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Soil Fertility Management in Organic Vegetable Production

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SOIL FERTILITY MANAGEMENT IN ORGANIC VEGETABLE PRODUCTION

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ABSTRACT

Organic vegetable production is a rapidly growing sector of agriculture. Due to limitations on synthetic inputs imposed by the USDA National Organic Program (NOP), research is necessary to determine which soil amendments are viable options for organic farmers. Field trials were conducted at the Clemson University Calhoun Fields Laboratory Student Organic Farm. A variety of vegetable crops were grown, including Jericho lettuce in the springs of 2005 and 2006, yellow crookneck squash in the summers of 2005 and 2006, and Early Jersey Wakefield cabbage in the fall of 2005. Soil amendment treatments consisted of combinations of the following: poultry compost, poultry litter, dairy compost, dairy manure, blood meal, feather meal, and Fertrell™ 5-5-3. Poultry litter and dairy manure were applied 120 days prior to harvest in accordance with NOP standards. Yield and weekly plant growth were measured. The Clemson University Agricultural Service Laboratory performed compost, manure, plant tissue and post-harvest soil analyses. Poultry compost resulted in the greatest yield and plant growth in all trials, though differences were not significant in the spring 2006 lettuce and summer 2006 squash trials. Poultry litter and dairy manure resulted in depressed yields and plant growth as compared to the compost treatments. Trends showed soil and tissue phosphorus to be greatest in poultry compost and poultry litter treatments. Application of poultry compost should be alternated with other soil amendments or applied according to phosphorus requirement of a crop to avoid phosphorus buildup in the soil.

DEDICATION

I dedicate this thesis to my children. They are the motivation for all my life work.

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CHAPTER ONE

INTRODUCTION

Over the last decade the demand for organic products in the U.S. has increased by approximately 20% per year and the amount of certified land has doubled, making organics the fastest growing sector of agriculture (OFRF, 2006). Currently the demand for organic products far outweighs the supply, and increasing numbers of small acreage landowners are considering a transition to certified organic production. Therefore research is needed to develop cost-effective soil fertility practices for small-scale organic farming operations.

The United States Department of Agriculture (USDA) regulates which substances are allowable in organic crop production. The National Organic Program's (NOP) Final Rule states that organic production must "maintain or improve" the soil and provide "soil fertility through rotations, cover crops, and the application of plant and animal materials" (www.ams.usda.gov/nop). The Final Rule prohibits most synthetic substances commonly used in conventional agricultural operations; therefore organic farmers have limited options in choosing soil amendments to enhance soil fertility. Furthermore, commercially available organic soil amendments may be cost-prohibitive for small, limited resource organic farms.

Over the last 50 years, synthetic fertilizers have become the primary nutrient source for agriculture. However widespread use of fertilizers has had adverse impacts on the environment raising serious public concern. Leaching of nitrates and phosphates from soil is problematic, and fertilizers have been linked to marine eutrophication and groundwater contamination (Crews et al, 2004). In addition, the production of synthetic fertilizers requires an immense amount of energy input and is dependent on the price of natural gas in the United States (GAO report, 2001). For these reasons recent research has focused on seeking effective sustainable and organic alternatives to enhance soil fertility and crop yields. Lee et al (2003) evaluated poultry manure compost as a supplement to inorganic sources of nitrogen. Their results indicated that the amount of added nitrogen could be reduced by 40% with the addition of poultry manure.

In contrast to conventional agriculture organic farmers approach soil fertility in a holistic manner by implementing production practices that improve the physical, chemical, and biological properties of a soil. Physical characteristics of soil include texture and structure. The texture of a given soil is the percent sand, silt, or clay and is generally unchangeable for a given location (Brady et al, 2002). Structure is the aggregation of these sand, silt, or clay particles into secondary clusters, and is readily altered by agricultural practices (Brady et al, 2002). Texture and structure are responsible for the porosity, drainage, water-holding capacity, compaction and tilth of a soil (Brady et al, 2002). Soil physical characteristics influence the ability of roots to grow and proliferate, extracting water and nutrients and stabilizing the plant. Wong et al (1999) found that livestock manure compost applied to soils of organic farms in Hong Kong improved soil physical properties with a significant decrease in bulk density and increase in soil porosity and hydraulic conductivity.

Soil chemical properties determine the availability of plant nutrients (Brady et al, 2002). Due to constraints on chemical inputs, organic farmers focus less on this component of soil fertility. Where conventional farmers place great emphasis on inputs of synthetic chemical fertilizers, organic farmers manage soil chemical properties with addition of organic matter thereby increasing cation exchange capacity of the soil (Baldwin, 2001).

The biological component of soil is perhaps the most important for organic farmers. Organisms living in a healthy soil include earthworms, arthropods, bacteria, fungi, algae, protozoa, and nematodes. These organisms break down plant material, feed on each other, and excrete nutrient-rich wastes, amino acids, sugars, antibiotics, gums, and waxes (Sullivan 2004). Much of these excreta are beneficial to soil structure and plant health. The balance in which these organisms reside in the soil is a delicate one, highly sensitive to chemical inputs and dependent on organic matter for food.

It is generally recognized that the foundation of good soil quality is organic matter. Sullivan (2004) describes a few of the benefits of a topsoil rich in organic matter, including rapid decomposition of crop residues, granulation of soil into aggregates, decreased crusting, better water infiltration and drainage, increased water and nutrient holding capacity, easier tillage, reduced erosion, better formation of root crops, and more prolific plant root systems. Addition of organic matter to agricultural soil can most easily be accomplished with incorporation of cover crops, manure, and/or compost (Sullivan 2004).

Many pre-packaged organic fertilizers are available commercially. Organic farmers need to be particularly careful when selecting these products to ensure that none of the ingredients are prohibited under the NOP. Unfortunately, the point of sale and shipping costs of many of these products may outweigh the yield benefits, sometimes resulting in a net loss (McAllister, 1987).

An objective of this study is to compare commercial organic fertilizer blends with other organic soil amendments in certified organic vegetable production. The soil amendments evaluated in this study included poultry and dairy manure and composted manures, blood meal and feather meal. Blood meal is dried blood from slaughter of livestock. It contains approximately 13% nitrogen (N), is prone to nitrogen loss from soil and may result in toxicity to plants from exposure to ammonia (Hall 1998). Feather meal products contain hydrolyzed poultry feathers, a byproduct from slaughter. The N content of feather meal is approximately 12% and N from feather meal is released into the soil more slowly than with application of blood meal (Hall 1998). The commercial organic fertilizer blend tested in this study was Fertrell™ 5-5-3, "an organic blend that provides balanced, slow-release nutrients" (Fertrell Company, Bambridge, Pennsylvania).

Several studies have shown that organic soil amendments are capable of producing comparable or better yields than conventional mineral fertilizers, particularly after several years of use. Smith et al (1988) compared the effect of ammonium nitrate, blood meal, feathermeal, and composted sewage sludge as N sources on yield of cabbage. When incorporated in the soil at rates of 250 kg N/ha and higher, the organic amendments produced plant fresh weight equal to that of the inorganic salt. A three-year study of carrots, cabbages, potatoes and sweet corn comparing a conventional N-P-K fertilizer with composted chicken/beef manure resulted in few differences in yield, and vitamin/mineral content of the vegetables (Warman et al 1996). The authors concluded that the use of high-quality, mature compost provided vegetables with approximately the same amount of essential nutrients as inorganic fertilizers. A study in Taiwan reported that rice yields from compost were initially depressed when compared with yields from ammonium sulphate application, but after ten years yields in the compost treatment were greater than in the inorganic fertilizer treatments (Huang, 1992). Rangarajan et al (1999) reported that poultry compost resulted in more vigorous growth of beets and lower incidence of root rot than in plots amended with synthetic fertilizer. Guertal et al (1997) examined the effect of using an equivalent mix of potting media and poultry litter in transplant production of cabbage, broccoli, collards, and tomato. Although the poultry litter mix initially depressed growth of cole crops compared to pure potting mix, all differences were gone by the fourth week and final yield was not affected. No differences in tomato growth or yield were observed.

Because N is commonly the most limiting plant nutrient, farmers generally apply fertilizers based on N requirements of a crop. All of 'total N' present in a fertilizer is not readily available to a crop when the crop has the highest N demands. To optimize application rates and timing, much research has been done on the N mineralization rates of various fertilizers (Jackson et al 1977; Van Faassen et al 1987; Bitzer et al 1988; Hadas et al 1994; Gordillo et al 1997; Chadwick et al 2000; reviewed by Nahm 2005; Kara et al 2006) with highly variable results. A discussion of N mineralization is beyond the scope of this paper. It is important for farmers to have manure, compost, or other fertilizer tested before application to avoid insufficient or excessive supply of nutrients, potentially resulting in pollution of nearby surface waters and/or phytotoxicity (Hachicha et al 2006).

Livestock manure is the most widely utilized organic fertilizer (Kuepper et al 2004). Strict regulations for manure use in organic production are detailed in the NOP final rule. Uncomposted raw manure may not be applied to food crops where edible portions come into contact with the soil within 120 days of harvest and may not be applied to food crops where edible portions do not have contact with the soil within 90 days of harvest (www.ams.usda.gov/nop). Manure as a nutrient source has numerous benefits and downfalls, which will be briefly discussed.

Manure provides both organic matter and nutrients. The quantity of each depends on a number of factors including: animal species, age, feed, bedding or other incorporated materials, housing system, manure collection and storage systems (Van Faassen et al 1987). Van Faassen reports overall higher total N content for poultry manure as compared with dairy manure (6.5% and 2.6% of dry matter, respectively). Farmers are frequently able to source manure locally and at low cost from livestock producers anxious to rid themselves of the by-product (Andrews et al 1999). Nine billion broiler chickens are produced annually in the United States, each of which produces approximately 2 kg of litter in 8 weeks (USDA-NASS 2005). Disposing of livestock waste in an environmentally sound manner is an increasing problem. Therefore, manure is likely the most readily available and easily accessible source for supplemental crop nutrients and soil organic matter.

There are also many problems inherent in the use of livestock waste as a fertilizer, including food quality and safety, fertility imbalances and subsequent pollution hazards, and potential weed problems (Kuepper 2003). Manure application may transport contaminants to agricultural land and crops. Because organic production allows the use of manure from non-organic sources, there is some concern that antibiotics, hormones, or pesticides used on the livestock may end up as contaminants in crops where manures have been applied. Heavy metal contamination is not likely to be ameliorated in the NOP time frame, and may potentially accumulate in soils with repeated manure applications. The NOP 90/120 day rule was also established as a safeguard to protect against contamination of food crops from human pathogens. It is generally accepted that this timeframe is sufficient to mitigate survival of human pathogenic microbes that may be introduced from application of manure.

Concerns have also been raised regarding the potential for arsenic contamination from the application of poultry litter. According to the National Center for Appropriate Technology, "poultry litter applied at agronomic levels, using good soil conservation practices, generally will not raise concentrations sufficiently over background levels to pose environmental or human health risks" (Bellows, 2005).

When used improperly, manures high in nitrogen have been shown to have phytotoxic effects. Hammermeister et al (2005) reported suppressed growth and yield of lettuce when poultry manure was applied at a rate of 800 kg N/ha, likely due to ammonium toxicity. Lower rates of application showed increased yield over chemical fertilization without phytotoxic effects. Willumsen (2001) found that mixes incorporating poultry manure resulted in reductions of plant growth due to salinity of the manure used. Ells et al (1991) showed that dairy manure applied at 200 t/ha did not produce toxic levels of ammonia, and therefore did not inhibit cucumber germination and growth. As with most other fertilizers, improper or over-application of manure has been shown to result in an overload of nutrients and subsequent contamination of surrounding land and water (Guertal et al 1996; Kuepper 2003).

