EVALUATION OF FOUR ORGANIC FERTILIZERS FOR VEGETABLE AND HERB TRANSPLANT PRODUCTION

by

WESLEY KEITH JENKINS

(Under the Direction of Juan Carlos Díaz-Pérez)

ABSTRACT

The objective of this study was to evaluate bat guano, blood meal, broiler litter, and feather meal as fertilizers for organic transplant production of broccoli, cabbage, lettuce, basil, tomato, and watermelon transplants. The results indicated the four organic fertilizers evaluated can produce quality transplants at a total of 4000 mg N/ kg medium and compared well to an inorganic fertilizer (200 mg N/ L weekly). Broiler litter raised the media pH. Bat guano and broiler litter had larger amounts of dissolved salts than the other organic fertilizers. Blood meal and feather meal had larger seedling mortality than the rest of the fertilizers for most species. Bat guano, blood meal, broiler litter, and feather meal are acceptable organic fertilizers but depending on the concentration they may increase the pH or the concentration of salts in the substrate to levels that may be deleterious to the transplants.

INDEX WORDS: Organic vegetable transplants, Feather meal, Blood meal, Bat guano, Broiler litter

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BS, Texas A&M University, 2003

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2009

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May 2009

DEDICATION

I dedicate this thesis to my wife Carly, who helped me stay motivated and positive. I thank her humbly and profusely for her willingness to sacrifice time and energy to help me during the research and thesis writing.

ACKNOWLEDGEMENTS

I would like to thank my advisor Dr. Juan Carlos Díaz-Pérez for his dedication to the project and willingness to mentor me throughout the process. I extend my gratitude to my committee members, Dr. David Knauft and Dr. Harry Schomberg. Thank you for your contributions to my research and understanding. I would also like to thank John Silvoy for helping with much of the greenhouse setup and materials acquisition.

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CHAPTER 1

INTRODUCTION

Purpose of the Study

This study was designed to evaluate the ability of blood meal, bat guano, broiler litter, and feather meal to provide adequate nutrition for the production of organic vegetable transplants. Six vegetable species were chosen, three cool season vegetables [broccoli (*Brassica oleraceae* 'De Cicco'), cabbage (*Brassica oleraceae* 'Red Express'), lettuce (*Lactuca sativa* 'Green Oakleaf')] and three warm season vegetables [basil (*Ocimum basilicum* 'Genovese'), tomato (*Lycopersium esculentum* 'Brandywine'), and watermelon (*Citrullus lanatus* 'Crimson Sweet'). The increasing demand for certified organic fruits and vegetables results in a greater need for transplants.

Transplants offer many benefits in vegetable production by having greater establishment in the field, better timing of harvest and production, earlier planting, greater uniformity among the plants, and in some cases a larger yield. Production of high quality transplants requires proper fertilization management. Organic transplants often have poor quality because of our limited knowledge on organic fertilizers and plant nutrition in organic production systems. There are many animal or plant based materials that have the potential as organic nitrogen sources. The availability of the nitrogen depends on many factors, such as temperature, media moisture, and microbial biomass. This reduced N availability may limit root and shoot growth during the transplant stage as well as during the establishment in the field.

Animal or plant based materials may also have unknown or unintended side effects on the growth and development of the transplants, which can cause losses in final plant count or poor transplant quality.

CHAPTER 2

LITERATURE REVIEW

The organic vegetable industry is growing rapidly and encompasses much of the world's fresh produce markets (Willer et al, 2008). The increased demand for certified organic fruits and vegetables by consumers is the result of concerns about the impact of synthetic chemicals and hormones in vegetable production on the environment and/or their personal health. Vegetable producers rely on the use of transplants to increase yield, improve reliability of the harvest date, and to bring their produce to market earlier in the season when prices are better (Dufault, 1998). Much care and understanding is required to produce quality transplants that meet the needs and requirements of producers. An important aspect of transplant production is the nutrition and timing of the fertilizers, since the transplants are produced in short time frames, often less than six weeks (Styer and Koranski, 1997). Organic fertilizers derived from animal waste and processing by-products are a possible source of nutrients. As long as the amendment is free of synthetic materials, it can help the transplant producer meet the organic certification standards. The use of individual components in the production of organic vegetable transplants needs further research to understand the impact on the overall health of the transplants and the ultimate yield.

Nutrition of organic vegetable transplants is dependent on the type of fertilizer used and how the fertilizer interacts with the soil environment. There are several organic fertilizers and most either need to be incorporated in the substrate or used as a water soluble solution.

The incorporated type of fertilizer usually consists of animal by-products or wastes that cannot be easily dissolved in water, such as composted chicken manure, feather meal, composted cow manure, or blood meal (Murray and Anderson, 2004; Hadad and Anderson, 2004). Water soluble types of fertilizers can be diluted in water, such as fish emulsion or enzymatically digested animal meals, and these products can be used in fertigation systems, provided the solution is filtered to prevent emitters from clogging (Hadad and Anderson, 2004; Murray and Anderson, 2004). Russo (2005) determined that a higher rate of application for a commercial water soluble organic fertilizer was required to produce comparable transplants to those resulting from the half rate application of a synthetic water soluble fertilizer. The need for a higher rate of application could result in greater costs of production for organic transplant producers. In addition to the nutrient availability of the fertilizers, production of quality vegetable transplants requires proper environmental conditions for the specific crop, adequate irrigation, appropriate pH and salinity levels of amended media, and sufficient amounts of sunlight within the greenhouse (Dufault, 1998).

Animal based fertilizers contain N in inorganic and organic forms and often require microbial decomposition for organically bound N to be available to the transplants (Agehara and Warncke, 2005; Hadas and Kautsky, 1994). Composted organic matter can also provide a source of N in a fertilization schedule for vegetable transplants and as a potential substitute for peat (Díaz-Pérez et al, 2008; Raviv et al, 1998; Sanchez-Monedero, 2004). Some animal based fertilizers of interest today include bat guano, blood meal, chicken manure, and feather meal.

Bat guano is the excrement of the bats that collects in caves and is harvested from the floor of the cave (Harris, 1970). The nutrient composition strongly depends on the diet of the bats and the species of bats, but there may be no differences in organic matter between species (Emerson, 2007). Guano can also come from other sources, such as seabirds, and has potential as a N source for organic transplant production (Hadas and Rosenberg, 1992). The N concentration in bat guano can range from 8% N to 13% N, depending on the source location of the guano (Penhallegon, 2003). While bat guano may have many benefits in the fertilization of plants, it is related to an infectious disease known as Histoplasmosis caused by fungal spores of the pathogen *Histoplasma capsulatum* (Kikuchi et al, 2008). This disease is known to cause epidemics worldwide and is associated with individuals that come into contact with guano, such as bridge workers, spelunkers, and individuals that collect guano for fertilization (Huhn, 2005).

Blood meal is the by-product of animal processing plants and can be the product of many different animal species. The use of blood meal has largely been as a feed supplement for livestock or aquaculture because of its high N concentration (~12%) in the form of protein (Sugiura, 2000; Hansen et al, 1993; Penhallegon, 2003). Blood meal as a plant fertilizer can be effective in vegetable transplant production and in greenhouse production of vegetables (Gagnon and Berrouard, 1994; Greer and Diver, 2000). While blood meal can be used as a N source, it is often low in other important nutrients, such as phosphorus and potassium (Penhallegon, 2003; Greer and Diver, 2000). This would require the organic transplant producer to supplement the missing nutrients with other fertilizers either by incorporation into the substrate or through the irrigation system.

Chicken manure (broiler litter) is a by-product of poultry production and offers a more balanced nutrient supply. Chicken manure typically has 3%-4% N, 3% phosphorus, and 2%-6% potassium and can contain 39% carbon (Penhallegon, 2003; Stephenson et al, 1990; Adeli et al, 2007). Díaz-Pérez et al (2008) found that incorporation rates as high as 20% (by weight) can produce quality tomato transplants, showing a potential for peat substitution while providing the nutrition needed. An added benefit is the lack of pathogens in properly composted chicken manure (Kelleher, 2002).

Chicken manure has also been used to increase the pH in acidic soil (Castillo et al., 2003; Hue, 1992). This ability to increase soil or media pH has been attributed to the presence of calcium carbonate in the manure (Mokolobate and Haynes, 2002; Naramabuye and Haynes, 2006). Calcium carbonate, in the form of limestone, is added to chicken feed to strengthen egg shells and to combat a skeletal condition known as tibial dyschondroplasia (Henry and Pesti, 2002). The pH adjustment of the soil is effective at high incorporation levels and has been shown to maintain an effect for over 5 months (Clark et al, 2007; Castillo et al, 2003). There could be problems with the liming effect of chicken manure, if the pH of the amended potting media is raised to levels >7, where there is a possibility of limiting nutrient availability to the transplants. This limitation could impact the overall growth of the vegetable transplant and ultimately the final yield of the vegetables in the field (Dufault, 1998). There are other potential issues with the use of chicken manure or broiler litter, specifically with excess application of phosphorus. Chicken manure has almost equal portions of N and phosphorus, which means for every kilogram of N applied to the fields, there is a similar portion of phosphorus applied. This phosphorus can build up over time and eventually the runoff from the field can carry the phosphorus to rivers and lakes, where it can cause algal blooms (Gascho, 2006). Given the amount of organic fertilizers used in transplant production, there is a much lower degree of contamination when compared to field scale applications. Another concerning factor is the presence of soluble salts in the chicken manure, which can severely limit the germination percentage or damage vegetable seedlings in species that are sensitive to soil salinity (Mokolobate and Haynes, 2002; Bayuelo-Jimenez et al, 2002; Finch-Savage and Phelps, 1993; Miyamoto et al, 1985). While there are many positive attributes of chicken manure, the use of this fertilizer needs to be carefully monitored and its rates adjusted depending on the plant species in order to reliably produce quality vegetable transplants.

Feather meal is a by-product of the poultry processing industry and is composed of ground feathers that have been steam processed to make the N more available (Hadas and Kautsky, 1994). Feather meal has N concentration up to 15% in the form of non-soluble keratin (Penhallegon, 2003; Hadas and Kautsky, 1994). Feather meal has been used as animal and fish feed as well as a plant fertilizer because of its high N protein content and abundant availability (Guimaraes et al, 2008; Hall et al, 2001). Given feather meal has its N bound in a non-soluble form, it requires interactions with microbial populations and soil moisture to make N available through decomposition (Agehara and Warncke, 2005; Hadas and Kautsky, 1994). Feather meal has been used to produce tomato transplants with positive results and can also be used in field production as well (Gagnon and Berrouard, 1994; Koller et al, 2004). A potential issue in transplant production is the consideration of feather meal as a semi-slow to slow release fertilizer, needing weeks or months to make its N available to the transplants (Hadas and Kautsky, 1994; Penhallegon, 2003). Feather meal has the potential to be a N fertilizer in transplant production depending on factors affecting the rate of N mineralization.

An important aspect of a fertilizer to be used for vegetable transplant production is providing enough N and other nutrients to meet the needs of the transplant. Nitrogen mineralization of an organic fertilizer is dependent on the microbial population, substrate temperature, and moisture content of the amended substrate (Agehara and Warncke, 2005; Hartz and Johnstone, 2006; Sierra et al, 2007; Whitmore, 2007). Consideration of temperature and soil moisture should be taken to ensure the proper availability of N from organic amendments when producing transplants. For feather meal, blood meal, and partially composted chicken manure, it has been determined that N mineralization increases with increasing temperatures (Hartz and Johnstone, 2006; Agehara and Warncke, 2005). The importance of N availability is heightened by the time frame of transplant production, which is eight weeks or less (Styer and Koranski, 1997). Gaskell et al (2006) determined the 8-week net N mineralization rates at 25°C of blood meal, and feather meal to be 70% and 63%, of the total organic N respectively, while Hartz and Johnstone (2006) found the 8-week rates at 25°C to be 60% and 66% for blood meal and feather meal respectively. For chicken manure, Agehara and Warncke (2005) found the rate of N mineralization at 25°C (daily) to be 45% and Gaskell et al (2006) determined the 8 week net N mineralization rate at 25°C to be 36%. These N rates of release indicate chicken manure might not release enough N to fulfill the transplant needs in the time allotted for production, but feather meal and blood meal could be suitable fertilizer candidates.

Vegetable seed germination potential can be affected by abiotic interactions in the substrate, such as salinity, which can cause irreparable damage to the seedlings and ultimately the final stand of the vegetable crop. Salinity of the media can also inhibit germination or damage the seed or the seedling through osmotic effects from cations in solution (Miyamoto et al, 1985). Many grain and vegetable species are sensitive to salt stress when germinating or during seedling development (Bayuelo-Jimenez, 2002; Bliss et al, 1986; Esechie, 1994; Goertz and Coons, 1991). Miyamoto et al. (1985) found that hypocotyl mortality was the cause of poor seed emergence for carrots and chili peppers. This type of effect can have drastic tolls on the production output of transplant producers and limit the availability of many transplants in a region during field planting. This limitation can put a farmer behind schedule and ultimately affect the farmer's final profit.

The production of organic vegetable transplants requires extra care and consideration when compared to conventionally produced transplants. Organic vegetable producers must meet strict guidelines in their vegetable production in order to be certified for organic labeling and sales. Organic fertilizers derived from animal and plant wastes and by-products are more variable in their rates of nutrient release compared to conventional fertilizer sources. There is also greater potential for losses from nutrient deficiencies and toxicity of fertilizer components, such as ammonia. Organic fertilizers can offer adequate nutrition in the correct environment and the use of these fertilizers presents opportunities to utilize local farm wastes that would otherwise be considered a problem instead of a financial opportunity.

CHAPTER 3

PHYSICAL AND CHEMICAL PROPERTIES OF BAT GUANO, BLOOD MEAL, BROILER LITTER (COMPOSTED), AND FEATHER MEAL

Abstract

The objective of this part of the study was to determine the effects of blood meal (BM), feather meal (FM), bat guano (BG), and composted broiler litter (BL) on water potential (WP), pH, buffering capacity (BC), and electrical conductivity (EC) of a peat-based substrate. The fertilizers had extremely low initial water potentials and when incorporated in the substrate, reduced the WP of the potting media to harmful levels. There was a higher salt concentration in the animal manures than in BM or FM. This suggested that animal manures contributed with a high osmotic component in the WP of the substrate. The effect of the amendment rate on pH level was measured 24 h after incorporation and revealed that BL increased pH above 7, while the rates of FM, BG, and BM had little effect on the pH of the medium. Broiler litter had an extremely high BC when compared to the other fertilizers. This may be attributed to $CaCO_3$ added to poultry feed, which would also explain the rise in pH of the medium amended with BL.

While FM and BM had a larger concentration of N, BG and BL contained larger concentrations of other macro and micro nutrients. Our results suggested the fertilizers could alter pH and EC to concerning levels. This study demonstrated a need to better understand the immediate effects of organic fertilizers in potting media, which could negatively impact germination and initiation of vegetable seeds.

Introduction

Organic fertilizers are required for production of certified organic vegetables, including organic transplant production. Many studies focus on fertilizer mixes, liquid or granular, and do not focus on interactions between the fertilizer and substrate used in organic transplant production (Russo, 2005; Anderson et al, 2004). The purpose of this study was to determine the pH, WP, EC, and BC of four individual organic fertilizers on an organic peat substrate. The pH of the amended substrate has been shown to determine nutrient uptake by plants and could negatively affect the growth potential of many vegetable transplants (Hue, 1992). Water potential of soil and soilless media can reduce germination of seeds and restrict the growth of the subsequent seedlings (Wang et al, 2005; Rowse and Finch-Savage, 2003). The osmotic potential is a constituent of WP and can also reduce seed germination and seedling vigor (Miyamoto et al, 1985). The BC of the fertilizers was studied to identify the fertilizers ability to control changes in pH in the amended substrate. Chicken manure has been shown to increase pH in several studies, thus use of chicken manure in transplant production could result in an increase in the pH of the peat substrate to concerning levels (Hue, 1992; Mokolobate and Haynes, 2002).

Materials and Methods

The organic fertilizers were bat guano (Ancient Organics, Chico, CA) (10N-2P_2O_5-1K_2O), blood meal (Boer Commodities, Inc, Fresno, CA) (13.6N-0P_2O_5-0K_2O), broiler litter (Stutzman Environmental Products, Canby, OR) (3N-2P_2O_5-2K_2O), and feather meal (Boer Commodities, Inc, Fresno, CA) (12.8N-0P_2O_5-0K_2O). Peter's All Purpose (Scott's Company, Marysville, OH) (20N-20P_2O_5-20K_2O) water soluble fertilizer was used as the inorganic fertilizer treatment. The organic fertilizers were incorporated into certified organic potting medium (Fafard FOF 20Conrad Fafard, Inc, Agawam, MA) at set rates of nitrogen (mg N/ kg medium). The fertilization rates were chosen based on literature of the efficiency of organic fertilizers at providing timely and adequate nutrition. The N rates of application of organic fertilizers range from 91mg N/ kg medium to 16,000 mg N/ kg medium (Thomsen et al, 2003; Díaz-Pérez et al, 2008). The mineral nutrient analysis of the fertilizers was conducted by the Soil, Plant, and Water Analysis Laboratory at the University of Georgia (Athens, GA). The C/N and C/S ratios were calculated from the results of the nutrient analysis.

Water Potential

The water potential of the fertilizers was measured with a Decagon Dewpoint Potentiameter WP4-T (Decagon Devices, Inc. Pullman, WA). This device determines the WP of a sample by employing a chilled mirror, light source, and photodetector. The sample is equilibrated with the headspace of the sealed chamber containing the mirror and condensation detection devices. When the sample and headspace are equilibrated, the WP of the air equals that of the sample. In the device, the temperature is controlled by a Peltier cooler and the detection of the condensation point is observed by a photoelectric cell. The WP4-T uses a beam of light reflected off of the mirror onto a photodetector cell to determine the point when the reflectance of the mirror changes due to the condensation of moisture. A thermocouple is used to determine the precise temperature at which the condensation is detected. The device uses an internal fan to reduce the time needed to equilibrate the sample with the headspace. In addition, the WP4-T employs a thermo-electrically controlled module to stabilize the temperature of the sample to reduce the measurement time. Sample materials were used directly from the original bag to simulate the normal use of the fertilizers. Coarse silica sand was used as a reference material or control. Sand was considered a control as it is crystalline, and has little porosity and low chemical reactivity. Four subsamples of each fertilizer were measured for WP.

Water potential changes were determined in potting medium (Fafard FOF 20) amended with fertilizers incorporated at 20% by weight. As a control, the potting medium was used without any addition of amendment materials. The soil mixtures received 10, 20, 30, 50, 70, or 100 grams of distilled water and were allowed to equilibrate for 48 h before measuring WP. The moisture levels of the medium were reported in grams of water per gram of dry weight of medium. To determine the dry weight of the medium, four bags of 100 g of the medium were dried at 65 °C for four days. The average dry weight was 49.1 g with a standard deviation of 0.6. Each moisture level was measured four times. The model lines were plotted using SigmaPlot (Systat Software, Inc, ver. 11) with the Exponential Rise function.

Electrical Conductivity (EC)

The relationship between EC and the rate of fertilizer was determined by adding increments (1000 mg N/ kg medium) of the fertilizers to distilled water in Erlenmeyer flasks. The flasks were sealed and placed on a shaker bed for five minutes. The mixed solutions were allowed to settle then the EC was measured with a conductimeter (D-24 EC/pH meter, Spectrum Technologies, Inc, Plainfield, IL) with an EC probe. The solution in the flasks was then amended to the next level of N rate and the mixing procedure was repeated. This method was performed for all of the fertilizers, plus KCl as a standard solution and reference line to compare the effects of the fertilizers (Westerman, 1990). Each increment of cation level was replicated four times.

pH and Buffering Capacities (BC)

The relationship of pH and the rate of fertilizer were determined on amended substrate sealed in bags for 24 h. The amendment levels were increments of 1,000 mg N/ kg medium from 0 mg N/ kg medium to 5,000 mg N/ kg medium. The pH was measured with a pH meter (IQ 150 pH meter, Spectrum Technologies, Inc, Plainfield, IL) with *in situ* probe. The measurements were replicated four times.

