# SOIL MANAGEMENT HISTORY AND COMPOST EFFECTS ON VEGETABLE SEED GERMINATION AND SEEDLING GROWTH PARAMETERS

A Thesis

Presented in Partial Fulfillment of the Requirements for

the Degree Master of Science in the

Graduate School of the Ohio State University

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2008

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# ABSTRACT

Soil quality can affect seed germination and seedling growth. Soil quality can be in turn affected by management history such as organic or conventional, or the application of compost. Soil management history and compost incorporation effects on seedling growth were tested in greenhouse-grown romaine lettuce (*Lactuca sativa*), sweet corn (*Zea mays*), and fresh market tomato (*Lycopersicon esculentum)* as well as on the germination of lettuce seeds. Silt loam soils cropped to conventionally and certified organically grown potato were collected from the upper 25-cm of the soil profile at two sites located near the OARDC in fall of 2005 and 2006. Moist soil was placed in Rootrainer cells on four different dates, either alone or after being mixed with composted dairy manure (15% soil-compost, v/v). A factorial set of treatments (soil history and compost) were arranged in a RCBD in climate-controlled greenhouses and irrigated (distilled water only) from the top and bottom. Emergence was recorded regularly and whole plants were removed from their cells at 14 and 35 days after planting (DAP). Shoot and root fresh and dry weight, root volume, leaf area and leaf number were measured and seven other variables were calculated. The study was repeated twice in sweet corn and tomato and four times in lettuce, which was also harvested seven weeks after seeding.

Compost and soil effects measured at 14 days were minimal in all crops except lettuce. Compost incorporation tended to increase crop growth measured at 35 and 50 days, regardless of soil type. At 35 and 50 DAP, incorporating compost significantly increased the values of 10 of 12 characteristics in lettuce. In tomato at 35 DAP, compost increased values for plants significantly for 8 of 12 variables. In sweet corn at 35 DAP, conventionally managed soil increased values for plants significantly in 8 of 12 variables.

In the greenhouse study, germination was poor in the organic treatments. Therefore a follow-up study was conducted to help discern why. Lettuce seeds were placed in Petri dishes filled with a factorial set of six soil treatments (three soil and two compost treatments), and a control and placed on a thermogradient table with a temperature range of 10-32 °C. Germination was recorded daily and unhealthy seed/seedling incidence was recorded at the end of the experiment (seven or eight days later). Unhealthy seed/seedlings were counted as a soft, “mushy” seed or a seedling with discoloration or sunken spots on the hypocotyls. Germination percentages and unhealthy seed/seedling incidence were both significantly affected by soil history and temperature but not compost. Germination and unhealthy seed/seedling incidence varied between conventional and organic soils. In general, as temperature increased, germination decreased, except in soils with conventional management. Poor germination was correlated with unhealthy seed/seedling incidence in organic soils, indicating that seed/seedling unhealthiness may have been the main factor inhibiting germination.

Dedicated to my family.

# ACKNOWLEDGMENTS

I would like to express my sincere thanks to my advisor, Matt Kleinhenz for giving me the opportunity and responsibility to complete this project. I would also like to thank my advisory committee: Dr. Bennett for his invaluable advice and suggestions, Dr. Cardina for generously opening up his lab and equipment, and Dr. Mullen for teaching me about statistics, soils and driving a tractor. All have been essential to the completion of this project. I also want to thank Dr. Joe Scheerans and Dr. Ann Chanon, for giving me words of wisdom and answering all the little questions I had, and also for their support. This research could not have been completed without all the hard work from our lab technicians Sonia Walker and Michelle Young. This project was also benefited from the assistance of our student workers Todd Barnett, Erica Kovacik, Stephan Haba, and Andrew Salerno, whom I thank for their help with the tedious labor involved. I would also like to thank Kesia Hartzler and Lee Duncan for all their help in the greenhouse and Bob Napier for his help in the field.

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1. Bogdan, Sasha, and M.D. Kleinhenz. 2007. Soil management history (conventional, organic) and compost incorporation affect lettuce, sweet corn, and tomato seedling growth. HortScience 42:860-861 (abstr.).

## FIELDS OF STUDY

Major Field: Horticulture and Crop Science

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# LITERATURE REVIEW

## 1.1. Introduction

The organic farming industry has grown dramatically within the last decade. The Organic Trade Association reports that growth has been increasing by approximately 20% each year since 1990. In 2005 alone, consumers spent 14.6 billion dollars on organic products. Organic sales make up 2.5% of all food sales in the U.S and organic vegetable and fruit products make up 39% of total sales, adding up to 5.4 billion dollars a year.

Consumers are interested in organic products for a variety of reasons. Buyers of organic products believe that they taste better (Davies et al., 1995; Makatouni, 2002; Zanoli and Naspetti, 2002). There is also a belief that organic products are healthier than their conventionally grown counterparts (Davies et al., 1995; Hutchins and Greenhalgh, 1997; Makatouni, 2002; Tregear et al., 1994; Zanoli and Naspetti, 2002;). In addition, consumers believe organic items contain less pesticide residue and are produced using fewer harmful chemicals. (Harper and Makatouni, 2002; Makatouni, 2002; Raab and Grobe, 2005). By using fewer chemicals, it is believed that organic products are "better" for the environment (Davies et al., 1995; Hutchins and Greenhalgh, 1997; Tregear et al., 1994). Consumers are willing to pay a premium price for these perceived benefits (Hutchins and Greenhalgh, 1997).

The organic movement began in the 1930s and 40s as a reaction to intensifying agriculture, and the subsequent heavy use of synthetic inputs (Lotter, 2003). With the passage of the Organic Foods Production Act of 1990, Congress established a legal definition of organic and required the USDA to create a certification body for the regulation of organic food claims. (OFPA, 1990) This Act resulted in the creation of the National Organic Program (NOP) which serves to certify independent inspection agencies for the oversight of individual organic producers.

Organic agricultural production systems use certain practices that aim to be socially, ecologically and economically sustainable (IFOAM, 2007). The goals of the system are to maintain or increase soil fertility, minimize pollution, avoid the use of synthetics, and to produce food of high quality in a sufficient quantity (Bourn and Prescott, 2002; Lotter, 2003). To become certified-organic, a farm must adopt organic practices for a minimum of three years before being evaluated for certification by a third party, usually an agency accredited by the USDA (USDA, 2007). Certified organic production forbids the use of mineral fertilizers, synthetic herbicides and pesticides, sewage sludge, genetically modified organisms, chemically pretreated seeds and irradiation. Certified-organic producers are allowed to use manures so long as they are either composted or applied at least 120 days before the food crop is harvested. (Lotter, 2003; NOP, 2002). Organic growers rely on other means of weed and pest control and sources of fertility, including biological control agents, legumes or cover crops. Organic growers must maintain or improve soil organic matter, regulate plant nutrient deficiencies or excesses and control erosion (Lotter, 2003).

Soil is a critical resource in agricultural production, and the differences between conventional and organic practices are often reflected in their respective soil characteristics. Organic systems are typically nitrogen-limited (Clark et al., 1999), but organic farmers can overcome nitrogen and other nutrient deficiencies by using composts and cultural practices to affect the physical, chemical and biological characteristics of organic soils. (Liebhardt, 2001; Lotter, 2003).

For example, Melero et al. (2006) found that under organic and conventional conditions broad bean performed the same while melon and watermelon performed significantly better in organic conditions. A study by Herencia et al. (2007) showed no differences in yield between organic and conventionally managed plots in 17 of 20 crops. Warman (2005) found numerically higher yields in carrot, pepper, onion and tomato, as well as statistically higher yields in green and yellow beans in organically fertilized plots compared to synthetically fertilized plots. After the three year transition period, corn yields were similar in certified-organic and conventional plots; also, soybean yields were similar with the exception of one extremely dry year during which the organic plots failed. However, organic plots had significantly higher yields in corn and soybean in other drought years (Lotter et al., 2003; Pimental et al., 2005). Other studies including those done by Stanhill (1990), Denison (1996), Lockeretz et al., (1981) and Clark et al. (1999) have all shown that organic systems can perform better than conventional systems in drought conditions or other extreme climate settings. Although organic systems use fewer synthetic inputs, their distinct physical, chemical and biological characteristics allow them to produce yields comparable to those of conventional systems.

### 1.2. Conventional versus Organic Crop Management

Crops may be grown using one of two general management methods: organic or conventional. Conventional systems may use synthetic inputs such as a pesticide to reduce insect populations, herbicides to reduce weed pressure, or fertilizers to provide nutrients. Conventional systems may also be defined as systems that are not organic. While this approach can effectively correct the situation, they may lead to other significant, long term problems such as dependence on fossil fuels, pesticide-resistant organisms, erosion and run-off issues. Organic systems attempt to correct for these problems (pests, weeds, etc.) using low-input additions or cultural practices to rectify the problems in a way that is sustainable (or minimizes the risk of future problems).

Although the concept of "organic production" may seem simple, there are many different definitions in use today. Some may be based on what type of inputs are used in the production of food, such as the USDA National Organics Program's definition of organic production which states,

> "organic crops are [to be] raised without using most conventional pesticides, petroleum-based fertilizers, or sewage sludge-based fertilizers".

Other definitions of organic farming address the health of the agro-ecosystem, such as this one from the online encyclopedia Wikipedia:

> "...a form of agriculture that relies on ecosystem management and attempts to reduce or eliminate external agricultural inputs,

> especially synthetic ones. It …promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity".

The Organic Farming Research Foundation's definition includes biological diversity and the preservation of soil fertility:

> "Organic farming management relies on developing biological diversity in the field to disrupt habitat for pest organisms, and the purposeful maintenance and replenishment of soil fertility".

This is just a small sample of the multitude of ways organic production has been defined. Despite their diversity, these definitions some common features: the exclusion of synthetic inputs and the substitution of organic amendments and cultural practices for those inputs.

This strategy has a profound effect on soil characteristics. It causes measurable differences between organic and conventionally managed soils, in terms of dissimilarities in their physical, chemical and biological properties.

The physical differences between organic and conventionally managed soils include soil organic matter content, bulk density, and soil penetration resistance. A high percentage of soil organic matter can help prevent erosion, increase water holding capacity and mineralization rates as well as increasing the buffer and cation exchange capacity of the soil (Havlin et al., 1999). For example, one study showed that organic grain fields had higher soil stability compared to conventional fields, which is an indicator of soil erosion potential (Entz et al., 2007). Soils in an organic, animal manure-based cropping system have been shown to hold more water than a conventional field with synthetic fertilizers and herbicides and a corn-soybean rotation (Pimentel et al., 2005). This is beneficial in situations where the water supply is limited.

Soil organic matter levels are also higher in organically managed systems, compared to their conventionally managed counterparts (Bulluck et al., 2002; Cardelli, 2004; Condron, 2000; Drinkwater et al., 1995; Reganold et al., 1993). Both soil bulk density and soil penetration resistance were found to be lower in organic soils compared to conventional (Bulluck et al., 2002; Condron, 2000; Reganold et al., 1993). A low bulk density and penetration resistance can lead to improved plant growth and productivity (Havlin et al., 1999).

Studies have shown measurable differences in some key chemical characteristics between organic and conventionally managed systems. In organically managed soils, cation exchange capacities and organic carbon amounts are generally higher (Bulluck et al., 2002; Clark et al., 1998; Condron, 2000; Herencia et al., 2007; Reganold et al., 1993; Schjønning et al., 2002). Pimentel et al.(2005) showed that total and mineralizable N concentrations in organic soils were higher than in the conventionally managed counterparts. Several studies have shown that Kjeldahl N was higher in organically managed soil compared to mineral fertilized plots (Herencia et al., 2007; Melero et al., 2006). Melero et al. (2006) found higher levels of P, while Herencia et al. (2007) found higher levels of P and K in organic soils. Warman (1998) and Bulluck et al. (2002) reported differences in mineral concentrations between soils differing in management history. Both studies found higher levels of Ca, Mg and Mn in organic soils, while

Bulluck et al. also found higher K and B levels. However, Warman (1998) found conventional soils to be higher in P and K than their organic counterparts.

Many aspects of the soil's biological activity are also affected by soil management history. Studies have shown that overall biological activity is increased in organic soils compared to conventional, (Drinkwater et al., 1995; Fließbach et al., 2007; Mäder et al., 2002). The numbers of larger organisms such as earthworms, spiders, predatory insects and predatory mites all increased in organically managed soils (Carpenter-Boggs, 2000; Mäder et al., 2002; Pulleman et al., 2003; Reganold et al., 1993; Ryan, 1999). The numbers of microorganisms, such as nematodes, bacteria and fungi also differed. Microbial biomass was 20-80% higher in organically fertilized soils (including manure and compost) than in soils fertilized with mineral nutrients alone (Fließbach et al., 2007). Total microbial biomass increased in organic soil along with related parameters such as catalase, dehydrogenase, and protease activity, soil respiration rate and total microbial N measured (Melero et al., 2006). Other studies have shown increases in the number of thermophilic bacteria, *Trichoderma* species and actinomycetes in organically managed soils as compared to conventional (Carpenter-Boggs, 2000; Clark et al., 1998; Cardelli, 2004; Condron, 2000; Fließbach and Mäder, 2000; Gunapala et al., 1998; Mäder et al., 2002; Reganold et al., 1993; Schjønning et al., 2002; Workneh and van Bruggen, 1994).