Composting of manures is a method by which nutrients in manure are stabilized and biomass is reduced (Sullivan 2004; Nahm 2005). Roe (2005) defines compost as “a partially stabilized product of microbial decomposition of organic materials”. Dick et al (1993) define a mature compost to be “a brown-black crumbly material with an earthy smell and a C:N ratio of approximately 10:1”. Like manure, the physical and chemical characteristics of compost are highly variable depending on the feedstocks and production methods used. Feedstocks can be any organic material including: municipal waste, sewage sludge, animal manures, food wastes, and plant materials. It should be noted that NOP regulations do not allow the use of municipal waste, sewage sludge and human manure in organic production. This study focuses on dairy and poultry manure as feedstocks.

Compost can be produced in a variety of ways that can generally be grouped in the following manner: static piles, aerated static piles, and in-vessel (Roe 2005). Static piles are the easiest, lowest-input method of composting in which feedstocks are simply piled and allowed to sit until fully composted. This is the slowest method of composting and ultimately all of the material may never become mature compost. Aerated piles are the most useful and productive farm-scale methods. These piles or windrows of feedstocks can be aerated in a number of ways including the introduction of air through pipes buried in the piles or turning with front-end loaders or specialized compost-turning equipment. A multitude of in-vessel composting systems are available commercially. They range from revolving barrels to vented trashcans with augers to anaerobic systems. In-vessel systems are generally more appropriate for small-scale, home composting purposes.

The NOP dictates specific time, temperature, and turning requirements for compost intended for use in organic crop production. Initial C:N ratios must be in the range of 25:1-40:1. Aerated piles or in-vessel composts must reach 55ºC-77ºC and remain in that temperature range for a minimum of 3 days. Windrows must reach 55ºC-77ºC and remain for a minimum of 15 days during which time the windrow must be turned at least 5 times (www.ams.usda.gov/nop). The use of compost as a fertilizer has both benefits and drawbacks.

As with manure, compost adds organic matter and plant nutrients to the soil. The composting process inherently reduces the total amount of manure biomass, and so aids in waste disposal. Though compost is lower in overall available nutrient content (particularly N) than the manure from which it was produced, the stabilized nutrient pool is released more slowly thus producing less pollution. After composting poultry manure with sulphur and phosphate rock, Mahimairaja et al (1995) reported that the composted product increased the agronomic effectiveness of manure and reduced associated environmental hazards. In general, compost has lower soluble salt content than manure and is therefore less likely to damage plants (Kuepper, 2003). The time and temperature requirements for compost production mandated by the NOP address the concerns regarding contamination by pathogenic microbes and from weed seeds being transferred to the crop.

Maynard (1992) found that addition of chicken manure compost before spring crop planting resulted in comparable yields of broccoli, cauliflower, eggplant, peppers and tomatoes compared with those amended with inorganic fertilizers. She concluded that in addition to sufficient plant nutrients, the high yields were probably due to increased water-holding capacity, soil aggregation and structure, aeration, and tilth observed in the compost-amended plots. Compost-amended soil has been shown to contain high populations of beneficial soil microbes that play a role in N mineralization and non-symbiotic nitrogen fixation (reviewed by Dick et al, 1993; Andrews et al 1995; Kara et al 2006).

As with manure, there is concern over the potential for heavy metal contamination of soil and crops through application of compost. Rather than being eliminated, heavy metals may become more concentrated during the composting process as biomass is reduced. Research using livestock manure compost on organic farms in Hong Kong found increasing plant accumulation of Cu and Zn with increasing amounts of compost (Wong et al 1999). Because compost has greater carbon content than manure, it has been shown that immature compost may rob the soil of nitrogen as microorganisms degrade the raw materials, resulting in inhibition of plant growth. Inbar et al (1993) investigated the effect of dairy compost maturity on ryegrass growth. The results indicated that the growth inhibition observed with 40-60 day old compost was eliminated after 80-90 days of composting.

While raw manure is usually cheap and easy to access, compost requires more labor and cost inputs for processing. Many packaged, finished compost products are commercially available, but they tend to be costly. On-farm composting is a viable alternative. Compost is a slow-release source of nutrients, all of which may not become available to a crop during the first growing season following application. In addition, nutrient content and availability are highly variable depending on feedstocks used and maturity of the compost, resulting in difficulty determining application rates. Adediran (2005) found increased growth and development of tomato and lettuce seedlings when soilless media was combined with 25% compost or manure. However, deleterious effects were observed when higher quantities of compost/manure were combined with the media.

As interest in the organic industry grows, so does the need for research to compare options for increasing soil fertility within the boundaries and guidelines of the NOP. Roe et al (2000) studied the efficacy of raw dairy manure and composted dairy manure applied at three rates on cantaloupe and broccoli. All treatments were found to decrease soil crusting and increase water-holding capacity compared with the un-amended control. Manure and the highest compost rate resulted in the greatest yields of cantaloupe, while the medium rate of compost resulted in the greatest broccoli yields. The economic analysis indicated that dairy manure had the greatest return per dollar invested. However, finished compost was purchased and on-farm composting was not considered. A study conducted at the Rodale Institute also compared raw dairy manure, conventional mineral fertilizer, and four composts "of various feedstocks, maturity, and nutrient content" applied on an N-equivalent basis (Reider et al 2000). Compost-amended corn showed depressed yields the first year, but recovered to equal yields by the second year. Pepper showed no differences in yield among treatments over the three years of the study.

The research in this study will compare soil fertility options that are both acceptable for USDA certified organic crop production and readily available to organic farmers in upstate South Carolina. Specific objectives of this study will compare dairy and poultry composts and manures with commercially available organic soil amendments and perform growth trials with a variety of high-value vegetables commonly grown in the southeastern U.S.

CHAPTER TWO

EXPERIMENTAL METHODS

Location

Experiments were conducted at the Clemson University Calhoun Fields Laboratory Student Organic Farm (SOF) on five acres certified for organic production. Each of the five trials summarized in this paper were run on different sites within the SOF. Vegetable transplants were produced in a certified organic greenhouse also located at the SOF. All research summarized in this paper was performed in accordance with the USDA National Organic Program's Final Rule (http://www.ams.usda.gov/NOP).

Ground preparation

Cover crops were mowed in the spring before planting and incorporated by tractor-mounted disc and rotary tiller. Beds were prepared with a four-foot bed-maker. Soil amendments were spread evenly over the treatment plots and incorporated with shovels. In the case of the yellow squash trials, black plastic mulch was applied to the ground. In summer 2005, the mulch was applied by hand. In summer 2006, a tractor-mounted plastic mulch layer was used.

Soil Amendments

Although compost was of primary interest in this study, a variety of alternative fertilizers available for organic vegetable production were also evaluated including:

blood meal, feather meal, Fertrell™ brand 5-5-3, raw dairy manure, raw poultry litter, and various combinations of these amendments.

The amounts of amendments applied were based on calculations to provide an equal quantity of plant available nitrogen to each treatment plot. Composts and manures were measured using an analog scale and other amendments were measured using a digital scale. Plant available nitrogen content of blood meal, feather meal, and the Fertrell™ blend are 13%, 12%, and 5% by weight, respectively. Analyses of manures for available nitrogen and composts for total nitrogen were performed by the Clemson Agricultural Service Laboratory (ASL). Plant available nitrogen of manures was estimated as 80% of ammonium N, 60% of organic N, and 100% of nitrate N. Total nitrogen of composts was converted into plant available nitrogen (PAN) using the following equation:

PAN = Total N (lbs/ton wet basis) X 0.20 (availability coefficient based on C:N ratio)

Recommended PAN application rate (120lbs/acre) / PAN (calculated above) = tons compost/acre (Baldwin, 2001)

Poultry Compost

Poultry compost was produced at Clemson University's Morgan Poultry Center. The compost was produced in designated composting bins by layering poultry manure and mortalities in the following manner and order from bottom to top: litter from cages (10 inches deep), 6 inches of fluffed straw, dead birds in mono-layer, water over birds (0.75 lbs water/lb carcass), dry litter (1.5 lbs litter/lb carcass). Subsequent layers were added in a similar fashion until the bin was full. The bins are built on a concrete slab with covered roof. Thermometers were placed at 46 and 92 cm depths and monitored on a daily basis. The temperature was observed to spike (~74ºC) for a minimum 3 days and then decline to approximately 49ºC. The compost was then aerated by turning and water was applied to attain a "damp sponge" consistency. Temperatures were again monitored daily and observed to spike to ~66ºC quickly and decline quickly. As temperatures dropped to ~49ºC, the compost was aerated and transferred to a secondary bin, watered again to damp sponge consistency and allowed to cure for 6-8 weeks prior to application.

Dairy Compost

Dairy compost was produced using manure from the Clemson University Lamaster Dairy Farm. Manure was composted on a concrete slab and left uncovered. Raw manure was combined with waste feed and hay, fresh hay, and sawdust/calf lagoon manure mix in a 5: 4: 2: 0.25: 4 ratio, respectively. The combination was blended using a tractor with front-end bucket loader. Thermometers were placed at 30, 50, and 70 cm depths. The temperature was observed to spike to approximately 65ºC for 15 days, then decrease slowly to approximately 15ºC after 60 days at which time the compost was considered finished.

Spring 2005

'Jericho' lettuce was transplanted into the field on March 4. Seeds for transplants were sown in 50-cell trays in organic potting soil (Fafard™ Organic Custom Formula, Conrad Fafard, Inc., Agawan, MA) and grown for eight weeks in the greenhouse. Treatment plots were 3 meters x 1.22 meters with 1-meter bare-ground buffers. A randomized complete block design was used with four replications of four treatments: no input (NI); 13.9 kg poultry compost (PC); 0.5 kg feather meal (F); 6.95 kg poultry compost / 0.25 kg feather meal (PC/F) (Table 1). Water was applied through a drop irrigation system. Lettuce was inter-planted with cabbage, though no data was obtained from the cabbage due to slug damage. Hand weeding and application of Diatomaceous Earth for slugs were performed in all treatment plots as needed. Data was collected on twelve plants per treatment plot. Weekly growth measurements (height and diameter), final yield weight, tissue analysis (N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, Na, B, Al) and soil analysis (pH, P, K, Ca, Mg, Zn, Mn, Cu, B, Na, NO_3-N, organic matter) data were collected.

Summer 2005

'Yellow crookneck' summer squash was direct-seeded into the field on May 19. Treatment plots were 1 meter X 6 meters with 2-meter bare-ground buffers between rows. A randomized complete block design with three replications of six treatments was used. Soil amendment treatments were as follows: no input (NI); 22.8 kg poultry compost applied at planting (PCp); 11.4 kg poultry compost applied at planting and 0.32 kg blood meal side-dressed at fruiting (PCpBf); 0.32 kg blood meal at planting and 0.32 kg blood meal side-dressed at fruiting (BpBf); 0.64 kg blood meal at planting (Bp); 11.4 kg poultry compost and 0.16 kg blood meal applied at planting and 0.16 kg blood meal side-dressed at fruiting (PCBpBf) (Table 2). Black plastic mulch was applied over the rows and plants were watered by drop irrigation. Holes were punched through the plastic mulch at 1-meter intervals and three seeds per hole were planted. One week after planting, seedlings were thinned to one plant resulting in 7 plants per treatment plot. Hand weeding and hand removal of pest insects were performed in all treatment plots as needed. Weekly growth measurements (height, diameter, length), final yield weight, tissue analysis analysis (N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, Na, B, Al), and soil analysis (pH, P, K, Ca, Mg, Zn, Mn, Cu, B, Na, NO_3-N, organic matter) data were collected.

