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Optimum compost application for raised bed organic vegetables

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ABSTRACT

The yield of organically grown raised bed vegetables was measured against four compost rates to determine the optimum compost application rates. Organic poultry mortality compost was applied at rates of 0, 10.7, 32.2, and 53.7 Mg/ha. Compost treatments were fall applied for two consecutive years in three cropping blocks and fall seeded with a winter rye, *Secale cereale*/hairy vetch, *Vicia villosa*/crimson clover, *Trifolium incarnatum*/cover crop. In 2008, squash *(Cucurbita pepo),* tomatoes *(Lycopersicon esculentum)*, and bell peppers (*Capsicum annuum)* were planted and rotated in 2009 with cabbage *(Brassica oleracea)*, onion *(Allium cepa),* bush green beans *(Phaseolus vulgaris)*, and beets *(Beta vulgaris).* Vegetable yield, soil properties, and crop and cover crop biomass were significantly and positively correlated to compost rate for both years. The highest rate (53.7 Mg/ha) did not give significantly higher yield results than the low (10.7 Mg/ha) and medium (32.2 Mg/ha) rates. Compost was also spring applied in one cropping block to test for differences in season of application. In 2008, tomatoes and, in 2009, sweet corn *(Zea mays)* were planted two weeks after compost application. The lower compost rate showed higher yield for 2008, and the medium compost rate showed higher yield for 2009. The optimum soil management practice in this study was the fall-applied compost between the low-to-medium application rate, and approximately 20 Mg/ha, with fall-seeded winter cover crop.
Keywords: compost rate, organic farming, vegetable yield, soil properties, crop biomass, cover crops.

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INTRODUCTION

Organic farming is a holistic, information based system that requires a healthy, productive soil. Soil building is accomplished not only by adding compost but also incorporating cover crops that fix N and add organic residue (Treadwell, 2009). The benefits of compost and cover crops in organic systems include greater soil quality as well as higher nutrient status over the long term (Delate et al., 2003; Sullivan, 2010). In contrast to conventional farming practices, which rely on applications of synthetic fertilizers to supply plant nutrition, the organic farm relies on soil building with compost, manures, cover crops, and residue incorporation for fertility management. Organic farm management utilizes a holistic system of attracting beneficial insects and organisms as predators of harmful insects and diseases and using cover crops and mulches for weed control, while conventional farming practices rely on pesticides for insect, disease, and weed control.

Worldwide concerns regarding the safety of the food supply, anthropogenic degradation of the natural environment, and ecological systems have led to an increased emphasis on the development of sustainable agriculture and organic farming systems (Wang et al., 2009).

New entrants and transitional producers should become familiar with sound and sustainable agricultural practices that often require more than a superficial knowledge of soil, crop, water, and organism interactions. To develop healthy, sustainable organic farming practices, it is essential to understand the interactions of soil, plants, climate, and ecological systems. Sustainable practices, by definition, are economically profitable, environmentally sound, and socially acceptable.

During the last 15 years, the market demand for organically produced food has increased by about 20% annually with new incentives from USDA and new research funds available for organic methods (Moyer, 2002; Francis, 2009). Under organic production, farmers must recycle nutrients through proper nutrient management practices. Recycling is accomplished through good manure and compost utilization, crop rotations, cover crops, and by reducing nutrient losses due to leaching, over fertilization, and poor compost and residue management. To obtain optimal yields, growers need to apply manure or compost to their soils (Government of New Brunswick, 2006; Francis, 2009). Compost that has been properly developed and applied to the soil in organic farming increases the organic matter and microbial populations, improves water retention, infiltration, soil structure, and soil fertility, and suppresses a variety of soil-borne plant diseases (Wisbaum, 2002; Preusch et al., 2002; Hitchings, 2007).

Appropriate application rates of compost depend on the initial fertility and organic matter content of field soil and the crops to be grown. On low-fertility soils, with low N and P availability and low organic matter content, compost applications of 60 to 75Mg/ha (25 to 30 t/ac) are appropriate (Francis, 2009). These high application rates may be especially suitable to build soil fertility during initial years of transitioning land to certified organic production. Compost may serve as the primary N source for some annual crops when applied at high rates. However, repeated heavy applications of compost as the main source of N over a period of years may cause excessive buildup of soil P and K (Toth et al., 2006; Wortmann and Walters, 2007; Owen et al., 2008). The N availability from compost to the succeeding crop is quite variable, ranging from low N recovery rates of 4%-15% to a high rate of 57%.

When 0.112-0.224 Mg/ha (100-200 lbs/ac) of N may be needed for the fertilized crop, using compost as the primary source of N may routinely require rates of application of 56 Mg/ha-67 Mg/ha (25-30 t/ac). However, the uncertainty of nutrient availability can lead to over or under fertilization and the potential hazard of nutrient contamination of ground or surface water. Clearly, there are important limitations for organic vegetable growers who base their N fertility program solely on compost (Gaskell and Smith, 2007).

On more fertile soils, routine compost application rates of 7 to 12 Mg/ha (3-5 t/ac) may be appropriate. In a study using common West Virginia and Maryland soils, it was reported that 42-64% of N was mineralized from additions of uncomposted poultry manure, while with additions of composted poultry manure from 1-9%, N was mineralized, depending on soil type (Preusch et al., 2002).

Other reports state that in the first year after application, 5-15% of the total applied N from compost may be recovered by a crop (Francis, 2009; Endelman et al., 2010). Thus, N from compost, supplies small amounts of N over several years. Crop N uptake from soil that has had repeated compost applications will be a combination of the N becoming available over several years. Predicting the amount of N that will be available for crops on compost-amended soil can be difficult (Sullivan et al., 2010; Watts et al., 2010). Soil testing, plant analysis, and crop growth observations play important roles in monitoring nutrient availability. It has been speculated that seasonal variation in soil moisture and temperature seem to have greater influence on plant production, through mineralization, than the source or amount of mature compost applied. Also, with long-term compost application, a higher level of available nutrients than predicted is probable due to the higher biological activity associated with long-term compost applications (Warman, 2002).

Organic vegetable plots commonly utilize raised-bed bio-intensive growing methods to maximize land use and crop production. Bio-intensive agriculture makes use of raised bed farming to reduce the amount of land needed and at the same time increase output of crops. Raised-bed culture is either carried out on permanent raised beds in which there is a border maintaining the integrity of the bed over time or temporary beds formed without borders. Permanent raised beds often consist of a high degree of manual labor to establish and maintain (Upton, 2007).