The presence of arbuscular mycorrhizal fungi can enhance a plants ability to absorb both nutrients and water from the soil by increasing the surface area of the roots. Organically managed soils have been found to have an increased number of arbuscular fungi spores and increased colonization of roots (Douds et al., 1993; Pimentel et al., 2005). Mäder et al. in 2000 and 2002 also found up to 40% more root length colonized in organically managed plant roots compared to conventionally managed soils.

Measures of diversity also differed between organically managed and conventionally managed soils. Mäder et al. (2002) reported increases in both microbe and weed diversity, a trend they attributed to healthier soils. Certain disease-causing organisms such as *Phytopthora* and *Pythium* were also reduced in organic systems (Bulluck et al., 2002). Drinkwater et al. (1995) and Workneh and van Bruggen (1994) both found corky root rot was suppressed in organic tomato fields. In a review by Ryan in 1999, the author reported that levels of root diseases and pests in organic fields were generally equal to or lower than the levels in conventionally managed systems.

Recent studies have shown that there are measureable differences between organically and conventionally managed soils. Some researchers have attributed many of these differences to the addition of organic matter, often in the form of compost, to organic production systems.

### 1.3. Compost

Composts can be used as an alternative to synthetic fertilizers and raw manures which have been linked to nutrient leaching and are also prohibited in organic systems (He et al., 2001). Because of this, composts can be a very important element in organic production. Many composts can be utilized in certified-organic systems, and can provide a valuable source of nutrients, especially N. Compost can also be produced on-farm, which helps minimize expensive, off-farm inputs and can increase the sustainability of the farm.

Composts are decomposed organic wastes (from plant or animal sources) often applied to soil in order to improve it in various ways (Roe, 1998; Roe et al., 1997). Composts can be made from a diverse range of starting materials, including animal manures, yard wastes, food processing wastes, or sewage sludge (Goldstein, 2001). Wastes are collected in bins or rows and are broken down by microorganisms (Day and Shaw, 2001). This process of decomposition raises the temperature of the compost, changing the structure of the starting materials and killing pathogenic microorganisms and weed seeds (Day and Shaw, 2001). The finished product is usually a brown to black loose material with no odor (Dick and McCoy, 1993).

Depending on the starting materials and environmental conditions, compost may differ in key characteristics. Some are physical in nature; others are chemical or biological. These features also determine the composition and characteristics of the finished compost. The C:N ratio of the starting materials is ideally between 25-35, and for cow manure, the average C:N is 18 (Hamoda et al., 1998; Polprasert, 1989 quoted in Day and Shaw, 2001). Although the starting C:N ratio is important in the rate of the decomposition of the manure, the final ratio can strongly affect the growth of a plant. Typically, a C:N ratio of between 10 and 20 is optimal (Kayhanian and Tchobanoglous 1993).

Another important compost quality parameter is cation exchange capacity (CEC). The CEC is a measurement of the ability of a substance to hold cations important to plant growth such as K, Ca, and Mg. A high CEC can help prevent nutrients from being leached from the soil. As compost ages and pH increases, the CEC increases (Day and Shaw, 2001). An average value for a mature compost is greater than 60 meq./100 g, and an optimum pH is between 6 and 8 (Day and Shaw, 2001).

Although the characteristics of the starting materials are important, the environmental conditions where the compost is being made may also affect the final product. Factors such as temperature, moisture content, aeration, and age may change the final outcome. Optimally, temperature within the compost heap should be kept between 54-60°C for rapid composting, though temperatures as low as 43°C can be used (Rynk and Richard, 2001). Although composting can be done at low temperatures, optimal results are achieved at higher temperatures because microorganisms can decompose waste materials faster. As the microorganisms decompose the starting materials they also generate heat, thus speeding up the process even more.

Water is also needed in certain amounts for rapid, complete composting. There must be enough water to support the growth and activity of the microorganisms, however, too much can compact the compost or cause it to develop a completely anaerobic environment, which is detrimental to the process. The ideal moisture range is between 50-60% (Rynk and Richard, 2001).

As the compost decomposes, air (specifically oxygen) must be available for the microorganisms and to cool the pile or row. Failure to properly aerate the compost will slow or stop the composting process and could result in undesirable odors (Rynk and Richard, 2001). Aeration can be accomplished several ways, including passive and forced aeration. Before compost is complete and ready to utilize, it must "cure." Curing occurs at the end of the decomposition cycle. At this time, decomposition slows and temperatures decline to under 40°C (Rynk and Richard, 2001). After curing, composts are biologically less active, and can be applied to plants without phytotoxicity.

### 1.4. Uses of Compost in Agricultural Settings

As mentioned above, compost is important in organic production systems, providing a vital nitrogen source. Composts are typically used as additives to soils and other rooting media. However, growing plants exclusively in composts has been tried, particularly when transplant production was the goal (Clark and Cavigelli, 2005; Fitzpatrick, 2001; Sterrett, 2001). In addition, composts are used as biodegradable mulches to suppress weed populations (Ozores-Hampton et al., 2001; Roe, 1998) and to control certain plant diseases (Hoitink et al., 2001; Reuveni et al., 2002; Zhang et al., 1998). Composts also have use in erosion control projects, nursery bed production and turf establishment (U.S. Composting Council, 2000).

### 1.5. General Effects of Compost on Soil and Plant Variables

As mentioned above, composts can have a wide range of effects on soils and because of that, an effect on plants or plant growth as well. For example, adding compost to rooting media, including soils, may shift their:

• physical condition, including bulk density, percent organic matter, and water-holding capacity (Giusquiani et al., 1995; Khaleel et al., 1981),

• chemical status, including pH, nutrient levels, cation exchange capacity, and C:N ratio (Day and Shaw, 2001; Eghball, 2002; Giusquiani et al., 1995), and

biological makeup and activity, including macro- and micro- fauna populations, which tend to increase in abundance and diversity following compost application (Drinkwater et al., 1995; Mäder et al., 2002; Pulleman et al., 2003).

In soils amended with compost, bulk density and soil penetration resistance were found to be lower than in unamended soils (Bulluck et al., 2002; Condron, 2000; Porter et al., 1999; Reganold et al., 1993). Increases in porosity have also been found in a variety of soil types (Dick and McCoy, 1993). This allows the roots of plants grown in these soils to be more effective in exploiting the soils resources. Opena and Porter (1999) report that in soils amended with compost, root length density was higher, due to increased aggregation from increased soil organic matter. Soil organic matter was found to be higher, which improved the soil water holding capacity, as well as providing microhabitats for microorganisms to live. Ryan (1999) found soil organic matter was strongly correlated with microbial biomass. Porter et al. (1999) found that after three consecutive, annual additions of compost, the percentage of organic matter changed from 3.7% to 4.9%. Giusquiani et al. (1995) found that as the compost rate increased from 0 to 90 t/ha, available water increased from 0.25 to 0.35 $m^3*m^{-3}$, and field capacity increased from 0.47 to 0.58 $m^3*m^{-3}$.

Soils with a high CEC retain more nutrients by slowing leaching. Soils treated with compost generally have a higher CEC then those not treated (Alexander, 2001;

Condron, 2000). Porter et al. (1999) suggests the increase in yield seen in organically managed potatoes was due to increased and improved cation exchange capacity as well as increased water holding capacity and organic matter amounts.

The concentration of mineral nutrients is another factor affected by compost application. Clearly, the addition of nitrogen via compost will improve plant growth, especially in organic situations, where nitrogen is a limiting factor in plant growth (Drinkwater et al., 1995). Compost can also add phosphorus, potassium, calcium, magnesium as well as micronutrients to the soil (He et al., 2001), all essential to plant growth.

Biological parameters in soil are also affected by compost additions. In organic plots, the number of earthworms was three times larger than in conventional plots (Mäder et al., 2002). The same study found that there were twice as many spiders in organic than conventional plots. The number of predatory mites, nematodes and insects were also found to be higher in organic fields, as compared to conventional, which would lower herbivory rates and damage on plants. Corn plants grown in conventionally managed soils (conventional tillage, fertility and pesticide use) were the preferred host for the European corn borer. Plants grown in organically managed soils were significantly less affected by the insects (Phelan et al., 1995). In organic soils, microbial biomass increased by 32% over mineral fertilized fields of the same soil type (Carpenter-Boggs, 2000). Schjønning et al. (2002) reported that organic fields had 36% more biomass C (a measure of microbial biomass) than conventional fields treated with the same composts, and 82% more then in conventional fields only receiving synthetic fertilizers.

When composts are combined with synthetic fertilizers in conventional systems, growth is increased in a synergistic manner, compared to mineral fertilizer or compost alone in a variety of crops (Sikora, 1997; Wang and Lin, 2002). This suggests that it is not only the nutrients supplied by compost that can benefit the plant. Some studies have attributed this to the presence of humic acids (organic molecules thought to promote plant growth) (Ayuso et al., 1996; Valdrighi et al., 1996), others believe it is the presence of plant hormone-like substances produced by microorganisms or through vermicomposting (Atiyeh et al., 2000). It is also possible that the increased growth is due to some or all of the factors discussed above (i.e., physical, chemical or biological parameters).

Incorporation of compost into a rooting medium may affect plants directly and/or indirectly and through three main pathways: physical, chemical and biological. Regardless of the path, compost in the root zone is thought to increase plant biomass (Dick and McCoy, 1993; Roe, 2001). For example, compost can act as a fertilizer, increasing the availability of essential plant nutrients (including N). Compost as a fertilizer may be especially advantageous in organic systems, which are known to be nutrient-limited (Clark et al., 1999; Drinkwater et al., 1995) and prohibit the use of synthetic fertilizers. Compost may also reduce the bulk density of rooting media, allowing plants to exploit the soil more efficiently. Other ways in which composts in rooting media may directly affect plant growth is in their ability to increase moisture holding capacity, making water available for uptake when it otherwise may have been lost through evaporation, runoff or leaching. The ability of compost to shift soil conditions may vary with soil management history. This has been looked at in a number of studies, as outlined above. However, few studies have compared the effect of compost on specific and detailed plant variables (not simply yield or mineral concentration data) using soils of the same basic type (e.g., loam) and similar cropping history (e.g., vegetable) but different management approach (conventional versus certifiable-organic). In addition, few studies have looked at germination and subsequent seedling growth in field soils.

### 1.6. Germination and Seedling Growth

Germination of seeds and subsequent seedling growth are important to crop production. If there is poor stand establishment, the consequence can be reduced yield and crop value. Crop density can affect canopy structure of a field, the time it takes to harvest the crop and the uniformity of the mature product. If there are differences in the timing of germination, these differences can translate into differences in the final, harvestable product (Finch-Savage, 2004).

Germination requires water, a sufficient temperature and oxygen (Hadas, 2004) and begins with the absorption of water by the seed and ends with the extension of the radicle (Bewley, 1997). Many soil characteristics can affect this sequence including soil compaction, temperature, light, moisture, salt concentration and the presence of germination inhibiting compounds. These factors can in turn be affected by the quality of the soil the seed is located in, such as whether the soil has been managed organically or conventionally.

Although low levels of compost extract can stimulate germination, high levels have been shown to inhibit germination in cress, ryegrass, tobacco and cauliflower (Asenjo et al., 2000; Ayuso et al., 1996; Kahn et al., 2005; Pare et al., 1997) so compost does have the potential to delay or prevent germination in a variety of seeds. High salinity, or the presence of phytotoxic compounds are often the cause of limiting factors in immature composts (Chen and Inbar, 1993).

Seedling growth is affected by soil properties, especially the addition of compost. Tomato seedlings grown in a dairy vermicompost/soil mixture had a higher shoot and root dry weight in than those receiving no compost. Plants grown in vermicompost also had a higher N, P and K concentrations than those grown without (Hashemimajd et al., 2004). When grown in compost mixtures, tomato, lettuce, pepper and marigold had significantly higher shoot and root dry weights compared to growth mixtures with no compost added. When a 20-10-20 fertilizer (which also contained Mg, B, Fe, Mn, Mo and Zn) was added to the medium, plants grown in compost amended mixtures still were significantly larger than those grown in unamended counterparts (Atiyeh et al., 2000), suggesting that compost is not acting solely as a fertilizer. Composted goat manure significantly increased shoot fresh and dry weights of cabbage seedlings in pinebark mediums (Mupondi et al., 2006). Compost increased the levels of N in cauliflower seedlings compared with a peat only mixture (Kahn et al., 2003). In addition, adding organic amendments such as compost significantly increases emergence over the control in wheat seedlings germinating in soils that have significant crusting at the soil surface (Seker, 2003).

### 1.7. Rationale and Significance

Most studies examining compost effects have focused on the enhancement of size of aboveground plant parts, and the increase in yield. Much less is known regarding compost effects on plant root mass and structure, possibly the site of the most direct plant-compost interaction. In addition, many of the comparisons between organic and conventional systems focus on either soil characteristics or the general effects on plants, such as yield. Although field experiments attempt to replicate actual practices, data can be variable. By using a relatively controlled greenhouse setting, it may be possible to better detect and analyze differences in soil-plant relations since more variables (such as light, water, and pests) are controlled. The physical, chemical and biological properties of a compost make it likely that, when added to soil, compost will affect various plant processes. We used vegetable seedlings to examine in depth differences between organic and conventional systems as well as the effect of compost on plant growth, including root parameters. Germination and subsequent stand establishment and growth, while important, are poorly studied in field soils (Hadas, 2004). Germination and stand uniformity is important to the value of the crop, as well as the ease with which it is harvested (Couture et al., 2004; Pavek and Thornton, 2005; Weidong et al., 2004; Weiner et al., 2001).