Fall 2005

'Early Jersey Wakefield' cabbage was transplanted into a high tunnel on October 13. A high tunnel, or hoophouse, is an unheated greenhouse under which crops are grown directly in the soil. Seeds were sown in 50-cell trays in organic potting soil (Fafard™ Organic Custom Formula, Conrad Fafard, Inc., Agawan, MA) for eight weeks in the greenhouse. Treatment plots were 1.5 meters X 0.8 meters with 0.4 meter bare-ground buffers between rows. A randomized complete block design with 4 replications of 5 treatments was used. Treatments were as follows: no input (NI), 6.2 kg poultry compost (PC), 0.13 kg blood meal (B), 0.33 kg Fertrell™ 5-5-3 (F), and 3.1 kg poultry compost/ 0.17 kg Fertrell™ 5-5-3 (PC/F) (Table 3). Water was applied through a drop irrigation system. Hand weeding and hand removal of lepidopterou*s* pest larvae were performed in all treatment plots as needed. Data was collected on seventeen plants per treatment plot. Weekly growth measurements (height and diameter), final yield weight, tissue analysis (N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, Na, B, Al, NO_3-N) and soil analysis analysis (pH, P, K, Ca, Mg, Zn, Mn, Cu, B, Na, NO_3-N, organic matter) data were collected.

Spring 2006

'Jericho' lettuce was transplanted into the field on April 6. Seeds were sown in 50-cell trays in organic potting soil (Fafard™ Organic Custom Formula, Conrad Fafard, Inc., Agawan, MA) for eight weeks in the greenhouse. Treatment plots were 2 meters X 1 meter with 1-meter bare-ground buffers between rows. Raw manure treatments were applied 120 days prior to harvest of lettuce on January 17, in accordance with USDA NOP regulations. Prior to transplant of seedlings, one soil sample per treatment plot was analyzed in half the raw manure plots, and Fertrell™ 5-5-3 fertilizer was applied based on nitrogen requirement. A randomized complete block design with 4 replications of 7 treatments was used. Treatments were as follows: no input (NI); 10.8 kg dairy manure (DM); 10.8 kg dairy manure + 0.54 kg Fertrell™ 5-5-3 (DM+F); 10.1 kg dairy compost (DC); 2.5 kg poultry manure (PM); 2.5 kg poultry manure + 0.54 kg Fertrell™ 5-5-3 (PM + F); 5.8 kg poultry compost (PC) (Table 4). Water was applied through a drop irrigation system. Hand weeding and hand removal of pest insects were performed in all treatment plots as needed. Data was collected on eleven plants per treatment plot. Weekly growth measurements (height and diameter), final yield weight, tissue analysis (N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, Na, B, Al, NO_3-N), and soil analysis (pH, P, K, Ca, Mg, Zn, Mn, Cu, B, Na, NO_3-N, organic matter) data were collected.

Summer 2006

'Yellow crookneck' summer squash was direct-seeded into the field on May 29. Test plots were 1 meter X 6 meters with 2-meter bare-ground buffers between. A randomized complete block design with three replications of six treatments was used. Treatments were as follows: no input (NI); 12.3 kg poultry compost at planting and 12.3 kg poultry compost side-dressed at fruiting (PC); 0.82 kg Fertrell™ 5-5-3 at planting and 0.82 kg Fertrell™ 5-5-3 side-dressed at fruiting (F); 0.32 kg blood meal at planting and 0.32 kg blood meal side-dressed at fruiting (B) (Table 5). Water was applied through a drip irrigation system. Black plastic mulch was applied using a tractor-mounted plastic mulch layer. Holes were punched through the plastic mulch at 1-meter intervals and three seeds per hole were planted. One week after planting, seedlings were thinned to one plant resulting in 7 plants per treatment plot. Hand weeding and hand removal of pest insects were performed in all treatment plots as needed. Growth measurements (Height, length, diameter), final yield weight, tissue analysis (N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, Na, B, Al, NO_3-N), and soil analysis data analysis (pH, P, K, Ca, Mg, Zn, Mn, Cu, B, Na, NO_3-N, organic matter) were collected.

Growth Measurements

Plant growth measurements were performed on a weekly basis for all trials except summer 2006 squash trial, where plant growth was measured once approximately halfway through the growing season. In the lettuce and cabbage trials, plant height and diameter measurements were taken. Height was measured as the distance between the intersection of the petiole of the lowest leaf (or scar) with the main stem and the top of the newest growth. Diameter was measured as the greatest dimension between the tips of any two leaves (usually the two oldest leaves on the plant). Plant volume was calculated for squash as the products of plant length, width, and height. Length was measured as the longest stem growth parallel to the row. Width was measured as the longest stem growth perpendicular to the row. Height was measured as the distance between the intersection of the petiole of the lowest leaf (or scar) with the main stem and the top of the plant.

<u>Crop Yield Measurements</u>

Lettuce was harvested when at least half of all heads were 18 cm in height and diameter. Yield was determined from random selection of 5 and 7 heads per treatment plot (2005 and 2006, respectively) excluding those on either end of the plot. All heads were of USDA No. 1 or USDA fancy quality. The butt was trimmed off as closely as possible to the attachment of the outer leaves. Each head was weighed using a digital scale to hundredths of a pound.

Squash yield was determined from harvest of five plants per treatment plot excluding end-row plants. All squash 13 cm and longer were harvested every 2-3 days for 6-8 weeks after the first appearance of fruit. Only those fruit that could be classified as USDA No. 1 quality were weighed using a digital scale to hundredths of a pound.

Cabbage was harvested when at least half of all heads were firm but before any splitting occurred. Yield was determined from random selection of 7 heads per treatment plot excluding those on either end of each plot. All heads were of USDA No. 1 quality. The butt was trimmed approximately 0.7 cm from the lowest leaf and two wrapper leaves were left attached. All seven heads from each treatment plot were weighed together using a digital scale to hundredths of a pound.

Plant Tissue Analysis

Plant tissue analysis was performed to determine the nutrient status of each crop. Mature bottom lettuce leaves were sampled mid-growing season. Cabbage samples consisted of 2 wrapper leaves per plant harvested mid-growing season. The two youngest fully expanded leaves were sampled from squash mid-growing season and stems removed. All leaves were rinsed gently with water to remove dust and debris and allowed to dry overnight before analysis by the Clemson Agricultural Service Laboratory (http://www.clemson.edu/agsrvlb/procedures2/photo.htm). Minerals for analyses included nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, copper, manganese, iron, sodium, boron, and aluminum. Nitrate nitrogen was quantified for cabbage 2005, lettuce 2006 and squash 2006.

Soil Analysis

Soil samples were obtained by soil probe and analyzed immediately prior to amendment application, and again immediately following final harvest or completion of crop. Soil samples represented soil surface to approximately 18 cm in depth. Cores were obtained from twelve locations (sub-samples) representing the treatment area and combined in a clean bucket, and the final sample was taken from the pooled sub-samples. The soil probe and bucket were cleaned between sampling of different treatment plots. Soil samples were submitted to the Clemson Agricultural Service Laboratory for analysis of soil pH, buffer pH, phosphorus, potassium, calcium, magnesium, zinc, manganese, copper, boron, sodium, nitrate-nitrogen, and percent organic matter (http://www.clemson.edu/agsrvlb/procedures2/interest.htm).

Compost and Manure Analysis

Compost and manure samples were taken immediately before application to treatment plots. Sub-samples taken at three depths from five locations within the pile (a total of 15 sub-samples) were combined in a clean bucket, mixed, and a final 2.2L sample was obtained from this mixture. The samples were submitted to the Clemson Agricultural Service Laboratory for analysis. Compost was analyzed for ammonium-nitrogen, total nitrogen, carbon, C:N ratio, phosphorus as P_2O_5, potassium as K_2O, calcium, magnesium, sulfur, zinc, copper, manganese, iron, sodium, organic matter, soluble salts, pH, nitrate-nitrogen, bulk density, and percent moisture (http://www.clemson.edu/agsrvlb/procedures2/compost.htm). Manure was analyzed for ammonium-nitrogen, organic nitrogen, nitrate-nitrogen, phosphorus as P_2O_5, potassium as K_2O, calcium, magnesium, sulfur, zinc, copper, manganese, iron, sodium, pH and percent moisture (http://www.clemson.edu/agsrvlb/procedures2/waste.htm).

Experimental Design and Statistical Analysis

All treatments were arranged in a randomized complete block design. Statistical analyses were performed using SAS software version 9.1 (SAS Institute Inc., Cary, NC, 2002-2003). The GLM procedure was used for simple analysis of variance among treatments. LSD values were used to determine differences in means at the alpha = 0.05 level.

CHAPTER THREE

RESULTS

<u>Lettuce 2005</u>

Yields were significantly different among all soil amendment treatments in the spring 2005 trial. Lettuce yield was greatest in the PC treatment followed by the PC/F, F, and NI treatments (Table 6).

Differences in plant growth among treatments followed a similar trend to yield and differences occurred as early as week 1 (Table 7). Greatest plant growth occurred in the PC treatment, and growth in this treatment was significantly greater than the F and NI treatments. Plants in the PC/F treatment plots were smaller than in the PC treatment and larger than the F treatment but differences were not significant. Plants in the NI treatment plots were significantly smaller than all other treatments.

Plant tissue analysis revealed several differences in nutrient concentration among treatments (Table 8). Nitrogen was significantly greater in the tissue of plants in the F treatment than all other treatments. No differences in nitrogen content occurred among the other treatments. Phosphorus was significantly greater in the tissue of plants in the PC and PC/F treatments than in other treatments. Plants in the NI treatment had significantly lower phosphorus tissue content than the PC and PC/F treatments, but significantly greater phosphorus tissue content than the F treatment. Potassium followed a similar trend to phosphorus. The PC treatment resulted in the greatest potassium tissue content, though not significantly different than the PC/F treatment. No significant differences in potassium tissue content occurred among the PC/F, F, and NI treatments.

Post-harvest soil analysis revealed differences in residual soil nutrient content among treatments (Table 9). Nitrate content was greatest in the F treatment, though only significantly greater than the NI treatments. No significant differences in nitrate content occurred among the PC, PC/F and NI treatments. Phosphorus content in soil was significantly greater in the PC treatment compared to all other treatments. The PC/F treatments had significantly greater soil phosphorus content than the F and NI treatments. No differences were found in soil phosphorus content between the F and NI treatments. Potassium content of the soil was significantly greater in the PC treatment than all other treatments; no significant differences occurred among the other treatments.

Squash 2005

The PCBpBf and PCpBf treatments resulted in significantly greater yields than all other treatments (Table 10). The PCp treatment resulted in significantly lower yields than the PCBpBf and PCpBf treatments but significantly greater yields than the BpBf, Bp, and NI treatments. No differences in yield occurred among the Bp, BpBf, and NI treatments.