Temporary raised beds are formed after the soil has been plowed, disked, and amended with organic compost. The bed is formed by either a bed press, which tills, gathers, and presses a formed bed either singly or in multiple rows. The bed may also be formed by throwing up soil into a bed using various sized discs pulled on a draw bar behind the tractor.

The advantage of these temporary beds is that they can be formed quickly and efficiently by machinery. These beds are then either covered by a synthetic or natural mulch or cover crop to control weeds and manage nutrients. There are several advantages of raised-bed farming, including improved soil drainage, no soil compaction, and higher yields with higher plant densities. Raised beds heat up earlier in the spring and are drier for earlier spring planting (Miller, 2006; Upton, 2007).

When applying compost to raised beds, it is important to consider the C:N ratio of the compost as it affects the availability of N to the crop (Francis, 2009). A lower C:N ratio has a higher available N content, and a higher C:N ratio has a lower available N content. Because compost quality and nutrient content can vary markedly, depending on source materials and time of year, an analysis of compost is advisable to determine nutrient content and C:N ratio (Owen, 2008). The C:N ratio in the organic matter of the furrow slice (the top 15 cm of soil) of arable soils commonly ranges from 8:1 to 15:1, with the median C:N ratio being 11:1. The C:N ratio in plant material is variable, ranging from 20:1 to 30:1 in legumes and farm manure to 100:1 in straw residues (Brady, 1974; Wang et al., 2005). Conversely, the C:N ratio of microorganisms is more narrow and more constant from 4:1 to 9:1. Therefore, most organic residues entering the soil carry large amounts of C and comparatively small amounts of total N, in relation to soil C:N ratios. Soil microorganisms must have N to break down the C in the soil since N is an essential building block of living tissue. Since organic matter is formed from decomposed plant and animal material, it follows that the amount of organic matter in the soil is dependent on the amount of organic N in the soil (Brady, 1974; Francis, 2009).

Soil organic matter is a term applied to a complex mixture of organic compounds synthesized in microbial tissue and resistant to breakdown that provides reactive sites for various nutrients to become available for plant growth. Organic matter enhances important soil properties in the soil complex, including soil color, soil nutrients, water holding capacity, microbial activity, soil structure, and high cation adsorption and exchange capacity (Brady, 1974). Research has shown that soil organic matter is the central indicator of soil quality and health affecting soil fertility. The C and N mineralization capacity of the soil and availability of plant nutrients is, therefore, dependent on soil organic matter (Watts et al., 2010). To maintain available N for plant growth (as microbe populations digest the C and grow numerically), it is important to have a relatively narrow C:N ratio both in the compost mix and in the finished product applied to the soils. This is generally agreed to be between 15:1 and 30:1 (Brady, 1974). The C:N ratio in soil and in compost is important for two reasons. Keen competition between microorganisms and crops for available N results when residues having a high C:N ratio are added to soils, reducing available N for plant growth; and because the C:N ratio is relatively constant in soils, from 10-12:1, the maintenance of C and, hence, soil organic matter is dependent, to no small degree, on the soil N level. One of the more challenging aspects of organic farming is the development of an appropriate fertility plan, which may include crop rotation, cover crops, or soil amendments. When fertility is maintained with manure and/or compost, a pressing question is how much should be applied (Endelman et al., 2010). Soil building through compost application is an integral component of organic farming, yet information on compost application rates and timing is lacking (Hitchings, 2007). Therefore, it is important to thoroughly study raised-bed organic vegetable farming using compost as a fertilizer and soil amendment in combination with cover crops. It is important to answer questions such as:

- How much compost should be applied and is compost better applied in spring or fall?
- How often should compost be applied to maintain soil fertility?
- How do cover crops interact with compost to improve soil and crop yields?

Based on available information in the literature, there is a need to determine optimum compost rates and timing of compost application to organic plots to ensure that crops have adequate soil nutrition in an organic farming system. The purpose of this research was to determine optimum compost application rates for organic vegetable production in a raised-bed field system.

MATERIALS AND METHODS

Tennessee Technological University (TTU) acquired the Water's Organic Farm in August 2007. It is located 10 miles south of TTU at 8426 Kermit LaFever Road. The soil is classified as a Sullivan fine sandy loam that had previously been in pasture for 20 years with no fertilizer applied and is in Land Capability Class I (Brady, 1974).

Four research blocks were designed using raised beds and consisting of nine rows with four plots per row for a total of 36 plots in each block (Figure 1). Research plot rows were separated by 1.2 m (4 ft) row middles, and each research block was separated by 3.05 m (10 ft) roadways on all sides.

BLOCK i

i-1-1	i-2-0	i-3-3	i-4-5
i-5-5	i-6-3	i-7-1	i-8-0
i-9-3	i-10-5	i-11-1	i-12-0
i-13-3	i-14-1	i-15-0	i-16-5
i-17-0	i-18-1	i-19-5	i-20-3
i-21-5	i-22-0	i-23-3	i-24-1
i-25-1	i-26-3	i-27-5	i-28-0
i-29-1	i-30-5	i-31-0	i-32-3
i-33-5	i-34-3	i-35-0	i-36-1

BLOCK iii

iii-37-3	iii-38-5	iii-39-0	iii-40-1
iii-41-0	iii-42-3	iii-43-5	iii-44-1
iii-45-5	iii-46-1	iii-47-0	iii-48-3
iii-49-1	iii-50-0	iii-51-3	iii-52-5
iii-53-5	iii-54-3	iii-55-0	iii-56-1
iii-57-1	iii-58-5	iii-59-3	iii-60-0
iii-61-1	iii-62-0	iii-63-5	iii-64-3
iii-65-3	iii-66-1	iii-67-5	iii-68-0
iii-69-0	iii-70-3	iii-71-5	iii-72-1

BLOCK ii

ii-73-5	ii-74-1	ii-75-3	ii-76-0
ii-77-0	ii-78-1	ii-79-3	ii-80-5
ii-81-1	ii-82-3	ii-83-0	ii-84-5
ii-85-1	ii-86-0	ii-87-5	ii-88-3
ii-89-3	ii-90-5	ii-91-1	ii-92-0
ii-93-1	ii-94-5	ii-95-0	ii-96-3
ii-97-3	ii-98-0	ii-99-5	ii-100-1
ii-101-0	ii-102-3	ii-103-1	ii-104-5
ii-105-5	ii-106-0	ii-107-3	ii-108-1

BLOCK iv

iv-109-5	iv-110-3	iv-111-1	iv-112-0
iv-113-1	iv-114-0	iv-115-3	iv-116-5
iv-117-3	iv-118-0	iv-119-5	iv-120-1
iv-121-1	iv-122-3	iv-123-5	iv-124-0
iv-125-1	iv-126-5	iv-127-0	iv-128-3
iv-129-3	iv-130-1	iv-131-5	iv-132-0
iv-133-5	iv-134-1	iv-135-3	iv-136-0
iv-137-1	iv-138-0	iv-139-3	iv-140-5
iv-141-5	iv-142-1	iv-143-3	iv-144-0

Figure 1: Research Block Plot map.