The buffering capacity of the organic amendments was determined at 2000 mg N/ kg medium with 0.1M HCl. The BC was studied to understand the impact of the fertilizers on the media's ability to buffer changes in pH. The acid (HCl) was titrated at small increments, mixed, and pH recorded (Wohlt et al, 1987). The increments of 0.1M HCl was varied as some materials were more sensitive to pH change than the other fertilizers. A control of distilled water was added to compare the changes in BC with the addition of the amendment. There were four replicates for each fertilizer and control.

Results

Nutrient Analysis

The N analysis showed differing levels of NH_4^+-N and NO_3^--N when comparing the fertilizers (Table 3.1). For BG, the amount of NH_4^+-N far exceeded the levels of the other fertilizers at 20,970 mg NH_4^+-N / kg fertilizer, while BL had the second highest level at 5,240 mg NH_4^+-N/ kg fertilizer. For NO_3^--N, BG had the highest level (12,860 mg NO_3^--N / kg fertilizer) and BL had the second highest level (252 mg NO_3^{-}N/ kg fertilizer).

Nutrient analysis showed that FM and BM had larger amounts of C as well as higher levels of N (Table 3.1). The calculated C/N ratios for FM, BM, and BG were similar among fertilizers (Table 3.1). BL had the lowest level of N which resulted in a larger C/N ratio than the other fertilizers. The S levels (<1.0%) for BL and BM were much lower and resulted in higher (up to 3X) C/S ratios.

Feather meal and blood meal offered drastically lower amounts of P and K (Table 3.2), confirming the analysis by the producer (Boer Commodities, Fresno, CA). Bat guano had the highest level of P, while BL had the highest level of K.

The analysis of the other individual elements showed BG and BL had the highest levels for most nutrients including: Al, Ca, Cr, Cu, Mg, Na, Ni, and Zn. This distinction for the animal manures is important for soils or media that are lacking in micro or macro nutrients and would benefit from amendments such as BG and BL.

Water Potential (WP)

The low WP’s of the fertilizer materials indicated a significant potential for reducing the WP of the medium (Fig. 3.1). The WP of the fertilizers was extremely low, the range being -25MPa to -145MPa. The fertilizer with the highest WP was BL and that with the lowest WP was FM. The cause for the low WP readings was either osmotic or matric potentials of the materials.

The addition of the fertilizers reduced WP of the media mixtures. The WP of the control was determined to be the highest of the experiment with a WP of -0.25MPa at saturation (Fig. 3.2). The fertilizer with the greatest reduction in WP was BG. The WP was significantly reduced compared to the control and the other treatments. All of the amended media treatments had similar trends as the water content increased to saturation.

Electrical Conductivity (EC)

There was a positive linear relationship between EC and the rate of fertilizer incorporation (Fig. 3.3), with BL having the highest effect (slope was steepest), followed by BG. The rates of application of FM and BM had little effect on the EC and were similar in trends based on their linear models and standard errors.

pH

Broiler litter had the largest effect on the pH of the amended substrate when compared to the other fertilizers (Fig. 3.4). It raised the pH quadratically to about 7.3 as the incorporation rates increased to 5,000 mg N/ kg medium. With the other fertilizers, there was little change in pH with increasing rates of fertilizer application.

Buffering Capacity

The organic amendments in solution with distilled water had significant effects on the BC and could impact the BC of the amended media (Fig. 3.5). The amendments with the lowest BC were FM and BM, which had a BC close to that of distilled water. Broiler litter had the highest pH throughout the titration process, indicating it had the highest BC. The presence of limestone was probably the cause of the high BC in BL. Bat guano, blood meal, and feather meal required much less meq of H^+ ions to reduce the solution's pH to <4 when compared to BL.

Discussion

Nutrients

The amount of minerals in fertilizers is important for short term growth and development of vegetable transplants, as well as for influencing the yield potential of the plants in the field (Melton and Dufault, 1991; Dufault, 1998). The results of the nutrient analysis showed that the total N was similar to that reported by the manufacturer of the fertilizers. The amounts of NH_4^+-N and NO_3^--N were also analyzed and revealed a significant difference among the fertilizers (Table 3.1). While high, BG's NH_4^+-N content constituted only 2.1% of the total N and the NH_4^+-N content for the other organic fertilizers was less than 1% of the total N of each fertilizer. BG was the highest source for NO_3^--N as well, comprising 1.3% of its total N levels. The other fertilizers had less than 1% NO_3^--N of the total N again. These levels indicate the majority of the N is bound in organic forms that require microbial activity to make the N available to the plants (Wainwright et al, 1985, Hadas and Kautsky, 1994). There was a difference between BL and the other fertilizers for the C/N ratio. The increased level in C could be the result of high $CaCO_3$ content and the substrate litter in broiler litters (Naramabuye and Haynes, 2006).

Water Potential

The effects of the fertilizers on the WP of the medium could have significant effects on the water availability to the plant in the amended media. The WP of the control was determined to be the highest of the experiment and the addition of the fertilizers reduced WP of the media mixtures (Fig. 3.2). The animal manures reduced the WP more than FM and BM despite FM and BM having lower original WP values.

The WP in the amended potting medium is determined by its matric potential (ψ_m), pressure potential (ψ_p), osmotic potential (ψ_s), and gravitational potential (ψ_g) (Kramer and Boyer, 1995), as shown in Equation 1

$$\psi_{soil} = \psi_m + \psi_p + \psi_s + \psi_g \qquad \text{[Eq. 3.1]}$$

which indicates the total WP of the amended medium is the result of the sum of the individual water potential components. The pressure and gravitational potential for the amended medium was considered negligible. The germination of seeds can be delayed or inhibited by the WP of the growing medium, in that as WP decreases the germination percentage decreases as well (Dahal and Bradford, 1994; Kebreab and Murdoch, 2000; Huarte and Benech-Arnold, 2005; Bradford, 1990; Rowse and Finch-Savage, 2003). While this effect of WP alone is important, the temperature of the medium interacts with WP on the germination of many species of seeds (Rinaldi et al, 2005; Wang et al, 2005; Rowse and Finch-Savage, 2003; Huarte and Benech-Arnold, 2005). Specifically, Dahal and Bradford (1994) showed the effect of delayed germination from the reduced WP was decreased as the temperature increased, and Huarte and Benech-Arnold (2005) found fluctuating temperatures reduced the osmotic potential effect on germination inhibition. The lower extreme for WP found in literature was -1.33MPa (Kebreab and Murdoch, 2000; Wang et al, 2005) and was larger than the WP measurements of the amended medium (Fig. 3.1&3.2). Feather meal, blood meal, and bat guano had concerning WP levels for the raw material. This concern dictated a need to understand the WP effect on the potting substrate. At 20% (by weight) incorporation rate, the reduction in WP could be dramatic enough to delay or inhibit the germination of seeds sown directly in the amended media.

The WP of the amended medium would be controlled primarily by the matric potential and the osmotic potential (Eq. 3.1). The measurements of WP and EC of the raw fertilizers indicated that BG and BL were predominantly controlled by osmotic potential of dissolved salts in solution (Fig. 3.3). This assumption is based on the high EC values on BG and BL.

Electrical Conductivity

The EC of the substrate is important for seed germination and seedling development. Seed germination of many vegetable species can be inhibited or delayed by high concentrations of salts in the amended substrate or in solution (Goertz and Coons, 1991; Bayuelo-Jimenez et al, 2002; Sanchez-Monedero et al, 2004; Esechie et al, 2002). Our data showed that BL and BF had high concentrations of salts and may pose potential negative effects to the germination of vegetable seeds in medium amended at high rates of these fertilizers (Fig. 3.3). Feather meal and blood meal had little effect on the EC of the solution and would not likely add any dissolved salts to the amended medium. Goertz and Coons (1991) showed a delay in germination by NaCl for *Phaseolus vulgaris* L. ‘Fleetwood’. Sanchez-Monedero et al (2004) also found tomato to be the most sensitive to substrate salinity, while onion was intermediate in sensitivity, and broccoli was the least sensitive among the species they evaluated. Esechie et al (2002) showed the lowest chickpea seedling emergence for the highest salinity, and an interaction between sowing depth and salinity in that the lowest seedling emergence occurred at lowest depth. Any delay in germination would have a negative impact on growing schedules of transplant producers. Since the use of BL is considered a substitute for peat, much consideration for the salinity of compost should be taken into account before amending the potting mixture (Díaz-Pérez et al, 2008; Sanchez-Monedero et al, 2004). Bat guano should also be tested for salinity levels when incorporation rates are high (Fig. 3.3).

Salinity levels can also have a negative impact during the initial growth stage of many species. Miyamoto (1989) found the limiting factor of onion germination was hypocotyl damage from high salinity. Poor seedling emergence for tomato, carrot, and chili pepper by salts in soil can be attributed to hypocotyl damage as well (Miyamoto et al, 1985). Eshesie et al (2002) implied salt damage of the hypocotyl restricted seed emergence for chickpea. Given the levels of EC recorded for BG and BL, there is potential for salt injury to the emerging seedling that would severely limit the transplant producer (Fig. 3.3). Our data showed that BL and BG applied at 4000 mg N/ kg medium could increase EC of the substrate by about 700 mS/m and 900 mS/m, respectively. This EC exceeds the salinity tolerance threshold of broccoli (270 mS/m), cabbage (180mS/m), lettuce (130 mS/m), tomato (250 mS/m), and watermelon (200 mS/m) (Kotuby-Amacher et al., 2000)

<u>pH</u>

Broiler litter raised the pH of peat based medium and this property should be considered when using it as a fertilizer. The other fertilizers did not alter pH with increasing rates of incorporation (Fig. 3.4). The pH of the medium can determine the nutrient availability of many micro and macro nutrients the plants may need for proper initial growth (Handreck and Black, 1991). The increase in pH caused by BL resulted in BL being used as a liming agent (Hue, 1992; Clark et al, 2007; Castillo et al, 2003). Castillo et al (2003) found the increase in pH occurred with time and increasing BL rates. Naramabuye and Haynes (2006) documented the increase in pH from the use of poultry manure and attributed the effect to the high content of $CaCO_3$ in the manure. This high $CaCO_3$ content in BL is attributed to the addition of limestone to poultry feed (Naramabuye and Haynes, 2006; Adeli et al, 2007; Henry and Pesti, 2002). Limestone is added to feed for layers to increase shell thickness and for general poultry nutrition to control a condition known as tibial dyschonroplaysia (Naramabuye and Haynes, 2006; Henry and Pesti, 2002). The liming effect of BL occurs early in the incorporation with peat based potting mixes and has the potential to last well beyond the growing period for most vegetable transplants (Clark et al, 2007). It would be highly recommended to measure the initial pH of the amended potting medium and adjust the medium pH to a proper range (6.0-6.5) to allow for the maximum availability of nutrients for the growing transplants.

The BC of the fertilizers is related to the pH changes seen in the medium. Limestone ($CaCO_3$) has a significant buffering effect in the medium. This property is important to a grower's ability to accurately adjust the pH of a growing medium. The BC of organic fertilizers and amendments should be analyzed prior to incorporation to prevent any negative consequences for nutrient availability.

Conclusion

Although organic fertilizers provide much needed nutrition for transplant growth and overall plant health, depending on the rate of application, they could produce undesirable effects in vegetable transplants. The organic fertilizers contained adequate N to allow for proper plant nutrition. Broiler litter and bat guano can also be a source of other macro and micronutrients. Bat guano, blood meal, feather meal, and broiler litter altered the water potential, electrical conductivity, pH, and the buffering capacity of the medium. These effects could directly affect transplant growth by limiting the availability of nutrients. To assess the degree of these potential negative impacts on transplants we developed additional studies to measure how these amendments would affect the growth of several organic vegetable transplants.

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Tables

Table 3.1. Total nitrogen, carbon, and sulfur contents and C/N and C/S ratios of the organic fertilizers

	g/g			mg/kg (ppm)			
Sample	Total Carbon[z,y]	Total Nitrogen[z,y]	Total Sulfur[z,y]	NH_4^+-N[z,y]	NO_3^--N[z,y]	C/N[x] Ratio	C/S[x] Ratio
BG	32.7	11.1	2.3	20595.0	12880.0	3.0	14.6
BM	49.0	14.8	1.0	387.0	35.6	3.3	50.7
BL	28.1	3.7	0.8	5325.0	316.5	7.6	35.0
FM	52.0	14.0	3.6	966.0	93.1	3.7	15.1

[z] Analysis performed by University of Georgia Soil, Plant, and Water Analysis Laboratory, Athens, GA

[y] Values averaged from two analyses of fertilizers

[x] C/N and C/S ratios calculated from analysis results

Table 3.2. Nutrient analysis of the organic fertilizers[z,y]

	mg/kg (ppm)														
Sample	Al	B	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	S	Si	Zn
BG	1471.0	5.8	34800.0	2.2	110.9	1348.0	18238.0	4223.0	168.6	5228.0	1.4	24525.0	12988.0	207.6	441.5
BM	294.9	6.2	1955.6	<0.5	2.7	2394.5	804.8	273.9	2399.6	2140.5	<1	1016.3	5653.5	206.0	16.0
BL	783.4	36.2	29070.0	5.8	930.8	1265.5	22780.0	5456.0	550.5	7097.5	7.6	17304.0	5966.0	834.4	420.6
FM	51.3	<1	1979.5	1.2	11.4	263.6	574.6	232.0	3.5	628.4	<1	1442.5	16330.0	145.6	66.7

[z] Analysis performed by University of Georgia Soil, Plant, and Water Analysis Laboratory, Athens, GA

[y] Values averaged from two analyses of fertilizers

Figures

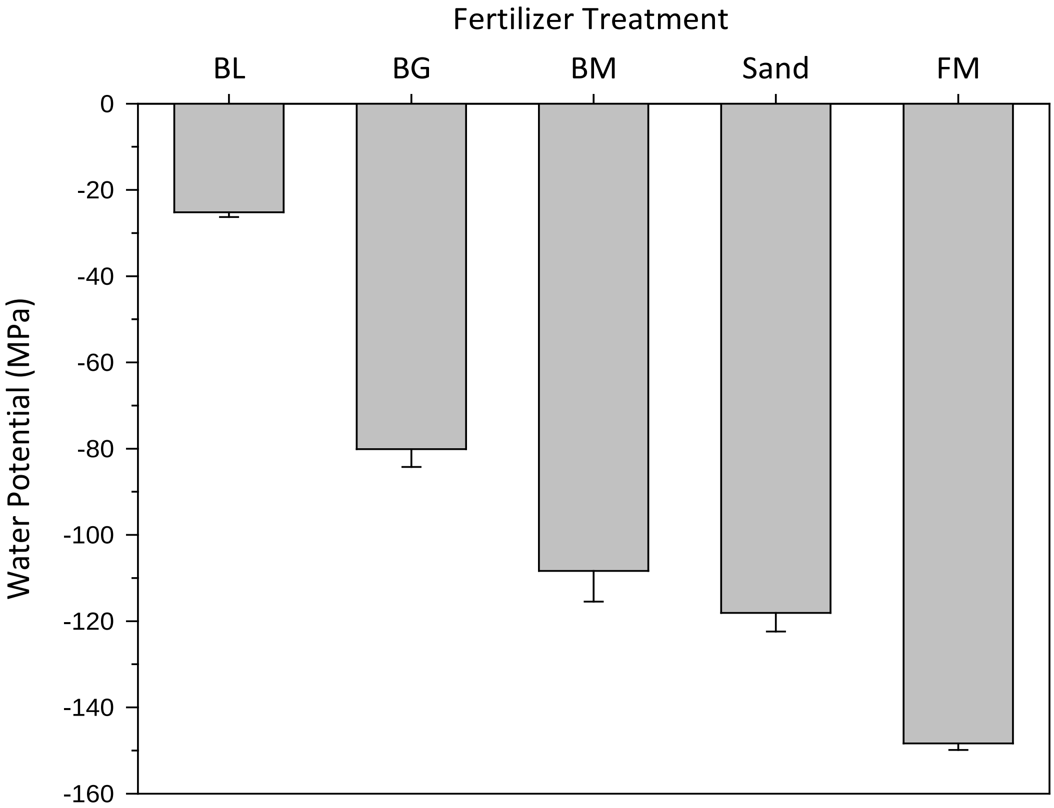

Figure 3.1. Water potential of the individual fertilizers. Water potential measurements exceeded the lowest recommended for seed germination. Error bars indicate standard error. Sand was used as a reference. (BL-Broiler litter, BG-Bat guano, BM-Blood meal, FM-Feather meal)

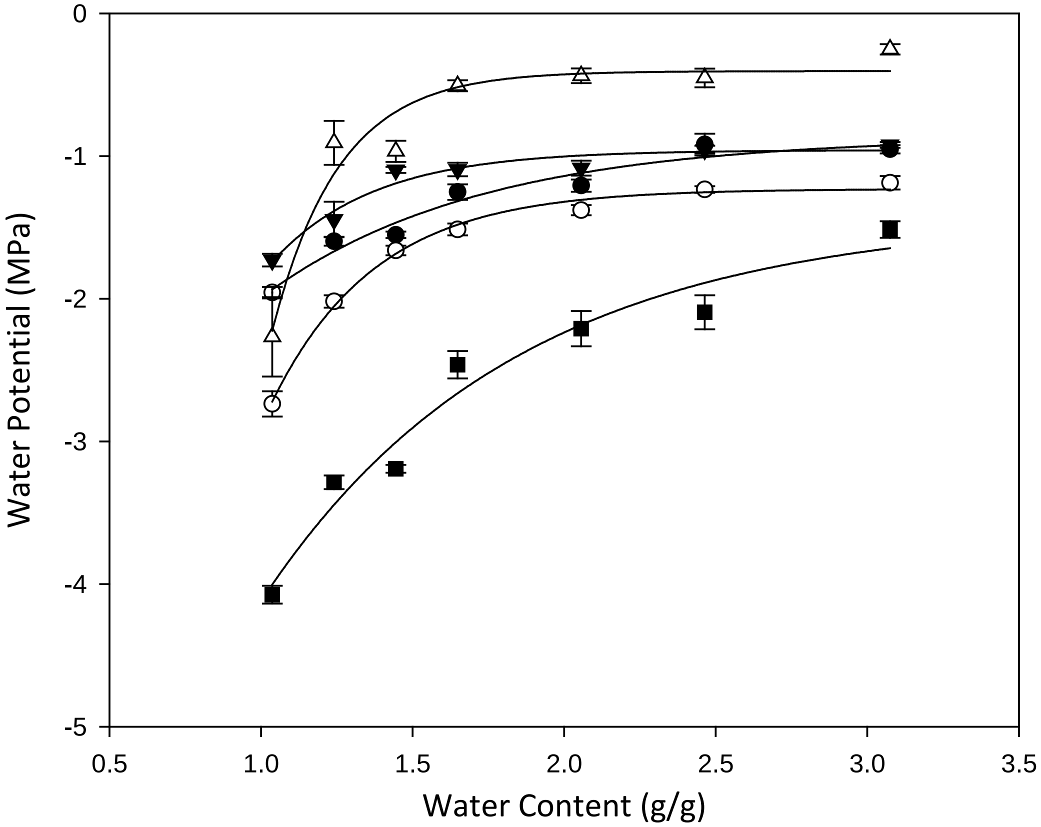

Figure 3.2. Relationship between water potential and water content of a peat-based potting medium amended with organic fertilizers applied at 20% by weight. Control was the unamended medium. Error bars indicate standard error. (■-Bat guano (p=0.0013),● -Blood meal (p=0.0015),○ -Broiler litter (p<0.0001), ▼-Feather meal (p=0.0019),△ -Control (p=0.0029))