Significant differences in plant growth occurred beginning with the first week of measurements, and trends were similar trend to yield (Table 11). The PCBpBf treatment resulted in significantly larger plants than all other treatments. The PCp and PCpBf treatments resulted in significantly larger plants than the BpBf, Bp and NI treatments. No differences occurred among the BpBf, Bp, and NI treatments.

Plant tissue analysis revealed few differences among treatments (Table 12). The Bp and NI treatments resulted in significantly lower nitrogen tissue content than the PCpBf treatment. The BpBf and Bp treatments resulted in significantly lower phosphorus tissue content than the PCp, PCpBf, and PCBpBf treatments. Tissue potassium content followed a similar trend to phosphorus. The BpBf treatment resulted in significantly lower potassium tissue content than all other treatments except the Bp treatment.

Post-harvest soil analysis revealed significant differences in residual nutrient content among treatments (Table 13). Soil phosphorus content was significantly greater in the PCBpBf, PCpBf, and PCp treatments than the BpBf, Bp and NI treatments. No differences in soil phosphorus content occurred among the BpBf, Bp and NI treatments. Soil potassium content followed a similar trend to that of soil phosphorus. The PCp and PCpBf treatments resulted in significantly higher potassium soil content than the Bp, BpBf and NI treatments. No differences in soil potassium occurred among the PCp, PCBpBf and PCpBf treatments. No differences in soil potassium occurred among the PCBpBf, Bp, BpBf and NI treatments. No differences in soil nitrate content occurred among any treatments.

Cabbage 2005

The PC treatment resulted in the greatest yields, followed by the B, F, PC/F, and NI treatments, respectively (Table 14). However, differences among the soil amendment treatments were not significant, but all soil amendment treatments resulted in significantly greater yields than the NI treatment.

Significant differences in plant growth occurred beginning with week 2, and by week 7 plant growth differences among treatments paralleled trends in yield (Table 15). PC resulted in significantly larger plants than the B, F, PC/F and NI, although differences in plant size between the PC and B treatments were not significant. No significant differences in plant size occurred among the B, F, and PC/F treatments. Surprisingly, plant growth did not differ significantly between the PC/F and NI treatments.

Few differences in plant tissue nutrient content among treatments occurred in the fall 2005 trial (Table 16). The B treatment resulted in significantly higher tissue nitrogen content than the PC/F and NI treatments. No significant differences in tissue nitrogen occurred among the PC, PC/F, F and NI treatments. Tissue phosphorus content was significantly higher in the PC treatment than the F and NI treatments. No significant differences in tissue phosphorus content occurred among the B, F, NI, and PC/F treatments. No significant differences in tissue potassium content occurred among any treatments.

Post-harvest soil analysis revealed no differences in soil nitrogen content among any treatments (Table 17). Similarly, no differences in soil phosphorus content occurred among any treatments. The PC treatment resulted in significantly higher soil potassium content than the PC/F treatment. However, no additional differences in soil potassium occurred among any other treatments.

Lettuce 2006

The PC treatment resulted in significantly greater yield than all other treatments (Table 18). Yield in the DC treatment was significantly lower than the PC treatment, but significantly greater than all other treatments. No difference occurred between the PM and PM+F treatments, although the PM+F treatment resulted in significantly greater yield than the DM and DM+F treatments. The NI treatment resulted in significantly lower yield than all other treatments.

Significant differences in plant growth were observed as early as week 2 (Table 19). By the last sample date at week 7 differences in plant growth among treatments paralleled the differences observed in yields. The PC treatment resulted in significantly larger plants than all other treatments and the NI treatment resulted in significantly smaller plants than all other treatments. No significant differences occurred among any other treatments.

Tissue nutrient content values did not differ greatly among soil amendment treatments (Table 20). Surprisingly, the NI treatment resulted in significantly higher tissue nitrogen than all other treatments. The PC treatment resulted in significantly higher tissue nitrogen than the DC treatment. Tissue phosphorus values were higher in the PC, PM and PM+F treatments compared with the DC, DM, DM+F and NI treatments, but differences were not significant. However, the PC treatment resulted in significantly higher tissue phosphorus content than the DM, DM+F, and NI treatments. Tissue potassium content was significantly higher in the DC and PC treatments than in all other treatments. The NI treatment resulted in significantly lower tissue potassium than all other treatments except the DM+F treatment.

Post-harvest soil analysis revealed few differences in nutrient content among treatments (Table 21). The PC treatment resulted in significantly higher soil nitrate levels than the PM and NI treatments. The NI treatment resulted in significantly lower soil nitrate than the DM+F and PM+F treatments. Soil phosphorus content was significantly higher in the PC treatment than all other treatments. PM and PM+F resulted in significantly higher soil phosphorus than all other treatments except PC. No differences in soil phosphorus occurred among the DM, DM+F and NI treatments. Soil potassium content was significantly higher in the PC treatment than in the PM, DM+F, DM and NI treatments. No differences in soil potassium occurred among the NI, DM, DM+F and PM treatments.

Squash 2006

Yields did not differ greatly among treatments in this trial (Table 22). The PC treatment resulted in significantly greater yield than the NI treatment. However, no significant differences in yield occurred among the PC, F and B treatments, or among the NI, F and B treatments.

At week 6, plant growth was greatest in the PC treatment, followed by the B, NI and F treatments, respectively (Table 23). However, no significant differences among treatments were observed.

The B treatment resulted in the highest tissue nitrogen content, followed by the F, PC and NI treatments, respectively (Table 24). Differences in tissue phosphorus and potassium were not significant.

Similarly, differences in soil nitrate and phosphorus were not significant (Table 25). Soil potassium content was significantly higher in the PC treatment than in the NI treatment. No differences in soil potassium occurred among the PC, F and B treatments, or among the NI, F and B treatments.

CHAPTER FOUR

DISCUSSION

Results of the yield and plant growth parameters will be of primary interest to agriculturalists. As was expected, yield and plant growth paralleled each other in observed trends. With a few exceptions, poultry compost resulted in greater yields and superior plant growth than all other soil amendments evaluated. A number of factors could have contributed to this effect. Blood meal and feather meal are primarily nitrogen sources while compost provides a host of plant nutrients including phosphorus, potassium, calcium and micronutrients. While the commercial product Fertrell™ 5-5-3 does provide phosphorus and potassium, compost also adds organic matter which enhances the soil microbial community and improves the structure of compacted clay soil (Baldwin, 2001). Although nitrogen mineralization rates for the various soil amendments were not evaluated in the current study, it is traditionally recognized that compost serves as a slow-release nitrogen fertilizer compared with blood meal, feather meal, and Fertrell™ 5-5-3 (Joel Gruver, Dept. of Soil Science, North Carolina State University, personal communication). Slower release of nutrients usually translates into greater plant use efficiency with less loss from leaching, runoff, and volatilization. This would have was most apparent in the 2005 squash trial due to the long duration of the growing and fruiting season of that particular crop.

Poultry compost resulted in significantly greater yield and superior plant growth than dairy compost in the 2006 lettuce trial. All compost-amended plots received equal quantities of nitrogen. Close evaluation of the nutrient analysis of the two composts reveals some notable differences that may be the cause for the variation in their performance. Poultry compost provided 18.69 kg/Mg P_2O_5, 16.43 kg/Mg K_2O, and 22.69 kg/Mg Ca while dairy compost provided 7.11 kg/Mg P_2O_5, 9.10 K_2O, and 6.45 kg/Mg Ca. The cumulative effect of these important plant nutrients could have skewed plant growth and yield in favor of the poultry compost plots. Additionally, poultry compost provided 6.02 kg/Mg organic matter while dairy compost only provided 3.64 kg/Mg organic matter. The benefits of organic matter to soil physical, chemical and biological characteristics and their relationship to plant health are well established (Brady 2002, Baldwin 2001, Sullivan 2004). Also worth noting is the pH of the composts: 4.7 for poultry and 8.0 for dairy. Considering the three crops grown in this study prefer a slightly acidic soil pH (Bradley et al 1992), the alkaline pH of the dairy compost may have been enough to hinder optimum performance.

In the spring 2006 lettuce trial raw dairy manure and poultry litter were applied to treatment plots 120 days prior to harvest, in accordance with USDA NOP regulations (www.ams.usda.gov/nop). Half of the manure treatments were supplemented with additional fertilizer in the form of Fertrell™ 5-5-3 applied at transplanting to the field. The manure treatments were then evaluated in comparison with the dairy and poultry compost treatments. The manure treatments resulted in significantly lower plant growth and yield compared with both composts, but not surprisingly had greater plant growth and yield than the no input control. The poultry manure resulted in greater plant growth and yield than the dairy manure, though differences were not significant. No significant differences in plant growth and yield were observed with the addition of Fertrell™ 5-5-3 to the raw manure plots. These results contrast sharply with those of Roe et al (2000) and Reider et al (2000), who found dairy manure resulted in equal or greater yields than all other amendments including inorganic fertilizer, dairy compost, and other composts made from various feedstocks. Timing of application could have accounted for the contrasting results. In both studies, dairy manure was spread on fields immediately prior to planting the crop, whereas in our study the manure treatments were applied 120 days before crop harvest to comply with the NOP Rules. The Roe et al (2000) and Reider et al (2000) studies provide valuable information for conventional farmers interested in saving the time, labor and cost involved in composting manure because they can obtain equivalent yields with the raw product (although leaching and groundwater contamination may be undesireable side effects of raw manure application). The results reported here provide information for certified organic farmers and those in transition to certification who will be restricted by the 120-day NOP Rule pre-harvest requirement for raw manure. The lower plant growth and yield values for the manure treatments in our study indicate that given the pre-harvest application requirement, many of the nutrients from manure application may be lost before they are available to the crop. Based on these results the application of raw dairy manure or poultry litter as a sole nitrogen source for organic vegetable farmers is not recommended.

There were two study trials in which application of poultry compost failed to result in significantly greater yields and plant growth than the other soil amendments. The first was the fall 2005 cabbage trial where poultry compost was compared to blood meal, Fertrell™ 5-5-3, and a poultry compost/Fertrell™ 5-5-3 blend. No significant differences in yield occurred among any of the soil amendment treatments and all treatments resulted in significantly greater yield than the no input control. However, although differences were not statistically significant, it should be noted that poultry compost did result in greater cabbage yields than the other soil amendments. It is also relevant to consider the experimental design of this particular trial, which made use of the smallest treatment plots, buffers, and total area as compared to all other trials summarized in this paper. It is probable that the small plot and buffer size resulted in cross-contamination of soil and plants benefiting from nutrients and organic matter available in a neighboring treatment plot. This idea is supported by the results of the post harvest soil analysis in Table 17, showing complete homogeneity across all parameters quantified.

In the 2006 squash trial application of poultry compost was compared to Fertrell™ 5-5-3 and blood meal. All soil amendments were applied in half quantity at planting and the other half as a side-dress application at fruiting. No significant differences in yield occurred among the soil amendment treatments, and only poultry compost resulted in significantly greater yield than the no input control. This is in contrast to the 2005 squash trial in which poultry compost resulted in significantly greater yields and plant growth than the blood meal treatments. However, in the 2005 trial, all of the poultry compost was applied at planting with or without a side-dress application of blood meal at fruiting. It is important to note that the poultry compost treatments that also received the blood meal side-dress did in fact result in greater yield and plant growth than the poultry compost treatment alone. It is possible that because nutrients are released more slowly from compost, the squash crop was able to utilize the compost nitrogen source throughout the entire growing season. Although the 2006 squash crop may not have had access to all of the nitrogen available from the side-dressed compost, it is likely that the side-dress of blood meal and Fertrell™ 5-5-3 provided a rapidly available supplemental nitrogen source, thus accounting for the high yields and plant growth.