*Note: Plot numbers indicate Block-Plot Number-and Treatment based on bags of R-Grow™ compost used. Treatments: 0 = 0 compost applied, 1 = 10 kg moist compost/plot, 3 = 30 kg moist compost/plot, 5 = 50 kg moist compost/plot.

Individual plots were 1.22 m x 7.62 m (4 ft. x 25 ft). There were 61 cm planted margins between plots with a 30 cm planted margin at the end of each row to prevent end effects on the plot area. Row middles and roadways were clean cultivated in 2008 because of drought conditions and were planted to annual rye grass and crimson clover in Spring 2009 and maintained by mowing. Compost treatments were randomized within each row.

Field preparation consisted of sub-soiling plot areas followed by plowing with a moldboard plow and disking with a standard four gang disk in August 2007. Dolomite limestone was applied at 1,112 kg/ha (1000 lbs/ac) using a walk-behind broadcast spreader prior to raised bed preparation. Beds were formed after tilling the plot area with a 122 cm (48 in) PTO tiller. After tilling, beds were formed using a twin disk carried on a three-point hitch tool bar with drag chains to smooth the beds. Beds were 1.22 m wide and 33 m long (40.26 m^2) on 2.24 m centers to accommodate equipment wheel base measurements.

Compost was derived from poultry carcasses, poultry litter, and wood chips from a regional producer (R-Grow™, Rollins Farm, Pulaski, TN). Compost rates were formulated on N requirements based on 25% N mineralized per year.

Compost (R-Grow™) was in 10 kg (22 lb) bags or approximately 0.30 m^3 (0.75 ft^3) consisting of 20.9% water, and on a dry weight basis 3.6% N, 2.71% P, 3.96% K, 11.27% Ca, 28,82% C, with a pH of 9.2 (Agricultural Diagnostic Laboratory University of Arkansas-Fayetteville).

Plot treatments consisted of zero bags; one bag, 10 kg (22 lbs); three bags, 30 kg (66 lbs); and five bags, 50 kg (110 lbs), uniformly applied per plot. Compost was applied as is from bags. Each row received all four compost treatments equivalent to 0, 10.7, 32.2, 53.7 Mg/ha (0, 4.8, 14.4, and 24 t/ac) moist compost. The compost N levels were 0, 0.304, 0.915, 1.530 Mg N/ha (0, 272.5, 817.6, and 1362.5 lbs N/ac on a dry weight basis).

Available nitrogen rates per hectare were computed as follows:

Zero	no compost added
Low	1.07 kg compost/m^2 x (79% solids x 10,000 m^2 x 0.036 [%N]) = 304 kg total N/ha equivalent of which 25% was calculated mineralized for <u>76 kg N/ha</u>.
Medium	3.22 kg compost/m^2 =915.76 kg total N/ha of which 25% was calculated mineralized at <u>229 kg N/ha</u>.
High	5.37 kg compost/m^2 =1530 kg total N/ha of which 25% was calculated mineralized at <u>382.5 kg N/ha</u>.

Year 1

Raised beds were formed on Blocks I-III (36 plots each) and fall-applied compost treatments were completed on September 18, 2007; rye/vetch/clover cover crops were planted over all treatments on September 21, and replanted October 25, 2007 due to extreme hot and dry weather. On Block IV, raised beds were formed and spring-applied compost treatments added May 7, 2008.

Plot areas in blocks I, II, and III were rolled/crimped on May 30, 2008 prior to planting. Squash, peppers, tomatoes and tomatoes, were planted in Spring, 2008 on blocks I, II, III and IV, respectively.

Year 2

Blocks I and II of the previous years' (2008) plot areas were worked using an Y70 Celli spading machine, tilled, raised beds formed, and compost treatments made on October 16, 2008. Compost treatments were applied on permanent raised beds in block III on October 22, 2008 and Block IV raised beds and compost treatments were completed on May 15, 2009.

Block I. Block I had drip tape and black plastic mulch applied on November 6, 2008. Cabbage was planted as transplants on March 24, 2009 in four of the nine rows in block I providing four replications for each compost treatment. Cabbage plots were harvested from the center 3.8 m (10 ft) of all plots consisting of 5 heads per plot on June 4, 2009. Onions were planted as transplants on April 22, 2009 in four of the nine rows in block I providing four replications for each compost treatment. Onion plants were harvested on July 7, 2009, and allowed to dry for two days before weighing on July 9, 2009.

Block II. The compost treatments of the long-term test were made over 3 new tillage treatments (conventional tillage, minimal tillage, and no-till) in a randomized block design with 3 replications over the test on October 22, 2008. Plots were mulched with rotted sawdust on October 28, 2008 and again on June 16, 2009 with cut rye straw. Beets were planted as transplants April 17, and harvested June 10, 2009. Green beans were planted on June 25, 2009 and harvested on Sept. 2, 2009.

Block III. Block 3 was planted to cover crops (winter rye 33.7 kg (30 lbs/ac); crimson clover 11.2 kg/ha (10 lbs/ac); and hairy vetch 28.1 kg/ha (25 lbs/ac) on October 22, 2008. Cover crop wet biomass data were obtained from four plots for each compost treatment on May 27, 2009.

Block IV. Block IV raised beds were formed and compost treatments applied on May 15, 2009 and sweet corn was seeded on May 18, 2009 and reseeded on June 2, 2009. Corn was harvested on July 27, and July 31, 2009.

Fall compost treatments were applied by hand using wooden frames which divided the plots into segments to ensure more accurate and uniform application over the plot area. Beds were tilled to incorporate the compost into beds and beds reformed using the original technique described above. Research blocks I, II, and III were sown to cover crops each Fall following bed preparations using a mixture of Winter Rye *Secale cereale*, Hairy Vetch *Vicia villosa*, and Crimson Clover *Trifolium incarnatum*, at 28.1 kg, 33.7 kg, 11.2 kg/ha (25 lbs, 30 lbs, and 10 lbs/ac), respectively. Research block IV was prepared in the spring in the same manner as blocks I, II, and III without cover crops. Rye straw was applied as organic mulch following crop planting to provide weed and moisture control in June 2008 to research block IV. In Spring 2009, buckwheat was over-seeded into block IV when the corn crop was approximately 50 cm tall to provide living mulch for the corn crop.