A variety of crops were chosen, for their widespread use and for their physiological diversity. In addition, these species are among the most popular crops to be grown organically (Lotter, 2003). If a difference is found, it may help establish what soil management history shows the best response to compost-plant interactions. In addition, it may provide information for future researchers to help understand how compost works and the differences between soils from organic and conventional production systems, especially when pertaining to the germination and subsequent growth of seedlings.

The objectives of this study are to:

1. Document the separate and combined effects of soil management history (conventional vegetable production versus certifiable organic production) and compost on vegetable seedling root and shoot growth parameters.
2. Document the separate and combined effects of soil management history and compost on germination of lettuce seeds and seedling development.

We will determine if soil management history or compost has an effect on seedling growth or germination. We will also examine any possible interactive effects between soil management history and compost.

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## CHAPTER 2

# SOIL MANAGEMENT HISTORY AND COMPOST EFFECTS ON SEEDLING GROWTH PARAMETERS

## 2.1 ABSTRACT

Soil management history and compost incorporation effects on seedling growth were tested in greenhouse-grown romaine lettuce (*Lactuca sativa)*, sweet corn (*Zea mays*), and fresh market tomato (*Lycopersicon esculentum*). Silt loam soils with extended conventional (over 20 years) and certified organic (over 5 years) management histories and cropped to potato the previous year were collected in November 2005 and October 2006 from the upper 25-cm of the soil profile at two nearby sites (located at the OARDC, Wooster, OH) placed in 130-L plastic containers and transferred to a greenhouse. Moist soil was placed in 4-cm x 2-cm x 20-cm hinged Rootrainer cells, either alone or after being mixed with composted dairy manure (15% soil-compost, v/v). Within 48 hr thereafter, seeds were sown in Rootrainer cells and covered with soil or the soil-compost mix. The factorial set of treatments (soil history, compost) were arranged in a RCBD (four replications with eight cells per replication or 6 replications with 4 cells per

replication) in climate-controlled greenhouses and irrigated (distilled water only) from the top and bottom. Emergence was recorded regularly and whole plants were removed from their cells at 14 and 35 days after planting (DAP). Shoot and root fresh and dry weight, root volume, and leaf area and number were measured and seven other variables were calculated. The study was repeated twice in sweet corn (cv. 'Xtra Tender 270A') and tomato (cv. 'Jet Star') (spring harvest) and four times in lettuce (cv. 'Green Towers'), which was also harvested twice at 50 DAP (fall harvest only). Compost and soil effects measured at 14 days were minimal in all crops except lettuce. Compost incorporation tended to increase crop growth measured at 35 and 50 days, regardless of soil type. At 35 and 50 DAP, incorporating compost significantly increased the values in 10 of 12 characteristics. In tomato at 35 DAP, compost effects were significant in 8 of 12 variables. In sweet corn at 35 DAP, soil management history significantly affected 8 of 12 variables.

## 2.2. INTRODUCTION

Soil characteristic differences between organic and conventional systems include dissimilarities in weed and disease pressure, nutrient inputs, amount of labor needed and cultural practices. The largest variations may be due to the physical, chemical and biological differences between organic and conventionally managed soils, which can be influenced by the use of compost as a soil amendment.

Physical differences between organic and conventionally managed soils include soil organic matter content, bulk density, and soil penetration resistance. Soil organic matter is higher in organically managed systems, compared to their non-manured, conventionally tilled and managed counterparts which can lead to better plant growth due to a variety of factors including higher water holding capacity, N mineralization rates, buffer and cation exchange capacity (Bulluck et al., 2002; Cardelli, 2004; Condron, 2000; Drinkwater, et al., 1995; Havlin et al., 1999; Reganold et al., 1993).

Chemical properties also differ between the organic and conventionally managed plots. It is reported that cation exchange capacities and organic carbon amounts in organically managed soils were higher (Bulluck et al., 2002; Clark et al., 1998; Condron, 2000; Herencia et al., 2007; Reganold et al., 1993; Schjønning et al., 2002) as well as total, Kjeldahl, and mineralizable N concentrations (Herencia et al., 2007; Melero et al., 2006; Pimentel et al., 2005). Various studies have shown differences in nutrient levels between the two systems including P, K, Ca, Mg, Mn, and B (Bulluck et al., 2002; Herencia et al., 2007; Melero et al., 2006; Warman, 1998).

Studies have shown that overall biological activity is increased in organic soils compared to conventional (Drinkwater et al., 1995; Fließbach et al., 2007; Mäder et al., 2002). The number of macro-organisms increased in organically managed soils (Carpenter-Boggs, 2000; Mäder et al., 2002; Melero et al., 2006; Pulleman et al., 2003; Reganold et al., 1993; Ryan, 1999).

Other studies have shown increases of plant-beneficial or disease suppressive microorganisms in organically managed soils as compared to conventional (Carpenter-

Boggs, 2000; Clark et al., 1998; Cardelli, 2004; Condron, 2000; Fließbach and Mäder, 2000; Mäder et al., 2002; Reganold et al., 1993; Schjønning et al., 2002; Workneh and van Bruggen, 1994). Mycorrhizal fungi colonization is also increased in organic soils (Douds et al., 1993; Mäder et al., 2000, 2002; Pimentel et al., 2005).

As shown above, studies have shown differences between organically and conventionally managed soils in many aspects. Many researchers have hypothesized that the basis of many of the differences observed could be the use of organic matter inputs, including composted animal manures (Bulluck et al.,. 2002; Fließbach et al., 2007; Melero et al., 2006.

Composts can be a very important element in certified-organic production since synthetic fertilizers are excluded. Many composts can be utilized in certified-organic systems, and provide a valuable source of nutrients, most importantly N. Composts can also be produced on-farm, which helps minimize expensive, off-farm inputs.

In soils amended with compost, bulk density and soil penetration resistance was found to be lower than in unamended soils (Bulluck et al., 2002; Condron, 2000; Porter et al., 1999; Reganold et al., 1993). Increases in porosity have also been found in a variety of soil types (Dick and McCoy, 1993). Opena and Porter (1999) report that in soils amended with compost, root length density was higher, due to increased aggregation from increased soil organic matter.

Soils amended with composts had increased organic matter percentages (Porter et al., 1999), increased plant available water and field capacity (Giusquiani et al., 1995), CEC (Alexander, 2001; Condron, 2000; Porter et al., 1999). The concentration of mineral nutrients is another factor affected by compost. Clearly, the addition of nutrients, especially nitrogen via compost will improve plant growth, especially in organic situations, where nitrogen is a limiting factor in plant growth (Drinkwater et al., 1995; Kirchmann et al., 2007).

In organically managed soils amended with compost, the number of macro- and microorganisms was larger than in conventionally fertilized and managed plots (Mäder et al., 2002; Carpenter-Boggs et al., 2000; Schjønning et al., 2002).

Studies have indicated when composts are combined with synthetic fertilizers in conventional systems, growth is increased in a synergistic manner, compared to synthetic fertilizer or compost alone in a variety of crops (Sikora, 1997; Wang and Lin, 2002). This suggests that compost not only supplies nutrients but other beneficial effects. Humic acids, plant hormone analogs, or chemicals produced by vermicomposting processes may be responsible for this increased growth (Atiyeh et al., 2002; Ayuso et al., 1996; Valdrighi et al., 1996). Other factors such as the physical, chemical and biological factors discusses above may be involved.

In any case, incorporation of compost into a rooting medium may affect plants directly and/or indirectly and through three main pathways, physical, chemical and biological. Regardless of the path, compost in the root zone is thought to increase plant biomass (Dick and McCoy, 1993; Roe, 2001). For example, compost can act as a fertilizer, increasing the availability of essential plant nutrients (including N, P and K). Compost may be useful as a fertilizer in organic systems, which are known to be nutrient-limited (Clark et al., 1999; Drinkwater et al., 1995) and prohibit the use of synthetic fertilizers. Compost application may also reduce the bulk density of rooting media, allowing plants to exploit the soil more efficiently.

The ability of compost to shift soil conditions may vary with soil management history. This has been investigated at in a number of studies, as outlined above. However, few studies have compared the effect of compost on specific and detailed plant variables (such as shoot and root weight, or leaf area) using soils of the same basic type, similar cropping history, but having a differing management approach.

In addition, the soil environment of the seed can affect germination and the subsequent growth of the seedling. In turn, this can affect the maintenance and the final crop. For instance, stand uniformity can reduce weed pressure (Weiner et al., 2001), or increase crop value (Couture et al., 2004; Pavek and Thornton, 2005; Weidong et al., 2004). Predictable and uniform germination and subsequent seedling growth is essential for the production of a crop and maximum yield (Hadas, 2004). Percent emergence affects crop density, and density strongly affects crop yield (Willey and Heath, 1969). Since compost and soil management history can affect soil characteristics, it follows that these treatments can affect seed germination and growth.

The study will be done in a relatively controlled greenhouse setting and will determine the response of vegetable seedlings to soil history and compost. Variables measured will include direct measurements, such as shoot fresh weight and calculated variables such as leaf weight ratio. This will show if the treatments imposed had any effect on the overall growth of the plant, as well as on the allocation of carbon to different areas of the plant. Chlorophyll readings will give an estimation of the nitrogen status of the plant, giving information on the nitrogen supplying power of the rooting medium.

## 2.3. MATERIALS AND METHODS

*Rooting medium*

There are characteristics that a well designed comparison between organically and conventionally grown crops must have according to Lester (2006). The two soils must have the same soil texture, be physically located close to each other, have identical previous crops, and have similar irrigation. The plants must be the same cultivar and be the same age when analyzed. To meet these requirements, a Wooster silt loam soil (Fine-loamy, Mixed, Mesic, Typic Fragiudalf) was collected on two separate occasions from the top 25 centimeters of soil from two potato fields, one certified organic and one managed using conventional methods. The first occasion was on November 20, 2005 and the second on October 20, 2006. Soils were located in nearby fields at the OARDC in Wooster, Ohio.

The organic soil had been met local organic certification requirements since 2000 and followed a cowpea, popcorn, lettuce/edamame, tomato/potato rotation. On the second date, two organic soils were collected: soil that had been historically amended with compost, and soil that had never received compost. For all organic soil treatments, potato plants were treated with organic fungicides and insecticides. Vines were mowed at the end of the growing season.

All conventionally managed soils in this study were generally in a potato-grain-vegetable rotation. The previous potato crop had followed a sorghum-sudangrass/wheat rotation and was unirrigated. The potato crop had regular applications of various manmade inputs, including insecticides, fungicides, as well as herbicides (both to suppress weeds and to kill vines) and fertilizers.

Both soils (organic and conventional) were collected from the edge of the field, approximately five to 10 feet from the grassy borders.

Composted dairy manure was obtained from the OARDC composting facility on November 20, 2005 and October 20, 2006. Starting materials consisted of dairy manure from the OARDC dairy calf, maternity, and heifer barns, in which the animals had been bedded on sawdust and straw. Sawdust was from a hardwood material. The barns were cleaned and the material was transported to the composting pad and positioned in uncovered, exposed windrows. No supplemental water (other than rainfall) was added at any point in the composting process. Windrows began as 90' x 10' x 4' rows and ended at 90 x 10' x 2.5'. Windrows were turned using an Aeromaster windrow turner once a week. Composting lasted between 14-16 weeks and temperature ranged from 55-71 °C in unturned windrows. After composting was complete, composts were left to cure on an adjacent cement pad until they were applied. (Walker, personal communication). Analysis was also done by the OARDC Service Testing and Research Lab (Table A.2).

Compost is considered organic by the National Organic Program if it meets three requirements: it must have a starting C:N ratio of 25:1-40:1, maintain a temperature of 55-77 °C for a minimum of 3 days, and if in windrows, be turned at least five times over the course of the composting process (National Organics Program, 2007). Although the compost used met the temperature and turning requirements, no data was collected on the starting C:N ratio.

Each soil (organic or conventional) was mixed with the dairy manure compost at a ratio of 15% by volume. This mixture was homogenized in a large soil mixer. Soils with no additional compost added were also homogenized. Thus, four soil treatments were obtained: conventional soil with compost (CNV-C), conventional soil without compost (CNV-NC), organic soil with compost (ORG-C) and organic soil without compost (ORG-NC). In the second set of experiments done in the fall, soil from an organic potato field that had historically been amended with compost for 4 years was also collected, mixed with additional compost (15%v/v) or mixed with no amendments and used in the experiment (OWC-C and OWC-NC). Analysis of these soils was done by the OARDC Service Testing and Research Lab (Table A.1).

*Plant materials and growing conditions*

Untreated seeds of a $sh_2$ sweet corn ('Xtra Tender 270A', Johnny's Selected Seeds, Winslow, ME), romaine lettuce ('Green Towers', Harris Seeds, Rochester, NY), and fresh market tomato ('Jet Star', Harris Seeds, Rochester, NY) were sown individually into Tinus style Rootrainer cells [1.5 in. wide, 2 in. long, 8 in. deep, 350 mL (Spencer-Lemaire Industries, Edmonton, Canada)] preloaded with soil, with or without compost added. Rootrainers are a specially designed container for growing and observing the roots on plants. They are four cells wide, and one cell deep. The container hinges at the bottom allowing the two sides of the container to separate and the root mass to be observed or removed without disturbing the soil or damaging the roots. Seeds were sown to a standard depth (approximately twice the width of the individual seed) into pre-moistened soil of all treatments (CNV-NC, CNV-C, ORG-NC, ORG-C, and the fall set of experiments also included OWC-NC and OWC-C.)