Based on these results, it is recommended that farmers utilizing compost do so at the beginning of the growing season and also consider a supplemental, side-dress application of a rapid-release form of nitrogen similar to those evaluated in this study.

A laboratory study to determine nitrogen mineralization rates of the various soil amendments used in this research was beyond the scope of this study, but would be valuable for future research. It would also be of value for future studies to compare soil amendments to incorporate a factorial design in which all soil amendment treatments applied at planting are combined with all possible soil amendments applied as a side-dress application at fruiting. This design would reveal synergistic interactions and could provide agriculturalists with a more definite answer as to the “best” combination of soil amendments to use in vegetable production.

The benefits of organic matter to a soil and plant health are well established (Sullivan 2004). Organic matter content was one parameter evaluated in the soil analysis component of this study. It was expected that compost would increase the organic matter content of the soil to a greater extent than blood meal, feather meal and Fertrell™ 5-5-3. A few significant differences in organic matter content were observed from various soil amendments but no clear trends emerged. Organic matter breaks down rapidly in warm, moist climates and its decomposition is enhanced by tillage (Sullivan 2004). Considering the current research was conducted in a hot humid climate under regular agricultural production including tillage, the observed results indicating no differences in organic matter can be explained. Due to the rapidly changing nature of soil, frequent soil analyses would have provided a more complete picture of the nutrient and organic matter cycling within the soil profile. This would have been particularly relevant immediately after soil amendment application, when differences in organic matter content among treatments would likely have occurred.

Post-harvest soil analyses revealed a clear trend with respect to phosphorus levels (as P_2O_5), which were consistently higher in the poultry compost treatment plots. This is not surprising given that the other soil amendment treatments are used primarily as sources of nitrogen. Buildup of soil phosphorus is well documented (Kuepper 2003) and is one of the primary concerns with repeated use of poultry waste in an agricultural setting. Although this problem is usually associated more with use of raw poultry litter than with poultry compost, more research is needed to evaluate the potential for buildup of phosphorus in soil following composts application. One potential solution to this problem was proposed by Andrews et al (1999) who recommend that application of composts and manures should be based on the phosphorus requirement rather than on the nitrogen requirement of a crop. This would in turn require additional nitrogen application to the soil for optimum crop performance, which could be accomplished with an amendment like blood meal or feather meal. Vegetable growth trials utilizing the phosphorus requirement with supplemental nitrogen approach to plant nutrition are needed to validate this option for organic farmers.

Although the studies reported here were conducted over multiple growing seasons, treatment plots were rotated to new land for each study. Therefore, the long-term benefits of compost application were not evaluated. Nonetheless it is important to note that because nutrients in compost are released over a long period of time (Roe 2000), the collective benefits of compost used as a soil amendment will not be realized during the first growing season following application. Dick and McCoy (1993) report that 25% of the nitrogen in compost will become available in the second year after application. Therefore it is likely that successive plantings of crops will benefit from previous compost application, thus the benefits to the crop continue long after the initial labor and application costs.

In summary, the results of this research indicate that poultry compost is a superior soil amendment for organic vegetable production in this geographical area. Greater availability of poultry compost would be supported by the large poultry production industry of South Carolina (USDA-NASS 2005) providing a ready supply of poultry litter. Additional work is needed to develop more cost-effective, on-farm composting systems to fully exploit this resource for organic vegetable producers.

APPENDICES

Appendix A

Tables

Table 1. Soil Amendment Application Rates, Spring 2005

Treatment	P_2O_5 (kg/Mg)	K_2O (kg/Mg)	PAN (kg/Mg)	Plot size (m^2)	Qty applied (kg/plot)
NI	0	0	0	3.7	0
PC	16.46	16.21	3.94	3.7	13.9
F	0	0	120	3.7	0.5
PC/F	16.46/0	16.21/0	3.94/120	3.7	6.95/0.25

NI=no input; PC=poultry compost; F=Feather meal; PC/F=poultry compost/feather meal
PAN=plant available nitrogen, calculated as 20% total N in composts

Table 2. Soil Amendment Application Rates, Summer 2005

Treatment	P_2O_5 (kg/Mg)	K_2O (kg/Mg)	PAN (kg/Mg)	Plot size (m^2)	Qty applied (kg/plot)
NI	0	0	0	6.1	0
PCp	14.23	14.56	3.58	6.1	22.8
PCpBf	14.23/0	14.56/0	3.58/130	6.1	11.4/0.32
BpBf	0	0	130	6.1	0.64
Bp	0	0	130	6.1	0.64
PCBpBf	14.23/0	14.56/0	3.58/130	6.1	11.4/0.32

NI=no input; PCp=Poultry compost all applied at planting; PCpBf=Poultry compost applied at planting and blood meal applied at fruiting; BpBf=Half blood meal applied at planting half applied at fruiting; Bp=Blood meal all applied at planting; PCBpBf=Poultry compost and half blood meal applied at planting and half blood meal applied at fruiting
PAN=plant available nitrogen, calculated as 20% total N in composts

Table 3. Soil Amendment Application Rates, Fall 2005

Treatment	P_2O_5 (kg/Mg)	K_2O (kg/Mg)	PAN (kg/Mg)	Plot size (m^2)	Qty applied (kg/plot)
PC	13.2	11.8	2.62	1.21	6.23
B	0	0	130	1.21	0.13
F	50	30	50	1.21	0.33
NI	0	0	0	1.21	0
PC/F	13.2/50	11.8/30	2.62/50	1.21	3.12/0.17

PC=Poultry compost; B=Blood meal; F=Fertrell™5-5-3; NI=no input; PC/F=Poultry compost/Fertrell™5-5-3
PAN=plant available nitrogen, calculated as 20% total N in composts

Table 4. Soil Amendment Application Rates, Spring 2006

Treatment	P_2O_5 (kg/Mg)	K_2O (kg/Mg)	PAN (kg/Mg)	Plot size (m^2)	Qty applied (kg/plot)
NI	0	0	0	2.02	0
DM	2.31	0.93	2.52	2.02	10.8
DM+F	2.31/50	0.93/30	2.52/50	2.02	10.8/0.54
DC	7.11	9.1	2.68	2.02	10.1
PM	40.09	27.89	10.95	2.02	2.5
PM+F	40.09/50	27.89/30	10.95/50	2.02	2.5/0.54
PC	18.69	16.43	4.68	2.02	5.8

NI=no input; DM=Dairy manure; DM+F=Dairy manure + Fertrell™5-5-3; DC=Dairy compost; PM=Poultry manure; PM+F=Poultry manure + Fertrell™5-5-3; PC=Poultry compost

All manure was applied 120 days prior to harvest according to USDA NOP specifications. All other amendments were applied immediately prior to transplanting to field.

PAN=Plant available nitrogen: calculated as 20% total N in composts;
calculated as 80% ammonium-N + 60% organic N + 100% nitrate-N in manures

Table 5. Soil Amendment Application Rates, Summer 2006

Treatment	P_2O_5 (kg/Mg)	K_2O (kg/Mg)	PAN (kg/Mg)	Plot size (m^2)	Qty applied (kg/plot)
NI	0	0	0	6.07	0
PC	14.6	13.22	3.32	6.07	24.6
F	50	30	50	6.07	1.63
B	0	0	130	6.07	0.64

NI=no input; PC=Poultry compost; F=Fertrell™ 5-5-3; B=Blood meal
Half quantities of all amendments applied at planting, the other half applied at fruiting
PAN=plant available nitrogen, calculated as 20% total N of compost

Table 6. Yield, Spring 2005 Lettuce

Treatment	Mean yield (g)
NI	41.05 +/- 12.9 d
PC	223.85 +/- 66.5 a
F	105.92 +/- 18.3 c
PC/F	168.74 +/- 39.5 b

NI=no input; PC=poultry compost; F=Feather meal; PC/F=poultry compost/feather meal
Mean +/- standard error
Means with the same letter are not significantly different at $\alpha=0.05$

Table 7. Plant Growth, Spring 2005 Lettuce

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
NI	31.12 +/- 5.24 b	38.35 +/- 6.60 b	61.62 +/- 12.66 c	107.04 +/- 25.50 b	147.62 +/- 36.53 c	186.37 +/- 45.59 c
PC	37.94 +/- 6.17 a	63.63 +/- 7.21 a	146.22 +/- 17.71 a	317.10 +/- 39.15 a	496.70 +/- 73.23 a	591.44 +/- 104.84 a
F	30.98 +/- 5.11 b	45.95 +/- 6.70 b	90.27 +/- 13.03 b	175.83 +/- 32.60 b	284.74 +/- 51.75 b	385.70 +/- 48.47 b
PC/F	36.85 +/- 5.90 a	60.05 +/- 9.01 a	134.38 +/- 16.60 a	285.97 +/- 37.16 a	456.42 +/- 53.97 a	558.70 +/- 75.95 ab

NI=no input; PC=poultry compost; F=Feather meal; PC/F=poultry compost/feather meal
Mean plant area (cm^2) +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 8. Plant Tissue Analysis, Spring 2005 Lettuce

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
NI	1.96 +/- 0.02 b	0.24 +/- 0.02 b	6.22 +/- 0.31 b	0.95 +/- 0.04 ab	0.26 +/- 0.01 a	0.22 +/- 0.03 a
PC	1.98 +/- 0.15 b	0.32 +/- 0.01 a	7.49 +/- 0.33 a	0.97 +/- 0.06 a	0.24 +/- 0.01 a	0.21 +/- 0.02 a
F	2.37 +/- 0.06 a	0.16 +/- 0.01 c	5.90 +/- 0.17 b	0.84 +/- 0.02 c	0.28 +/- 0.01 a	0.21 +/- 0.02 a
PC/F	1.90 +/- 0.06 b	0.29 +/- 0.02 a	6.78 +/- 0.29 ab	0.88 +/- 0.05 bc	0.24 +/- 0.02 a	0.22 +/- 0.01 a

Treatment	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	B (ppm)	Al (ppm)
NI	38.00 +/- 6.78 a	5.25 +/- 0.63 a	165.50 +/- 4.52 a	347.75 +/- 65.84 a	518.25 +/- 49.39 c	24.25 +/- 2.66 a	569.00 +/- 107.35 a
PC	30.50 +/- 1.26 a	3.25 +/- 0.25 bc	120.25 +/- 10.77 b	120.25 +/- 46.68 ab	1245.75 +/- 83.84 a	22.50 +/- 0.96 ab	400.75 +/- 88.30 b
F	28.50 +/- 1.89 a	4.00 +/- 0.41 b	128.25 +/- 9.23 b	178.00 +/- 15.05 b	505.50 +/- 87.98 c	18.50 +/- 0.65 b	260.50 +/- 29.00 b
PC/F	33.75 +/- 1.80 a	3.00 +/- 0 c	144.75 +/- 9.66 ab	210.00 +/- 31.45 b	793.00 +/- 101.78 b	20.75 +/- 0.48 ab	305.00 +/- 39.14 b

NI=no input; PC=poultry compost; F=Feather meal; PC/F=poultry compost/feather meal
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 9. Soil Analysis, Spring 2005 Lettuce