The crop rotation schedule for block I in 2008 was rye/vetch/crimson clover; zucchini squash, *Cucurbita pepo,* "Green Wave" variety, and in 2009 was cabbage, *Brassica oleracea,* "Artost " variety; sweet onions, *Allium cepa,* "Yellow Granex" variety, on plastic followed by rye/vetch/crimson clover. The rotation schedule for block II in 2008 was rye/vetch/crimson clover; tomato, *Lycopersicon esculentum,* "Mountain Fresh" variety, and in 2009, a double crop of beets, *Beta vulgaris,* "Detroit Dark Red" variety; beans, *Phaseolus vulgaris*, "Bush Blue Lake" variety, followed by rye/vetch/crimson clover. The block III rotation in 2008 was rye/vetch/crimson clover; sweet pepper, *Capsicum annuum*, "Revolution" variety, and in 2009, rye/vetch/crimson clover; rye/vetch/crimson clover. The block IV rotation in 2008 was bare/fallow, tomatoes, and in 2009, was bare/fallow, sweet corn, *Zea mays,* "Xtra-Tender 270-A" variety, and buckwheat, *Fagopyrum esculentum.*

Soils were sampled in test plots for pH, P, K, Ca, and Mg, using a soil probe and obtaining samples from 0-15 cm and 15-30 cm. Samples were composited from 10 randomly collected subsamples for each plot and analyzed at the University of Tennessee Plant and Soil Analytical Laboratory. Sampling was conducted under the following regime:

Block I: Fall 2008, Spring 2009
Block II: Fall 2008
Block III: Fall 2008, Summer 2009
Block IV: Spring 2009

Transplants for tomato, pepper, and cabbage blocks were produced using a compost- based plant media from compost consisting of poultry litter and sawdust litter produced at TTU's Shipley Farm. For crop year 2009, onion plants were purchased from an organic supplier (Johnny's Select Seeds, Albion, Me.). All other organic crops were direct seeded.

Cover crop biomass measurements were taken in the spring from randomly selected plots in blocks I, II, and III. Three sites from the south end of blocks within the plots at 1.5 m, 4 m, and 7.5 m were harvested for cover crop biomass within a 30 cm^2 frame using handheld grass sheers. All above-ground plant parts from the three sites were bagged and weighed separately. Wet weights were taken and samples dried in a drying oven for 24 hr at 57°C and weighed from the three biomass samples from three replications of each treatment. After obtaining cover crop biomass, each row was mechanically crimped using a 2.4 m (8 ft) chevron roller/crimper developed by the Rodale Institute in Kutztown, Pennsylvania. Crimping cover crops after they reach approximately 50% flower breaks the stems and causes the death of these crops. The roller flattens the cover crop, providing organic mulch, which provides weed and moisture control for most of the growing season (Kornecki et al., 2006; Francis, 2009).

Field crop biomass samples were taken three times during the growing season at 10-day intervals from randomly selected test plots prior to first harvest date. Three sites were selected in each plot at 1.5 m, 4 m, and 7.5 m from the south end of each randomly selected plot using handheld grass shears. All above-ground biomass from the three sites in each plot were weighed separately and analyzed. Fruit was excluded from the analysis. Wet and dry weights of samples were weighed using an analytical top-loading scale. Samples were dried in a drying oven for 24 hours at 57.2°C (135°F), prior to weighing.

Tomatoes from blocks 3 and 4 were harvested weekly on the same day into 55 kg tomato boxes and weighed on a top-loading analytical scale. All breaking fruit were harvested on each harvest day along with any fruit with visible color. Breaking fruit are those with noticeable coloring at the blossom end of the tomato fruit. Peppers from block II were harvested weekly or as matured during the growing season. Mature fruit with strong blocking shape were harvested regardless of fruit size. Peppers were harvested into tomato boxes and weighed on a top-loading analytical scale in the field. Squash in block I was harvested daily Monday through Friday with data analyzed from the Tuesday through Friday harvest dates. Thereby, overgrown fruit that had matured over the weekend was not included in the data. Fruit were harvested at the 12-15 cm size. Crop weights were measured on a top-loading analytical scale immediately after harvest in the field. All crops were harvested from the center 3.8 m of each plot for determining crop weight.

Crop yield, biomass data, and soil nutrients were statistically analyzed using Statistical Analysis System (SAS®)(Cary, N.C.). The General Linear Model Program, ANOVA, regression and Tukey's mean separation techniques were used to test for differences between compost treatments over the two-year crop rotation. Correlations between compost treatment, crop yield, and soil nutrients were conducted. Comparisons of crop yield by year and between spring- and fall-applied compost applications were conducted. Alpha values were compared at the 0.05 level.

RESULTS AND DISCUSSION

Crop Yield Year 1

Yields for tomato, squash, and pepper were significantly lower in the zero compost treatment when compared with the other compost treatments in the three fall-applied compost research blocks (Figure 2). ANOVA values for tomato yield and compost rate were $r^2 = 0.907$, $F = 39.01$, $p < 0.0001$; for squash, yield and compost rate were $r^2 = 0.852$, $F = 23.04$, $p < 0.0001$; and for pepper, yield and compost rate were $r^2 = 0.786$, $F = 14.73$, $p < 0.001$. Crop yield increased numerically with increasing compost rates but was not statistically significant at the 95% level based on Tukey's grouping, except for the tomato and pepper block comparing the 10.7 Mg/ha compost treatment with the two higher compost treatments (32.2 and 53.7 Mg/ha).

Therefore, based on the first year organic crop yield results, the optimum compost rate could not be determined, although the high compost rate (53.7 Mg/ha) resulted in larger numeric crop yields. This finding corresponds to previous research that showed a low yield response to compost treatments in the beginning of long-term tests (Erhart et al., 2005). Gaskell and Smith (2007) found that even the most efficient N-supplying composts, cover crops, or other organic N sources do not release appreciable N to a subsequent crop beyond six to eight weeks from incorporation, which may not synchronize with crop N requirements.

Endelmann et al. (2010) reported that only from 0-50% of the total N is bio-available within the season of application, depending on the materials and their state of decomposition. The remaining N is in organic forms that slowly mineralize over several years. They also found that a defining feature of compost use in organic systems is that its effects on crop yield are evident for many years after application. One reason is that not all nutrients present in compost are immediately available for plant use and that the remaining N and any subsequent N added slowly mineralizes and become available over time. The buildup and slow release of N has a greater long-term effect on crop yield over time. These findings may explain why crop yield is not significantly different between the three compost addition levels during the first few years of treatment by compost alone.