*Experimental design*

Rootrainer racks were arranged in the greenhouse room using a completely randomized design within species. Different species were treated as separate experiments and were not mixed. There were 20 seeds sown per replication and 4 replications, for a total of 80 plants. Eight plants were measured at each sampling time. This experiment was repeated twice. The first experiment was run from February 1 to March 14 (spring set). It was repeated from March 27 to May 4 (spring set). A third and fourth repetition of the experiment were completed on lettuce only between October 30 and December 17 (fall set). The third and fourth repetitions had six replications of four plants each.

*Sampling times and procedures*

Sampling times were approximately 14 days after planting (DAP) for the first harvest and 35 DAP for the second harvest in the spring set. Sampling times in the fall set were approximately 35 and 50 DAP for the first and second harvests, respectively. See Table 2.1 for a complete list.

The plants were kept in a 20' x 18' greenhouse room located in Gourley Greenhouse, OARDC, Wooster, OH with a 16 hour day and had a 25/ 20°C day/night temperature cycle. Plants were watered from the top or bottom once or twice a week, depending on climate conditions with the aim of keeping the soil slightly below field capacity.

At the sampling time, the whole plant including soil attached to the roots was removed from the Rootrainer cell and placed in a room-temperature, 10 L distilled water bath with a drop of dishsoap to disperse the smallest particles of soil and debris from the roots. They were allowed to soak in shallow containers for up to one hour. Roots were then washed clean by hand, using a gentle agitation of the soil and root mass. Multiple rinses with clean water were used to remove a majority of the soil. Cleaned roots were stored up to 24 hours in distilled water. Measurements were taken the following day and included leaf area (LI-3100 Area Meter, Li-Cor Biosciences, Lincoln, NE)), root and shoot weight (B2002-S, Mettler Toledo Inc. Columbus, OH), number of expanded leaves and stem length. Root volume was measured by suspending the whole root in a beaker of distilled water on a balance. The weight of the suspended root subtracted from the weight of the water was the volume of the root (Burdett, 1978). After measurements, root portions were frozen at -20°C to await further analysis, while shoot portions were dried for three days, then weighed. Specific leaf area was calculated by dividing the total leaf area with the shoot fresh weight. Leaf area ratio was calculated by dividing the leaf area by the total plant weight, and leaf weight ratio was obtained by dividing the shoot fresh weight by the total plant weight. Chlorophyll index was recorded only in the fall set using a chlorophyll meter (SPAD-502, Konica-Minolta Sensing Inc. Osaka, Japan). The first fully expanded leaf on each plant was chosen and a reading was taken on an area of the leaf next to, but not containing, the midrib.

*Statistical analysis*

Results from analysis of variance using a fully-specified model statements in Proc GLM of SAS showed that the spring and fall sets of lettuce could not be combined at 35 DAP since the interactive effects of time, soil, and compost differed in direction, therefore they were analyzed separately. Within sets, preliminary analysis showed that the majority of variables measured were not significantly different between the two experimental repeats, therefore the data were combined. Only 5% of the variables looked at were significantly different between repeats of the experiment. Analysis of variance (GLM, SAS) was used on the combined data. Effects were significant when $p \leq 0.05$. Means were separated using the LSD test ($\alpha < 0.05$).

## 2.4. RESULTS

In general, soil management history and compost amendment affected many physical seedling variables. Plants grown in organic soil were typically larger in size than those grown in conventionally managed soil. Compost also significantly affected seedling size, with seedlings grown in soils containing compost being typically larger than seedlings grown without compost, regardless of soil history. Harvest timing also influenced the results; typically, plants collected 35 or 50 DAP were more influenced by soil management history or compost than those harvested at 14 DAP.

In our comparisons, there were 102 tests to determine if soil by compost interactions were present. Of the 102, 20 were significant. Most of these interactive effects were found in lettuce (Figures 2.1-15). Generally, in lettuce, variables followed the pattern: ORG-NC<CNV-NC<CNV-C<ORG-C. The interactions within the other crops (sweet corn and tomato) were generally of magnitude, but the variables did not follow any pattern (Figures A.1-5)

*Spring set of experiments*

Sweet corn was largely unaffected by soil or compost at 14 DAP (Table 2.2). However, at 35 DAP, there were a number of significant soil treatment effects in the variables pertaining to growth. There was a smaller soil and compost treatment effect on growth ratios such as shoot:root.

Tomato was unaffected by soil treatments and slightly affected by compost at 14 DAP. At 35 DAP, variables were not influenced by soil treatments, but were affected significantly by compost treatments, primarily in the shoot zone of the plant (Table 2.3).

Compost, but not soil, strongly influenced the growth of 14 DAP lettuce plants (Table 2.4). Soil did not affect lettuce growth at 35 DAP, but compost had a strong effect on growth parameters.

Irrespective of soil type, tomato and lettuce plant size was greatest in those soils amended with compost (Tables 2.7-8). In sweet corn, irrespective of compost, plant size was largest in organically managed soils (Table 2.6).

*Fall set of experiments*

Soil and compost strongly affected a majority of directly measured growth parameters, as well as chlorophyll index, in 35 and 50 DAP lettuce (Table 2.5). At 35 DAP, variables were largest in the organic soils (ORG and OWC were not significantly different) (Table 2.9).Compost increased the growth variables and chlorophyll index. Generally, at 50 DAP, OWC<ORG<CNV. Compost increased all directly measured variables in lettuce, as well as some growth ratios (Table 2.9).

## 2.5. DISCUSSION

Increased plant growth may be due to a variety of reasons. Nutrients, water supply, access to sunlight, disease and weed pressure, beneficial genes, and temperature can all affect how quickly or how large a plant can grow. The strategy for this experiment was to attempt to keep most of these variables equal, in order to more accurately observe the effects of soil and compost on seedling growth. The plants were kept in identical containers, and received identical amounts of water at the same time to minimize differences in water supply, although differences in organic matter and water-holding capacity may have complicated this setup. Growing the plants in a greenhouse room with a set temperature and light regimen attempted to control for the various other aspects of climate, such as temperature and light. The same seed lots were used in each crop and run of the experiment to minimize genetic differences. Although field soil containing an intact seed bank was used, pressure was minimized by hand pulling any non-experimental plants. Disease was present in the form of a damping-off, but only affected a few seedlings. Clearly, there was a difference between the two (or three) soil management histories and between compost treatments. Differences in environment can be ruled out for the most part. However, nutrients, water supply, disease and weed pressure can be influenced by the rooting medium.

Crop response differed in each of the treatments. Sweet corn, having a large seed and a very fibrous, monocot root system was not affected by compost treatment, but was affected by soil management history. Lettuce, having a small seed, and a substantial taproot, was affected by both soil and compost. The tomato plants had a medium seed, and a root system in between lettuce and tomato; a small taproot was present with many fibrous roots. Large seeds tend to have more internal resources and therefore an improved chance to germinate in a wide range of environments (Bennett, 2004; Moles and Westoby, 2004). This could explain why the smallest seeded species (lettuce) was affected more than larger seeded crops. The lettuce may have had to depend on soil resources at an earlier age than the sweet corn or tomato seedlings.

It has been well-documented that there are measurable differences between organic and conventionally managed soils. These dissimilarities could contribute to the differences shown in the experiment. For example, it is known that organic soils, which tend to have a higher organic matter content (Bulluck et al., 2002; Cardelli, 2004; Condron, 2000; Drinkwater, et al., 1995; Reganold et al., 1993), especially those that have been amended with a source of organic matter, such as compost, have a higher water-holding capacity (Havlin et al., 1999; Pimentel et al.,. 2005).

Increased growth could also have been caused by a difference in nutrients. Although organic soils typically are nitrogen limited (Drinkwater, 1995; Clark et al., 1999; Kirchmann et al., 2007), it is possible that there is more nitrogen stored in the soil (Herencia et al., 2007; Melero et al., 2006; Pimentel et al., 2005). This nitrogen would not be available for immediate use, but could be mineralized in the future, contributing to growth. Organically managed soils may have a faster mineralization rate compared to conventionally managed (Reganold et al., 1993; Workneh and van Bruggen, 1994) In addition to nitrogen, organic soils may also have greater amounts of other nutrients such as calcium and magnesium (Bulluck et al., 2002; Warman, 1998), which are essential for plant growth. In the spring experiment, our soils were similar in % nitrogen, K, and Mg. The conventionally managed soil had a larger amount of P, while the organically managed soil had a higher amount of Ca. In the fall experiment, the previously amended soil (OWC) had considerably larger amounts of N, P, K, Ca, and Mg, compared to the conventional (CNV), or the unamended organic (ORG).

In addition to different nutrient profiles, the pH differed between the organically and conventionally managed soils. The pH was very low in the conventional field soil, perhaps due to fertilization with synthetic nutrients (Havlin et al., 1999). The low pH could have caused some nutrients to have reduced solubility, leading to a deficiency in that nutrient. Lettuce, tomato, and sweet corn have different optimum pH ranges as well. Tomato and sweet corn grow best in a range between 5.5-7.0. Lettuce benefits from a pH range between 6.0-7.0 (Havlin, et al., 1999). The pH in the conventionally managed soils was below the optimum range for lettuce, which could explain why the plants grown in unamended conventional soil did not grow as well as those in organic soils, or soils with compost added (compost tends to raise pH.).

Organically managed soils also have a higher percentage of plant roots colonized by mycorrhizae (Douds et al., 1993; Mäder et al., 2000, 2002; Pimentel et al., 2005). Roots that are colonized by mycorrhizae have a greater surface area, and are able to explore and exploit nutrients in the rooting medium more efficiently (Taiz and Zeiger, 1998).

Compost also tends to add nutrients such as nitrogen and phosphorus to the soil, which could result in increased plant growth (Clark et al., 1998; Drinkwater et al., 1995). In addition, compost can increase water holding capacity, decrease bulk density, or add beneficial microorganisms, all of which can contribute to an increase in plant productivity. The chlorophyll index is often used as an indicator of nitrogen supply (i.e. if the plant has adequate nitrogen, the index tends to be higher, while it is lower in nitrogen stressed plants). The results from the chlorophyll meter suggest it was a difference in nitrogen that caused the differences in plant growth between organic and conventional soils. It should be noted that this measurement was only taken at the fall planting, on lettuce only. The difference in nitrogen could have two causes: there was simply a greater amount of nitrogen (whether due to a greater total amount available, or having a more easily mineralizable organic nitrogen fraction) available to the plant over the time of its growth, or the seedlings had enhanced resource-gathering ability due to increased mycorrhizal colonization.

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| Set | Crop | Harvest | Experimental Repeat | Days after planting |
|---|---|---|---|---|
| Spring | Tomato | First | 1 | 14 |
| Spring | Tomato | First | 2 | 15 |
| Spring | Tomato | Second | 1 | 36 |
| Spring | Tomato | Second | 2 | 35 |
| Spring | Sweet Corn | First | 1 | 15 |
| Spring | Sweet Corn | First | 2 | 16 |
| Spring | Sweet Corn | Second | 1 | 35 |
| Spring | Sweet Corn | Second | 2 | 33 |
| Spring | Lettuce | First | 1 | 14 |
| Spring | Lettuce | First | 2 | 16 |
| Spring | Lettuce | Second | 1 | 35 |
| Spring | Lettuce | Second | 2 | 37 |
| Fall | Lettuce | First | 3 | 35 |
| Fall | Lettuce | First | 4 | 36 |
| Fall | Lettuce | Second | 3 | 50 |
| Fall | Lettuce | Second | 4 | 51 |

Table 2.1. Sampling times and crops in the spring and fall runs of the greenhouse experiment.

| Source | leaf # | shoot dry weight (g) | fresh weight (g) total | shoot | root | root vol. (mL) | leaf area ($cm^2$) | stem length (cm) | shoot : root | % moist. | specific leaf area ($cm^2/g$) | leaf weight ratio (g/g) | leaf area ratio ($cm^2/g$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 DAP | | | | | | | | | | | | | |
| S | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| C | ns | ns | ns | ns | ns | ns | ns | * | ns | ns | ns | ns | ns |
| SxC | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| 35 DAP | | | | | | | | | | | | | |
| S | * | * | ** | ** | * | * | ** | ns | * | ns | ns | * | ns |
| C | * | ns | ns | ns | ns | ns | ns | ns | * | ns | ns | ns | * |
| SxC | ns | ns | * | ns | * | ns | ns | * | ns | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 2.2. Analysis of variance for the influence of soil management history (S) and compost (C) on growth variables measured 14 and 35 days after planting (DAP) in sweet corn seedlings of the spring set.

| : | | shoot dry | fresh weight (g) | | | root | leaf | stem | | | specific leaf | leaf weight | leaf area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | leaf # | weight (g) | total | shoot | root | vol. (mL) | area ($cm^2$) | length (cm) | shoot : root | % moist. | area ($cm^2/g$) | ratio (g/g) | ratio ($cm^2/g$) |
| 14 DAP | | | | | | | | | | | | | |
| S | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| C | ns | ns | ns | ns | ns | * | ns | ns | ns | ns | ** | ns | * |
| SxC | ns | ns | * | ns | ns | ** | ns | ns | ns | ns | ns | ns | ns |
| 35 DAP | | | | | | | | | | | | | |
| S | ns | ns | ns | ns | ns | ns | ns | ns | * | ns | ns | ** | ns |
| C | ** | ns | ** | ** | ns | ns | ** | * | *** | *** | ns | *** | ns |
| SxC | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 2.3. Analysis of variance for the influence of soil management history (S) and compost (C) on growth variables measured 14 and 35 days after planting (DAP) in tomato seedlings of the spring set.