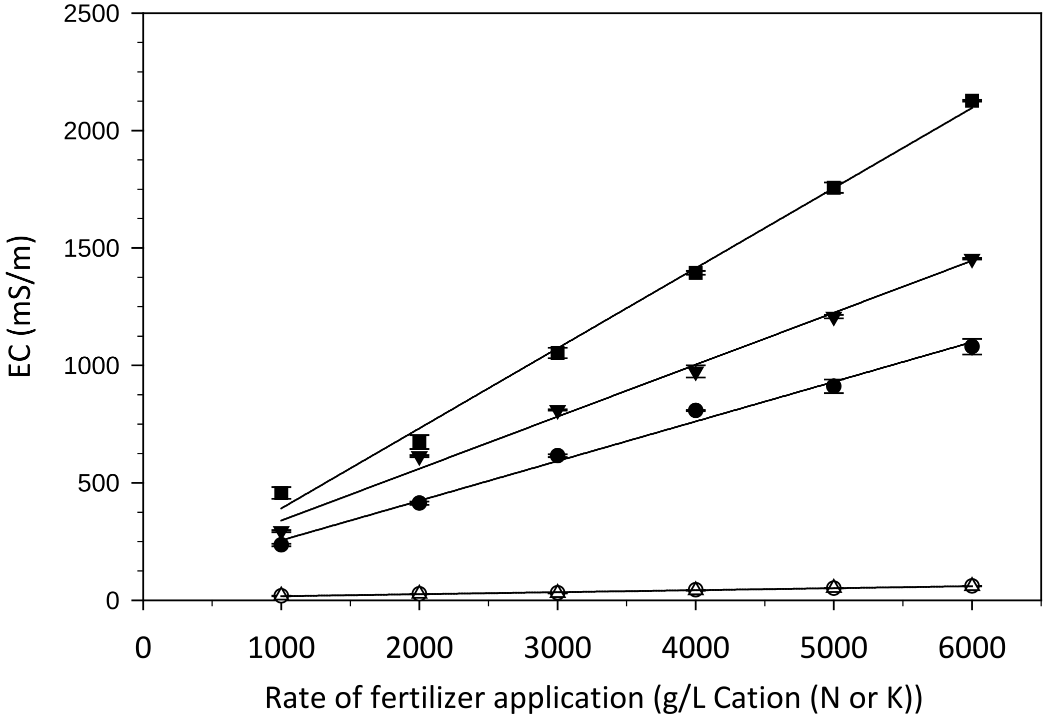

Figure 3.3. Influence of the rate of organic fertilizer amendment on electrical conductivity of distilled water. KCl was used as a reference. The error bars indicate standard error. ● -Bat guano ($p<0.0001$), ○-Blood meal ($p<0.0001$),▼ -Broiler litter ($p<0.0001$), △-Feather meal ($p<0.0001$), ■-KCl ($p<0.0001$))

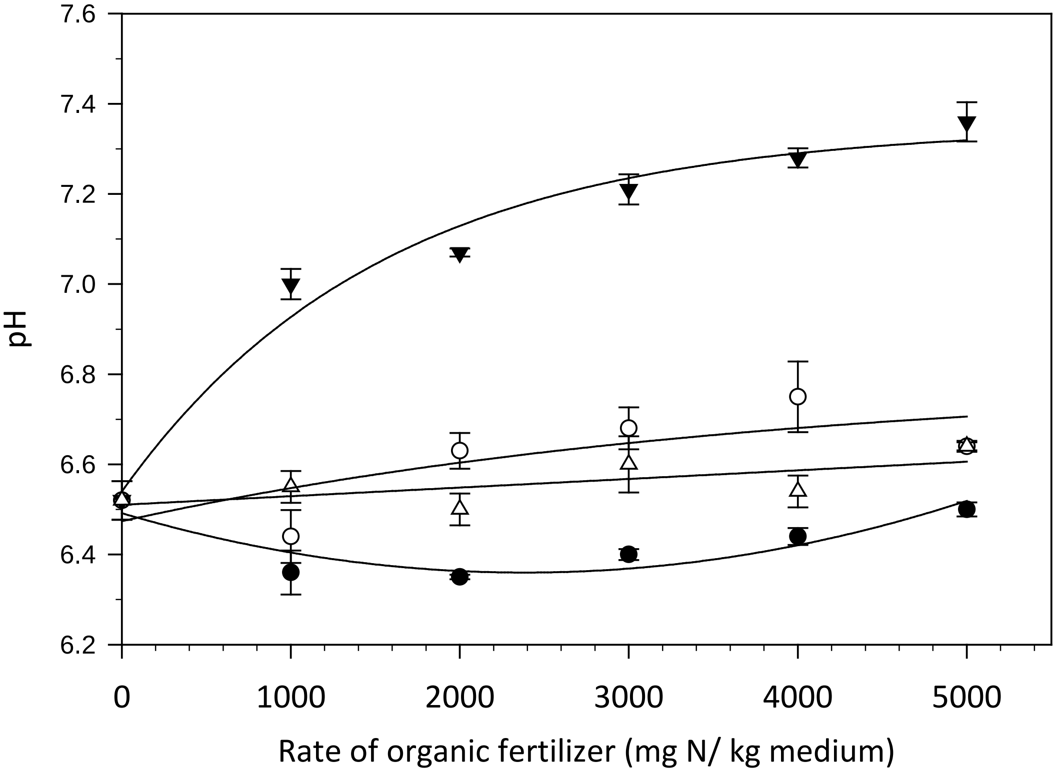

Figure 3.4. pH of the potting medium as affected by rate of organic fertilizers. pH was measured one day after incorporation to the potting medium. pH remained about constant for bat guano, blood meal, and feather meal. Error bars indicate standard error. (● -Bat guano (p=0.0788),○ -Blood meal (p=0.2454),▼ -Broiler litter (p=0.0041), △ -Feather meal (p=0.1335))

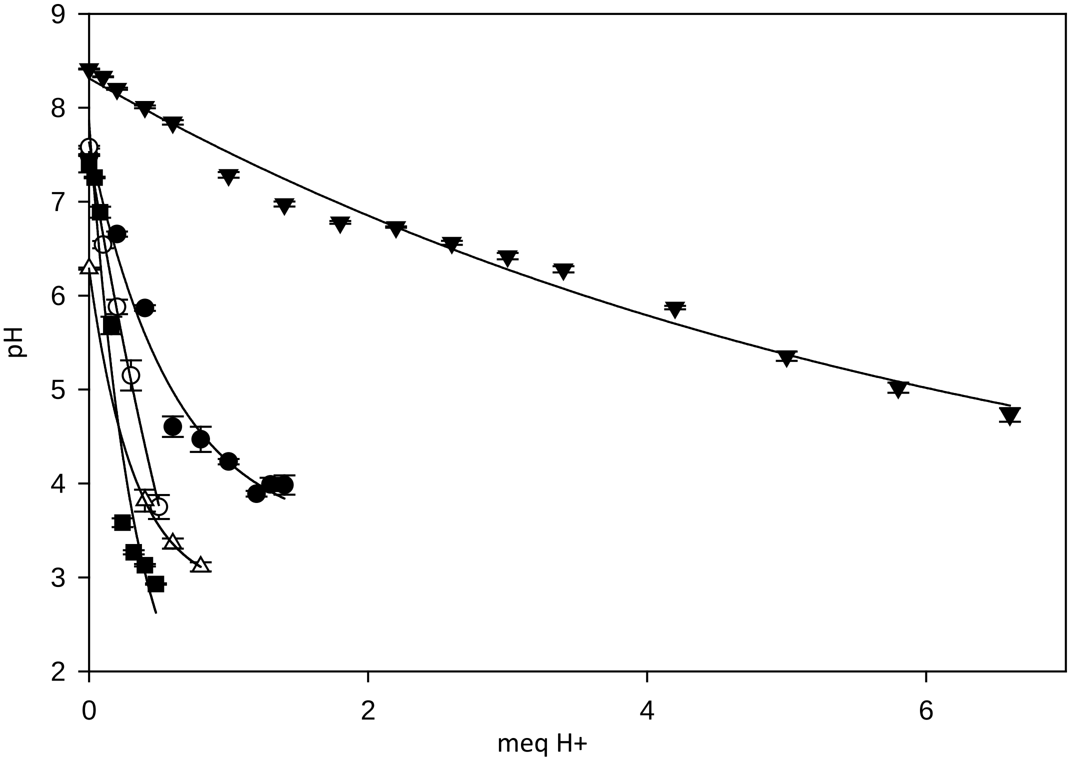

Figure 3.5. Buffering capacities of the organic fertilizers added to distilled water and titrated with 0.1M HCl. Fertilizers were applied at a rate equivalent to 2000 mg N/ kg medium. Water was used as a negative control to determine changes with material addition. Error bars indicate standard error. (●-Bat guano (p<0.0001),○-Blood meal (p=0.0023), ▼-Broiler litter (p=<0.0001), △-Feather meal (p=0.0006),■-Water (p=0.0006))

CHAPTER 4

DETRIMENTAL EFFECTS OF BLOOD MEAL AND FEATHER MEAL ON GERMINATION OF TOMATO SEEDS

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Abstract

Organic vegetable transplant production requires a greater understanding of fertilization management and how organic fertilizers may affect seed germination. Successful fertilization of vegetable transplants requires control of nitrogen release and adequate nitrogen availability for the seedlings. The purpose of this study was to determine the relationship between the rate of application of blood meal (BM) and feather meal (FM) on the pH of the propagating medium and the germination of tomato seeds. Both fertilizers were applied as amendments at rates from 0 mg N/ kg medium to more than 50000 mg N/ kg medium in peat-based organic potting medium. Seeds were sown in styrofoam trays and grown in a greenhouse. The germination of tomato seeds was recorded over several days until the germination percentage remained unchanged. The pH of the medium varied as a function of rates of application of BM and FM The pH of the medium decreased from 7.8 (at 0 mg N/ kg medium) to about 6.3 (at 8000-9000 mg N/ kg medium) with increasing rates of fertilization, and then increased to about pH 8 (BM) and pH 7.5 (FM) with further increases in rates of fertilization (to about 25000 mg N/ kg medium). There was a significant reduction in seed germination and mortality of plants with rates of fertilization > 5400 mg N/ kg medium for BM and > 5100 mg N/ kg medium for FM. We propose that the cause of the reduced germination and increase plant mortality was ammonia toxicity.

Introduction

There are limited studies on organic transplant production. One aspect that requires attention is the understanding of how the types and rates of organic fertilizers affect seed germination, plant growth, and quality of vegetable transplants. Díaz-Pérez et al (2008) used composted chicken manure at rates of 1000 mg N/kg medium to 16,000 mg N/kg medium to grow tomato transplants. Gagnon and Berrouard (1994) used rates at approximately 2200 mg N/kg medium with blood meal and feather meal and Koller et al (2004) had fertilization rates for feather meal at approximately 2700 mg N/kg medium. The fertilization of conventional transplants varies among plant species and typically follows the irrigation schedule when soluble fertilizers are used (Boyhan and Granberry, 2003). For organic fertilizers, it has been shown that higher fertilization rates are required (on a per unit N basis) to compete with soluble synthetic fertilizers (Russo, 2005; Murray and Anderson, 2004). Results from unpublished data of ours (Chapt. 5) on several vegetable species showed a need of 4000 mg N/ kg medium or more to produce adequate organic transplants. There needs to be a greater understanding of the relationship between rate and germination reduction (Dufault, 1998). There are few studies on blood and feather meal as single components for fertilization, but more needs to be done to understand the benefits and drawbacks (Gagnon and Berrouard, 1994; Koller et al, 2004). Blood and feather meal have higher levels of N than other organic fertilizers, at 14% and 13% respectively. This makes both fertilizers an attractive option in organic transplant production as less fertilizer material is needed to provide nitrogen compared to other organic fertilizers. Several studies show a positive effect of BM and FM on growth of tomato, lettuce, and cabbage (Gagnon and Berrouard, 1994; Koller et al, 2004), and a negative effect on rooting of rosemary (Pitchay and Díaz-Pérez, 2008). The hypothesis of this study was that germination of tomato seed would be reduced by increasing rates of BM or FM. The objective of this study was to determine the effect of rate of application of BM or FM on tomato seed germination.

Materials and Methods

Certified organic tomato (*Lycopersicum esculentum*) seeds 'Brandywine' (Johnny's Selected Seeds Winslow, Maine) were planted in Styrofoam trays with 200 cells (Speedling, Inc, Sun City, Fl) filled with organic potting medium (Fafard's FOF 20) composed of 70% Canadian Sphagnum Peat, perlite, dolomitic limestone, gypsum, and Perdue-AgriRecycle Microstart60 (4-2-3). The seeding rate was two seeds per cell. After germination, thinning was done to leave one plant per cell.

Blood meal (13.6N-0P_2O_5-0K_2O) and feather meal (12.8N-0P_2O_5-0K_2O) [both from Boer Commodities (Boer Commodities, Fresno, CA)] were applied by mixing with the potting medium immediately before seeding. For BM, the incorporation rates were: 0, 2720, 5440, 6800, 13600, 20400, 23360, 27200, and 54400 mg N/ kg medium (Trial 1) and 0, 2720, 5440, 13600, 17520, 20400, 27200, and 54400 mg N/ kg medium (Trial 2). For FM, the incorporation rates were: 0, 2560, 5120, 6400, 12800, 19200, 25600, and 51200 mg N/ kg medium (Trial 1&2). To ensure proper mixing, the medium and each fertilizer were placed in a plastic bag and vigorously shaken for a short period. Trial 1 and 2 were both repeated once.

An additional study was performed with BM (at 13600 mg N/ kg medium) in perlite alone and was used to study the effect of BM without peat. The germination percentage was recorded as previously mentioned for the peat-based medium.

The germination percentage was measured once the seedlings started emerging through the substrate surface. The percentage was recorded daily until there was no change in germination percentage.

The pH of the amended medium was measured with a pH meter (IQ 150 pH meter Spectrum Technologies, Plainville, IL) using the ISFET probe for *in situ* measurements. The pH for two cells per experimental unit was averaged. The measurements were taken 21 days after seeding, which was the end of the trial.

The experimental design was a randomized complete block with four replications for each treatment. The experimental unit consisted of 12 plants (one plant/cell). The trays were laid out to 4 X 3 cells with one line of cells between each experimental unit. The tray was set up to house two blocks, one on each side of the longest dimension of the tray. The fertilizer trials were conducted two times with the first BM trial started 3 June, the second BM trial started 18 Aug, the first FM trial started 24 July and the second FM trial started 15 Aug. The data were analyzed using the General Linear Model Procedure of SAS software (SAS Institute Inc., ver. 9.1) using the Duncan's Multiple-Range Test (alpha=0.05) to separate the treatment means.

Results and Discussion

Germination Effects

Blood meal had no effect on tomato seed germination at rates ≤5,000 mg N/ kg medium. However, there was a rapid decline in germination with increasing rates of application at > 5000 mg N/ kg medium (Fig. 4.1). The germination rate declined from ca 100% at 5,000 mg N/ kg medium to 0% germination at 8,000 mg N/ kg medium. For FM, there was no effect on tomato seed germination at rates < 8000 mg N/ kg medium. At rates >8000 mg N/ kg medium, there was a decreased germination, but the decline was slightly less dramatic compared to that of BM. Germination percentage was 70% at 10240 mg N/ kg medium of FM incorporation and 24% at about 15,000 mg N/ kg medium (Fig. 4.1).

A perlite-BM trial was initiated to determine whether the germination restriction found with peat-based medium may be a product of interactions between the peat and the fertilizer. The perlite study resulted in 94% germination for the negative control (perlite alone) and 0% germination for the perlite mixed with BM at 13600 mg N/ kg medium. The lack of germination was the result of damage to the seeds during germination.

Several seeds were removed from the perlite-BM medium. The seeds showed signs of decay and were soft to the touch. When pressure was applied to the seeds, the internal parts of the seed emerged in a rotted state. This indicated the seeds initiated germination, but the radicle was damaged in the media. Since the reduced germination in perlite was similar to that observed in peat, it probably means that BM was likely the cause of the reduced germination.

The effects of BM and FM on tomato seed germination and seedling growth is probably attributed to ammonia toxicity. Research on organic and inorganic fertilizers has shown negative effects of ammonia on seed germination and seedling growth of corn, cotton, soybean, peanut, cucumber, canola, chickpea, wheat, and cabbage causing symptoms such as delayed emergence and growth, inhibition of germination, and even death of the seeds or seedlings (Allred and Ohlrogge, 1964; Megie, et al, 1967; Woodstock and Tsao, 1986; Ells, et al, 1991; Dowling, 1996; and Wong, et al, 1983). The symptoms of reduced germination observed in this study mirror those of prior research on both conventional fertilizers and plant/animal based fertilizers. Ells et al (1991) found that ammonium hydroxide and alfalfa (chopped or extract) inhibited germination and subsequent seedling growth for cucumber, demonstrating similar effects by conventional and potential organic sources of fertilizers. Wong et al (1983) observed reduced root growth and seed germination caused by chicken and swine manure. Bremner and Krogmeier (1988) demonstrated the inhibition effect of urea on the germination of grain seeds, and suggested that the negative effect on germination was largely due to ammonia.

Supportive evidence for ammonia effects also resides in studies on the N mineralization of BM and FM, as well as animal manures and plant materials. Hartz and Johnstone (2006) found a rapid mineralization of N from BM and FM and Agehara and Warncke (2005) observed the net N released from BM was second only to urea. N mineralization depends on temperature, where an increase in temperature results in an increase in N mineralization (Zak et al, 1999; Agehara and Warncke, 2005). Hartz and Johnstone (2006) showed an increase in N mineralization with increasing temperature for BM and FM with the highest NH_4^+-N production occurring in the first week, while Koller et al (2004) found the highest level of NH_4^+-N at 2 weeks. Agehara and Warncke (2005) observed an increase in N mineralization with an increase in temperature for BM and most of the NH_4^+-N production occurred in the first week. Khalil et al (2005) also observed a rapid increase in NH_4^+-N production in the first two weeks for crop residues and chicken manure, which conforms to the results mentioned above.

pH

The rate of application of BM and FM caused changes in the pH of the substrate. The unamended medium had a pH of about 7.8. Medium pH decreased with increasing rates of fertilization to about 6.3 at 8000-9000 mg N/ kg medium. Then pH increased with increasing rates of fertilization to about pH 8 (BM) and pH 7.5 (FM at about 25000 mg N/ kg medium) (Fig. 4.2). The pH was recorded for the higher application rates, despite the lack of germination, to determine the overall trend of pH. The trends in pH for both fertilizers were similar, but FM tended to have a lower pH throughout the incorporation levels. The changes in pH with increasing rates of incorporation of both fertilizers were possibly a result of the mineralization of the nitrogen. The nitrification process contributes to the acidity of the soil as seen in Fig. 4.2 and is dependent on the buffering capacity of the media (Engelstad, 1985). As the pH of the medium decreases, the ability of the bacteria involved in nitrification to survive is reduced. Therefore, as the nitrification process begins, the pH decreases which causes stress on the microorganisms that are responsible for nitrification. This reduction in nitrification allows ammonia to build up in the soil, which increases the pH as ammonia is an alkali. This increase in pH (Fig. 4.2) has been reported previously (Megie et al, 1967).