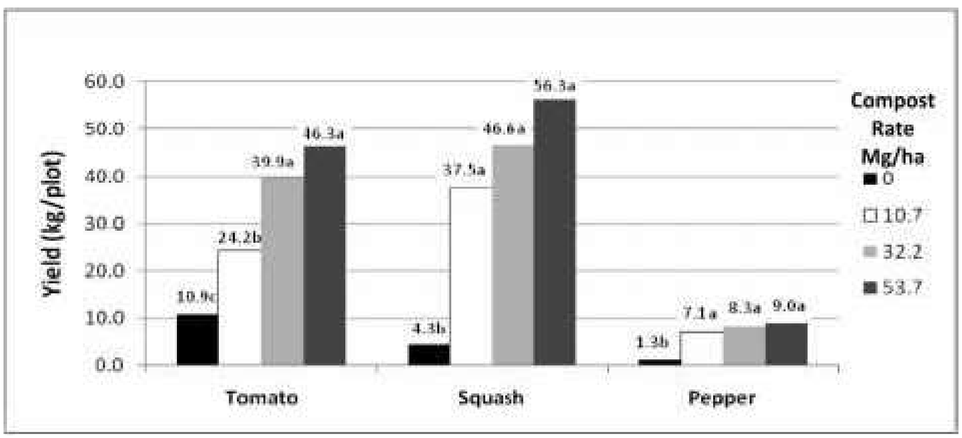

Figure 2: Crop yield versus fall-applied compost rate in Blocks 1 (squash), 2 (tomatoes) and 3 (peppers) in 2008.

* Note: Letters indicate Tukey grouping. Individual crop yields followed by the same letter do not differ significantly at $p < 0.05$ by Tukey's Honestly Significantly Different (HSD) test.

Cover Crop Biomass Year 1

During the 2008 season, poor germination of the legumes in the winter rye, hairy vetch, and crimson clover cover crop mix resulted in an almost pure stand of winter rye. Winter rye maintains N in the plant-soil system by absorbing the N that would otherwise be lost to leaching. The N is assimilated into the plant tissue and then, as the cover crop decomposes, it is released to subsequent crops (Creamer and Baldwin, 1999). However, winter rye straw's high C:N ratio of about 80:1 can immobilize N that might be needed for early plant growth. In contrast, legume cover crops provide a quick release of plant available N early in the season because of their relatively low C:N ratio of 15:1 (Brewer and Sullivan, 2003). The fact that the legume portion of the cover crop was minimal in the first year limited early bio-available N to the crop and may also have contributed to the lack of significant differences in the compost treatments due to the probable slow early N mineralization of the applied compost.

In 2008, cover crops winter rye and hairy vetch wet biomass showed no difference with the compost treatment for the squash plots (block 1). The tomato and pepper blocks (2 and 3) showed a significant difference in the cover crop biomass between the zero compost treatment and the other compost treatments (Figure 3). ANOVA values for squash crop biomass and compost rate were $r^2 = 0.537$, $F = 3.10$, $p < 0.0893$, tomato crop biomass and compost rate were $r^2 = 0.742$, $F = 7.67$, $p < 0.0097$, and pepper crop biomass and compost rate were $r^2 = 0.632$, F = 4.59, $p < 0.0377$. Investigators have found

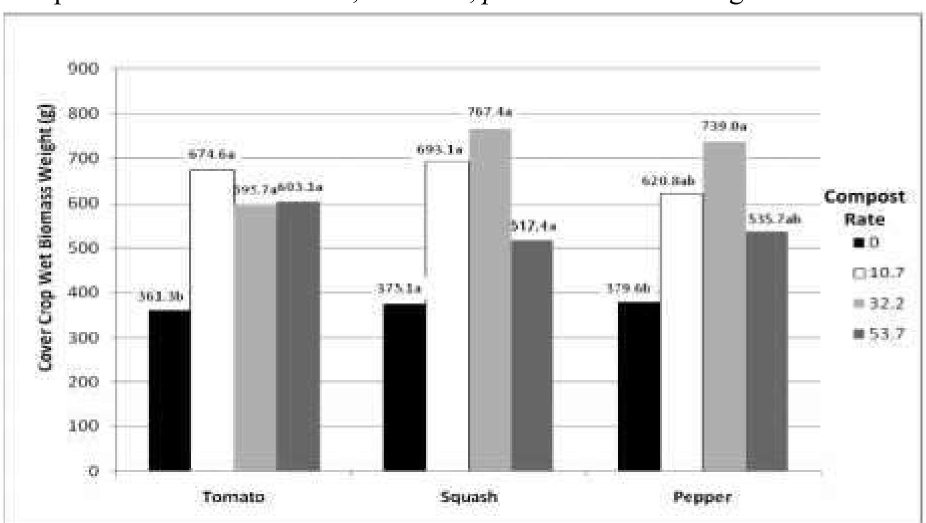

Figure 3: Cover crop wet biomass weight versus fall-applied compost rate in Blocks I, II, and III in 2008.

* Note: Letters indicate Tukey grouping. Individual crop yields followed by the same letter do not differ significantly at $p < 0.05$ by Tukey's Honestly Significantly Different (HSD) test.

that cereal plants in compost treatment tests were sufficiently supplied with N in the early growth stages, but at booting (when the head is enclosed by the sheath) N was in short supply when the crop needed it most (Erhart et al., 2005). Early plant growth of the cover crops took place in the Fall of 2007 with more biomass and mature plant parts being completed in early Spring 2008.

Cover crop wet biomass was lower for the zero compost rate compared to the other compost rates in all blocks (Figure 3). Unlike the crop yields, the highest compost rate did not result in larger cover crop biomass weights.

Owen et al. (2008) found that compost application in their test at the 3X treatment rate had a decrease in nitrate N supply rather than an increased supply with increasing compost amendment, indicating N was being immobilized and less was available for plant growth. Warman (2002) found that mineralization of N in recently added and previously applied compost influences plant response in a particular crop year, and that seasonal variations in soil moisture and temperature have a greater influence on plant production through mineralization than the source and amount of mature compost applied. This could explain why the higher compost rate treatment had lower cover crop biomass weights than the two lower compost rates due to the drought conditions experienced during the 2007-2008 growing season.