| Source | leaf # | shoot dry weight (g) | fresh weight (g) total | fresh weight (g) shoot | fresh weight (g) root | root vol. (mL) | leaf area ($cm^2$) | shoot : root | % moist. | specific leaf area ($cm^2/g$) | leaf weight ratio (g/g) | leaf area ratio ($cm^2/g$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 DAP | | | | | | | | | | | | |
| S | ns | ns | ns | ns | ns | ns | ns | ns | ns | * | ns | ns |
| C | *** | *** | ** | ** | * | * | ** | ns | ns | ns | ns | ns |
| SxC | ns | ns | ns | ns | ns | ns | ns | ns | * | * | ns | ns |
| 35 DAP | | | | | | | | | | | | |
| S | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| C | *** | *** | *** | *** | *** | *** | *** | ns | *** | ns | ns | ns |
| SxC | * | ** | ** | ** | ** | * | ** | ns | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 2.4. Analysis of variance for the influence of soil management history (S) and compost (C) on growth variables measured 14 and 35 days after planting (DAP) in lettuce seedlings of the spring set.

| | | | fresh weight (g) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | leaf # | shoot dry weight (g) | total | shoot | root | root vol. (mL) | leaf area ($cm^2$) | chl index | shoot : root | % moist. | specific leaf area ($cm^2/g$) | leaf weight ratio (g/g) | leaf area ratio ($cm^2/g$) |
| 35 DAP | | | | | | | | | | | | | |
| S | *** | *** | *** | *** | *** | ** | *** | *** | ns | ns | ns | ns | ns |
| C | *** | *** | *** | *** | *** | *** | *** | *** | ** | ns | ns | ns | ns |
| SxC | ns | ns | ns | ns | ns | ns | ns | ** | * | ns | ns | ns | ns |
| 50 DAP | | | | | | | | | | | | | |
| S | *** | *** | *** | *** | *** | *** | *** | *** | ns | ns | ns | ns | ns |
| C | *** | *** | *** | *** | *** | *** | *** | *** | ** | *** | ns | ** | ns |
| SxC | ns | ns | ns | ns | ns | ns | ns | * | ns | * | * | ns | * |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 2.5. Analysis of variance for the influence of soil management history (S) and compost (C) on growth variables 35 and 50 days after planting (DAP) in lettuce seedlings of the fall set.

| source | $n^w$ | leaf # | shoot dry weight (g) | fresh weight (g) total | fresh weight (g) shoot | fresh weight (g) root | root vol. (mL) | leaf area ($cm^2$) | stem length (cm) | shoot : root | % moist. | specific leaf area ($cm^2/g$) | leaf weight ratio (g/g) | leaf area ratio ($cm^2/g$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 DAP | | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | | |
| Conv. | 16 | 3.7 | 0.24 | 4.2 | 2.1 | 2.1 | 1.8 | 45.9 | 8.8 | 1.0 | 88.6 | 22.9 | 0.49 | 11.29 |
| Org. | 16 | 3.7 | 0.26 | 4.2 | 2.1 | 2.0 | 1.7 | 45.7 | 9.1 | 1.1 | 88.3 | 21.3 | 0.51 | 10.69 |
| $LSD_{0.05}$ | | 0.3 | 0.06 | 0.6 | 0.3 | 0.3 | 0.3 | 5.9 | 0.6 | 0.1 | 1.5 | 2.3 | 0.03 | 1.24 |
| Compost | | | | | | | | | | | | | | |
| No | 16 | 3.7 | 0.26 | 4.2 | 2.2 | 2.2 | 1.8 | 47.8 | 9.4 | 1.0 | 88.0 | 23.0 | 0.50 | 11.37 |
| Yes | 16 | 3.7 | 0.26 | 4.1 | 2.1 | 2.0 | 1.7 | 43.7 | 8.6 | 1.1 | 88.9 | 21.2 | 0.50 | 10.62 |
| $LSD_{0.05}$ | | 0.3 | 0.06 | 0.6 | 0.3 | 0.3 | 0.3 | 5.9 | 0.6 | 0.10 | 1.5 | 2.3 | 0.04 | 1.24 |
| 35 DAP | | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | | |
| Conv. | 16 | 5.2 | 0.88 | 11.6 | 6.2 | 5.4 | 5.0 | 126.2 | 12.3 | 1.2 | 85.7 | 20.9 | 0.53 | 10.96 |
| Org. | 16 | 5.5 | 1.13 | 14.2 | 8.2 | 6.0 | 5.6 | 164.6 | 12.9 | 1.4 | 86.0 | 20.2 | 0.57 | 11.38 |
| $LSD_{0.05}$ | | 0.2 | 0.17 | 1.3 | 1.1 | 0.4 | 0.45 | 20.52 | 0.7 | 0.17 | 0.9 | 1.0 | 0.03 | 0.75 |
| Compost | | | | | | | | | | | | | | |
| No | 16 | 5.2 | 0.96 | 12.6 | 6.7 | 5.5 | 5.5 | 135.2 | 12.6 | 1.2 | 85.6 | 20.3 | 0.53 | 10.72 |
| Yes | 16 | 5.5 | 1.05 | 13.2 | 7.6 | 5.9 | 5.1 | 155.5 | 12.7 | 1.4 | 86.1 | 20.7 | 0.57 | 11.62 |
| $LSD_{0.05}$ | | 0.2 | 0.17 | 1.3 | 1.1 | 0.4 | 0.45 | 20.52 | 0.7 | 0.17 | 0.9 | 1.0 | 0.03 | 0.75 |

Table 2.6. Effect of soil management history and compost on growth parameters measured 14 and 35 days after planting (DAP) in sweet corn seedlings of the spring planting.

$n^w$ = number of data points used in statistical analysis of individual main effects.

| | | | shoot | fresh weight | | | | | | | | | leaf | leaf |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| source | $n^w$ | leaf # | dry weight (g) | total | shoot | root | root vol. (mL) | leaf area ($cm^2$) | stem length (cm) | shoot :root | % moist. | specific leaf area ($cm^2/g$) | weight ratio (g/g) | area ratio ($cm^2/g$) |
| 14 DAP | | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | | |
| Conv. | 16 | 2.5 | 0.14 | 1.8 | 1.2 | 0.5 | 0.4 | 26.3 | 6.0 | 2.6 | 89.2 | 21.2 | 0.70 | 14.85 |
| Org. | 16 | 2.5 | 0.14 | 1.8 | 1.3 | 0.6 | 0.4 | 26.3 | 5.9 | 2.7 | 88.4 | 21.1 | 0.73 | 14.95 |
| $LSD_{0.05}$ | | 0.3 | 0.04 | 0.4 | 0.3 | 0.1 | 0.08 | 6.5 | 0.5 | 0.44 | 0.9 | 1.6 | 0.04 | 1.24 |
| Compost | | | | | | | | | | | | | | |
| No | 16 | 2.5 | 0.13 | 1.6 | 1.1 | 0.5 | 0.3 | 24.5 | 6.1 | 2.4 | 88.6 | 22.6 | 0.72 | 15.80 |
| Yes | 16 | 2.5 | 0.16 | 2.0 | 1.4 | 0.6 | 0.4 | 28.0 | 5.8 | 2.8 | 89.0 | 19.7 | 0.71a | 13.99 |
| $LSD_{0.05}$ | | 0.3 | 0.04 | 0.4 | 0.3 | 0.1 | 0.08 | 6.5 | 0.5 | 0.4 | 0.9 | 1.6 | 0.04 | 1.24 |
| 35 DAP | | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | | |
| Conv. | 16 | 5.1 | 0.85 | 9.2 | 6.8 | 2.3 | 2.0 | 114.9 | 12.3 | 2.9 | 87.2 | 17.1 | 0.72 | 12.23 |
| Org. | 16 | 5.2 | 1.03 | 11.0 | 8.6 | 2.4 | 2.1 | 141.4 | 12.9 | 3.6 | 87.9 | 16.6 | 0.77 | 12.74 |
| $LSD_{0.05}$ | | 0.3 | 0.26 | 2.5 | 2.3 | 0.4 | 0.4 | 38.5 | 1.1 | 0.5 | 0.8 | 0.9 | 0.03 | 0.98 |
| Compost | | | | | | | | | | | | | | |
| No | 16 | 4.9 | 0.79 | 7.8 | 5.6 | 2.2 | 1.9 | 96.5 | 11.7 | 2.6 | 86.2 | 17.3 | 0.71 | 12.32 |
| Yes | 16 | 5.5 | 1.09 | 12.4 | 9.9 | 2.5 | 2.2 | 159.9 | 13.5 | 3.8 | 88.9 | 16.4 | 0.78 | 12.71 |
| $LSD_{0.05}$ | | 0.3 | 0.26 | 2.5 | 2.3 | 0.4 | 0.4 | 38.5 | 1.1 | 0.5 | 0.8 | 0.9 | 0.03 | 0.98 |

Table 2.7. Effect of soil management history and compost on growth parameters measured 14 and 35 days after planting (DAP) in tomato seedlings of the spring planting.

$n^w$ = number of data points used in statistical analysis of individual main effects.

| source | $n^w$ | leaf # | shoot dry weight (g) | fresh weight (g) total | fresh weight (g) shoot | fresh weight (g) root | root vol. (mL) | leaf area ($cm^2$) | shoot: root | % moist. | specific leaf area ($cm^2/g$) | leaf weight ratio (g/g) | leaf area ratio ($cm^2/g$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 DAP | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | |
| Conv. | 16 | 4.9 | 0.15 | 2.3 | 1.6 | 0.8 | 0.7 | 42.0 | 2.1 | 90.4 | 27.4 | 0.66 | 18.03 |
| Org. | 16 | 4.8 | 0.14 | 2.4 | 1.6 | 0.7 | 0.6 | 40.0 | 2.5 | 90.8 | 26.0 | 0.67 | 17.43 |
| $LSD_{0.05}$ | | 0.3 | 0.03 | 0.5 | 0.4 | 0.2 | 0.2 | 9.9 | 0.8 | 1.1 | 0.1 | 0.05 | 1.25 |
| Compost | | | | | | | | | | | | | |
| No | 16 | 4.4 | 0.11 | 1.8 | 1.2 | 0.7 | 0.5 | 31.2 | 1.9 | 90.9 | 26.7 | 0.65 | 17.28 |
| Yes | 16 | 5.4 | 0.18 | 2.9 | 2.0 | 0.9 | 0.8 | 52.4 | 2.7 | 90.4 | 26.8 | 0.68 | 18.30 |
| $LSD_{0.05}$ | | 0.3 | 0.03 | 0.5 | 0.4 | 0.2 | 0.2 | 9.9 | 0.8 | 1.1 | 0.8 | 0.06 | 1.25 |
| 35 DAP | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | |
| Conv. | 16 | 8.9 | 0.80 | 11.9 | 8.1 | 3.8 | 3.6 | 176.2 | 2.2 | 89.5 | 22.0 | 0.67 | 14.79 |
| Org. | 16 | 9.1 | 0.93 | 13.0 | 8.8 | 4.2 | 3.8 | 178.8 | 2.2 | 88.0 | 21.1 | 0.67 | 13.94 |
| $LSD_{0.05}$ | | 0.6 | 0.16 | 2.5 | 1.8 | 0.9 | 0.9 | 32.0 | 0.4 | 1.1 | 1.1 | 0.03 | 0.89 |
| Compost | | | | | | | | | | | | | |
| No | 16 | 8.5 | 0.64 | 8.2 | 5.5 | 2.7 | 2.5 | 118.3 | 2.2 | 87.5 | 22.0 | 0.66 | 14.52 |
| Yes | 16 | 9.9 | 1.10 | 17.0 | 11.6 | 5.3 | 5.0 | 240.6 | 2.2 | 90.1 | 21.0 | 0.68 | 14.23 |
| $LSD_{0.05}$ | | 0.6 | 0.16 | 2.5 | 1.8 | 0.9 | 0.9 | 32.0 | 0.4 | 1.1 | 1.1 | 0.03 | 0.89 |

Table 2.8. Effect of soil management history and compost on directly observed growth parameters measured 14 and 35 days after planting (DAP) in lettuce seedlings of the spring planting.