Treatment	Soil pH	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Zn (kg/ha)
NI	5.65 +/- 0.03 a	32.23 +/- 2.68 c	126.00 +/- 5.73 b	1367.24 +/- 64.86 b	248.08 +/- 9.02 a	3.92 +/- 0.48 bc
PC	5.70 +/- 0.04 a	68.60 +/- 1.24 a	181.16 +/- 11.92 a	1576.12 +/- 34.97 a	258.44 +/- 2.72 a	8.88 +/- 1.49 a
F	5.60 +/- 0.04 a	30.52 +/- 3.46 c	115.92 +/- 8.53 b	1365.56 +/- 32.27 b	248.92 +/- 3.70 a	3.62 +/- 0.19 c
PC/F	6.42 +/- 0.03 a	49.84 +/- 3.79 b	134.12 +/- 6.60 b	1529.64 +/- 27.65 a	256.20 +/- 2.26 a	7.26 +/- 1.12 ab

Treatment	Mn (kg/ha)	Cu (kg/ha)	B (kg/ha)	Na (kg/ha)	NO_3-N (ppm)	%OM
NI	31.36 +/- 6.01 a	2.33 +/- 0.06 a	0.48 +/- 0.03 b	30.52 +/- 0.9 c	1.75 +/- 0.25 b	6.00 +/- 0.11 ab
PC	36.68 +/- 2.56 a	2.16 +/- 0.03 b	0.56 +/- 0 a	38.64 +/- 1.33 a	3.75 +/- 0.48 ab	6.10 +/- 0.15 a
F	26.04 +/- 2.56 a	2.33 +/- 0.03 a	0.48 +/- 0.03 b	33.88 +/- 1.55 b	5.25 +/- 1.31 a	6.00 +/- 0.25 ab
PC/F	30.80 +/- 2.35 a	2.27 +/- 0.06 ab	0.54 +/- 0.03 ab	36.96 +/- 1.88 a	3.00 +/- 0.41 ab	5.70 +/- 0.08 b

NI=no input; PC=poultry compost; F=Feather meal; PC/F=poultry compost/feather meal
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 10. Yield, Summer 2005 Squash

Treatment	Mean yield (kg)
NI	0.29 +/- 0.13 c
PCp	1.60 +/- 0.24 b
PCpBf	2.21 +/- 0.13 a
BpBf	0.45 +/- 0.09 c
Bp	0.32 +/- 0.09 c
PCBpBf	2.26 +/- 0.18 a

NI=no input; PCp=Poultry compost all applied at planting; PCpBf=Poultry compost applied at planting and blood meal applied at fruiting; BpBf=Half blood meal applied at planting half applied at fruiting; Bp=Blood meal all applied at planting; PCBpBf=Poultry compost and half blood meal applied at planting and half blood meal applied at fruiting

Mean yield per plant +/- standard error

Means with the same letter are not significantly different at α=0.05

Table 11. Plant Growth, Summer 2005 Squash

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5
NI	0.063 +/- 0.03 bc	0.171 +/- 0.08 b	0.230 +/- 0.09 c	0.254 +/- 0.12 c	0.171 +/- 0.08 c
PCp	0.171 +/- 0.06 a	0.692 +/- 0.30 a	0.991 +/- 0.41 b	1.256 +/- 0.39 b	1.053 +/- 0.36 b
PCpBf	0.170 +/- 0.05 ab	0.788 +/- 0.24 a	1.071 +/- 0.33 b	1.460 +/- 0.48 b	1.062 +/- 0.37 b
BpBf	0.036 +/- 0.02 c	0.127 +/- 0.06 b	0.311 +/- 0.10 c	0.394 +/- 0.13 c	0.374 +/- 0.16 c
Bp	0.032 +/- 0.01 c	0.109 +/- 0.03 b	0.301 +/- 0.06 c	0.350 +/-0.09 c	0.309 +/- 0.12 c
PCBpBf	0.204 +/- 0.06 a	0.746 +/- 0.18 a	1.477 +/- 0.36 a	1.905 +/- 0.49 a	1.882 +/- 0.80 a

NI=no input; PCp=Poultry compost all applied at planting; PCpBf=Poultry compost applied at planting and blood meal applied at fruiting; BpBf=Half blood meal applied at planting half applied at fruiting; Bp=Blood meal all applied at planting; PCBpBf=Poultry compost and half blood meal applied at planting and half blood meal applied at fruiting
Mean plant volume (m^3) +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 12. Plant Tissue Analysis, Summer 2005 Squash

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
NI	2.33 +/- 0.16 c	0.42 +/- 0.05 ab	3.24 +/- 0.07 a	2.66 +/- 0.75 a	0.74 +/- 0.18 a	0.49 +/- 0.07 a
PCp	3.37 +/- 0.40 ab	0.53 +/- 0.06 a	2.99 +/- 0.33 ab	2.45 +/- 0.25 a	0.69 +/- 0.06 a	0.39 +/- 0.02 ab
PCpBf	4.09 +/- 0.37 a	0.52 +/- 0.05 a	3.25 +/- 0.37 a	1.90 +/- 0.63 a	0.52 +/- 0.11 ab	0.37 +/- 0.02 b
BpBf	3.32 +/- 0.03 abc	0.31 +/- 0.03 b	2.15 +/- 0.10 c	1.41 +/- 0.10 a	0.34 +/- 0.02 b	0.28 +/- 0.02 b
Bp	2.99 +/- 0.34 bc	0.31 +/- 0.06 b	2.34 +/- 0.20 bc	1.86 +/- 0.08 a	0.45 +/- 0.02 ab	0.32 +/- 0.05 b
PCBpBf	3.86 +/- 0.15 ab	0.56 +/- 0.07 a	3.01 +/- 0.12 ab	2.18 +/- 0.50 a	0.60 +/- 0.09 ab	0.36 +/- 0.01

Treatment	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	B (ppm)	Al (ppm)
NI	61.67 +/- 8.78 b	8.67 +/- 0.58 a	258.33 +/- 22.22 ab	181.00 +/- 21.79 a	16.33 +/- 2.47 a	30.67 +/- 3.33 ab	187.00 +/- 29.32 ab
PCp	93.33 +/- 12.29 a	8.33 +/- 0.29 a	179.00 +/- 28.12 ab	170.33 +/- 39.34 a	12.00 +/- 2.18 a	33.00 +/- 2.79 a	108.33 +/- 25.40 ab
PCpBf	65.00 +/- 5.29 b	8.33 +/- 0.76 a	142.33 +/- 26.65 b	106.00 +/- 11.30 a	9.00 +/- 1.81 a	30.67 +/- 2.85 ab	67.67 +/- 7.29 b
BpBf	49.67 +/- 4.31 b	8.33 +/- 0.29 a	234.00 +/- 22.25 ab	135.67 +/- 18.42 a	9.67 +/- 0.29 a	22.00 +/- 0.50 b	138.00 +/- 24.90 ab
Bp	47.00 +/- 1.50 b	8.33 +/- 0.76 a	334.67 +/- 90.25 a	184.33 +/- 55.83 a	15.67 +/- 4.65 a	26.33 +/- 5.06 ab	231.00 +/- 112.47 a
PCBpBf	95.67 +/- 4.65 a	8.33 +/- 0.76 a	181.00 +/- 32.11 ab	111.67 +/- 5.06 a	11.33 +/- 0.76 a	29.33 +/- 1.61 ab	68.00 +/- 9.66 b

NI=no input; PCp=Poultry compost all applied at planting; PCpBf=Poultry compost applied at planting and blood meal applied at fruiting; BpBf=Half blood meal applied at planting half applied at fruiting; Bp=Blood meal all applied at planting; PCBpBf=Poultry compost and half blood meal applied at planting and half blood meal applied at fruiting
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 13. Soil Analysis, Summer 2005 Squash

Treatment	Soil pH	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Zn (kg/ha)
NI	5.80 +/- 0.09 a	25.76 +/- 2.57 b	42.93 +/- 3.08 b	874.35 +/- 89.01 bc	94.45 +/- 16.32 ab	2.05 +/- 0.09 c
PCp	5.67 +/- 0.12 ab	99.31 +/- 18.24 a	82.88 +/- 9.25 a	1223.04 +/- 80.58 a	102.67+/- 5.20 a	7.50 +/- 0.4 a
PCpBf	5.60 +/- 0.1 b	92.96 +/- 7.58 a	92.96 +/- 13.17 a	1197.28 +/- 67.26 a	99.68 +/- 7.78 ab	7.43 +/- 0.40 a
BpBf	5.67 +/- 0.08 ab	28.00 +/- 2.02 b	40.69 +/- 5.20 b	755.25 +/- 48.95 c	77.28 +/- 4.98 b	2.09 +/- 0.23 c
Bp	5.67 +/- 0.03 ab	30.24 +/- 2.44 b	43.31 +/- 1.97 b	764.21 +/- 45.36 c	76.91 +/- 7.09 b	2.24 +/- 0.15 c
PCBpBf	5.67 +/- 0.13 ab	69.07 +/- 10.02 a	66.83 +/- 7.22 ab	1046.83 +/- 71.35 ab	90.35 +/- 7.31 ab	5.94 +/- 0.37 b
Treatment	**Mn (kg/ha)**	**Cu (kg/ha)**	**B (kg/ha)**	**Na (kg/ha)**	**NO_3-N (ppm)**	**%OM**
NI	24.27 +/- 1.41 a	2.17 +/- 0.17 a	0.37 +/- 0.03 b	22.4 +/- 1.12 ab	2.67 +/- 0.29 a	3.10 +/- 0.30 a
PCp	33.23 +/- 2.26 a	2.05 +/- 0.37 a	0.41 +/- 0.03 ab	32.48 +/- 7.76 ab	9.33 +/- 4.62 a	3.43 +/- 0.23 a
PCpBf	28.37 +/- 1.17 a	2.13 +/- 0.31 a	0.49 +/- 0.03 a	34.72 +/- 6.79 ab	9.33 +/- 2.75 a	3.27 +/- 0.12 a
BpBf	31.36 +/- 4.23 a	1.83 +/- 0.17 a	0.34 +/- 0 b	19.79 +/- 0.65 b	3.67 +/- 0.76 a	2.97 +/- 0.08 a
Bp	28.37 +/- 3.73 a	2.39 +/- 0.23 a	0.34 +/- 0 b	19.79 +/- 0.65 b	3.00 +/- 0.50 a	3.00 +/- 0.1 a
PCBpBf	27.63 +/- 0.86 a	1.61 +/- 0.03 a	0.41 +/- 0.03 ab	35.84 +/- 2.02 a	6.33 +/- 2.89 a	3.47 +/- 0.08 a

NI=no input; PCp=Poultry compost all applied at planting; PCpBf=Poultry compost applied at planting and blood meal applied at fruiting; BpBf=Half blood meal applied at planting half applied at fruiting; Bp=Blood meal all applied at planting; PCBpBf=Poultry compost and half blood meal applied at planting and half blood meal applied at fruiting
Mean) +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 14. Yield, Fall 2005 Cabbage

Treatment	Mean Yield (kg)
PC	3.34 +/- 0.36 a
B	2.83 +/- 0.52 a
F	2.79 +/- 0.46 a
NI	1.04 +/- 0.21 b
PC/F	2.32 +/- 0.33 a

PC=Poultry compost; B=Blood meal; F=Fertrell™5-5-3; NI=no input; PC/F=Poultry compost/Fertrell™5-5-3
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 15. Plant Growth, Fall 2005 Cabbage