Conclusion

Blood meal and feather meal are rich sources of N for organic transplants. However, at high rates of application, blood meal and feather meal may be associated with toxic effects on tomato seedling germination and seedling growth. Our results indicate that blood meal and feather meal inhibited seed germination when applied in combination with potting mixes at more than 6800 mg N/ kg medium or 5100 mg N/ kg medium, respectively. To avoid possible toxicity damage to vegetable seeds and seedlings, growers should be aware of how much of either fertilizer is being used in their personal formulations or commercially available fertilizers.

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Figures

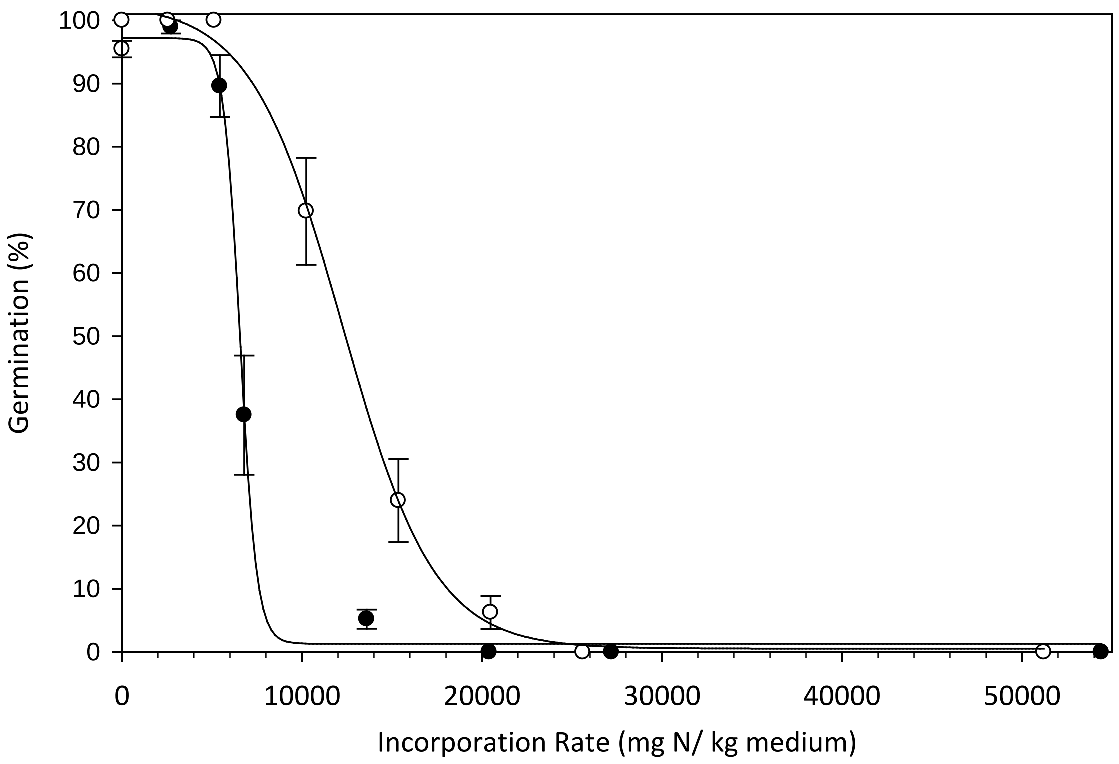

Fig. 4.1. Effect of incorporation rate of blood meal and feather meal on germination of tomato seeds. The curves were determined with SigmaPlot based on best fit regressions of data. Bars indicate standard error of the means. (●- Blood meal (p<0.0001), ○- Feather meal (p<0.0001)

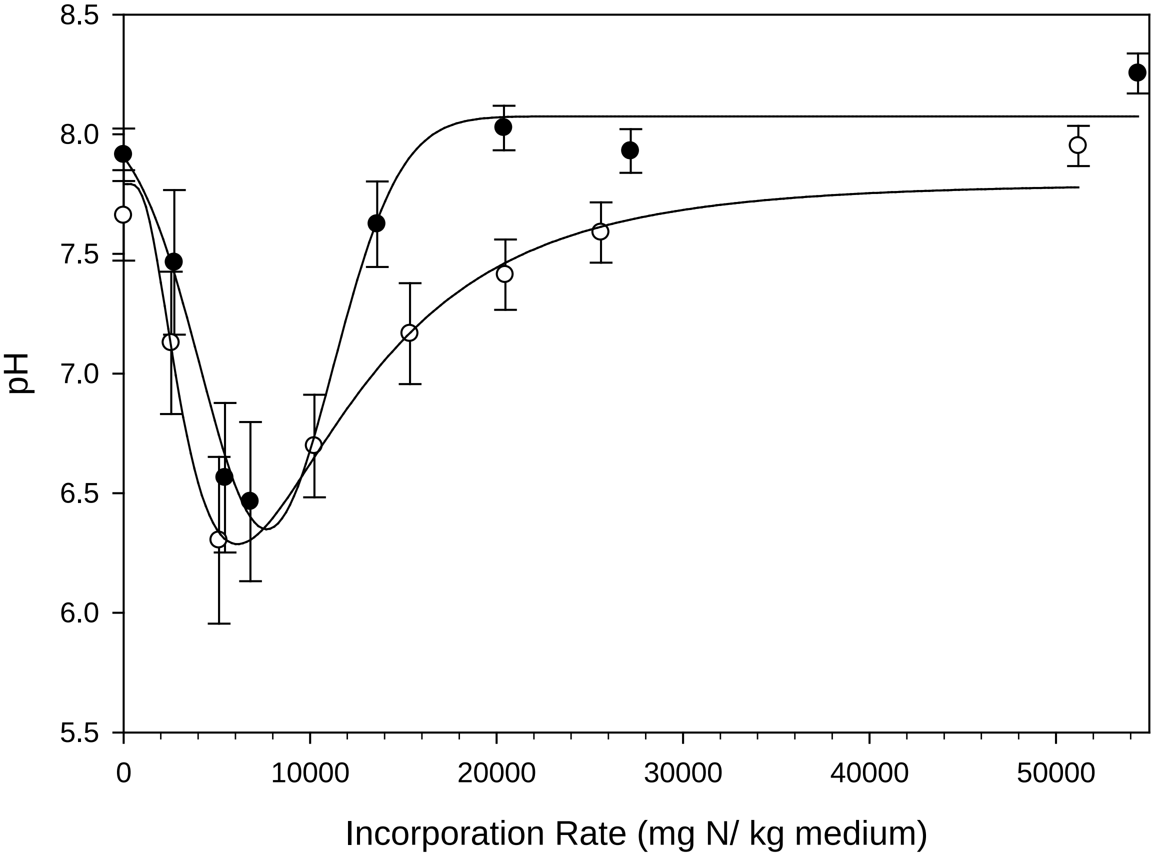

Figure 4.2. Relationship between pH of the amended medium and the rate of application of blood meal and feather meal. The pH was measured at the end of each trial. Error bars indicate standard error of the means. Best fit regression of data points determined in SigmaPlot. (●- Blood meal (p<0.0001), ○- Feather meal (p<0.0001)

CHAPTER 5

EVALUATION OF ORGANIC FERTILIZERS FOR THE PRODUCTION OF COOL SEASON VEGETABLE TRANSPLANTS

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Abstract

The production and consumer demand for organic fruits and vegetables is on the rise and with that rise comes greater demand for quality transplants. The use of incorporated organic fertilizers offers an opportunity to fertilize transplants throughout the growing period and to utilize sustainable materials that can be available locally. The objective of this study was to evaluate the effects of four organic fertilizers [bat guano (BG), blood meal (BM), broiler litter (BL), and feather meal (FM)] against a water soluble inorganic fertilizer treatment [Peter's All Purpose (IFT) (20-20-20)] on growing substrate pH and EC and on the growth of broccoli, cabbage, and lettuce. The organic fertilizers were applied, at planting, at 2000 mg N/ kg medium (Trial 1) and 4000 mg N/ kg medium (Trial 2), while the inorganic fertilizer was applied weekly at 200 mg N/ kg water. The plant mortality in the two trials was typically highest for BM and FM. The pH of the amended media was measured at three points during the plant growing period. Broiler litter initially raised the media pH above 8 for both treatment levels, and the other fertilizers did not initially affect the media's pH. Blood meal and feather meal, at 4000 mg kg^{-1} (Trial 2), did reduce the pH <7 for the three species by the midpoint of the study and increased again by the end of the study. The dry weights of the plants were higher at 4000 mg N/kg medium (Trial 2) than at 2000 mg N/kg medium (Trial 1). There were no differences in leaf number and leaf areas of plants among fertilizers. At 2000 mg N/ kg medium (Trial 1), the highest chlorophyll readings were associated with the IFT, BM, and FM treatments in broccoli, while at 4000 mg N/ kg medium (Trial 2), BM tended to have the highest chlorophyll readings. In broccoli, cabbage, and lettuce, the highest N concentration at 2000 mg N/ kg medium (Trial 1) was for IFT, while at 4000 mg N/ kg medium (Trial 2), it varied among the fertilizers for the

species. The organic fertilizers surpassed the inorganic fertilizer treatment plant biomass when the incorporation rate was 4000 mg N/ kg medium and similar with the IFT for the other measured attributes. The high mortality rate of the seedlings was attributed to ammonia toxicity and the pH change observed with the BL treatment suggests more information is needed about the effect of organic fertilizers on the potting medium, seed germination, and seedling growth.

Introduction

The world production of organic vegetables is currently increasing which can cause an increase in demand for certified organic transplants (Willer et al, 2008). Producers need availability of local materials that may be used as organic fertilizers for vegetable transplants. The use of transplants is highly recommended as transplants offer many benefits, such as earlier planting in the field, earlier yield, better field establishment, predictability of yield, and timing of maturity of the fruit (Dufault, 1993). The nutrition of the transplants can have significant effects on the final yield of the vegetable and would require greater knowledge of the nutrient availability of organic fertilizers (Dufault, 1998). In transplant production, the time spent growing transplants can be shorter than the time needed to decompose the organic N forms in organic fertilizers (Hadas and Kautsky, 1994). The N release rates for many organic fertilizers have been studied and show considerable variation among the different types of fertilizers (Table 5.1). The hypothesis of this study was that the organic fertilizers contained the necessary amount of N to produce quality transplants. The objective of this study was to evaluate the effects of BG, BM, BL and FM for the production of high quality, broccoli (*Brassica oleracea* ‘De Cicco’), cabbage (*Brassica oleracea* ‘Red Express’) and lettuce (*Lactuca sativa*

'Green oakleaf') transplants. The variables measured included: plant heights, media pH, the number of empty cells at the end of the transplant growing period, stem diameter, leaf number, leaf area, dry weights of leaf, stem, and root tissue, root: shoot ratio, chlorophyll level, and shoot nitrogen concentration for broccoli, cabbage, and lettuce transplants. The variables were determined to evaluate the overall growth and quality of the transplants.

Materials and Methods

Certified organic seed of lettuce (*Lactuca sativa*) 'Green oakleaf', cabbage (*Brassica oleracea*) 'Red Express', and broccoli (*Brassica oleracea*) 'DeCicco' (Johnny's Selected Seeds, Winslow, ME) were planted in 200 cell Styrofoam trays (Speedling, Inc, Sun City, Fl) filled with organic medium (Fafard FOF 20,Conrad Fafard, Inc, Agawam, MA).The medium was composed of 70% Canadian Sphagnum Peat, perlite, dolomitic limestone, gypsum, and Perdue-AgriRecycle Microstart60 (4N-2P_2O_5-3K_2O).

Styrofoam trays were chosen for their ability to be easily cut in to smaller sections for the layout of this study. The trays were cut into three sections with each section being 10 cells wide by 6 cells wide. The trays were then washed, sterilized in a 10% water-bleach solution, and allowed to dry before being filled with the substrate.

Bat guano (BG) (10N-2P_2O_5-1K_2O, Ancient Organics, Chico, CA), blood meal (BM) (13.6N-0P_2O_5-0K_2O, Boer Commodities, Inc, Fresno, CA) , broiler litter (BL) (3N-2P_2O_5-2K_2O, Stutzman Environmental Products, Canby OR), and feather meal (FM) (12.8N-0 P_2O_5-0K_2O, Boer Commodities, Inc, Fresno, CA) were evaluated in this trial as sources of nitrogen for seedling growth. Peter's All Purpose (20N-20P_2O_5-20K_2O, Scott's Company, Marysville, OH) was used as an inorganic fertilizer treatment.

The rate of fertilizer incorporation was based on rate for organic amendments from previous studies in the literature (Table 5.1). Organic fertilizers were mixed in the substrate at a concentration equivalent to 2000 mg N/ kg medium for Trial 1. Based on observations of reduced transplant growth in Trial 1, the N rate was doubled to 4000 mg N/ kg medium for Trial 2. The fertilizer and medium were mixed for several minutes with intermittent misting sprays of water to hydrate the media mix. Once thoroughly mixed, the trays were filled with the media mixture. The inorganic fertilizer (Peter's All Purpose) was applied weekly at 200 mg N/ kg water.

The seeds in Trial 1 were started 14 Feb for the broccoli, 15 Feb for the cabbage, and 22 Feb for the lettuce. The planting date for Trial 2 was 6 Sep for all species. The seeds were planted (2 seeds per cell) about 6mm deep in the media. The seeding rate was determined to be best for ensuring maximum germination percentages.

The irrigation system was the Sterling 8 Controller (Superior Controls Co, Inc, Valencia, CA). This system used overhead misting heads to reduce water stress in the seedlings and soil evaporation. The system was scheduled to irrigate three times a day for 2 minutes each early in the study and then increased to five times a day for 3 minutes each. Additional watering was done by hand with a hand sprayer and water hose, as necessary to prevent seed or seedling drought stress.

Plant height was measured from the substrate surface to the highest growth point (broccoli and cabbage) or the tip of the longest leaf (lettuce).

The germination percentages were recorded to determine adverse seed effects, such as seed inhibition, from the organic fertilizers on germination. The percentage of empty cells was recorded at the end of each trial to determine seedling mortality. The percentage of empty cells was subtracted from 100% to determine the percentage of plants remaining ("Plant Survival"). "∆Plant Number" was calculated as the difference between the percentage of plants remaining and the last germination percentage. "∆Plant Number" was used to determine the percentage of plants lost during the study and any delay in germination due to fertilizer treatment.

The media pH was measured *in situ* with a pH meter (IQ 150 pH meter, Spectrum Technologies, Plainville, IL) using the ISFET probe. Five cells per tray were measured three times during the trial (0 DAS to 50 DAS).

Electrical conductivity (EC) of the organic fertilizers was determined prior to the study to estimate their potential influence on the salinity of the amended media. The fertilizers were added to distilled water in amounts equivalent to 1000 mg N/ kg water increments in Erlenmeyer flasks. The flasks were sealed and placed on a shaker bed for 5 mins, then allowed to settle before measuring the EC with a pH/conductivity meter (D-24 EC/pH meter, Spectrum Technologies, Inc, Plainfield, IL) with an EC probe. The solution in the flask was amended to the next N rate level and the measuring process was repeated. This method was repeated four times for each fertilizer, with KCl used as the standard.

Dry weight of roots, stems, and leaves was determined by drying in an oven at 65 °C for 4 d. Since lettuce plants lack typical stem structures due to their short internodes, the basal material for leaf support was added to the leaf dry weights. The root-shoot ratio was calculated from the shoot (stem + leaves) and the root dry weights. The basal stem diameter was measured (20 plants per experimental unit) 1 cm above the substrate surface with a digital micrometer. The number of leaves was counted per replicate and calculated per plant.

Leaf area of detached leaves was measured with a leaf area meter (LI- 3000 Portable Leaf Area Meter, LI-COR Environmental, Lincoln, NE) attached to a Transparent Belt Conveyor Accessory (LI-3050, LI-COR Environmental, Lincoln, NE). The total leaf area was measured for each replicate and calculated per plant for each treatment.

Relative leaf chlorophyll level was measured with a chlorophyll meter (SPAD-501 Chlorophyll Meter, Spectrum Technologies, Inc, Plainfield, IL) for each replicate at the end of each trial. Five measurements were recorded for one leaf per plant.

Nitrogen concentration of the shoots material was determined at the University of Georgia Plant, Soil and Water Analysis Laboratory (Athens, GA). The dried plant material from the stem and leaf dry weight measurements was combined and ground with a bench-top plant tissue grinder using a #60 sieve.

The design was a randomized complete block with four replications and five treatments (fertilizers). Each plant species was laid out on a single bench in a glass greenhouse. Data analysis for each species was performed with the General Linear Model Procedure in SAS software (SAS Institute Inc., ver. 9.1) using the Duncan's Multiple-Range Test (alpha=0.05) to separate the treatment means.

Results

Trial 1 (2000 mg N/ kg medium)

pH

For broccoli, the substrate pH was >7 for all fertilizer treatments during the growing period. In the beginning and the middle of the growing period, the pH levels of IFT and FM were significantly lower than those of the other treatments (Fig. 5.1). At the end of the broccoli trial, the IFT treatment had the lowest pH (7.5), while the BM, FM, and BL treatments had pH> 8 at the end of the growing period. For cabbage, the pH levels were >7 throughout the trial period (Fig. 5.1). At day 22 and day 35, the pH was greatest in the BL treatment, while the pH was lowest in the IFT treatment. At the end of the growing period, FM had the highest pH (8.4). The lettuce transplants had similar results with the pH levels > 7 (Fig. 5.1). Broiler litter had the highest pH levels at day 14 and FM had the highest at day 31. The IFT treatment had the lowest pH early in the study, and at the end. In the end, BM, BL, and FM had the highest pH increase, with levels > 7.5.

Heights

At 13 days after seeding (DAS), BL resulted in the tallest broccoli plants, while at 28 DAS, the BG, BL, and IFT treatments produced the tallest plants (Table 5.2). The smallest plants at 13 DAS and 28 DAS were in the BM and FM treatments. At the end of the broccoli trial, the IFT treatment resulted in the tallest plants, while the BM and FM treatments had the shortest ones. For cabbage, BL produced the tallest plants and BM the shortest plants at 14 DAS (Table 5.2). At the end of the cabbage trial, the IFT treatment had the tallest plants, while BM and FM had the smallest ones. The lettuce transplants responded similarly to fertilizers as broccoli and cabbage. The inorganic fertilizer treatment and bat guano resulted in the tallest plants, while FM and BM produced the smallest plants at 14 DAS (Table 5.2). At the end of the lettuce study, the IFT treatment resulted in the tallest plants, while the shortest ones were in the BM treatment.

Percentage of Empty Cells

Blood meal and feather meal had significantly higher percentage of empty cells per tray for broccoli at 47% and 53%, respectively, and for cabbage transplants at 61% and 35%, respectively (Table 5.3). For lettuce, the FM treatment had higher percentage of empty cells (20%). There was a negative correlation between the percentage of empty cells and the electrical conductivity of the fertilizers in broccoli and cabbage, but no correlation in lettuce (Table 5.4).

Stem Diameter

For the broccoli, cabbage, and lettuce transplants, the IFT treatment had the largest stem diameter (Table 5.5). The BG and BM treatments had the smallest stem diameters in broccoli, FM in cabbage, and BM in lettuce. Root dry weight and stem diameter were positively correlated in cabbage and lettuce, but not related in broccoli (Table 5.4).

Leaf Number

Broccoli transplants had the maximum number of leaves in BM, IFT, and FM, and the minimum number of leaves in BG and BL (Table 5.6). Cabbage had the largest number of leaves per plant in IFT and the smallest in BG (Table 5.6). In lettuce, the BG fertilizer treatment resulted in the highest leaf number, while the BM and FM treatments had the lowest number (Table 5.6).