Crop Biomass Year 1

Squash, tomato, and pepper plant biomass were positively correlated with the respective crop yields for the fall-application compost treatments in 2008 (squash r = 0.902, p <0.0001; tomatoes r = 0.688, p < 0.0133; peppers r = 0.755, p < 0.0045). Crop biomass and crop yield were positively correlated (r = 0.773, F = 51.03, p < 0.0001).

The squash and tomato blocks crop biomass followed a similar pattern as the cover crop biomass. The highest rate of compost resulted in lower biomass than the low and medium compost rates. The pepper crop plant biomass, however, did show a much higher biomass and significant difference as compost rate increased.

Crop Yield Year 2

Block I

In year two of this study (2009), new crops were introduced to the crop rotation for each block. Block 1 was divided between onion and cabbage crops with the same compost treatments applied to plots as the previous year with three replications. The onion and cabbage were grown using black plastic for weed control. The plastic mulch was laid in the late Fall 2008 after compost application. Crop yield and compost rates were significantly and positively correlated. ANOVA values for onion yield and compost rate were $r^2 = 0.555$, $F = 4.98$, $p < 0.018$, and for cabbage yield and compost rate ANOVA values were $r^2 = 0.851$, $F = 22.79$, $p < 0.0001$.

All compost treatment means were significantly different than the zero compost treatment mean in the onion plots, and the two highest rates of compost treatments had significantly larger crop yields than the lower rate of compost treatment in the cabbage plots. This could possibly be due to the deeper and more extensive rooting and higher nutrient feeding capacity of the cabbage, which could take advantage of the higher nutrient content of the higher compost rates compared to the onions, which are shallow rooted (Willumsen and Thorup-Kristensen, 2001). In both 2008 and 2009, crop yields were lower for the zero compost treatment compared to the other compost treatments for squash and onions and not for the cabbage at the 0 and 10.7 Mg/ha rates (Figure 4). Yields increased numerically with increasing compost rate treatments.

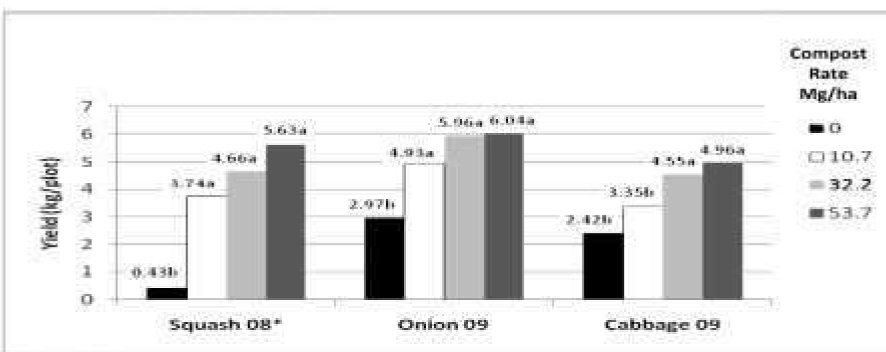

Figure 4: Block 1 crop yield versus fall-applied compost rate for years 2008 (squash) and 2009 (onion and cabbage).

*For visual comparison with other crops, squash yields are 10 times greater than depicted.

*Note: Letters indicate Tukey grouping. Individual crop yields followed by the same letter do not differ significantly at $p < 0.05$ by Tukey's Honestly Significantly Different (HSD) test.

Block II

In the second year (2009), block II was split between two crops (bush beans and beets). Bush bean yields were positively correlated with increasing compost application treatment (Figure 5). ANOVA values for bean yield and compost rate were, (r = 0.425, F = 3.08, p < 0.0097). Bean yields were significantly lower in the zero compost treatment compared to the two highest compost treatments. Beet yields were not tested for significance since only two replications were harvested. The two higher compost rate treatments had significantly higher tomato yields than the 0 and 10.7 Mg/ha compost treatment in 2008 (Figure 5).

Cover Crop Biomass

Block III

In year two (2009), cover crop biomass data was collected on one research block only (block III). The compost applications were made in Fall of 2007 and 2008. The cover crop wet biomass was positively correlated to compost treatments with some variation over the two treatment years (r = 0.631, F = 5.94, p < 0.01). Cover crop biomass was significantly lower in the zero compost treatment compared to the other compost treatments for both years (Figure 6). It is interesting to note that biomass for the highest compost rate (53.7 Mg/ha) was lower than biomass for the middle compost rate (32.2 Mg/ha) for 2008 (Figure 6). Due to the high amount of carbonaceous materials in the higher compost treatment, increased microbial growth may have contributed to N immobilization. Cover crop biomass yields flattened out in the second year probably due to carry-over effects of compost treatments and incorporated cover crop biomass from the first year growth (2008). Cover crop biomass for the zero compost rate was significantly reduced in year two of the test as inherent nutrients were depleted by plant growth.

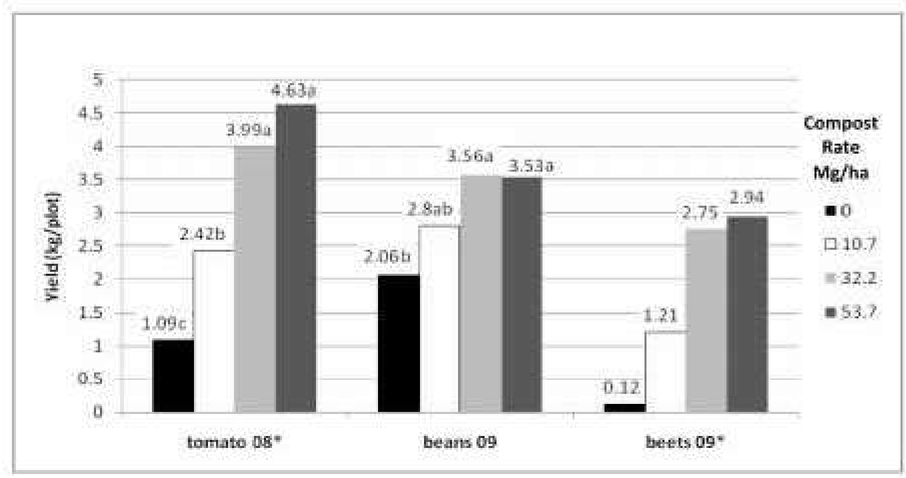

Figure 5: Crop yield versus fall-applied compost rate in Block II for years 2008 (tomatoes) and 2009 (beans and beets).

*For visual comparison with beans, tomato yields are 10 times greater than depicted and beet yields are 10 times less than depicted.