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
PC	344.58 +/- 43.41 a	559.53 +/- 91.47 a	1216.64 +/- 153.29 a	1473.62 +/- 206.50 a	1711.98 +/- 204.45 a	1717.26 +/- 204.45 a	1610.46 +/- 196.41 a
B	324.32 +/- 32.01 a	414.20 +/- 57.88 bc	906.82 +/- 127.06 b	1213.16 +/- 190.10 ab	1373.56 +/- 168.85 b	1352.60 +/- 168.85 b	1377.10 +/- 166.25 ab
F	330.99 +/- 34.21 a	473.55 +/- 50.50 ab	855.19 +/- 121.96 b	1092.66 +/- 144.76 b	1266.66 +/- 148.93 b	1192.80 +/- 148.93 b	1220.48 +/- 164.02 b
NI	309.98 +/- 46.38 a	327.79 +/- 41.55 bc	494.16 +/- 75.07 c	633.71 +/- 100.51 c	696.38 +/- 127.48 c	752.28 +/- 127.48 c	879.50 +/- 146.53 c
PC/F	344.31 +/- 43.27 a	500.67 +/- 67.08 ab	862.28 +/- 121.63 b	1067.67 +/- 158.23 b	1262.55 +/- 137.45 b	1181.32 +/ 137.45 b	1161.10 +/- 164.22 bc

PC=Poultry compost; B=Blood meal; F=Fertrell™5-5-3; NI=no input; PC/F=Poultry compost/Fertrell™5-5-3
Mean plant area (cm^2) +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 16. Plant Tissue Analysis, Fall 2005 Cabbage

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)
PC	2.60 +/- 0.12 ab	0.32 +/- 0.01 a	2.22 +/- 0.17 a	2.96 +/- 0.16 a	0.51 +/- 0.02 a	0.90 +/- 0.06 ab	14.50 +/- 1.32 a
B	2.68 +/- 0.21 a	0.27 +/- 0.03 ab	1.92 +/- 0.27 a	3.28 +/- 0.20 a	0.58 +/- 0.04 a	0.76 +/- 0.09 b	12.50 +/- 0.87 a
F	2.53 +/- 0.17 ab	0.24 +/- 0.01 b	1.76 +/- 0.12 a	2.74 +/- 0.18 a	0.50 +/- 0.06 a	0.87 +/- 0.07 ab	20.75 +/- 8.42 a
NI	2.27 +/- 0.10 b	0.24 +/- 0.02 b	1.57 +/- 0.22 a	2.93 +/- 0.32 a	0.55 +/- 0.09 a	0.81 +/- 0.04 ab	14.75 +/- 0.25 a
PC/F	2.36 +/- 0.17 b	0.27 +/- 0.02 ab	2.01 +/- 0.28 a	3.13 +/- 0.15 a	0.54 +/- 0.05 a	0.96 +/- 0.01 a	15.50 +/- 1.04 a

Treatment	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	B (ppm)	Al (ppm)	NO_3-N (ppm)
PC	1.00 +/- 0 a	34.25 +/- 1.38 ab	65.50 +/- 4.11 ab	1594.25 +/- 169.02 a	16.50 +/- 1.04 a	35.25 +/- 6.28 b	1997.50 +/- 386.88 b
B	1.25 +/- 0.25 a	41.25 +/- 2.84 a	62.50 +/- 2.87 ab	2650.25 +/- 970.95 a	13.50 +/- 0.96 a	41.00 +/- 5.99 ab	2807.50 +/- 732.24 b
F	1.00 +/- 0 a	25.00 +/- 1.68 c	55.50 +/- 2.02 b	1515.75 +/- 660.55 a	15.00 +/- 1.68 a	29.25 +/- 2.02 b	7677.50 +/- 3274.63 a
NI	1.00 +/- 0 a	25.00 +/- 2.08 c	80.50 +/- 12.26 a	1580.00 +/- 918.77 a	15.75 +/- 2.56 a	121.75 +/- 57.67 a	1841.00 +/- 385.79 b
PC/F	1.00 +/- 0 a	33.75 +/- 2.81 b	58.50 +/- 6.81 ab	1728.00 +/- 880.92 a	16.75 +/- 2.69 a	41.50 +/- 4.57 ab	4170.00 +/- 955.21 ab

PC=Poultry compost; B=Blood meal; F=Fertrell™5-5-3; NI=no input; PC/F=Poultry compost/Fertrell™5-5-3
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 17. Soil Analysis, Fall 2005 Cabbage

Treatment	Soil pH	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Zn (kg/ha)
PC	6.23 +/- 0.08 a	98.56 +/- 5.51 a	65.24 +/- 6.60 a	1336.64 +/- 440.74 a	247.52 +/- 5.47 a	4.73 +/- 0.11 a
B	6.18 +/- 0.08 a	86.52 +/- 11.29 a	55.72 +/- 6.19 ab	1728.44 +/- 76.29 a	238.00 +/- 16.03 a	4.23 +/- 0.28 a
F	6.25 +/- 0.06 a	117.88 +/- 10.64 a	51.24 +/- 3.81 ab	1908.20 +/- 109.84 a	244.72 +/- 17.99 a	3.81 +/- 0.08 a
NI	6.18 +/- 0.03 a	97.44 +/- 16.94 a	50.68 +/- 6.58 ab	1727.60 +/- 89.44 a	228.48 +/- 16.44 a	3.81 +/- 0.09 a
PC/F	6.20 +/- 0.04 a	94.36 +/- 19.81 a	46.48 +/- 5.65 b	1646.12 +/- 99.86 a	218.96 +/- 12.88 a	4.40 +/- 1.10 a
Treatment	**Mn (kg/ha)**	**Cu (kg/ha)**	**B (kg/ha)**	**Na (kg/ha)**	**NO_3-N (ppm)**	**%OM**
PC	20.16 +/- 1.45 a	1.40 +/- 0.06 a	0.36 +/- 0.03 a	29.12 +/- 1.21 a	0.50 +/- 0.29 a	4.25 +/- 0.12 a
B	20.44 +/- 0.96 a	1.51 +/- 0.10 a	0.36 +/- 0.03 a	27.44 +/- 2.95 a	0.25 +/- 0.25 a	4.30 +/- 0.16 a
F	18.48 +/- 0.03 a	1.37 +/- 0.03 a	0.42 +/- 0.03 a	29.68 +/- 4.15 a	0.00 +/- 0 a	4.23 +/- 0.16 ab
NI	19.60 +/- 0.07 a	1.40 +/- 0.07 a	0.36 +/- 0.03 a	27.16 +/- 3.75 a	0.00 +/- 0 a	3.95 +/- 0.23 ab
PC/F	17.36 +/- 0.07 a	1.40 +/- 0.07 a	0.36 +/- 0.03 a	25.76 +/- 3.33 a	0.25 +/- 0.25 a	3.80 +/- 0.18 b

PC=Poultry compost; B=Blood meal; F=Fertrell™5-5-3; NI=no input; PC/F=Poultry compost/Fertrell™5-5-3
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 18. Yield, Spring 2006 Lettuce

Treatment	Mean yield (g)
NI	19.76 +/- 6.24 e
DM	69.82 +/- 18.88 d
DM+F	63.50 +/- 12.00 d
DC	135.11 +/-32.31 b
PM	92.83 +/- 29.13 cd
PM+F	100.12 +/- 25.07 c
PC	309.10 +/- 56.79 a

NI=no input; DM=Dairy manure; DM+F=Dairy manure + Fertrell™5-5-3; DC=Dairy compost; PM=Poultry manure; PM+F=Poultry manure + Fertrell™5-5-3; PC=Poultry compost
All manure was applied 120 days prior to harvest according to USDA NOP specifications. All other amendments were applied immediately prior to transplanting to field.
Mean yield per plot +/- standard error
Means with the same letter are not significantly different at $\alpha=0.05$

Table 19. Plant Growth, Spring 2006 Lettuce

Treatment	Week 1	Week 2	Week 3	Week 4
NI	85.18 +/- 14.17 a	66.61 +/- 9.25 e	123.98 +/- 22.27 e	179.73 +/- 23.36 c
DM	95.79 +/- 16.68 a	99.84 +/- 15.49 cd	259.05 +/- 38.19 cd	372.53 +/- 51.39 b
DM+F	81.91 +/- 11.30 a	81.90 +/- 9.80 de	232.93 +/- 27.82 d	365.53 +/- 44.97 b
DC	83.05 +/- 11.60 a	162.30 +/- 19.62 b	370.25 +/- 70.15 b	476.23 +/- 81.00 b
PM	82.42 +/- 13.50 a	120.33 +/- 22.70 c	291.04 +/- 55.11 cd	424.17 +/- 82.52 b
PM+F	89.25 +/- 11.54 a	113.39 +/- 15.82 c	311.31 +/- 49.15 bc	451.63 +/- 73.64 b
PC	84.65 +/- 13.81 a	214.30 +/- 34.38 a	574.13 +/- 95.02 a	835.21 +/- 123.61 a

NI=no input; DM=Dairy manure; DM+F=Dairy manure + Fertrell™5-5-3; DC=Dairy compost; PM=Poultry manure; PM+F=Poultry manure + Fertrell™5-5-3; PC=Poultry compost

All manure was applied 120 days prior to harvest according to USDA NOP specifications. All other amendments were applied immediately prior to transplanting to field.

Mean plant area (cm^2) +/- standard error

Means with the same letter are not significantly different at α=0.05

Table 20. Plant Tissue Analysis, Spring 2006 Lettuce

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)
NI	3.11 +/- 0.19 a	0.28 +/- 0.02 bc	4.36 +/- 0.31 c	0.70 +/- 0.03 abc	0.33 +/- 0.01 a	0.22 +/- 0.01 ab	39.50 +/- 3.43 a
DM	2.52 +/- 0.06 bc	0.27 +/- 0.02 c	5.76 +/- 0.23 b	0.66 +/- 0.06 bc	0.27 +/- 0.01 b	0.18 +/- 0.01 b	37.75 +/- 4.77 a
DM+F	2.52 +/- 0.10 bc	0.27 +/- 0.01 c	5.28 +/- 0.11 bc	0.60 +/- 0.04 c	0.28 +/- 0.02 b	0.20 +/- 0.01 ab	34.75 +/- 3.57 ab
DC	2.15 +/- 0.06 c	0.31 +/- 0.01 abc	7.31 +/- 0.30 a	0.75 +/- 0.06 ab	0.27 +/- 0.02 b	0.18 +/- 0.02 b	31.00 +/- 4.10 ab
PM	2.51 +/- 0.10 bc	0.34 +/- 0.04 ab	5.79 +/- 0.25 b	0.74 +/- 0.03 ab	0.30 +/- 0.02 ab	0.21 +/- 0.01 ab	33.25 +/- 4.61 ab
PM+F	2.25 +/- 0.08 bc	0.31 +/- 0.01 abc	5.83 +/- 0.34 b	0.71 +/- 0.03 abc	0.27 +/- 0.02 b	0.19 +/- 0.02 ab	25.25 +/- 0.85 b
PC	2.66 +/- 0.25 b	0.36 +/- 0.01 a	6.94 +/- 0.48 a	0.78 +/- 0.02 a	0.29 +/- 0.01 ab	0.23 +/- 0.01 a	25.25 +/- 1.31 b
Treatment	**Cu (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Na (ppm)**	**B (ppm)**	**Al (ppm)**	**NO_3-N (ppm)**
NI	7.25 +/- 0.63 a	85.00 +/- 5.34 ab	208.00 +/- 33.59 a	1717.75 +/- 136.53 abc	15.50 +/- 0.5 c	254.75 +/- 62.85 a	1736.00 +/- 127.28 ab
DM	5.75 +/- 0.63 abc	68.00 +/- 8.26 c	128.50 +/- 11.00 a	1126.00 +/- 73.57 c	17.00 +/- 1.58 bc	155.75 +/- 43.80 a	1363.00 +/- 209.02 b
DM+F	6.50 +/- 0.65 a	63.25 +/- 4.21 c	163.25 +/- 23.15 a	1651.25 +/- 272.33 abc	15.50 +/- 0.29 c	153.25 +/- 16.70 a	1633.00 +/- 540.08 b
DC	4.75 +/- 0.48 bcd	95.25 +/- 6.20 a	168.25 +/- 24.95 a	1603.00 +/- 230.23 bc	19.50 +/- 0.87 a	207.00 +/- 1.58 a	1166.00 +/- 342.40 b
PM	6.00 +/- 0.58 ab	72.50 +/- 2.87 bc	181.50 +/- 19.27 a	1531.00 +/- 395.06 bc	17.75 +/- 0.48 abc	195.00 +/- 25.07 a	1215.00 +/- 205.16 b
PM+F	4.25 +/- 0.25 cd	69.25 +/- 2.63 c	190.00 +/- 44.98 a	2058.00 +/- 227.57 ab	17.25 +/- 0.85 abc	213.75 +/- 49.07 a	3507.00 +/- 1124.45 a
PC	3.75 +/- 0.25 d	85.50 +/- 2.66 ab	203.50 +/- 15.24 a	2369.50 +/- 112.15 a	18.50 +/- 0.5 ab	205.75 +/- 18.25 a	2747.00 +/- 856.49 ab