$n^w$ = number of data points used in statistical analysis of individual main effects.

| source | $n^w$ | leaf # | shoot dry weight (g) | fresh weight (g) total | fresh weight (g) shoot | fresh weight (g) root | root vol. (mL) | leaf area ($cm^2$) | chl. index | shoot: root. | % moist. | specific leaf area ($cm^2/g$) | leaf weight ratio (g/g) | leaf area ratio ($cm^2/g$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 DAP | | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | | |
| Conv. | 16 | 5.1 | 0.27 | 3.6 | 2.8 | 0.9 | 0.8 | 69.0 | 31.8 | 3.26 | 90.8 | 25.7 | 0.75 | 19.06 |
| Org. | 16 | 6.2 | 0.38 | 5.3 | 4.1 | 1.3 | 1.1 | 103.6 | 36.4 | 3.71 | 92.3 | 34.0 | 0.74 | 19.33 |
| Am. Org | 16 | 6.5 | 0.40 | 5.9 | 4.5 | 1.4 | 1.2 | 111.2 | 37.8 | 3.67 | 92.5 | 25.1 | 0.77 | 20.98 |
| $LSD_{0.05}$ | | 0.3 | 0.05 | 0.7 | 0.5 | 0.2 | 0.2 | 11.9 | 1.63 | 0.52 | 1.8 | 12.2 | 0.04 | 2.22 |
| Compost | | | | | | | | | | | | | | |
| No | 16 | 5.2 | 0.24 | 3.2 | 2.3 | 0.8 | 0.7 | 60.7 | 33.8 | 3.18 | 91.1 | 31.4 | 0.73 | 20.17 |
| Yes | 16 | 6.7 | 0.47 | 6.9 | 5.3 | 1.5 | 1.3 | 130.9 | 36.8 | 3.95 | 92.7 | 24.8 | 0.78 | 19.37 |
| $LSD_{0.05}$ | | 0.3 | 0.04 | 0.6 | 0.4 | 0.1 | 0.2 | 9.7 | 1.3 | 0.42 | 1.5 | 9.9 | 0.03 | 1.81 |
| 50 DAP | | | | | | | | | | | | | | |
| Soil | | | | | | | | | | | | | | |
| Conv. | 16 | 7.3 | 0.49 | 5.7 | 3.9 | 1.8 | 1.6 | 89.3 | 30.0 | 2.38 | 86.9 | 24.1 | 0.69 | 16.44 |
| Org. | 16 | 9.2 | 0.89 | 9.6 | 6.7 | 2.9 | 2.5 | 148.3 | 33.5 | 2.52 | 86.9 | 23.3 | 0.70 | 16.17 |
| Am. Org. | 16 | 9.8 | 1.11 | 13.2 | 9.2 | 4.0 | 3.7 | 194.8 | 36.5 | 2.39 | 86.7 | 21.8 | 0.69 | 14.96 |
| $LSD_{0.05}$ | | 0.8 | 0.18 | 2.2 | 1.7 | 0.6 | 0.6 | 28.2 | 2.2 | 0.3 | 0.8 | 1.6 | 0.02 | 1.08 |
| Compost | | | | | | | | | | | | | | |
| No | 16 | 7.6 | 0.56 | 5.9 | 3.9 | 2.0 | 1.7 | 88.9 | 30.1 | 2.24 | 85.8 | 23.8 | 0.67 | 15.91 |
| Yes | 16 | 9.9 | 1.09 | 12.9 | 9.2 | 3.7 | 3.4 | 197.6 | 36.4 | 2.63 | 87.9 | 22.3 | 0.71 | 15.82 |
| $LSD_{0.05}$ | | 0.6 | 0.15 | 1.8 | 1.4 | 0.5 | 0.5 | 23.0 | | 0.23 | 0.7 | 1.3 | 0.02 | 0.88 |

Table 2.9. Effect of soil management history and compost on growth parameters 35 and 50 days after planting (DAP) in lettuce seedlings of the fall planting.

$n^w$ = number of data points used in statistical analysis of individual main effects.

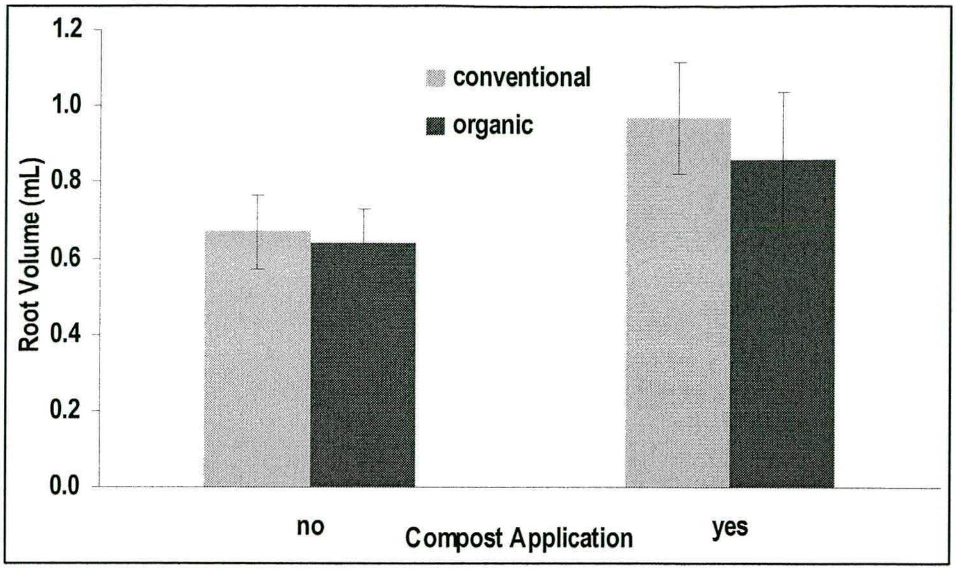


Figure 2.1. Interactive effect of soil management history and compost on percent moisture in 14 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

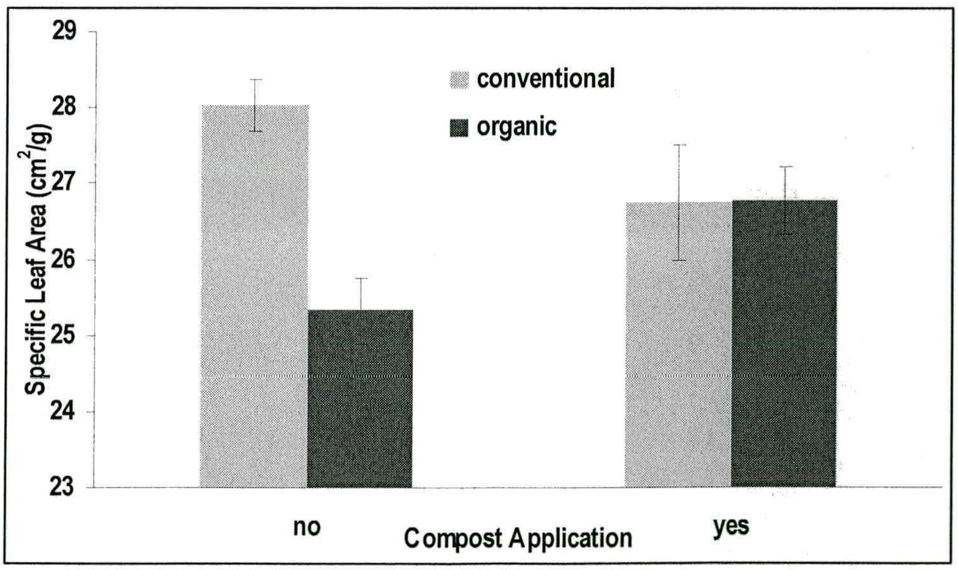


Figure 2.2. Interactive effect of soil management history and compost on specific leaf area in 14 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

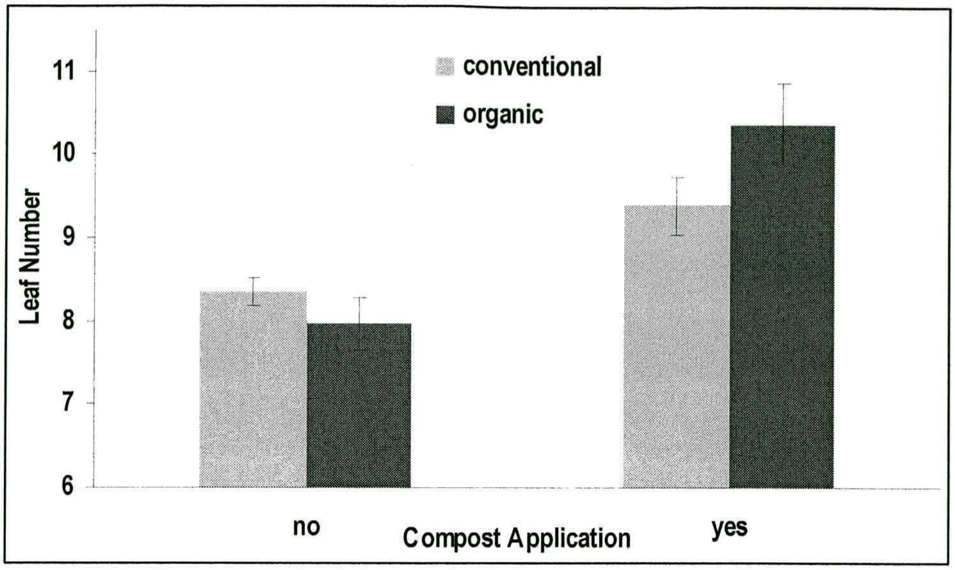


Figure 2.3. Interactive effect of soil management history and compost on leaf number in spring 35 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

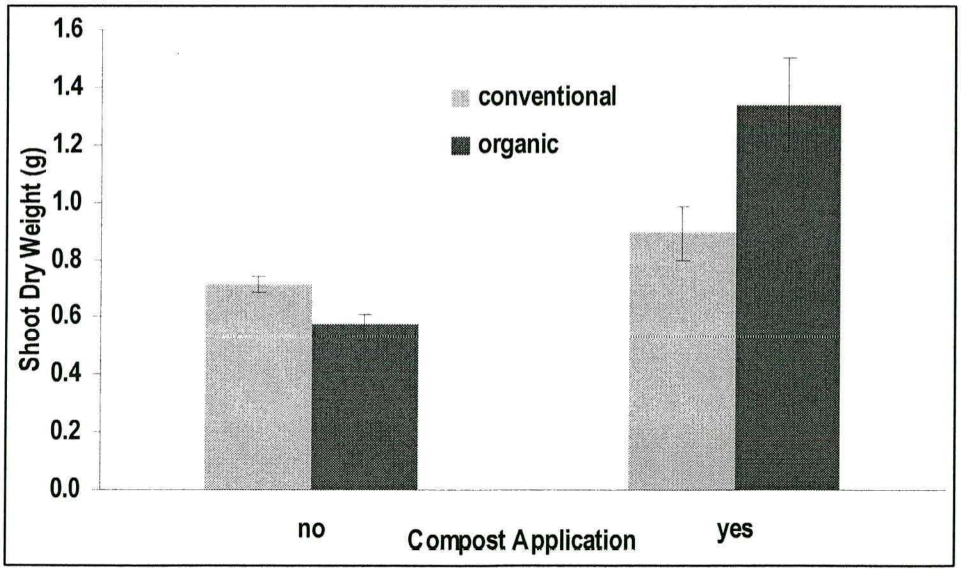


Figure 2.4. Interactive effect of soil management history and compost on shoot dry weight in spring 35 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

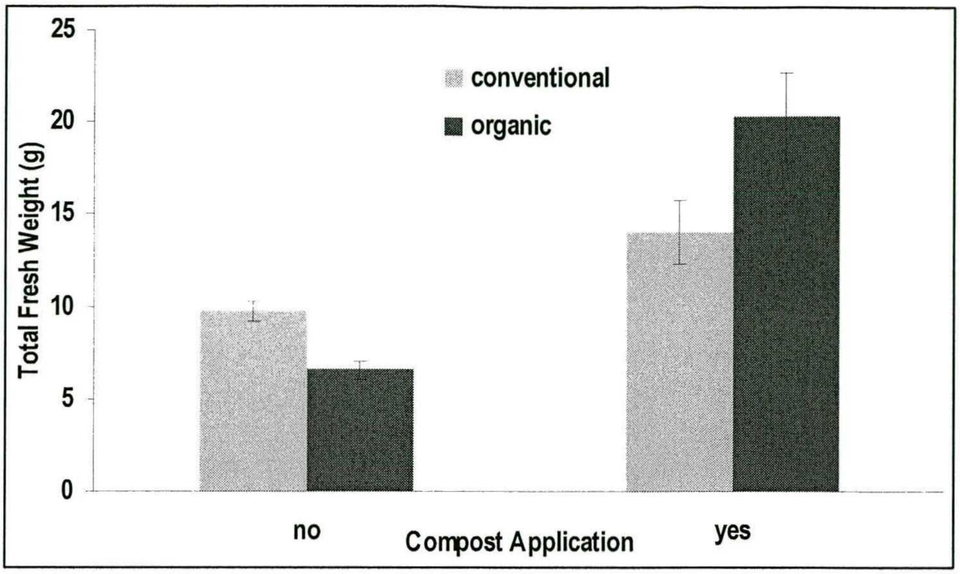


Figure 2.5. Interactive effect of soil management history and compost on total fresh weight in spring 35 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