*Note: Letters indicate Tukey grouping. Individual crop yields followed by the same letter do not differ significantly at $p < 0.05$ by Tukey's Honestly Significantly Different (HSD) test.

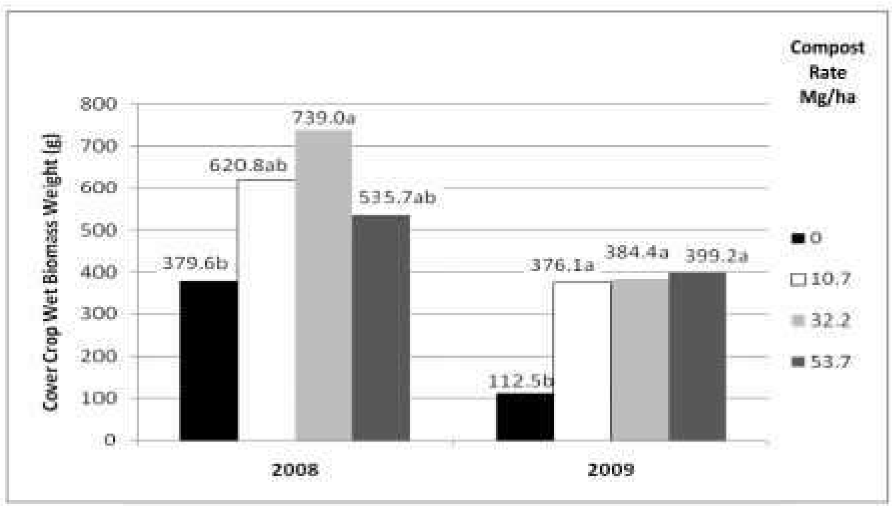

Figure 6: Cover crop biomass weight versus fall-applied compost rate for 2008 and 2009 in Block III.

*Note: Letters indicate Tukey grouping. Individual crop yields followed by the same letter do not differ significantly at $p < 0.05$ by Tukey's Honestly Significantly Different (HSD) test.

Spring-Applied Compost Results in Block IV

Crop yields were also measured for the spring-applied compost treatments in block IV. This block had identical compost application rates as the fall-applied test. The differences were season of application (spring vs. fall) and cover crop (winter cover in blocks I, II, and III vs. bare fallow and added organic mulch or living mulch in block IV). No cover crops were sown as winter cover and winter rye/ hairy vetch straw were applied after planting tomatoes the first year to provide weed and moisture control and to approximate conditions in the fall- applied compost treatments with crimped winter cover crops. The second year (2009) buckwheat was under sown after corn had reached 0.5 m in height to provide weed control as a living-mulch.

Year 1. Tomatoes in year 1 (2008) did not follow expected yield results. Higher yield was measured from the low compost treatment (10.7 Mg/ha) compared to the middle (32.2 Mg/ha) and high (53.7 Mg/ha) compost treatment rates (Figure 7). Tomato yield in 2008 was not correlated to compost rate (r = 0.089, $p < 0.781$). It is difficult to explain these results because of the many factors involved in the mineralization and bio-availability of N, which affects crop yield. Soil temperature and moisture, soil biology, soil texture, soil physical conditions, and compost application effects immediately prior to planting in the spring may have contributed to the highest yield in the low compost rate (Briggs, 2008). Other treatment yield means did not differ significantly from the zero compost treatment plots, indicating that the two highest rates of compost did not increase yield as in the fall-applied treatments.

Year 2. Corn yields from the second year (2009) showed much variability with the middle treatment (32.2 Mg/ha) measuring higher yield than all other treatments (Figure 7). Corn yields followed a more predictable pattern than the previous years' tomato crop even as the higher rate of compost treatment saw a lower yield than the two lower compost rates (Figure 7). Corn yield also correlated positively to compost rate, but it was not a significant correlation (r = 0.236, $p < 0.164$). Clearly, fall-applied compost treatments gave more reliable and predictable results than spring-applied compost treatments in this study. This could indicate that compost may need several months to mix and be affected by soil processes for optimum benefits.

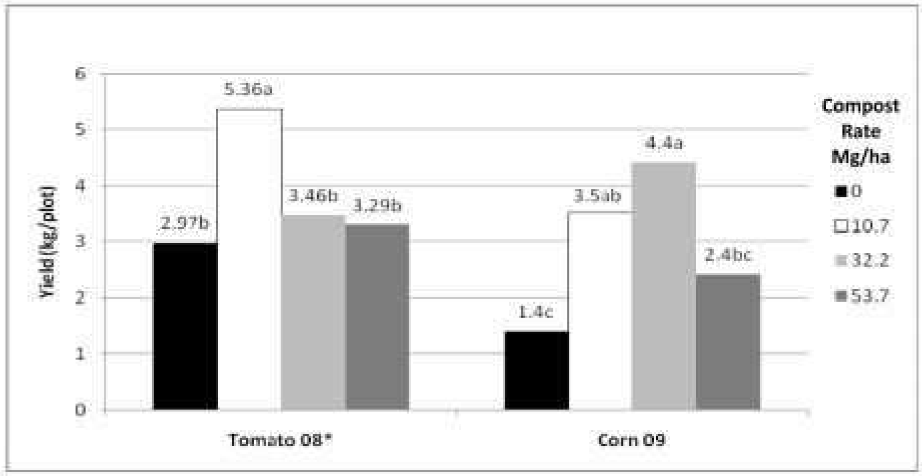

Figure 7: Crop yield versus spring-applied compost rate for Block IV in years 2008 (tomatoes) and 2009 (corn).

* For visual comparison with corn, tomato yields are 10 times greater than depicted.

*Note: Letters indicate Tukey grouping. Individual crop yields followed by the same letter do not differ significantly at $p < 0.05$ by Tukey's Honestly Significantly Different test.

Correlations: Crop Yield, Compost Rate, and Soil Variables

Year 1

Correlations between crop yield, compost rate, and measured crop and soil variables for 2008 are shown in Table 1. Squash, tomato, and pepper yields were positively and significantly correlated with fall-applied compost rates in 2008. Cover crop plant wet biomass of rye/hairy vetch in blocks I, II, and III was significantly and positively correlated with the fall application of compost rates in 2008 (Table 1).

Soil measurements of pH, Ca, Mg, K, and P were positively correlated with crop yield in all blocks. Soil organic matter was significantly and positively correlated with crop yield in the pepper block (block III) but not in the squash (block I) and tomato blocks (block II). Soil nitrate was correlated positively with crop yield in the tomato block (block II). Crop biomass was positively correlated to crop yield for all blocks. These positive correlations between compost rate and the measured parameters indicate that compost applications increase nutrients and yield, which is important to transitioning organic farmers.