Leaf Area

Leaf areas for broccoli, cabbage, and lettuce were largest in IFT (Table 5.6), and for lettuce areas were smallest in BM and FM. The correlation between leaf area and leaf number was positively significant for cabbage and lettuce (Table 5.4).

Leaf Chlorophyll

The highest chlorophyll reading for broccoli and lettuce was in BM, IFT, and FM (Table 5.6). For cabbage and lettuce, the highest chlorophyll reading was in IFT, while for broccoli the lowest chlorophyll reading was in BL (Table 5.6).

Dry Weights

The dry weights (leaf, stem, and root) were recorded at the end of the trial. The leaf dry weights for the broccoli, cabbage, and lettuce transplants were highest for IFT and lowest in BG, BM, and BL (Table 5.7). The highest stem dry weights for broccoli and cabbage were in IFT. Blood meal and feather meal in cabbage had the smallest stem dry weights. Broccoli and cabbage root dry weights were largest in IFT, while lettuce root dry weights were largest in BG, BL, and IFT (Table 5.7). Root dry weight for cabbage was lowest in FM, and for lettuce in FM and BM. There were significant positive correlations between leaf area and leaf dry weight in broccoli, cabbage, and lettuce, and between leaf dry weight and leaf number in cabbage and lettuce (Table 5.7).

For all the organic fertilizer treatments, the root and shoot dry weights were lower compared to IFT by as much as 67%, with the lettuce root dry weights showing significant differences between the treatments (Table 5.8).

Root/shoot Ratios

The BL treatment had the largest root/shoot ratio for lettuce and broccoli, with a value of 0.68 and 0.29 respectively, while BM had the highest ratio for cabbage at 0.34 (Table 5.7).

Shoot nitrogen Concentration (%)

In broccoli, the highest shoot N concentration was in IFT, while in cabbage the highest was in BM and IFT (Table 5.9). In broccoli and cabbage, the lowest N concentration was in BG and BL (Table 5.9). In lettuce, there were no significant differences in N concentration between the treatments (Table 5.9).

Germination Effects

The effects of the fertilizers on seed germination and seedling survival were analyzed from the initial germination measurements and the percentage of empty cells at the end of each plant species trial. ∆Plant Number was the difference between the final plant number per tray and the number of plants at the last germination measurement. Fertilizers had no significant effect on the germination of broccoli but did affect the number of remaining plants, with BM and FM having the largest loss of broccoli seedlings, with 44.2% and 50.4%, respectively (Table 5.10). In cabbage, there was reduced germination by BM, and there was increased seedling mortality in FM and BM (Table 5.10). The germination of lettuce seeds was unaffected by fertilizer treatments, and there were plant losses of 15.4% and 10% in FM and BM, respectively (Table 5.10).

Trial 2 (4000 mg N/ kg medium)

pH

In broccoli, the BL treatment had the highest pH at 2 DAS and 21 DAS. The lowest pH levels were in the BG treatment at 2 DAS and in BM and FM treatments at 21 DAS (Fig. 5.1). In cabbage, the highest pH was in BL for all three measurement points, and the lowest pH levels were in BG at 2 DAS and in FM at 23 DAS and 48 DAS (Fig. 5.1). The greatest pH levels in lettuce were in BL at 2 DAS and 22 DAS (Fig. 5.1). At 2 DAS, the lowest pH level was in BG, at 22 DAS and 48 DAS the pH in FM was among the lowest.

Heights

In broccoli, the tallest transplants at 16 DAS were in BG and at 39DAS in BM, while the shortest one at 16 DAS were in BM and FM and at 39 DAS in IFT (Table 5.2). In cabbage, the tallest transplants at 19 DAS were in BG and at 45 DAS in BG and BL, while the shortest ones at 19 DAS and 45 DAS were in BM (Table 5.2). In lettuce the tallest transplants at 17 DAS were in BG and at 44 DAS in BG and FM (Table 5.2). In lettuce, the smallest transplants at 17 DAS were in BM and at 44 DAS in BM and IFT.

Percentage of Empty Cells

In broccoli, the percentage of empty cells per tray was not significant among treatments (Table 5.3). In cabbage, the highest percentages of empty cells per tray were in BM and FM, while in lettuce the highest percentages were in BG and FM (Table 5.3). In cabbage, there was a negative correlation between the percentage of empty cells at the end of the trial and the electrical conductivity of the organic fertilizers (Table 5.4).

Stem Diameter

In broccoli the smallest stem diameter was in IFT, while in cabbage stem diameter was not affected by fertilizers ($p>0.05$) (Table 5.5). In lettuce the largest stem diameters were in BG and FM (Table 5.4). The correlations between root dry weight and stem diameter were positive for cabbage and lettuce transplants (Table 5.4).

Leaf Number

In broccoli, the transplants with largest number of leaves were in BM, while the smallest number of leaves was in BG and BL (Table 5.6). In cabbage, the FM treatment had the most leaves and BL and IFT treatments had the least (Table 5.6). In lettuce, the BG and FM treatments produced the largest number of leaves (Table 5.6).

Leaf Area

Broccoli leaf area was smallest in the IFT treatment, while cabbage and lettuce the leaf areas were not significantly different among fertilizer treatments ($p>0.05$) (Table 5.6). There was a positive correlation between leaf area and leaf number for broccoli, cabbage and lettuce (Table 5.4).

Chlorophyll

Broccoli and lettuce chlorophyll levels were highest in the BM treatment, while cabbage chlorophyll levels were not significantly different among treatments ($p>0.05$) (Table 5.6).

Dry Weights

In broccoli leaf dry weights were highest in BG, BM, and FM and in lettuce in BG and FM (Table 5.7). In cabbage, leaf dry weight was lowest in IFT and in lettuce in BM and IFT. In broccoli stem dry weight was lowest in IFT, while in cabbage, stem dry weight was not significantly different among fertilizers ($p>0.05$) (Table 5.7). In broccoli root dry weights were highest in BL (Table 5.7), while in cabbage and lettuce root dry weights were not significantly different among fertilizers ($p>0.05$) (Table 5.7). Leaf dry weight and leaf area and number were positively correlated for broccoli, cabbage, and lettuce (Table 5.4).

In broccoli, except for BM, all fertilizers had values of root dry weight larger than in the IFT (Table 5.8). Broiler litter had the highest increase over IFT at 61.8%. The root dry weight differences over IFT were not significant for cabbage and lettuce. There were no differences in shoot dry weight among fertilizer treatments in broccoli, cabbage, and lettuce (Table 5.8).

Root/shoot Ratios

In broccoli and lettuce, root/shoot ratios were highest in BL (Table 5.7). In broccoli, root/shoot ratio was lowest in BM and in lettuce in FM. The root/shoot ratios for the cabbage plants were not different among treatment ($p>0.05$) (Table 5.7).

Shoot Nitrogen Concentration (%)

The broccoli transplants with the highest shoot N concentration were in BM and FM, and the ones with the lowest N concentration were in the BL and IFT treatments (Table 5.9). The cabbage transplants with the highest shoot N were in BM and FM, while the ones with the lowest N concentrations were in BL and IFT (Table 5.9). The N concentrations for the lettuce transplants were not significantly different among fertilizers (Table 5.9).

Germination Percentage

In broccoli, germination percentage and seedling survival were not different among treatments (Table 5.10). In cabbage, germination was highest in IFT and lowest in BL (Table 5.10). In cabbage the difference between seed germination at the beginning and the remaining plants at the end were positive in all treatments, but were not significantly different among treatments. In lettuce, germination percentages ranged from 55% (BM) to 95.8% (BG and IFT) (Table 5.10). In lettuce the differences between seed germination and percentage of remaining plants were negative for all treatments, but were not significantly different among treatments.

Discussion

Bat Guano

In the trial with the lower N rate [2000 mg N/ kg medium], BG reduced growth of broccoli, cabbage, and lettuce transplants, and there were fewer losses of plants when compared to the other organic fertilizers. This suggests BG does not restrict germination or seedling growth and has the ability to provide adequate nutrition at 2000 mg N/ kg medium for the three species studied. At the higher N rate [4000 mg N/ kg medium (Trial 2)], plant biomass in all fertilizers increased compared to IFT, but there was an increased number of lost seedlings in the BG treatment for lettuce. The loss could be attributed to the high levels of dissolved salts in BG (Figure 5.2), as high salinity can reduce seed germination or seedling survival (Leskovar and Stoffella, 1995). Bat guano, at the 4000 mg N/ kg medium rate, was able to produce plants of similar quality as to those produced by IFT and could be a potential component in organic substrates to produce vegetable transplants.

Blood meal

In Trial 1, at low N rate (2000 mg N/ kg medium), BM limited the growth of the transplants probably due to the slow release of N. The plant N concentrations in BM were inferior to those of IFT suggesting this incorporation rate was not adequate in providing sufficient N to the transplants by the end of the study. In Trial 2, at higher N level (4000 mg N/ kg medium), the transplants had values of N similar or larger than those of IFT, implying this level of N was adequate in producing quality transplants. The biggest concern with BM was the significant percentage of empty cells for all species (Table 5.3). Blood meal caused a severe loss in the number of plants by the end of the study for both N rates, except in the case of cabbage;

there was also a delay in seed germination (Table 5.10). Blood meal has been shown to release up to 66% of its total N within eight weeks of incorporation (Hartz and Johnstone, 2006). The loss of plants during the growing period could be attributed to the early release of large amounts of inorganic forms of N, such as ammonia, which has the potential to delay seed germination, damage the seeds, or destroy the seedlings (Allred and Ohlrogge, 1964; Ells et al, 1991; Woodstock and Tsao, 1986). The negative impact on germination could postpone the planting dates and disrupt a producer's ability to depend on the timing of the yield. Blood meal was able to produce plants of quality similar to that of plants produced using IFT, but BM reduced seed germination and increased seedling mortality. Therefore, the use of BM incorporation should be kept at levels that would not cause severe losses in transplants.

Broiler litter

Trial 1, the BL treatment had a low number of empty cells for broccoli, cabbage, and lettuce and produced transplants of heights comparable to those of IFT, although the root and shoot dry weights were lower than those of IFT (Table 5.2, 5.3, & 5.8). In Trial 2, BL produced taller and heavier plants than those of IFT (Table 5.2 & 5.8). Díaz-Pérez et al (2008) found that incorporated BL was able to produce bigger tomato transplants versus compost. Based on the leaf chlorophyll readings and shoot nitrogen concentration, BL was not able to supply N as well as some of the other organic fertilizers or the IFT. The pH of the media amended with BL increased to pH > 8 (Fig. 5.1). This pH increase has been observed in previous studies and has been associated with the presence of $CaCO_3$. $CaCO_3$, as crushed limestone, is added to chicken feed to increase the thickness of egg shells and to combat a condition known as tibial dyschondroplaysia, a serious skeletal condition caused by calcium and phosphorus deficiency

(Henry and Pesti, 2002; Mokolobate and Haynes, 2002; Hue, 1992). The increase in pH can reduce nutrient availability and the alteration of soil pH has been shown to last up to 174 days (Dufault 1998; Clark et al, 2007). The calcium carbonate also increases soil buffering capacity which makes it difficult to adjust soil pH to preferred levels. The germination and subsequent seedling growth for the three species was unaffected at the lower BL rates, but there were losses in lettuce seedlings and delayed germination for cabbage and lettuce at the higher BL rates. This plant mortality could be caused by the high salt concentration in BL (Figure 5.2). The presence of salts has been shown to inhibit the germination of barley and sorghum, and could damage the root system of the seedlings (Bliss et al, 1986; Esechie, 1994, Leskovar and Stoffella, 1995). The use of BL has many benefits to the overall health of transplants, but could negatively impact seedling development of plant species that are not tolerant to moderate levels of dissolved salts or pH levels >7. Therefore, BL as a fertilizer should be used only when the tolerance of a species to BL is understood or the impacts on substrate chemical properties can be controlled.

Feather Meal

Feather meal as a fertilizer (at 4000 mg N/ kg medium) provided enough nutrition to increase plant size when compared to the IFT, but had deleterious effects on the initial seedling emergence and the final plant stand. Feather meal greatly increased the shoot dry weights of broccoli, cabbage, and lettuce, probably due to the high early release rate of inorganic N (Hartz and Johnstone, 2006; Hadas and Kautsky, 1994). This release could have made N available early in the development of the transplants, which can greatly influence the final height and dry weight of the shoot (Dufault, 1998). Related to the high N release was the reduction in seed germination and final number of plants, especially in Trial 2 (Table 5.10). There was also a delay in germination in cabbage seeds. These impacts have been noted in other species when the amount of ammonia reached critical levels in the substrate (Allred and Ohlrogge, 1964; Ells et al, 1991; Megie et al, 1967). The pH increased in the FM amended substrate, possibly due to increased ammonia concentration (Fig. 5.1). With the presence of ammonia in the substrate, nitrification could release excess H+ ions, which could explain the drop in pH observed in the higher N rate at the mid-point of Trial 2 (Fig. 5.1) (Englestad, 1985). This drop in pH could benefit the plants by making more nutrients available, thereby improving the growth and development of the vegetable transplants. The use of FM as a fertilizer source could provide adequate nutrition for the transplants but, at high rates, has the potential to severely limit the number of plants in the final stand. Feather meal should be used with caution in broccoli, cabbage, or lettuce and in lower quantities in conjunction with another organic fertilizer.

Conclusion

We evaluated bat guano, blood meal, broiler litter, and feather meal as organic fertilizers in the production of broccoli, cabbage, and lettuce transplants. While feather meal and blood meal have high N concentrations, they can have negative impacts on the final number of plants per tray. Broiler litter and bat guano offered a more balanced nutrition based on the amount of N, P, and K, but they can increase EC of the medium; broiler litter can also increase the pH of the propagating medium. A convenience of the organic fertilizers was the ability to incorporate the fertilizers in the medium and reduce time spent fertilizing after seeding. Organic fertilizers may present challenges in predicting their ability to release nitrogen and their effects on the physical and chemical properties of the medium. Much more research needs to be done to better understand and utilize organic fertilizers and amendments for producing organic vegetable transplants.

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Tables

Table 5.1. Net nitrogen release rates for organic fertilizers from the literature.

Author(s)	Fertilizer	N Use Rate (mg N/ kg medium)	Net N Release Rate	Length of Study (week)
Agehara and Warncke (2005)	Blood meal	92	56-61%	12
	Chicken manure	1501	37-45%	12
Chae and Tabatabai (1986)	Chicken manure	493	67%	26
Hartz and Johnstone (2006)	Feather meal	474	66%	8
	Blood meal	426	60%	8
	Seabird guano	351	61%	8

Table 5.2. Height of broccoli, cabbage, and lettuce transplants at different growth stages as affected by organic fertilizer.

Trial 1

	Heights (mm)							
	Broccoli			Cabbage			Lettuce	
Treatment	DAS 13	DAS 28	DAS 41	DAS 14	DAS 28	DAS 42	DAS 35	DAS 60
Bat guano	16.7 b[z]	33.3 a	54.1 b	14.6 b	29.5 ab	45.8 b	69.8 a	87.1 b
Blood meal	11.1 c	20.6 b	32.6 c	7.5 d	18.1 c	30.1 c	31.7 c	63.7 d
Broiler litter	18.9 a	35.1 a	51.6 b	15.7 a	30.6 a	47.9 b	55.0 b	88.8 b
Inorganic Fertilier	17.0 b	33.6 a	75.2 a	14.8 b	28.3 b	56.1 a	70.0 a	106.8 a
Feather meal	11.9 c	18.2 c	33.9 c	9.3 c	19.3 c	32.5 c	34.4 c	72.4 c
Significance	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

Trial 2

	Broccoli		Cabbage		Lettuce	
Treatment	DAS 16	DAS 39	DAS 19	DAS 45	DAS 17	DAS 44
Bat guano	43.4 a	74.5 ab	49.2 a	73.7 a	73.7 a	146.5 a
Blood meal	29.0 d	76.7 a	27.2 d	53.2 d	38.7 e	117.0 c
Broiler litter	33.0 c	70.5 bc	33.4 c	71.7 a	56.6 b	130.5 b
Inorganic Fertilizer	39.7 b	65.3 c	37.7 b	57.9 c	48.7 c	113.6 c
Feather meal	29.6 d	75.2 ab	33.2 c	64.6 b	43.7 d	150.9 a
Significance	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Means followed by the same letter are not significantly different within a column and trial (Duncan's Multiple Range Test α=0.05)

Table 5.3. Percentage of empty cells in the propagation tray as affected by type of fertilizer.

	Trial 1			Trial 2		
	Broccoli	Cabbage	Lettuce	Broccoli	Cabbage	Lettuce
Bat guano	1.3% b[z]	0.0% b	4.6% ab	4.6%	9.6% b	41.7% bc
Blood meal	46.7% a	61.3% a	10.4% ab	28.8%	56.3% a	66.7% a
Broiler litter	1.3% b	0.8% b	2.9% ab	5.4%	21.7% b	57.5% ab
Inorganic Fertilizer	0.4% b	0.4% b	0.8% b	2.9%	7.5% b	30.0% c
Feather meal	52.5% a	35.4% a	19.6% a	11.1%	42.5% a	68.8% a
Significance	*0.0006*	*<0.0001*	*0.0466*	*0.0539*	*0.0114*	*0.0052*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test α=0.05)

Table 5.4. Correlations among different plant growth attributes

Trial 1 Treatment	Leaf Area x Leaf DW	Leaf Area x Leaf Number	Leaf DW x Leaf Number	Root DW x Stem Diam	Emp Cell (%) x EC
Broccoli	0.83216[z]	0.33717	0.30516	0.37251	-0.78096
p	*<0.0001*	*0.146*	*0.1908*	*0.1058*	*0.0027*
Cabbage	0.98194	0.77951	0.7958	0.76678	-0.88341
p	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0001*
Lettuce	0.85289	0.60951	0.70574	0.8133	-0.55696
p	*<0.0001*	*0.0043*	*0.0005*	*<0.0001*	*0.0600*
Trial 2					
Broccoli	0.89223	0.5604	0.6114	0.04676	-0.53744
p	*<0.0001*	*0.0102*	*0.0042*	*0.8448*	*0.0882*
Cabbage	0.9782	0.57587	0.66106	0.70259	-0.78488
p	*<0.0001*	*0.0079*	*0.0015*	*0.0006*	*0.0025*
Lettuce	0.87658	0.78152	0.86079	0.83078	-0.44301
p	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.1492*

[z] Correlations determined with CORR procedure in SAS software; alpha=0.05

Table 5.5. Stem diameters as affected by the type of fertilizer.

	Trial 1			Trial 2		
Treatment	Broccoli	Cabbage	Lettuce	Broccoli	Cabbage	Lettuce
Bat guano	1.93 c[z]	1.85 c	3.48 b	1.52 a	1.32	3.17 a
Blood meal	1.89 c	1.73 cd	2.92 d	1.60 a	1.29	2.53 b
Broiler litter	2.01 bc	2.02 b	3.08 c	1.53 a	1.26	2.75 b
Inorganic Fertilizer	2.57 a	2.55 a	3.66 a	1.41 b	1.19	2.60 b
Feather meal	2.33 ab	1.71 d	3.18 c	1.60 a	1.30	3.30 a
Signficance	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0768*	*<0.0001*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test α=0.05)

Table 5.6. Leaf properties of broccoli, cabbage, and lettuce transplants as affected by type of fertilizer.