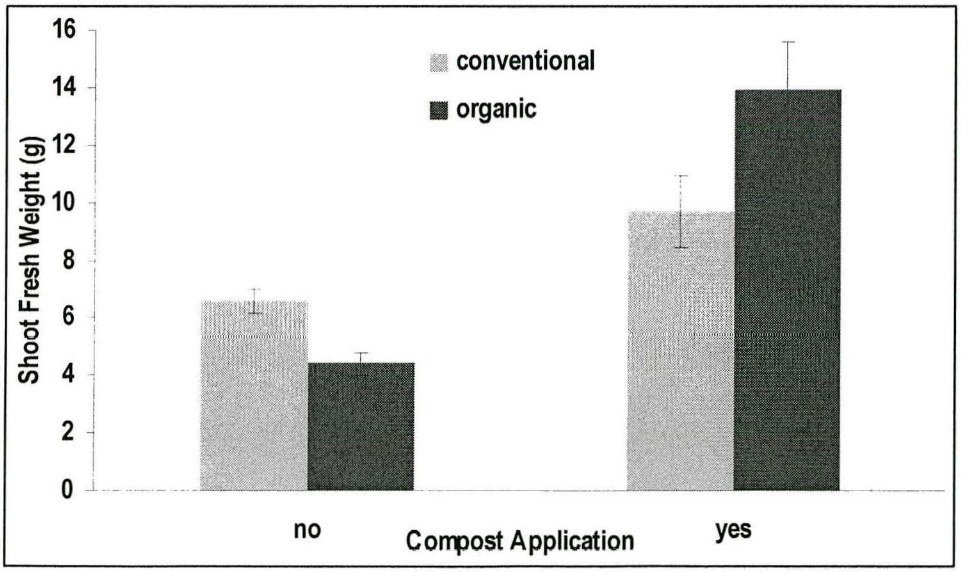


Figure 2.6. Interactive effect of soil management history and compost on shoot fresh weight in spring 35 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

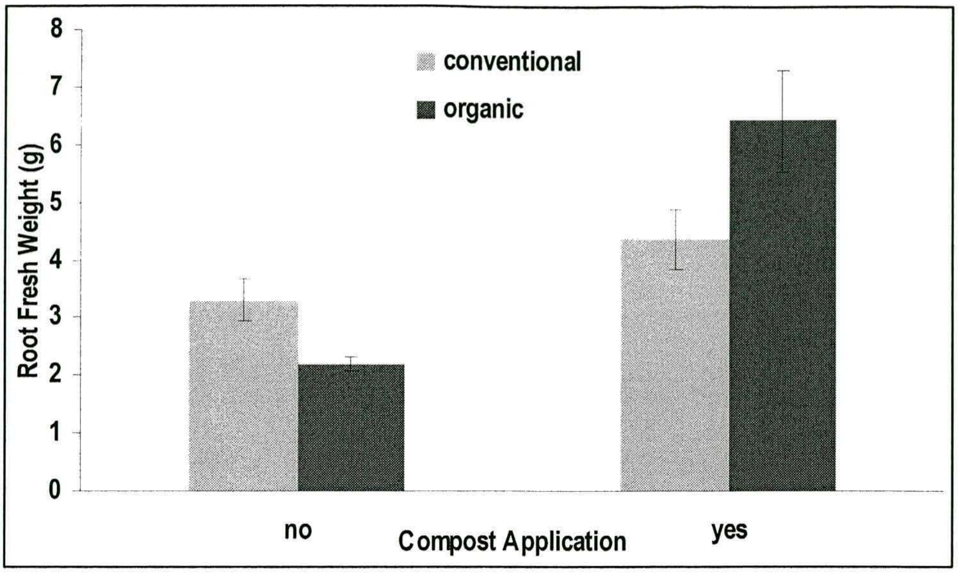


Figure 2.7. Interactive effect of soil management history and compost on root fresh weight in spring 35 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

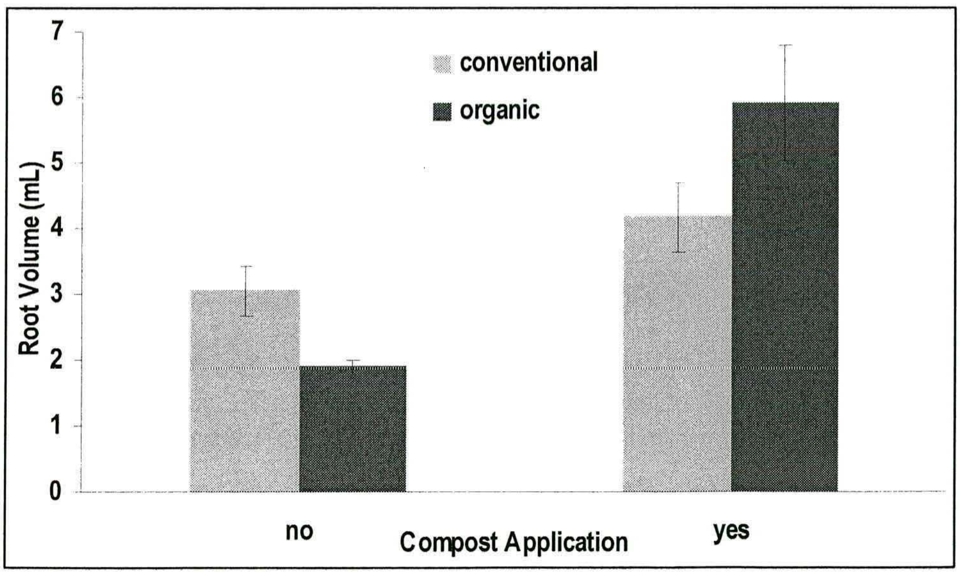


Figure 2.8. Interactive effect of soil management history and compost on root volume in spring 35 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

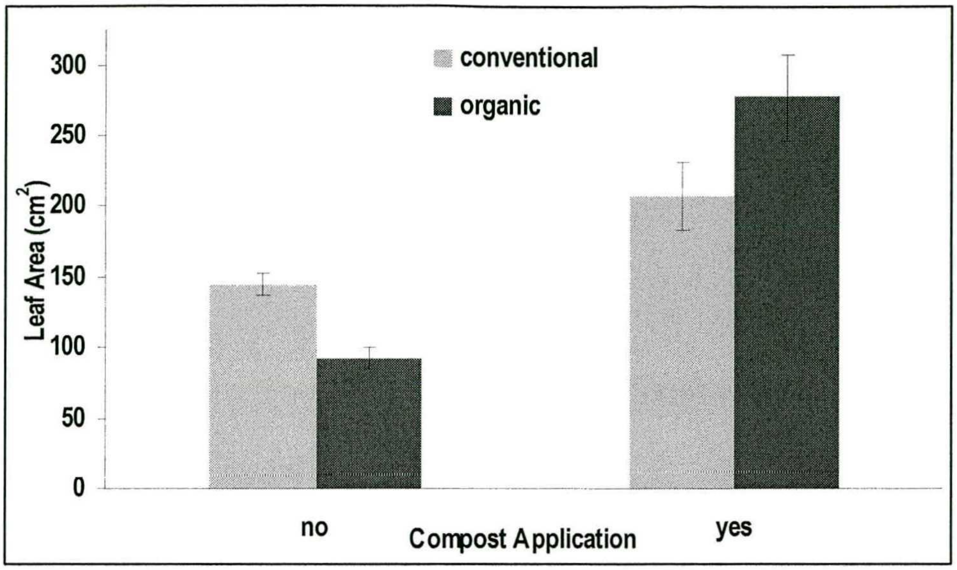


Figure 2.9. Interactive effect of soil management history and compost on leaf area in spring 35 DAP lettuce seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

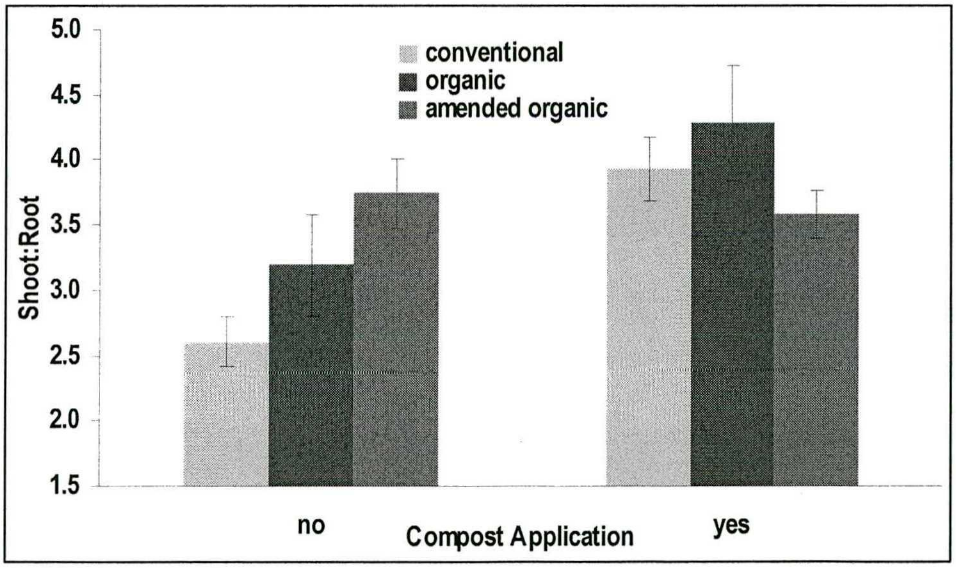


Figure 2.10. Interactive effect of soil management history and compost on shoot to root ratio in fall 35 DAP lettuce seedlings. Each bar is the mean of 12 values. Error bars are the standard error of the mean.

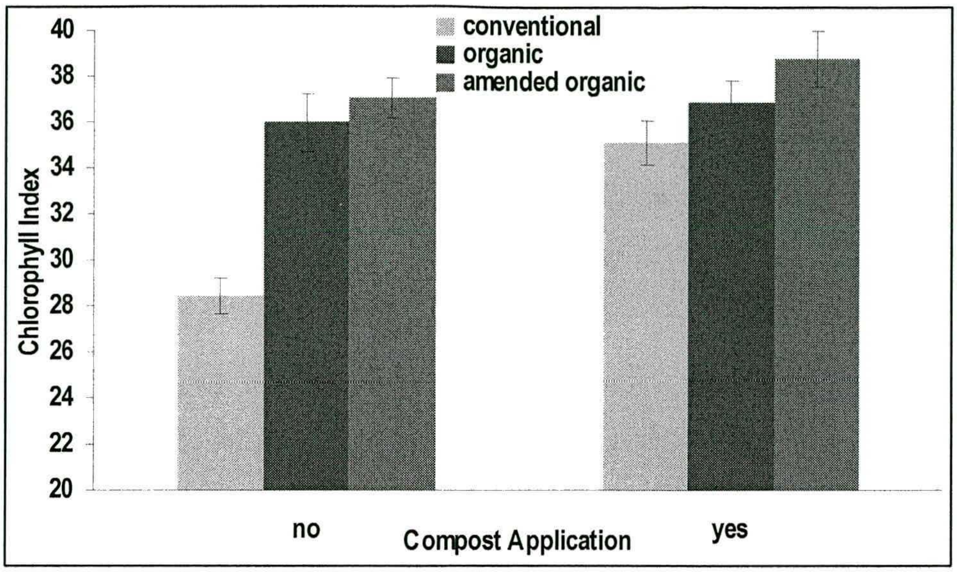


Figure 2.11. Interactive effect of soil management history and compost on chlorophyll index in fall 35 DAP lettuce seedlings. Each bar is the mean of 12 values. Error bars are the standard error of the mean.

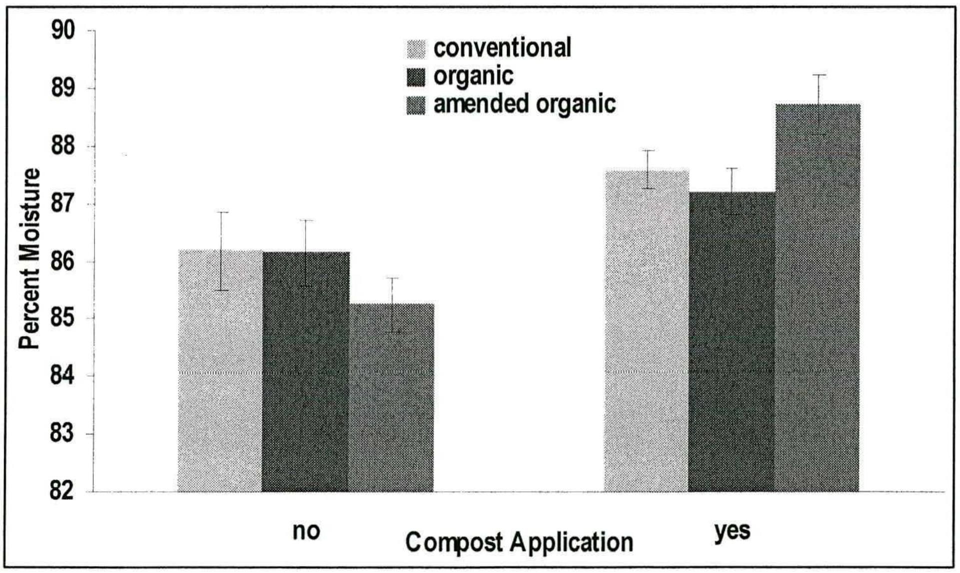


Figure 2.12. Interactive effect of soil management history and compost on percent moisture in 50 DAP lettuce seedlings. Each bar is the mean of 12 values. Error bars are the standard error of the mean.