NI=no input; DM=Dairy manure; DM+F=Dairy manure + Fertrell™5-5-3; DC=Dairy compost; PM=Poultry manure; PM+F=Poultry manure + Fertrell™5-5-3; PC=Poultry compost
All manure was applied 120 days prior to harvest according to USDA NOP specifications. All other amendments were applied immediately prior to transplanting to field.
Mean +/- standard error
Means with the same letter are not significantly different at $\alpha=0.05$

Table 21. Soil Analysis, Spring 2006 Lettuce

Treatment	Soil pH	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Zn (kg/ha)
NI	5.78 +/- 0.06 b	22.40 +/- 1.37 d	56.00 +/- 2.86 d	942.48 +/- 32.97 c	111.16 +/- 3.43 c	1.88 +/- 0.18 b
DM	5.98 +/- 0.03 a	29.68 +/- 3.59 cd	84.84 +/- 19.36 bcd	1026.20 +/- 19.68 c	167.16 +/- 16.40 a	2.74 +/- 0.17 b
DM+F	5.80 +/- 0.06 b	30.52 +/- 2.87 cd	69.16 +/- 1.61 cd	1059.24 +/- 99.09 bc	162.68 +/- 10.25 ab	3.08 +/- 0.31 b
DC	5.83 +/- 0.05 b	36.68 +/- 3.46 c	112.28 +/- 11.01 ab	1030.68 +/- 69.28 c	156.80 +/- 12.77 ab	3.67 +/- 0.37 b
PM	5.90 +/- 0.04 ab	72.80 +/- 8.76 b	84.00 +/- 2.55 bcd	1294.16 +/- 146.61 a	143.36 +/- 11.12 ab	5.24 +/- 0.93 b
PM+F	5.85 +/- 0.05 ab	71.96 +/- 5.63 b	95.48 +/- 6.50 abc	1291.64 +/- 56.41 a	147.84 +/- 5.25 ab	5.07 +/- 0.33 b
PC	5.80 +/- 0.04 b	92.68 +/- 3.31 a	115.36 +/- 14.06 a	1278.76 +/- 46.16 ab	137.20 +/- 6.31 bc	11.54 +/- 5.23 a

Treatment	Mn (kg/ha)	Cu (kg/ha)	B (kg/ha)	Na (kg/ha)	NO_3-N (ppm)	%OM
NI	14.56 +/- 3.00 ab	1.32 +/- 0.05 b	0.22 +/- 0 c	30.8 +/- 1.68 c	5.04 +/- 0.29 c	3.64 +/- 0.10 a
DM	14.00 +/- 0.97 b	1.48 +/- 0.03 a	0.28 +/- 0.03 abc	30.8 +/- 2.12 c	7.00 +/- 0.63 abc	3.39 +/- 0.09 a
DM+F	16.52 +/- 1.40 ab	1.48 +/- 0.07 a	0.25 +/- 0.03 bc	38.64 +/- 2.48 a	8.68 +/- 0.85 ab	3.61 +/- 0.08 a
DC	19.04 +/- 1.65 ab	1.46 +/- 0.05 ab	0.31 +/- 0.03 ab	36.96 +/- 2.38 ab	7.00 +/- 0.48 abc	3.67 +/- 0.09 a
PM	18.20 +/- 1.47 ab	1.51 +/- 0.10 a	0.31 +/- 0.03 ab	31.36 +/- 0.46 bc	6.72 +/- 0.58 bc	3.67 +/- 0.09 a
PM+F	19.32 +/- 1.06 a	1.48 +/- 0.03 a	0.34 +/- 0 a	40.32 +/- 4.50 a	8.68 +/- 0.75 ab	3.50 +/- 0.14 a
PC	19.32 +/- 3.08 a	1.46 +/- 0.05 ab	0.31 +/- 0.03 ab	37.24 +/- 2.30 ab	8.96 +/- 0.71 a	3.47 +/- 0.07 a

NI=no input; DM=Dairy manure; DM+F=Dairy manure + Fertrell™5-5-3; DC=Dairy compost; PM=Poultry manure; PM+F=Poultry manure + Fertrell™5-5-3; PC=Poultry compost
All manure was applied 120 days prior to harvest according to USDA NOP specifications. All other amendments were applied immediately prior to transplanting to field.
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 22. Yield, Summer 2006 Squash

Treatment	Mean Yield (kg)
NI	3.52 +/- 0.39 b
PC	5.13 +/- 0.63 a
F	4.32 +/- 0.46 ab
B	4.62 +/- 0.73 ab

NI=no input; PC=Poultry compost; F=Fertrell™ 5-5-3; B=Blood meal
Half quantities of all amendments applied at planting, the other half applied at fruiting
Mean yield per plant +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 23. Plant Growth, Summer 2006 Squash

Treatment	Volume (m^3)
NI	1.53 +/- 0.29 a
PC	1.66 +/- 0.36 a
F	1.37 +/- 0.42 a
B	1.65 +/- 0.41 a

NI=no input; PC=Poultry compost; F=Fertrell™ 5-5-3; B=Blood meal
Half quantities of all amendments applied at planting, the other half applied at fruiting
Mean plant volume (m^3) +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 24. Plant Tissue Analysis, Summer 2006 Squash

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (ppm)
NI	4.19 +/- 0.24 d	0.32 +/- 0.04 a	5.33 +/- 0.05 a	3.63 +/- 0.56 a	0.59 +/- 0.05 a	0.43 +/- 0.05 a	43.17 +/- 4.77 a
PC	4.58 +/- 0.14 c	0.35 +/- 0.04 a	5.84 +/- 0.39 a	3.80 +/- 0.72 a	0.58 +/- 0.08 a	0.36 +/- 0.05 a	45.00 +/- 4.74 a
F	5.10 +/- 0.18 b	0.31 +/- 0.04 a	5.79 +/- 0.30 a	3.46 +/- 0.40 a	0.58 +/- 0.04 a	0.40 +/- 0.05 a	38.83 +/- 4.08 a
B	5.71 +/- 0.11 a	0.34 +/- 0.03 a	5.24 +/- 0.29 a	3.31 +/- 0.33 a	0.54 +/- 0.04 a	0.41 +/- 0.05 a	44.67 +/- 2.20 a

Treatment	Cu (ppm)	Mn (ppm)	Fe (ppm)	Na (ppm)	B (ppm)	Al (ppm)	NO_3-N (ppm)
NI	6.83 +/- 1.32 ab	92.50 +/- 10.61 a	72.83 +/- 10.50 ab	15.33 +/- 1.60 b	44.17 +/- 4.19 a	48.33 +/- 8.36 a	7686.67 +/- 725.88 b
PC	5.50 +/- 0.42 b	89.83 +/- 18.30 a	60.00 +/- 12.74 b	21.33 +/- 2.79 a	43.50 +/- 5.62 a	42.50 +/- 6.96 a	10306.67 +/- 938.97 ab
F	6.17 +/- 0.80 ab	116.17 +/- 8.93 a	74.33 +/- 4.22 ab	19.83 +/- 2.42 ab	42.83 +/- 2.25 a	48.00 +/- 8.50 a	16546.67 +/- 4804.42 a
B	8.00 +/- 0.63 a	123.50 +/- 20.81 a	78.33 +/- 7.21 a	17.00 +/- 2.17 ab	42.50 +/- 4.13 a	41.33 +/- 2.32 a	12400.00 +/- 828.85 ab

NI=no input; PC=Poultry compost; F=Fertrell™ 5-5-3; B=Blood meal
Half quantities of all amendments applied at planting, the other half applied at fruiting
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

Table 25. Soil Analysis, Summer 2006 Squash

Treatment	Soil pH	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Zn (kg/ha)
NI	5.67 +/- 0.05 a	83.44 +/- 8.85 a	87.73 +/- 10.20 b	1873.20 +/- 53.13 a	162.21 +/- 5.00 b	4.93 +/- 0.38 b
PC	5.58 +/- 0.12 ab	103.60 +/- 21.08 a	145.04 +/- 35.15 a	1959.07 +/- 157.93 a	186.11 +/- 21.57 ab	6.61 +/- 0.74 a
F	5.48 +/- 0.09 ab	118.16 +/- 23.11 a	135.33 +/- 23.00 ab	1964.48 +/- 151.88 a	196.75 +/- 17.91 a	4.85 +/- 0.31 b
B	5.40 +/- 0.05 b	87.17 +/- 11.51 a	100.80 +/- 9.54 ab	1904 +/- 79.17 a	170.05 +/- 8.63 ab	5.11 +/- 0.47 b

Treatment	Mn (kg/ha)	Cu (kg/ha)	B (kg/ha)	Na (kg/ha)	NO_3-N (ppm)	%OM
NI	27.07 +/- 3.08 a	1.77 +/- 0.07 a	0.47 +/- 0.02 a	34.16 +/- 2.76 b	11.33 +/- 5.75 a	5.37 +/- 0.13 a
PC	32.48 +/- 4.70 a	1.77 +/- 0.06 a	0.47 +/- 0.02 a	46.48 +/- 8.39 ab	31.83 +/- 21.83 a	5.48 +/- 0.19 a
F	32.11 +/- 3.89 a	2.97 +/- 1.47 a	0.49 +/- 0.03 a	58.80 +/- 13.82 a	27.83 +/- 10.04 a	5.18 +/- 0.09 a
B	36.59 +/- 4.67 a	1.79 +/- 0.15 a	0.47 +/- 0.02 a	35.47 +/- 3.52 b	30.50 +/- 10.50 a	5.38 +/- 0.11 a

NI=no input; PC=Poultry compost; F=Fertrell™ 5-5-3; B=Blood meal
Half quantities of all amendments applied at planting, the other half applied at fruiting
Mean +/- standard error
Means with the same letter are not significantly different at α=0.05

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