Table 1: Correlation coefficient (r) of crop yield with compost rate, crop biomass and soil properties for 2008 Fall compost application in Blocks 1 (squash), 2 (tomatoes), and 3 (peppers).

	Squash		Tomatoes		Peppers	
	r	P	r	P	R	P
Compost Rate	0.871	<0.0001	0.941	<0.0001	0.794	0.0002
Soil pH	0.830	<0.0001	0.738	<0.0011	0.640	0.0076
Soil P	0.680	0.0038	0.881	<0.0001	0.525	0.0367
Soil K	0.700	0.0026	0.896	<0.0001	0.525	0.0366
Soil Ca	0.731	0.0013	0.819	<0.0001	0.513	0.0422
Soil Mg	0.690	0.0031	0.881	<0.0001	0.556	0.0253
Soil O.M.	0.144	0.5956	0.273	0.3058	0.549	0.0276
Soil Nitrate	NA	NA	0.729	0.0013	NA	NA
Crop Biomass	0.902	<0.0001	0.688	0.0133	0.755	0.0045

Soil pH. Soil pH increased with increasing compost rate in 2008 (Figure 8). At the highest compost rate, soil pH increased by at least 0.7 pH units compared to the zero compost rate. Soil pH levels did show significant differences for the compost treatments. Small increases of 0.1 pH units have a significant chemical effect in the soil (r^2= 0.583, F = 16.00, p < 0.0001). The increases in soil pH above pH 6 translate to more availability of nutrients needed for plant growth, including N, Ca, Mg, K, and P.

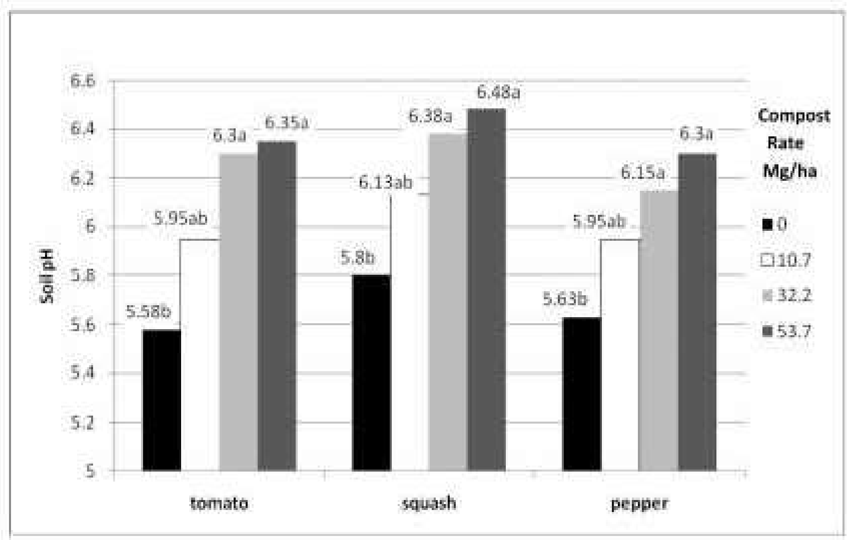

Figure 8: Soil pH versus fall-applied compost rate for 2008 in Blocks I (squash), II (tomatoes) and III (peppers).
*Soil pH means followed by the same letter do not differ significantly at $p < 0.05$ by Tukey's Honestly Significantly Different (HSD) test.

Year 2

Correlations between crop yield and soil phosphorous for all blocks were conducted on soil sampled to a 15 cm depth in 2009. Crop yield and soil P were positively correlated in blocks I, II, and III and not for corn in block IV.

Soil P. In block II, soil P was found to be positively and highly correlated to increasing compost rates in 2009 ($r = 0.881$, $p < 0.0001$). Tukey's means separation showed significant differences for compost rate and soil P (Table 2). These results are consistent with previous research measuring higher soil P with increasing compost application rates. Soil P at high compost rates could cause excessive soil P resulting in leaching or runoff contamination (Francis, 2009). Soil phosphorous is important because, with the exception of soil nitrogen, no other element is as critical for growth. A lack of P may prevent other nutrients from being acquired by plants (Brady, 1974).

Table 2: Soil phosphorous versus compost rate for fall-applied compost block in 2009, Block II.

Compost Rate (Mg/ha)	Phosphorus (kg/ha)	Tukey grouping+
0	26	D
10.7	292	C
32.2	652	B
53.7	1,035	A

*Soil sampled July 27, 2009
+Phosphorous means followed by the same letter do not differ significantly at $P < 0.05$ by Tukey's Honestly Significantly Different test.

SUMMARY AND CONCLUSIONS

This study was conducted to determine optimum rates of compost application in a raised-bed organic vegetable system based on four compost rates over a two-year period by measuring crop yields, cover crop biomass, and crop biomass weights. The study also compared fall application versus spring application of compost to determine if season of compost application affected crop yield. The soil chemical properties of Ca, Mg, K, P, organic matter, soil nitrate and pH were monitored for two years to measure compost rate effects on levels of these properties in the soil.

Results indicated that compost application rate did significantly and positively affect cover crop biomass, crop biomass, and crop yield for the fall-applied compost treatments compared to the zero compost rate, although few mean weights showed significant differences with Tukey's Honestly Significantly Different (HSD) Test between the three higher compost treatments. Crop yields and biomass measurements were positively and significantly correlated to compost treatment for both years as yields increased numerically with increasing compost rates. Spring application of compost gave inconsistent and unpredictable results for yield over both years of the study. Yield was not significantly correlated with compost rate. This could be due to the absence of fall cover that stabilizes soil moisture and adds organic matter to soil when turned into the beds in the spring or the slow rate of mineralization of nutrients for crop uptake based on complex soil physical, chemical, and biological factors. Measured soil chemical properties were also positively affected by compost rates in the fall application treatments in 2008, including soil pH, Ca, Mg, K, and P. Increasing compost rate does positively affect these vital plant growth nutrients in the soil. The effect on increasing soil organic matter with increasing compost rate was inconclusive for this short-term project with some measurements increasing and others showing no significant change. The optimum compost rate for this study based on application rate versus yield and plant biomass was between the lowest rate (10.7 Mg/ha) and the middle rate (32.2 Mg/ha) or approximately 20 Mg/ha. The fall application of compost with mixed legume and cereal cover crop appear to be the optimum soil management practice based on crop yield compared to spring-applied compost.

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