	Broccoli			Cabbage			Lettuce		
Trial 1 Treatment	Leaf Number	Leaf Area (cm^2)	Chlorophyll	Leaf Number	Leaf Area (cm^2)	Chlorophyll	Leaf Number	Leaf Area (cm^2)	Chlorophyll
Bat guano	3.7 b[z]	30.8 b	42.3 b	4.9 c	28.08 b	40.8 c	6.0 a	46.83 ab	6.7 b
Blood meal	4.6 a	27.1 b	47.5 a	4.9 bc	22.92 b	44.7 b	5.1 c	29.17 b	7.9 b
Broiler litter	3.7 b	28.5 b	39.5 c	5.2 bc	33.24 b	40.1 c	5.7 b	47.79 ab	7.0 b
Inorganic Fertilizer	4.5 a	65.1 a	48.1 a	5.7 a	72.66 a	48.4 a	5.9 ab	65.15 a	10.5 a
Feather meal	4.6 a	36.1 b	46.3 a	5.2 b	24.80 b	43.5 b	5.3 c	37.75 b	7.6 b
Significance	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0052*	*<0.0001*
Trial 2 Treatment	Leaf Number	Leaf Area (cm^2)	Chlorophyll	Leaf Number	Leaf Area (cm^2)	Chlorophyll	Leaf Number	Leaf Area (cm^2)	Chlorophyll
Bat guano	3.5 c[z]	34.39 a	31.3 b	5.1 c	23.81	36.7	6.7 a	114.27	9.11 b
Blood meal	4.5 a	37.46 a	35.5 a	5.6 b	21.07	37.7	5.9 b	64.25	11.10 a
Broiler litter	3.5 c	31.79 a	29.7 b	4.6 d	21.66	40.0	5.6 b	103.44	6.87 c
Inorganic Fertilizer	3.9 b	18.61 b	31.4 b	4.6 d	13.72	36.5	5.5 b	51.88	7.36 c
Feather meal	4.1 b	37.98 a	31.1 b	6.0 a	22.32	36.3	7.0 a	113.25	9.93 ab
Significance	*0.0001*	*0.0003*	*0.0035*	*<0.0001*	*0.2527*	*0.1122*	*<0.0001*	*0.0548*	*<0.0001*

[z] Means followed by the same letter are not significantly different within a column and trial (Duncan's Multiple Range Test α=0.05)

Table 5.7. Dry weights (g/plant) of broccoli, cabbage, and lettuce as affected by type of fertilizer.

Trial 1	Broccoli				Cabbage				Lettuce			
Treatment	Leaf	Stem	Root	R/S Ratio[y]	Leaf	Stem	Root	R/S Ratio	Leaf	Stem	Root	R/S Ratio
Bat guano	0.24 b[z]	0.13 b	0.097 b	0.26 ab	0.16 bc	0.10 bc	0.072 bc	0.28 ab	0.22 ab	N/A	0.12 a	0.53 b
Blood meal	0.23 b	0.10 b	0.075 b	0.23 ab	0.13 c	0.07 c	0.069 bc	0.34 a	0.14 c	N/A	0.06 b	0.44 b
Broiler litter	0.23 b	0.14 b	0.11 b	0.29 a	0.20 bc	0.12 b	0.086 b	0.27 ab	0.16 bc	N/A	0.11 a	0.68 a
Inorganic Fertilizer	0.37 a	0.33 a	0.17 a	0.25 ab	0.38 a	0.24 a	0.12 a	0.20 b	0.27 a	N/A	0.13 a	0.48 b
Feather meal	0.25 ab	0.11 b	0.076 b	0.22 b	0.14 c	0.07 c	0.056 c	0.27 ab	0.17 bc	N/A	0.07 b	0.43 b
Significance	*0.00092*	*<0.0001*	*<0.0001*	*0.0192*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0173*	*<0.0001*	*N/A*	*0.0001*	*0.0004*

Trial 2

	Leaf	Stem	Root	R/S Ratio	Leaf	Stem	Root	R/S Ratio	Leaf	Stem	Root	R/S Ratio
Bat guano	0.18 a	0.08 a	0.05 b	0.21 bc	0.11 a	0.07	0.04	0.22	0.32 a	N/A	0.08	0.25 bc
Blood meal	0.19 a	0.08 a	0.04 b	0.16 c	0.10 a	0.06	0.03	0.20	0.18 b	N/A	0.05	0.30 abc
Broiler litter	0.12 b	0.08 a	0.08 a	0.41 a	0.10 a	0.06	0.04	0.26	0.22 ab	N/A	0.08	0.39 a
Inorganic Fertilizer	0.10 b	0.06 b	0.05 b	0.29 b	0.07 b	0.05	0.03	0.26	0.14 b	N/A	0.05	0.36 ab
Feather meal	0.18 a	0.08 a	0.05 b	0.21 bc	0.11 a	0.06	0.03	0.21	0.35 a	N/A	0.08	0.22 c
Significance	*0.0007*	*0.0044*	*0.0002*	*0.0001*	*0.0120*	*0.3679*	*0.2766*	*0.2233*	*0.0248*	*N/A*	*0.0492*	*0.0282*

[z] Means followed by the same letter are not significantly different within a column and trial (Duncan’s Multiple Range Test α=0.05)

[y] R/S Ratio = root/shoot ratio

Table 5.8. Percent differences in root and shoot dry weights of the organic fertilizer treatments with respect to the inorganic fertilizer treatment.

	Root Dry Weight			Shoot Dry Weight		
Trial 1	Broccoli	Cabbage	Lettuce	Broccoli	Cabbage	Lettuce
Bat guano	-42.6% [y]	-41.3%	-9.8% a[z]	-46.1%	-57.0% ab	-18.0%
Blood meal	-55.2%	-43.8%	-54.2% b	-52.0%	-67.3% b	-50.3%
Broiler litter	-38.1%	-30.4%	-14.6% a	-47.8%	-46.8% a	-39.3%
Feather meal	-54.4%	-54.8%	-44.5% b	-48.6%	-66.4% b	-38.6%
Significance	*0.3157*	*0.1090*	*0.0015*	*0.9395*	*0.0311*	*0.0360*
Trial 2						
Bat guano	7.7% b	35.5%	72.3%	63.0%	56.7%	153.0%
Blood meal	-11.2% b	21.6%	6.4%	68.2%	43.6%	30.1%
Broiler litter	61.8% a	42.9%	53.4%	25.5%	36.2%	50.9%
Feather meal	4.7% b	14.4%	44.1%	73.6%	50.9%	144.7%
Significance	*0.0002*	*0.3823*	*0.2278*	*0.0795*	*0.4561*	*0.1403*

[z] Means followed by the same letter are not significantly different within a column and trial (Duncan's Multiple Range Test α=0.05)

[y] Difference (%)=[(Treatment DW-Inorganic Fertilizer Treatment DW)/Inorganic Fertilizer Treatment DW]*100

Table 5.9. N concentrations (g/g) in shoots of broccoli, cabbage, and lettuce as affected by type of fertilizer

	Trial 1			Trial 2		
Treatment	Broccoli	Cabbage	Lettuce	Broccoli	Cabbage	Lettuce
Bat guano	0.92 c[z]	1.14 c	0.86	1.86 ab	1.91 ab	1.88
Blood meal	1.09 b	1.52 a	0.95	2.53 a	2.17 a	2.03
Broiler litter	0.87 c	1.08 c	0.95	1.67 b	1.67 b	2.03
Inorganic Fertilizer	1.29 a	1.61 a	0.91	1.62 b	1.44 b	1.52
Feather meal	1.08 b	1.34 b	0.90	2.54 a	2.34 a	1.81
Significance	*<0.0001*	*<0.0001*	*0.4209*	*0.0254*	*0.0065*	*0.2582*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test α=0.05)

Table 5.10. Germination percentage in broccoli, cabbage, and lettuce as affected by type of fertilizer.

	Broccoli			Cabbage			Lettuce		
Trial 1	Germination (%)	Plant Survival (%)	ΔPlant Number[y] (%)	Germination (%)	Plant Survival (%)	ΔPlant Number (%)	Germination (%)	Plant Survival (%)	ΔPlant Number (%)
Bat guano	99.2	98.8 a[z]	-0.4 a	99.6 a	100.0 a	0.4 a	97.9	95.4 a	-2.5 a
Blood meal	97.5	53.3 b	-44.2 b	81.3 b	38.8 c	-42.5 c	99.6	89.6 ab	-10.0 ab
Broiler litter	98.8	98.8 a	0.0 a	100.0 a	99.2 a	-0.8 a	97.0	97.1 a	-0.4 a
Inorganic Fertilizer	98.3	99.6 a	1.3 a	98.3 a	99.6 a	1.3 a	99.2	99.2 a	0.0 a
Feather meal	97.9	47.5 b	-50.4 b	96.7 a	64.6 b	-33.1 b	95.8	80.4 b	-15.4 b
Significance	*0.5058*	*0.0006*	*0.0007*	*0.0212*	*<0.0001*	*<0.0001*	*0.1063*	*0.0466*	*0.0390*
Trial 2									
Bat guano	95.8	95.4	-0.4	57.9 ab	90.4	32.5	95.8 a	58.3 a	-37.5
Blood meal	92.9	71.3	-21.7	32.5 bc	43.8	11.3	55.0 d	33.3 b	-21.7
Broiler litter	95.0	94.6	-0.4	26.3 c	78.3	52.1	83.3 b	42.5 a	-40.8
Inorganic Ferilizer	94.9	97.1	-0.8	69.6 a	92.5	22.9	95.8 a	70.0 a	-25.8
Feather meal	96.7	88.9	-6.7	35.4 bc	57.5	22.1	71.7 c	31.3 b	-40.4
Significance	*0.3776*	*0.0539*	*0.0833*	*0.0117*	*<0.0001*	*0.0938*	*<0.0001*	*0.0142*	*0.4174*

[z] Means followed by the same letter are not significantly different within a column and trial (Duncan's Multiple Range Test α=0.05)

[y] ΔPlant Number= Plants Survival Percentage – Germination Percentage; This variable represents the percent change in number of plants between the final plant stand recording and the last germination measurement.

Figures

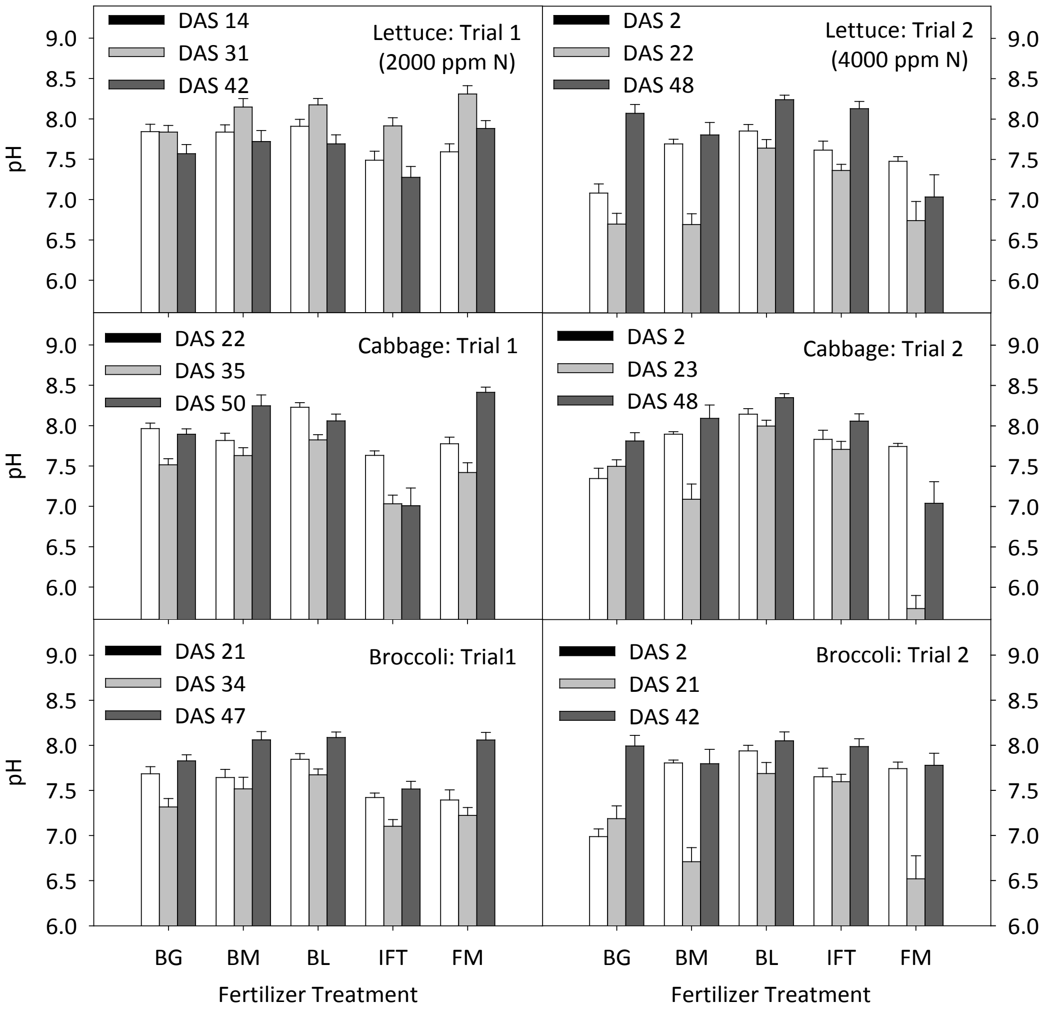

Figure 5.1. Effects of organic fertilizers on the pH of the amended media during the growth period of broccoli, cabbage, and lettuce. The measurements were taken at three different times in the study. The two trials are displayed horizontally while the three species are presented vertically. The error bars indicate the standard error within the trial.

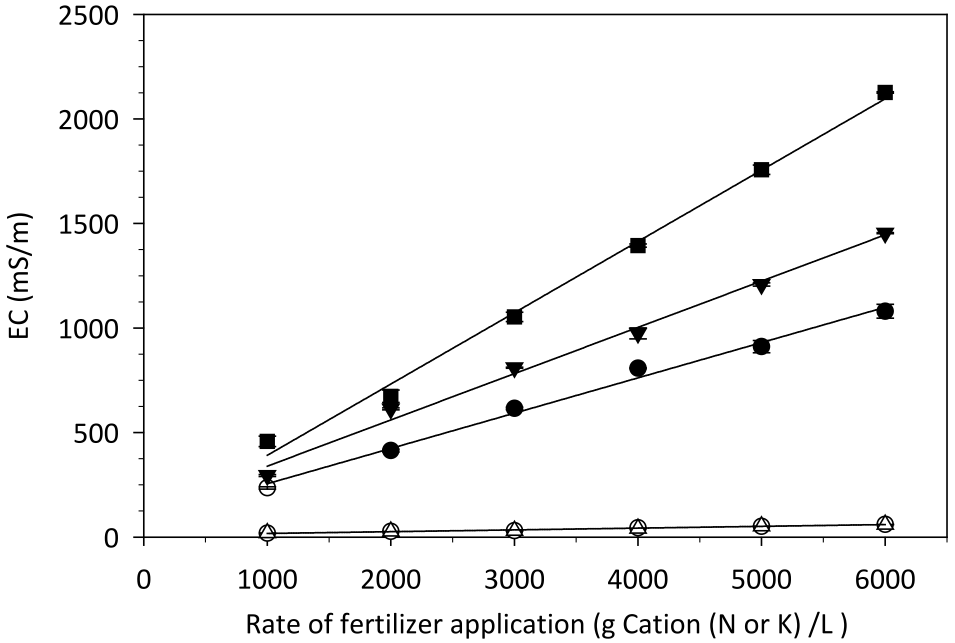

Figure 5.2. Influence of organic fertilizer amendment on the electrical conductivity of distilled water. KCl was used as a known reference. The error bars indicate standard error. ● -Bat guano (p<0.0001), △-Blood meal (p<0.0001), ▼-Broiler litter (p<0.0001), ○ -Feather meal (p<0.0001), ■ -KCl (p<0.0001))

CHAPTER 6

EVALUATION OF ORGANIC FERTILIZERS FOR THE PRODUCTION OF BASIL, TOMATO, AND WATERMELON TRANSPLANTS

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Abstract

The use of organic fertilizers for herb and vegetable transplant production is gaining interest as the need for organic transplants increases with a growing demand for organic produce. The application effects of single component organic fertilizers for transplant production are still poorly understood. The objective of this study was to evaluate the effects of four organic fertilizers [bat guano (BG), blood meal (BM), broiler litter (BL), and feather meal (FM)] and an inorganic fertilizer treatment [Peter's All Purpose (20N-20P_2O_5-20K_2O)] (IFT) as a control on the growing substrate pH and EC and the growth of basil, tomato, and watermelon transplants. The variables measured or calculated included: percentage of empty cells per tray, plant heights, media pH, root, stem, and leaf dry weights, root-shoot ratio, stem diameter, leaf number (per plant), leaf area, leaf chlorophyll levels, and N concentration of shoot material. There was a negative correlation between the percentage of empty cells in the tray (i.e., non-germinated seeds or dead plants) and the EC of the fertilizers in tomato and a positive correlation in watermelon. Most of the organic fertilizers outperformed IFT for the final plant heights of the three species. The media pH increased to >7 within the first 6 d in all of the fertilizer treatments and then decreased. Broiler litter raised the pH to >8 initially and maintained a pH > 7 throughout the study. Feather meal incorporation decreased the pH with time to levels < 7. Broiler litter produced the highest root dry weight and FM produced the highest stem and leaf dry weights for all species. Leaf area and leaf number measurements were greatest for the FM treatment. Chlorophyll levels in basil and watermelon were highest in BM and in tomato they were highest in FM. The N concentration in basil transplants was highest with the use of BM and FM, in tomato transplants with FM, and in watermelon with BM. Organic fertilizers

produced greater quality transplants than the IFT, but BM and FM produced fewer transplants, likely due to ammonia toxicity from the early release of inorganic N.

Introduction

The production of organic produce has increased worldwide with growth in demand as well as growth in the number of acres certified for organic production (Willer et al, 2008). This increase in production will create higher demands for certified organic vegetable transplants. In order to keep pace with this increase, producers must be able to use fertilizer sources that can be found locally, such as from animal processing facilities. The use of vegetable transplants has many benefits for growers, such as better field establishment, predictability of yield timing and amount, and earlier planting in the field (Dufault, 1993). Transplant nutrition requires understanding the fertilizer’s ability to make the nutrients available during the short time that transplants are produced and the impact on the final yield (Dufault, 1998). One aspect of interest is the release rate of N for organic fertilizers, as the bulk of the nitrogen is in the organic form and requires microbial decomposition to make the N available (Hadas and Kautsky, 1994). The N mineralization rates for blood meal, broiler litter, feather meal, and bird guano have been studied and have shown large amounts of variability in the amount of N released and the length of time required (Table 6.1). The objective of this study was to evaluate the effects of four organic fertilizers and an inorganic fertilizer treatment as a control on the growing substrate pH and electrical conductivity (EC) and the growth of basil, tomato, and watermelon transplants. The variables measured were percent of empty cells per tray, plant height, media pH, root, shoot, and leaf dry weight, root-shoot ratio, stem diameter, leaf number, chlorophyll level, and nitrogen concentration for basil, tomato, and watermelon transplants.

Materials and Methods

The organic fertilizers evaluated were bat guano (BG) (10N-2P_2O_5-1K_2O;Ancient Organics, Chico, CA), blood meal (BM) (13.6N-0P_2O_5-0K_2O; Boer Commodities, Inc, Fresno, CA), composted broiler litter (BL) (3N-2P_2O_5-2K_2O; Stutzman, Environmental Products, Canby, OR), and feather meal (FM) (12.8N-0P_2O_5-0K_2O; Boer Commodities, Inc, Fresno, CA). Peter's All Purpose (IFT) (20N-20P_2O_5-20K_2O; Scott's Company, Marysville, OH) was used as an inorganic fertilizer treatment. The organic fertilizers were incorporated with the medium at 4,000 mg N/ kg medium prior to seeding. The N fertilization rate was chosen based on preliminary data and the ranges of N mineralization and incorporation (transplants) in literature for organic fertilizers, from 91 mg N/ kg medium to 16,000 mg N/ kg medium (Thomsen et al, 2003; Díaz-Pérez et al, 2008). Peter's All Purpose was applied as a liquid feed in the irrigation water, once a week, at 200 mg N/ kg water, which was set based on the average recommendations of Styer and Koranski (1997) for the species in this study.

