station, Michigan about 1.5 km east of the research field. The total rainfall of 6 months from 20 April to 20 October of 2009 was 445 mm and of 2010 was 373 mm. The number of rainy days in 2009 = 2010 = 65 days. (Source: http://enviroweather.msu.edu).

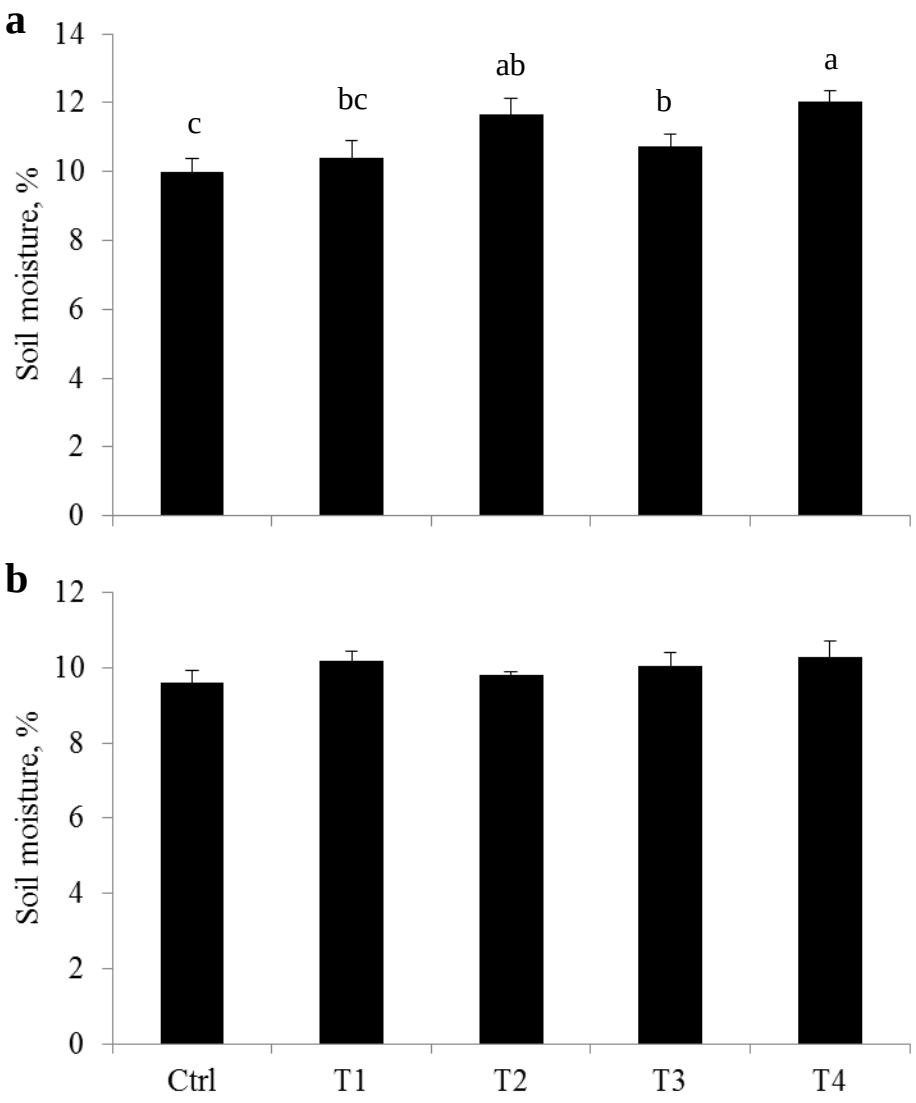

Figure 2.15. Average soil moisture in the potato systems over the growing season 2009/Phase 1 (a) and 2010/Phase 2 (b). Means with different letters are significantly different ($p < 0.05$).

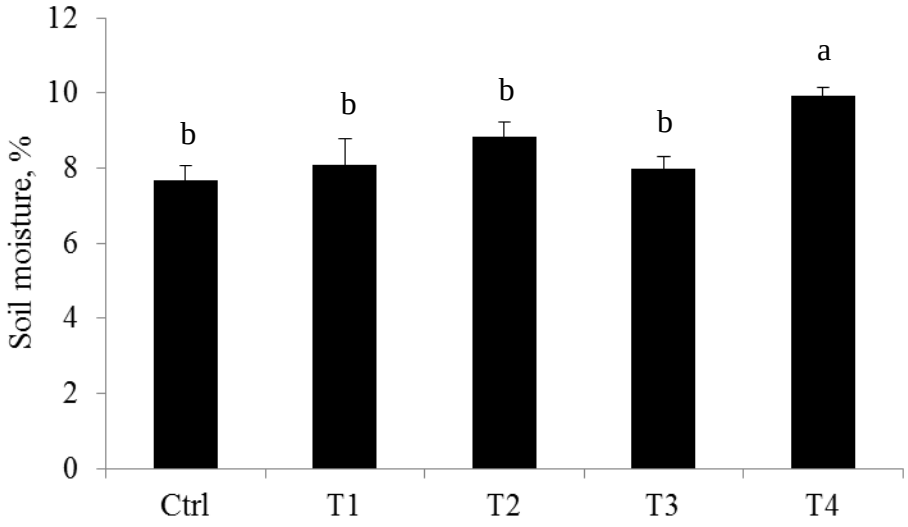

Figure 2.16. Average soil moisture in the corn systems in 2010/Phase 1 (Mean±SE). Means with different letters are significantly different ($p < 0.05$).

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REFERENCES

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