Seeds of tomato (*Lycopersicum esculentum*) 'Brandywine', basil (*Ocimum basilicum*) 'Genovese', and watermelon (*Citrillus lanatus*) 'Crimson Sweet '(Johnny's Selected Seeds, Winslow, Maine) were planted in Styrofoam trays filled with organic potting medium. The trays were 200 cell Styrofoam trays (Speedling, Inc, Sun City, FL). The trays were cut to 6 cells X 10 cells, washed thoroughly, and sanitized (between trials) with 10% bleach: water solution. The medium (Fafard's FOF 20, Conrad Fafard, Inc, Agawam, MA) was composed of 70% Canadian sphagnum peat, perlite, dolomitic limestone, gypsum, and Perdue-AgriRecycle Microstart60 (4-

2-3). The seeding rate was 2 seeds per cell. After germination, thinning was performed to one seedling per cell.

The irrigation system used overhead misting heads to control water stress and soil evaporation. The system was scheduled to irrigate five times a day for three minutes early in the study. This schedule helped to reduce drought stress on the seedlings. Additional watering was done by hand with a hand sprayer and water hose.

The media pH was measured *in situ* with a pH meter (IQ 150 pH meter, Spectrum Technologies, Plainville, IL) using the ISFET probe. Five cells per experimental unit were measured three times (up to 42 d) during the growth period for the species.

Electrical conductivity of the organic fertilizers was determined prior to the study to estimate their potential influence on the salinity of the amended media. The fertilizers were added to distilled water in amounts equivalent to 1000 mg N/ kg water increments in Erlenmeyer flasks. The flasks were sealed and placed on a shaker bed for 5 mins, then allowed to settle before measuring the EC with a pH/conductivity meter (D-24 EC/pH meter, Spectrum Technologies, Inc, Plainfield, IL) with an EC probe. The solution in the flask was amended to the next N rate level and the measuring process was repeated. This method was repeated four times for each fertilizer, with KCl used as the standard.

Plant height was measured twice during each trial from substrate surface to the tallest growth point on the plant. For tomato and basil transplants the height data from the two trials were averaged, while for watermelon height data from the two trials were analyzed separately because height was measured at different days after seeding.

Germination percentage was recorded to determine adverse seed effects of organic fertilizers on germination. To determine seedling mortality, the percentage of empty cells was recorded at the end of each trial. The percentage of empty cells was subtracted from 100% to determine the percentage of plants remaining (“Plant Survival”). The change in the number of plants per tray (“ΔPlant Number”) was calculated as the difference between the percentage of plants remaining and the germination percentage at the last germination measurement. This measurement was used to determine the percentage of plants lost during the study and any delay in germination due to fertilizer treatment.

Dry weight of roots, stems, and leaves of the three species was determined at the end of the study by drying plant samples at 65°C for 4 d. The root/shoot ratio was calculated from the shoot (stem + leaves) and the root dry weights. The basal stem diameter was measured (20 plants per experimental unit) 1 cm above the substrate surface with a digital micrometer.

The number of leaves was determined per plant. Leaf area of detached leaves was measured with a leaf area meter (LI- 3000Portable Leaf Area Meter, LI-COR Environmental, Lincoln, NE) attached to a Transparent Belt Conveyor Accessory (LI-3050, LI-COR Environmental, Lincoln, NE).

Relative leaf chlorophyll level was measured with a chlorophyll meter (SPAD-501 Chlorophyll Meter, Spectrum Technologies, Inc, Plainfield, IL) for each replicate at the end of each trial. One leaf of the same approximate growth stage per plant was measured at five separate points on the leaf and averaged by the chlorophyll meter.

N concentration of the shoots was determined per replicate at the University of Georgia Soil, Plant and Water Analysis Laboratory (Athens, GA). The dried stem and leaf tissue was combined and ground with a bench-top plant tissue grinder to pass through a #60 sieve.

The experimental design was a randomized complete block with five treatments (fertilizers) and four replicates. The study was conducted twice. The data were analyzed as a randomized complete block with the General Linear Model Procedure of SAS software (SAS Institute Inc., ver. 9.1) using the Duncan's Multiple-Range Test (alpha=0.05) to separate the treatment means. Pearson correlation coefficients were determined with the CORR procedure of SAS.

Results

Germination Percentage

The information in Table 6.2 shows the effect of fertilizers on germination and seedling mortality. In basil and tomato, there was no difference in germination percentage among fertilizers, but there was a significant loss in basil plants for BM (17.3%) (Table 6.2). In tomato, there was no significant difference between fertilizer treatments. In watermelon plant survival was lowest in BG and BL and there were significant reductions in ΔPlant Number in BG, BL, and IFT and delayed germination in BM.

The number of plants lost by germination inhibition and seedling mortality (measured as percentage of empty cells) was significant for basil and watermelon transplants (Table 6.3). For basil, BM had the highest percentage of empty cells at 29%, while for watermelon, BG had the highest percentage (14.8%). The percentage of empty cells was low in tomato and there was no difference among fertilizer treatments. The percentage of empty cells at the end of the trial was negatively correlated with EC (4000 mg kg^{-1}) in tomato and positively correlated in watermelon (Table 6.4).

Heights

Heights of basil plants showed greater variation among treatments early in development (17 DAS), and BG, BL, and FM had the tallest plants at the end of the trials ($p<0.05$) (Table 6.5). In the period between the two measurement times (21 days), basil plants more than doubled in height for all treatments. In tomato transplants, BG had the tallest plants 18 DAS, and BL and FM did 32 DAS. Tomato heights more than doubled between measurements (22 days) for all of the treatments except IFT. Watermelon transplants in FM and BM were tallest from 14 DAS to the end of the study (Table 6.4). From 19 DAS to 26 DAS, watermelon transplants in FM and BM doubled in height, while the transplants grown with the other treatments were <1.5times taller for the same period.

pH

In basil there was a decline of pH with time, except for FM, in which pH remained relatively unchanged throughout the study although it tended to be lowest at the end of the transplant growing period (Fig. 6.1). Broiler litter had the highest and FM the lowest pH values. All of the fertilizer treatments, except FM, changed the media to pH >7 at the beginning, and only BL and IFT remained with pH >7 until the end of the basil study. In tomato, BM, BL, and FM had declining trends in the media pH, while BG and IFT had increasing pH trends (Fig. 6.2). Feather meal and blood meal had pH ≤7 by the end of the tomato study, while the BL, BG, and IFT treatments kept the media's pH above 7.5 by the end of the tomato study (Fig 6.2). In watermelon, pH trends were similar to those of basil and tomato (Fig 6.3). All of the fertilizers, except FM, initially had substrate pH >7.5, with highest pH values occurring in BL and lowest ones in FM.

Dry Weights

In basil, BL had the highest root dry weight, while BM had the lowest (Table 6.6). FM had the highest basil leaf dry weights, and basil stem dry weights were not significantly different among fertilizer treatments. In tomato, root dry weight was highest for BL and lowest for BM and IFT, and tomato stem dry weight was highest for BL, BG, and FM, while leaf dry weights were larger for FM and lowest for IFT. In watermelon, root dry weights were not significantly different among treatments, and FM had the highest watermelon stem and leaf dry weights.

The basil and tomato transplants with the greatest root dry weight increase over IFT were in BL, while BM had a decrease in basil root dry weight (Table 6.7). In watermelon, there was no difference between the organic fertilizers over IFT, but all treatments had root dry weight increases. The largest basil shoot dry weight increase was in FM, while BG and FM produced the greatest shoot weight increase for watermelon. In watermelon, the lowest positive increase was in the BG, while BL had a negative difference.

Root/Shoot Ratios

The root/shoot (R/S) ratios were calculated from the root and shoot (stems + leaves) dry weights. In basil, the largest R/S ratios were in the BL and IFT treatments, while the smaller ratios were in the FM and BM treatments (Table 6.6). In tomato, the highest R/S ratio was in BL and the lowest ratios were in FM and BM. In watermelon, the largest R/S ratio was in BL and the smallest ratios were in FM and BM.

Stem Diameters

The stem diameters of basil transplants showed significant differences among the treatments, with the largest stem diameter being in FM and the smallest in IFT (Table 6.8). The largest tomato stem diameter was in BL, while the smallest one was in IFT. For watermelon, the largest stem diameter was in FM, and the smallest one in BL. Root dry weight and stem diameter were significantly correlated in tomato and watermelon, but not in basil ($p>0.05$) (Table 6.4).

Leaf Number

Feather meal had the largest number of leaves for basil, tomato, and watermelon, although in watermelon BM was also among the treatments with the highest number of leaves (Table 6.9). Broiler litter and IFT had the fewest leaves in basil, while IFT produced the fewest leaves in tomato. For all of the species, leaf number was positively correlated with leaf dry weight (Table 6.4).

Leaf Area

In basil, tomato, and watermelon leaf areas in FM were among the greatest (Table 6.9). The smallest leaf areas were in IFT and BL (basil), in IFT (tomato), and in BG, BL, and IFT (watermelon) (Table 6.9). For the three species, leaf area was positively correlated with leaf dry weight and leaf number (Table 6.4).

Chlorophyll

In basil, FM and BM had the highest chlorophyll readings (Table 6.9). In tomato, the highest chlorophyll readings were in the FM treatment. In watermelon, the highest chlorophyll readings were in BM, and the smallest in IFT.

Shoot Nitrogen Concentration (%)

For basil and watermelon transplants, BM had the highest shoot N concentration (Table 6.10). The IFT and BL treatment had the lowest N concentration in basil transplants. For tomato, the FM, BG, and BM treatments resulted in the highest concentration of N, and the lowest in BL. In watermelon, BG, BL, and IFT had the lowest N concentration.

Discussion

Bat Guano

Bat guano had no effects on the germination percentage of basil and tomato transplants, but resulted in a significant loss of plants for watermelon. This loss of watermelon plants could be attributed to the presence of dissolved salts in the guano and the salt sensitivity of the seeds or seedlings (Miyamoto et al, 1985). Bat guano increased final plant heights of basil and tomato over other organic treatments and IFT. There was moderate root and shoot growth for basil and tomato, and low shoot growth for watermelon (Table 6.6). Bat guano also maintained a higher R/S ratio compared to BM and FM, that there was less restriction on the root growth within the amended media with BG compared to BM and FM. Bat guano was not as favorable for shoot development as other fertilizers. It resulted in moderate to low levels of N (shoot) in basil and watermelon and would not be able to compete with FM and BM in N availability. Bat guano was able to increase the root and shoot dry weights (Table 6.7) when compared to IFT and would be an acceptable substitute for a conventional water soluble fertilizer as long as the EC levels of the amended media were monitored during critical growth periods.

Blood meal

Blood meal as a N source was able to produce transplants that were similar in height to or larger than the inorganic fertilizer treatment, but had negative effects on germination and plant survival. Blood meal resulted in an increase in plant height compared to IFT and was able to produce intermediate levels for root and shoot dry weights, leaf number, and leaf area for basil, tomato, and watermelon, respectively. It reduced the pH of the media five days after incorporation for all of the species studied. This effect was probably attributed to the rapid mineralization of N within the first weeks of incorporation (Hadas and Kautsky, 1994; Hartz and Johnstone, 2006). Hartz and Johnstone (2006) found that 51% of organic N was released (at 25°C) in the first week for BM. When NH_3-N is released in the presence of nitrifiers, nitrification occurs with the potential to release H^+ ions in the production of NO_2^--N (Sylvia et al, 2005). The conversion of NH_4^+-N to NH_3 also releases H+ ions in basic media environment (Engelstad, 1985). These excess H^+ ions can reduce the media pH, which may explain the pH reduction as seen in this study for BM. There was a significant mortality of basil and tomato plants after germination. This mortality could be related to the high release of ammonia early in the germination stage, which can inhibit germination, or destroy seeds (Allred and Ohlrogge, 1964; Ells et al, 1991; Woodstock and Tsao, 1986). While BM was able to increase the plant's dimensions compared to IFT, it also restricted seed germination and damaged emerging seedlings. Therefore, BM has potential for organic transplant production when the incorporation quantities are kept to a level that does not affect plant germination or inhibits seedling survival and growth.

Broiler litter

Broiler litter was effective at producing basil, tomato and watermelon transplants but it raised the EC and pH levels of the media. It had little impact on germination for basil and tomato, but was detrimental for watermelon seedlings with a 12% plant loss at the end of the trial. Plant mortality was attributed to dissolved salts in the BL which was determined to be 974 mS/m (± 26 mS/m) (Fig. 6.4). Goertz et al (1991) found that navy bean germination is negatively impacted by the osmotic potential from salt solutions and Miyamoto et al (1985) determined that salts can damage the hypocotyl of the emerging vegetable seedlings. High salinity levels would, in part, explain the positive correlation between the number of empty cells for the watermelon trays and the EC of BL (Table 6.4). The initial pH increase of the substrate that contained BL was consistent with previous studies and is attributed to $CaCO_3$ present in chicken manure (Mokolobate and Haynes, 2002; Naramabuye and Haynes, 2006; Hue, 1992). Calcium carbonate is added to chicken diets to increase shell thickness and to reduce the incidence of tibial dyschondroplaysia, a major skeletal problem related to calcium and phosphorus deficiency (Henry and Pesti, 2002). The pH increase by chicken manure was maintained throughout the study and has been shown to alter soil pH for up to 174 days (Clark et al, 2007). The liming potential of chicken manure has been shown to be useful as an amendment for acidic soils (Hue, 1992; Castillo et al, 2003; Mokolobate and Haynes, 2002). Compared to the IFT, the BL treatment increased root and shoot dry weights in basil and tomato, and shoot dry weight in watermelon. For watermelon seedlings, the rate of plant growth was faster than basil and tomato, which could be an issue in nutrient availability given the slower N release rate in BL compared to the other organic fertilizers, such as BM (Agehara and Warncke, 2005). Transplants fertilized with BL had moderate numbers of leaves and levels of N in all of the species, which is also attributed to the slower N release rate when compared to BM and FM. Broiler litter is a popular N source for transplant production, but has chemical properties that should be monitored to ensure proper nutrient availability and to prevent excessive salinity levels in the medium.

Feather Meal

Feather meal increased plant growth when compared to the IFT, but also increased plant mortality. The plant mortality could be attributed to ammonia toxicity in the medium from the N mineralization of FM (Allred and Ohlrogge, 1964; Ells et al, 1991; Woodstock and Tsao, 1986). Feather meal increased the heights of the basil, tomato, and watermelon, and it also had some of the highest shoot dry weights when compared to IFT. The FM treatment, compared to IFT, also increased root dry weight for tomato and watermelon, but decreased it for basil (Table 6.7). Feather meal reduced the pH of the amended media immediately after incorporation and kept it lower than the other fertilizers through the end of the study. This pH reduction could be attributed to the release of H^+ ions into solution during the nitrification process (Engelstad, 1985). The lower pH could contribute to increase nutrient availability and improve transplant growth. Feather meal also had higher leaf number, leaf area, and chlorophyll levels for the three species compared to the other fertilizers. This could be related to the rapid mineralization of N from FM, as determined by Hartz and Johnstone (2006), when the plant could readily uptake the N. Feather meal does have promise as a N source for organic transplant production, but should be used in moderated levels to lessen pH reduction and ammonia toxicity.

Conclusion

Bat guano, blood meal, broiler litter, and feather meal were able to meet many of the nutritional needs of basil, tomato, and watermelon transplants. These fertilizers could be useful materials as individual components for potting media used by growers worldwide trying to meet the increasing demand for organically produced vegetables. Each fertilizer had positive attributes that can be utilized in transplant production, such as the rapid release of inorganic N by blood meal and feather meal, which can provide N early in the plant growth stages. The increased root growth by broiler litter could allow greater root establishment, which helps the transplant during establishment in the field. Feather meal and blood meal may reduce the final transplant count, while bat guano and broiler litter can introduce elevated salinity levels. Also, broiler litter can increase the pH of the medium and thus affect the nutrient availability. Organic fertilizers produce high quality transplants but may be detrimental to seed germination and transplant growth in some species when used at high rates of application.

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Tables

Table 6.1. Net nitrogen release rates for organic fertilizers from literature.

Author(s)	Fertilizer	N Use Rate (mg N/ kg medium)	Net N Release Rate	Length of Study (week)
Agehara and Warncke (2005)	Blood meal	92	56-61%	12
	Broiler litter	1501	37-45%	12
Chae and Tabatabai (1986)	Broiler litter	493	67%	26
Hartz and Johnstone (2006)	Feather meal	474	66%	8
	Blood meal	426	60%	8
	Seabird guano	351	61%	8

Table 6.2. The effect of fertilizers on germination percentage and the percentage of plants per tray remaining at the end of the trial.

	Basil			Tomato			Watermelon		
Treatment	Germination (%)	Plant Survival (%)	ΔPlant Number[y] (%)	Germination (%)	Plant Survival (%)	ΔPlant Number (%)	Germination (%)	Plant Survival (%)	ΔPlant Number (%)
Bat guano	89.8	98.8 a[z]	9.0 a	99.8	98.5	-1.2	97.3 a	85.2 b	-12.1 b
Blood meal	88.3	71.0 b	-17.3 b	99.0	97.1	-1.9	82.1 b	91.3 a	9.2 a
Broiler litter	91.7	94.6 a	2.9 a	99.8	99.2	-0.6	94.4 a	87.9 b	-6.5 b
Inorganic Fertilizer	95.4	98.1 a	2.7 a	100.0	99.2	-0.8	96.9 a	92.9 a	-4.0 b
Feather meal	96.7	94.0 a	-2.7 a	99.2	96.5	-2.7	94.8 a	94.0 a	-0.8 ab
Significance	*0.1135*	*0.0043*	*0.0152*	*0.4087*	*0.3859*	*0.4018*	*0.0410*	*0.0292*	*0.0089*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test $p<0.05$)

[y] ΔPlant Number=Plant Survival – Germination Percentage; This variable represents the change in number of plants between the final plant stand and the last germination measurement. The difference (ΔPlant Number) was calculated to determine the effect of the fertilizers on the seedlings after germination and if any delay in germination occurred.

Table 6.3. Percentage of empty cells per tray for basil, tomato, and watermelon as recorded at the end of the trial.

	Percentage of Empty Cell		
	Basil	Tomato	Watermelon
Bat guano	1.3 b[z]	1.5	14.8 a
Blood meal	29.0 a	2.9	8.8 b
Broiler litter	5.4 b	0.8	12.1 ab
Inorganic Fertilizer	1.9 b	0.8	7.1 b
Feather meal	6.0 b	3.5	6.0 b
Significance	*0.0043*	*0.3859*	*0.0292*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test $p<0.05$)

Table 6.4. Correlations among plant attributes for basil, tomato, and watermelon plant.

	Leaf Area x Leaf DW	Leaf Area x Leaf Number	Leaf DW x Leaf Number	Root DW x Stem Diam	Empty Cell (%) X EC
Basil	0.83517[z]	0.81004	0.78658	-0.23409	-0.44523
p	*<0.0001*	*<0.0001*	*<0.0001*	*0.3205*	*0.1469*
Tomato	0.95563	0.88992	0.89487	0.79525	-0.64259
p	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*0.0242*
Watermelon	0.9828	0.81919	0.80875	0.45932	0.67082
p	*<0.0001*	*<0.0001*	*<0.0001*	*0.0416*	*0.0169*

[z] Correlations determined with CORR procedure in SAS; alpha=0.05

Table 6.5. Height (mm) of basil, tomato, and watermelon transplants recorded at intervals of DAS, with the final measurement at the trial termination.

	Basil		Tomato		Watermelon[y]			
	DAS 17	DAS 39	DAS 18	DAS 32	DAS 8	DAS 14	DAS 19	DAS 26
Bat guano	53.3 b[z]	156.5 a	66.2 a	134.0 b	49.2 a	89.6 c	90.7 c	128.8 c
Blood meal	35.4 e	136.9 b	51.9 d	107.4 c	42.4 c	98.9 b	112.5 b	218.8 b
Broiler litter	41.1 d	158.8 a	61.8 bc	142.7 a	37.5 d	73.8 e	77.9 d	110.8 d
Inorganic Fertilizer	46.5 c	144.0 b	59.6 c	99.5 d	45.8 b	83.2 d	82.1 d	103.0 d
Feather meal	56.8 a	162.5 a	63.0 b	146.2 a	48.4 a	113.7 a	123.7 a	261.9 a
Significance	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test $p<0.05$)

[y] Watermelon heights were not averaged and represent Trial 1 (DAS 8&19) and Trial 2 (DAS 14&26) measurements

Table 6.6. Dry weights (g/plant) at the end of the trial for basil, tomato, and watermelon transplants, as affected by the organic fertilizer bat guano (BG), blood meal (BM), broiler litter (BL), and feather meal (FM) and an inorganic fertilizer (IFT).

	Basil				Tomato				Watermelon			
	Root	Stem	Leaf	R/S Ratio[y]	Root	Stem	Leaf	R/S Ratio	Root	Stem	Leaf	R/S Ratio
BG	0.098 b[z]	0.099	0.18 b	0.38 ab	0.049 b	0.11 a	0.09 ab	0.28 b	0.05	0.14 c	0.12 c	0.22 b
BM	0.076 c	0.081	0.18 b	0.30 bc	0.033 c	0.07 b	0.08 b	0.22 c	0.05	0.19 b	0.18 b	0.15 c
BL	0.12 a	0.095	0.16 b	0.47 a	0.063 a	0.10 a	0.09 ab	0.33 a	0.05	0.10 c	0.11 c	0.27 a
IFT	0.090 b	0.080	0.16 b	0.41 a	0.033 c	0.07 b	0.06 c	0.31 ab	0.05	0.12 c	0.11 c	0.24 ab
FM	0.091 bc	0.120	0.23 a	0.25 c	0.048 b	0.12 a	0.11 a	0.21 c	0.06	0.25 a	0.22 a	0.14 c
Significance	*0.0019*	*0.0784*	*0.0015*	*0.0021*	*0.0009*	*0.0130*	*0.0027*	*0.0007*	*0.1089*	*<0.0001*	*<0.0001*	*0.0003*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test $p<0.05$)

[y] R/S: Root/shoot ratio. Shoot = stem + leaves

Table 6.7. Percent difference in dry weight for the organic fertilizers relative to the inorganic fertilizer.

	Root Dry Weight			Shoot Dry Weight		
	Basil	Tomato	Watermelon	Basil	Tomato	Watermelon
Bat guano	5.4% b[z]	47.6% b	3.1%	20.8% b	61.2%	14.6% b
Blood meal	-16.9% c	2.8% c	6.6%	13.0% b	37.2%	77.4% a
Broiler litter	28.2% a	92.9% a	8.0%	13.4% b	73.3%	-4.4% b
Feather meal	-0.7% bc	45.5% b	21.5%	54.4% a	95.9%	116.4% a
Significance	*0.0008*	*0.0003*	*0.2240*	*0.0392*	*0.0691*	*0.0009*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test $p<0.05$)

Table 6.8. Stem diameter in transplants of basil, tomato, and watermelon as affected by fertilizer

	Stem diameter (mm)		
	Basil	Tomato	Watermelon
Bat guano	1.51 c[z]	2.24 b	3.12 c
Blood meal	1.61 b	2.03 c	3.37 b
Broiler litter	1.49 c	2.37 a	2.89 d
Inorganic Fertilizer	1.42 d	1.79 d	3.01 cd
Feather meal	1.70 a	2.31 ab	3.62 a
Significance	*<0.0001*	*<0.0001*	*<0.0001*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test p<0.05)

Table 6.9. Leaf properties of basil, tomato, and watermelon transplants as affected by fertilizer

	Basil			Tomato			Watermelon		
	Leaf Number (plt^{-1})	Leaf Area (cm^2/plant)	Chlorophyll[y] Level	Leaf Number (plt^{-1})	Leaf Area (cm^2/plant)	Chlorophyll Level	Leaf Number (plt^{-1})	Leaf Area (cm^2/plant)	Chlorophyll Level
Bat guano	9.7 b[z]	55.09 ab	23.4 b	7.1 b	27.18 ab	26.5 b	4.1 b	33.80 c	25.1 cd
Blood meal	10.0 b	59.23 ab	24.6 a	7.2 b	23.63 b	26.5 b	5.3 a	55.49 b	27.7 a
Broiler litter	9.3 c	51.87 b	22.7 b	7.1 b	25.12 b	26.0 b	4.3 b	29.29 c	26.3 bc
Inorganic Fertilizer	9.1 c	45.81 b	22.7 b	5.6 c	15.36 c	25.2 b	4.3 b	29.40 c	24.5 d
Feather meal	10.8 a	67.07 a	25.3 a	8.4 a	33.86 a	28.1 a	5.5 a	70.70 a	27.4 ab
Significance	*<0.0001*	*0.0339*	*<0.0001*	*<0.0001*	*0.0111*	*0.006*	*<0.0001*	*<0.0001*	*<0.0001*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test $p<0.05$)

[y] Chlorophyll level measured with SPAD-501 chlorophyll meter

Table 6.10. Nitrogen concentration of basil, tomato, and watermelon shoot material at the end of the trial as affected by fertilizer

	Nitrogen Concentration (%)		
	Basil	Tomato	Watermelon
Bat guano	1.6 cb[z]	3.1 a	1.8 c
Blood meal	2.6 a	3.2 a	2.6 a
Broiler litter	1.3 c	1.6 b	1.9 c
Inorganic Fertilizer	1.4 c	2.7 ab	2.0 c
Feather meal	2.3 ab	3.5 a	2.4 b
Significance	*0.0050*	*0.0122*	*<0.0001*

[z] Means followed by the same letter are not significantly different within a column (Duncan's Multiple Range Test $p<0.05$)

Figures

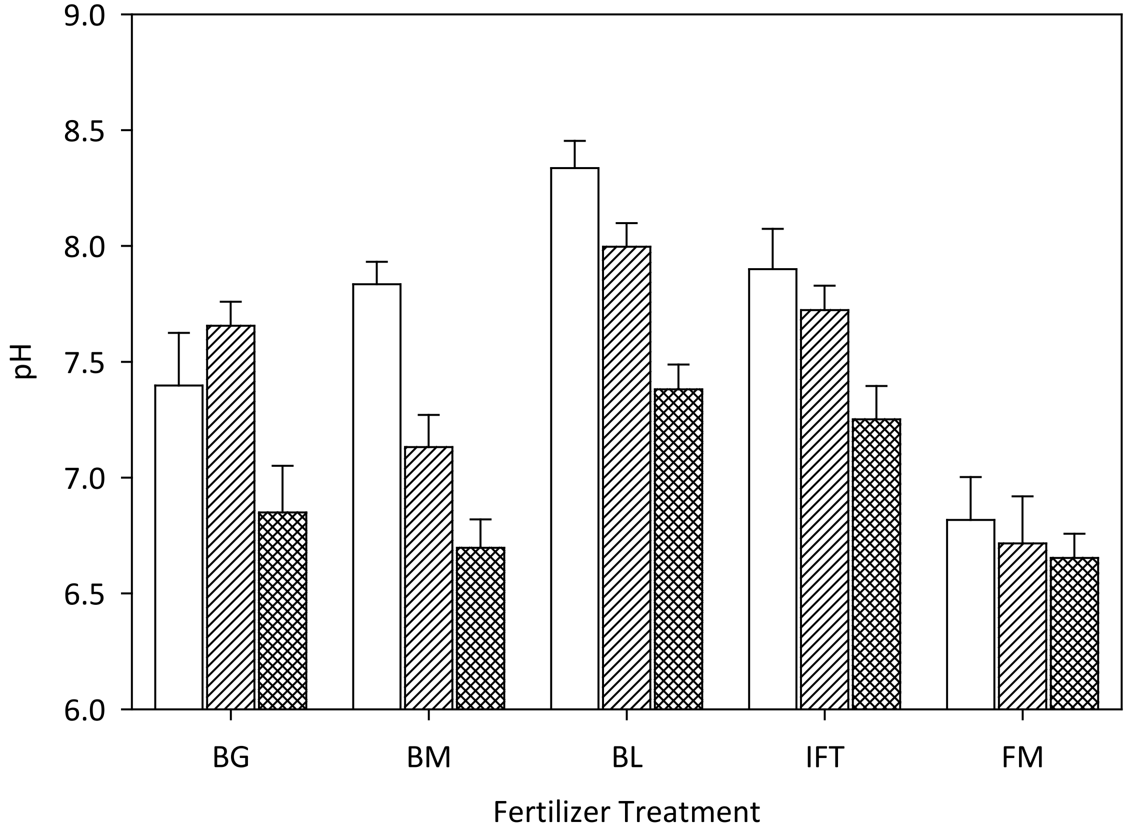

Figure 6.1. Changes in pH change in the basil plant root zone during the transplant growing cycle as affected by the fertilizers. Error bars indicate standard error. (□ 5 DAS, ▨ 13 DAS, ▩ 42 DAS) (BG-Bat guano, BM-Blood meal, BL-Broiler litter, IFT-Inorganic fertilizer treatment, FM-Feather meal)

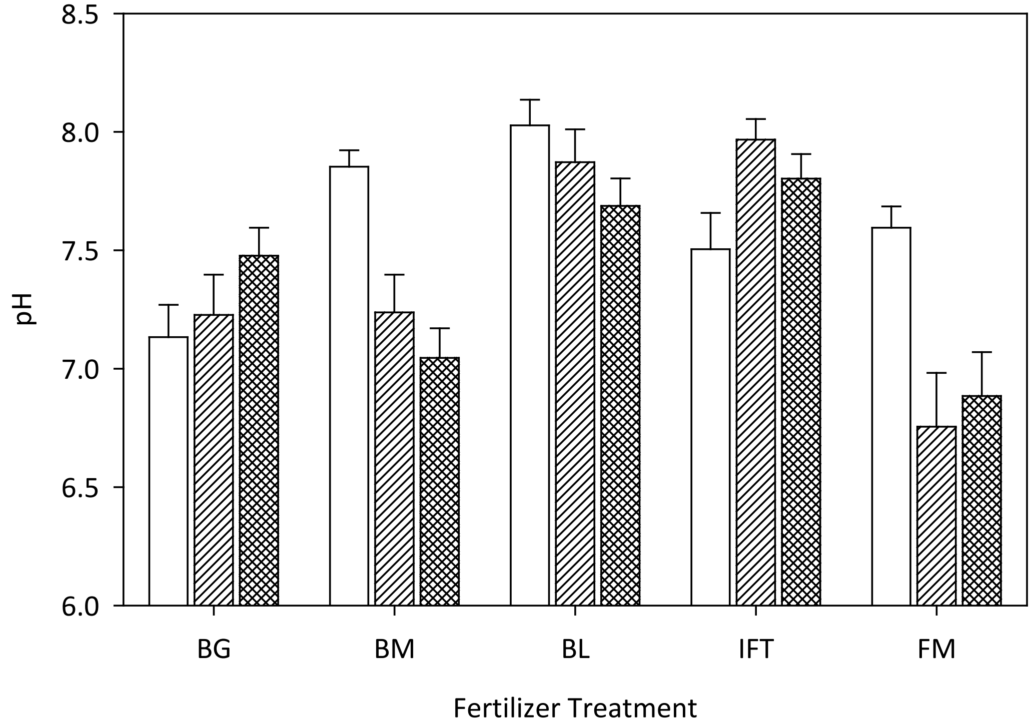

Figure 6.2. Changes in pH in the tomato plant root zone during the transplant growing cycle as affected by the fertilizers. Error bars indicate standard error. (□ 0 DAS, ▨ 13 DAS, ▩ 38 DAS) (BG-Bat guano, BM-Blood meal, BL-Broiler litter, IFT-Inorganic fertilizer treatment, FM-Feather meal)

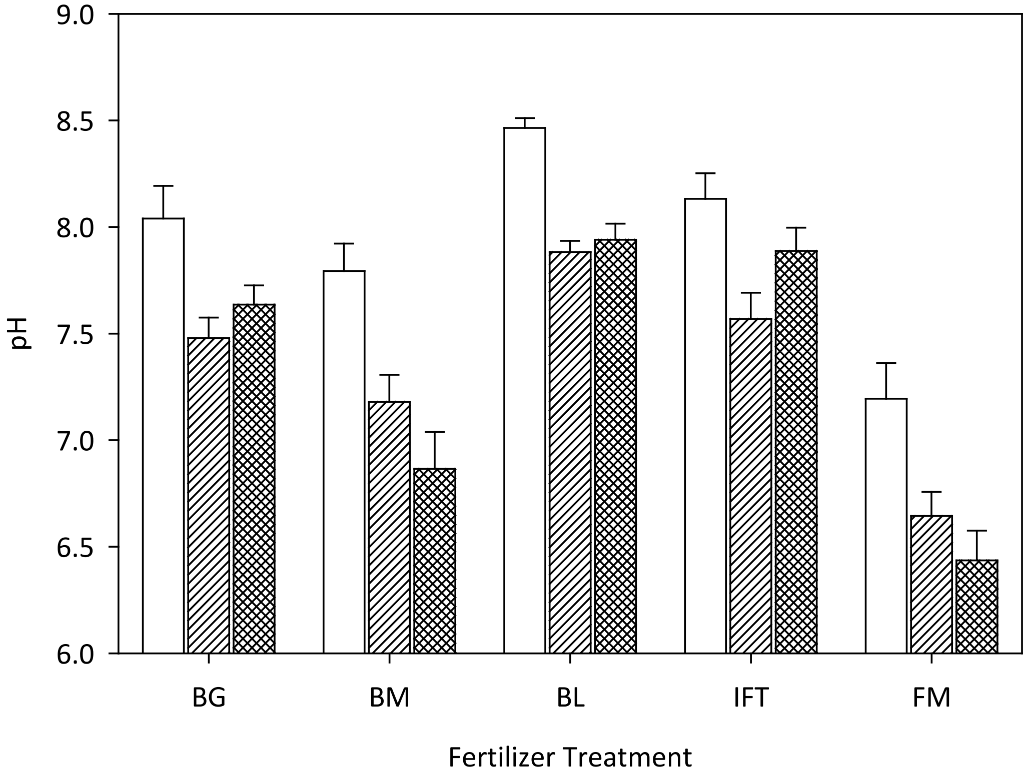

Figure 6.3. Changes in pH in the watermelon plant root zone during the transplant growing cycle as affected by the fertilizers. Error bars indicate standard error. (□6 DAS, ▨13 DAS, ▦28 DAS) (BG-Bat guano, BM-Blood meal, BL-Broiler litter, IFT-Inorganic fertilizer treatment, FM-Feather meal)

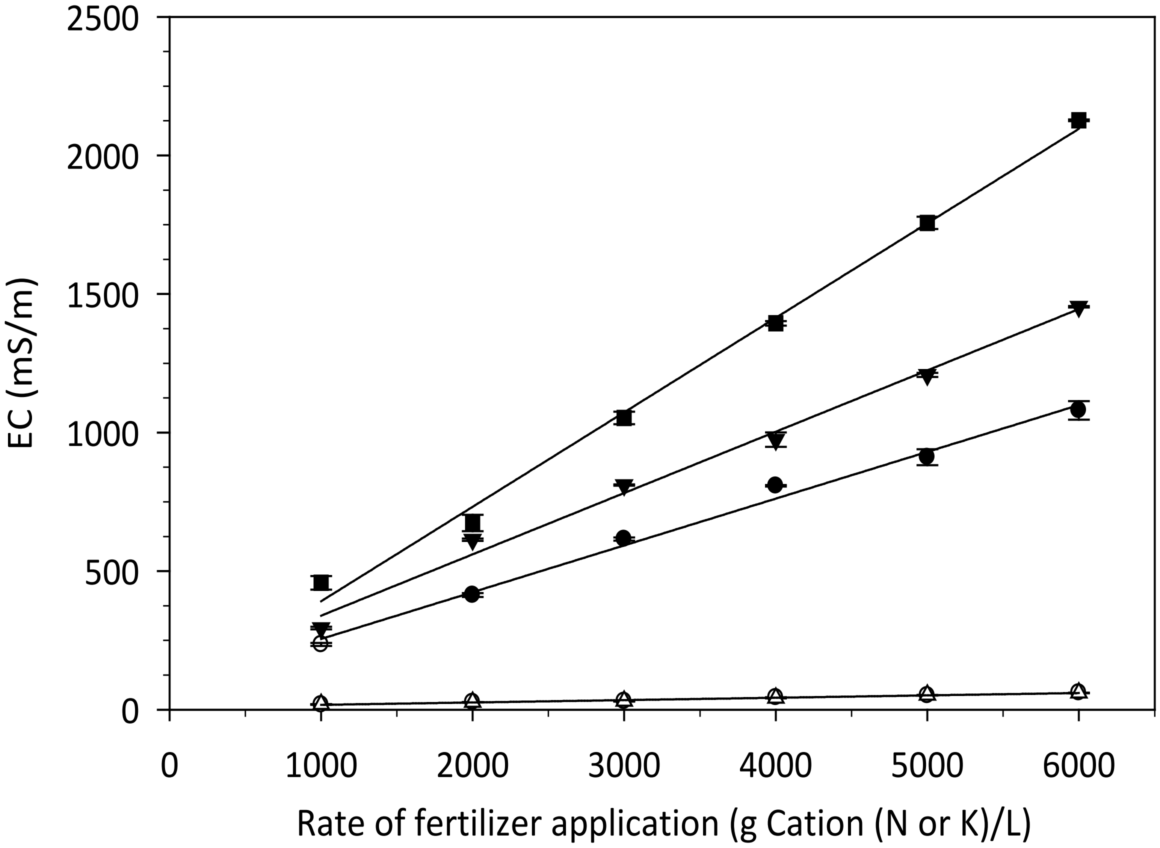

Figure 6.4. Influence of organic amendment fertilizer on the electrical conductivity of distilled water. KCl was used as a known reference. The error bars indicate standard error. (● -Bat guano (p<0.0001),○ -Blood meal (p<0.0001),▼-Broiler litter (p<0.0001),△ -Feather meal (p<0.0001), ■-KCl (p<0.0001))

Chapter 7

Conclusions

Bat guano, blood meal, broiler litter, and feather meal offer many benefits as organic fertilizers in the production of quality organic vegetable transplants. These fertilizers give transplant producers the opportunity to utilize by-product materials that would normally be considered wastes. This utilization of waste products coincides with the basic principles of organic standards and relieves farmers of the task of disposing of the materials. Our results showed that these organic fertilizers may modify the electrical conductivity and pH of the substrate. These changes in EC and pH may be deleterious to some species, reducing or delaying germination and increasing seedling mortality. Thus, bat guano, blood meal, broiler litter, and feather meal should be used in proper quantities and in the correct environment for transplant production. More information needs to be determined on the interaction between the substrate pH and nutrient availability of organic fertilizers as pH can control many factors, such as nitrogen mineralization, ammonia volatilization, and microbial biomass. The results of these studies indicate the fertilizers can be utilized by incorporation in organic vegetable transplant production, so long as the producer monitors and maintains proper growth environments.

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