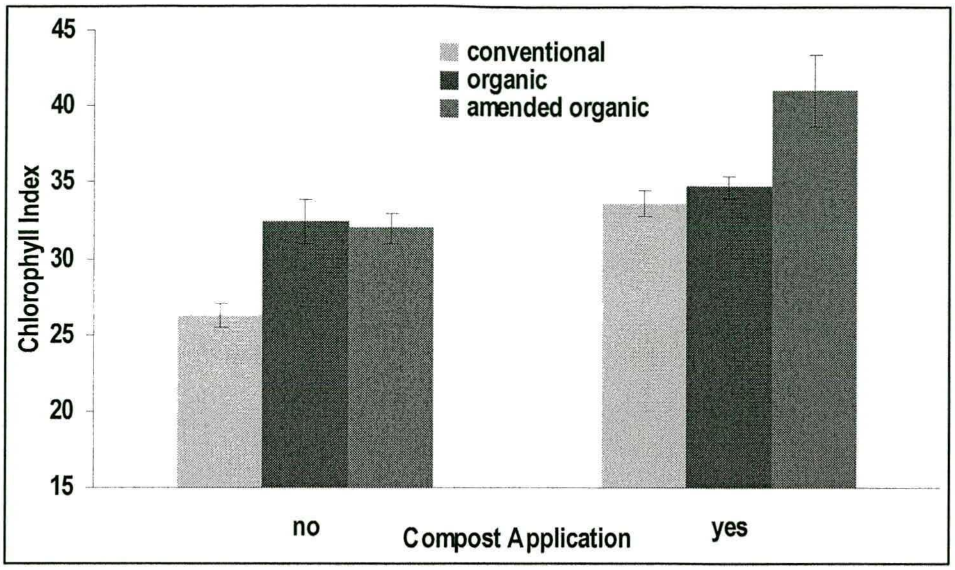


Figure 2.13. Interactive effect of soil management history and compost on chlorophyll index in 50 DAP lettuce seedlings. Each bar is the mean of 12 values. Error bars are the standard error of the mean.

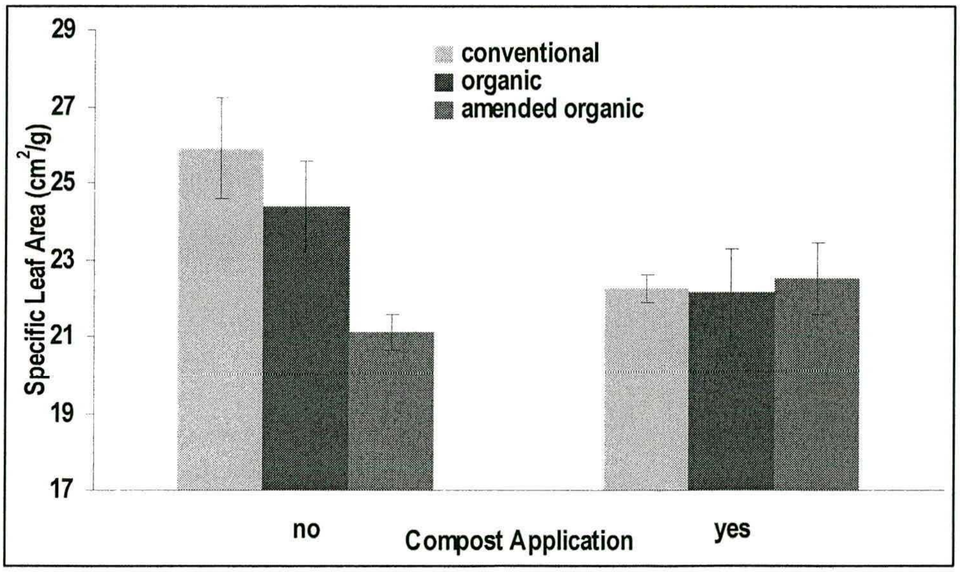


Figure 2.14. Interactive effect of soil management history and compost on specific leaf area in 50 DAP lettuce seedlings. Each bar is the mean of 12 values. Error bars are the standard error of the mean.

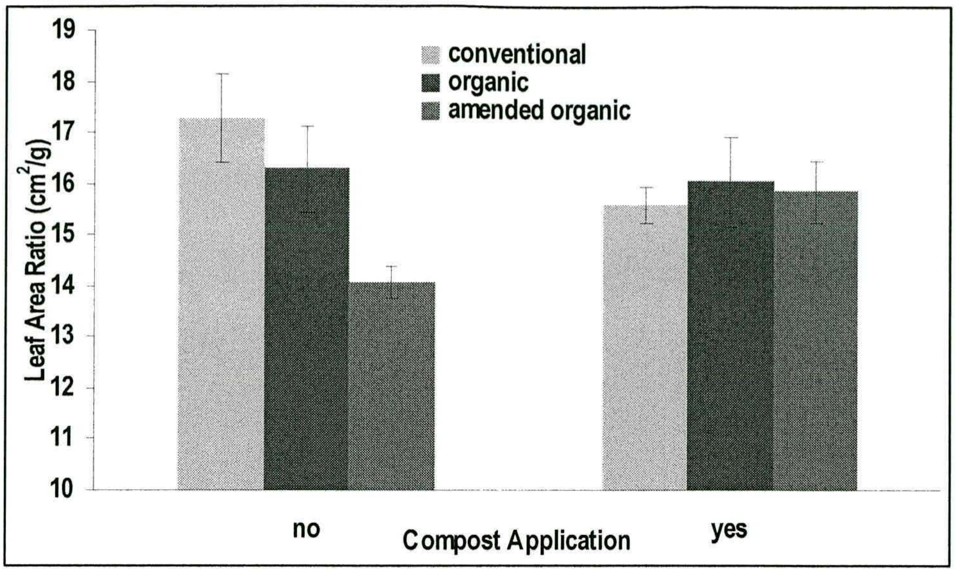


Figure 2.15. Interactive effect of soil management history and compost on leaf area ratio in 50 DAP lettuce seedlings. Each bar is the mean of 12 values. Error bars are the standard error of the mean.

# CHAPTER 3

# TEMPERATURE AND SOIL EFFECTS ON VEGETABLE SEED GERMINATION

## 3.1. ABSTRACT

Soil properties can influence rate and final percentage of seed germination. Previous experiments suggest that germination is reduced in organic soils and soils with compost added. Laboratory-based germination tests involving a factorial set of temperature and soil treatments were used to better discern the effects of these factors on germination. Untreated, romaine-type lettuce seeds (cv. 'Green Towers') were placed in Petri dishes filled with six soil treatments and a blotter paper control and held at a range of temperatures (10-32 °C) on a thermogradient table. Germination and unhealthy seed/seedling incidence were recorded for eight days. Germination and unhealthy seed/seedling percentages were both significantly affected by soil treatment and temperature. Seed/seedling percentages differed between conventional and organic soils. Compost medium did not significantly affect any variable. As the temperature of organic soils increased, germination decreased. Low temperatures had low rates of unhealthy

seed/seedlings while high temperatures had higher rates of unhealthy seeds/seedlings in organic soils. Low germination was linearly correlated with unhealthy seeds/seedlings in organic soils, indicating this was the main factor inhibiting germination.

## 3.2. INTRODUCTION

Seed germination and subsequent seedling growth are important in crop production. Inadequate or staggered stand establishment can reduce yield and profit potential (Couture et al., 2004; Pavek and Thornton, 2005; Weidong et al., 2004). It can also affect weed infestation and competition for nutrients and water (Hadas, 2004; Weiner et al., 2001). Crop density can affect crop canopy structure, the time required to harvest the crop and the uniformity of the mature product. Percent emergence affects crop density, and density strongly affects crop yield (Willey and Heath, 1969). Staggered or erratic germination often complicates all other areas of crop management and harvest and potentially the value of the harvested product (Finch-Savage, 2004)

Germination requires water, oxygen, and a specific temperature range (Hadas, 2004). Moisture levels at field capacity are typically optimal for germination. Sub-optimal temperatures can slow or completely inhibit germination. Supra-optimal temperatures can lead to thermodormancy or the denaturing of proteins needed for germination. The optimum germination temperature is between 15 and 30 °C for most seeds (Ryder, 1999). The optimum temperature for lettuce typically ranges from 15 to 22 °C, although this can range from 5 to 25 in some genotypes (Cantliffe et al., 2000). This is the range where the largest numbers of seeds germinate within the shortest time. Oxygen is necessary at certain levels to allow the seed to maintain respiration. In general, seeds placed in environments with too little oxygen (below 20%) or too high carbon dioxide (over 0.03%) will not germinate (Copeland and McDonald, 2001). Germination begins with the absorption of water by the seed and ends with the extension of the radicle (Bewley, 1997). Many factors can affect this sequence including soil compaction, temperature, light, moisture, salt concentration and the presence of germination inhibiting compounds. These factors can in turn be affected by the properties of the soil into which it is placed.

Seed coat and size can also have an effect on time to germination and overall plant quality. For example, larger seeds produce more vigorous seedlings and can germinate in a broader range of environments (Bennett, 2004).

In the first experiment, it was noted that germination was poor in organic soils, mainly in organic soils with compost added compared to conventional soils. Although low levels of compost extract can stimulate germination, high levels have been shown to inhibit germination in cress, ryegrass, tobacco and cauliflower (Asenjo et al., 2000; Ayuso et al., 1996; Kahn et al., 2005; Pare et al., 1997), so compost does have the potential to delay or prevent germination in a variety of seeds. High salinity or the presence of phytotoxic compounds such as short-chain organic acids, or $NH_3$ is often the cause of limiting factors in immature composts (Sullivan and Miller, 2001). Many low molecular weight acids (such as acetic acid) are typically present in immature composts (Chen and Inbar, 1993). Allelopathic compounds from the source materials can also have a detrimental effect on germination. However, both these type of compounds are destroyed in fully mature composts (Chen and Inbar, 1993). Temperature can also promote or inhibit germination, especially in lettuce. Temperatures above 28 C are known to cause thermodormancy in lettuce seeds, while lower temperatures can delay germination (Maynard and Hochmuth, 1997).

Seedling growth is affected by soil properties, especially the addition of compost. Tomato seedlings grown in a dairy vermicompost/soil mixture had a higher shoot and root dry weight in than those receiving no compost. Plants grown in vermicompost also had a higher N, P and K concentrations than those grown without (Hashemimajd et al., 2004). Adding organic amendments such as compost significantly increases emergence over the control in wheat seedlings germinating in soils that have a significant crusting (Seker, 2003). Compost mixtures had significantly higher shoot and root dry weights compared to mixtures with no compost added in tomato, lettuce, pepper and marigold. When a complete fertilizer was added to the medium, compost amended mixtures still were significantly larger than their unamended counterparts (Atiyeh et al., 2000), suggesting that compost is not acting solely as a fertilizer. Composted goat manure significantly increased shoot fresh and dry weights of cabbage seedlings in pinebark mediums (Mupondi et al., 2006). Compost increased the levels of N in cauliflower seedlings compared with a peat only mixture (Kahn et al., 2005).

The justification of this experiment was two part: first, the greenhouse experiment suggested that there was a factor affecting germination that was not expected or controlled. Second, germination and subsequent seedling growth and stand establishment is vital to crop production and tied to economic gains, especially to those crops that are directly seeded in the soil. Little information in known about the germination environment as it pertains to field soils and seeds (Hadas, 2004).

## 3.3. MATERIALS AND METHODS

*Soil collection and treatment*

Wooster silt loam soil (Fine-loamy, Mixed, Mesic, Typic Fragiudalf) was collected on two separate occasions from the top 25 centimeters of soil from two potato fields, one certified organic and one managed using conventional methods. It was collected October 20 of 2006. Soils were located at the OARDC in Wooster, Ohio. The organic soil had been certified organic for 4 years and followed a cowpea, popcorn, lettuce/edamame, tomato/potato rotation. Previous to certification, land was cropped to a agronomic rotation typical for the area. One half of the organic soil historically received compost (amended organic), the other half had not (unamended organic). The conventional soil was in use for approximately 30years.After the soil was collected, half of each type was mixed with a composted dairy manure (15% v/v) (Table A.2). A description of the compost in more detail can be found in chapter 2. Soil and compost were combined and mixed in a soil mixer for ten minutes. Unamended soil was also mixed for ten minutes. Following mixing, the soil was stored in plastic containers in a greenhouse. Analysis of mixed soil was done by the STAR Lab, OARDC, Wooster, OH (Table A.1).

Six soil-compost combinations were investigated: unamended organic without compost (ORG-NC), unamended organic with compost (ORG-C), conventional without compost (CNV-NC), conventional with compost (CNV-C), amended organic without compost (OWC-NC), amended organic with compost (OWC-NC).

*Plant materials and experimental conditions*

Fifty grams of each of the six soil-compost combinations were placed in 100 x 25 mm extra deep Petri dishes (LabTek, Nalge Nunc International, USA). The germination medium was moistened with either 6 or 12 mL of distilled water, corresponding to approximately 75% of field capacity and 100% field capacity. For the control, blue blotter paper was covered with a single sheet of 9 cm P8 filter paper (Whatman International Ltd, England) and moistened with distilled water.

A blotter paper seeding template with 50 holes was placed over the soil or filter paper. A single untreated seed of 'Green Towers' romaine lettuce (Johnny's Selected Seeds, Winslow, ME) was placed in each hole, for a total of 50 seeds total in each Petri dish. Plates were then covered and placed on a thermogradient table similar to the one used by Chatterton and Kadish (1969) and employed by Cardina and Hook (1989). Ends of an aluminum plate were placed in separate water baths kept at constant temperatures to create a gradient. Large metal plates were used on the table, designed to lessen the gradient experienced by the individual plates. Temperature ranged from 10-32.5 °C with eight temperature increments: 10, 13, 16, 19, 21.5, 25, 29 and 32.5° C. Temperatures varied by no more than ±1 °C throughout the entire experiment (Figure 3.1). The temperatures 32.5 and 29 °C were excluded after the first and second runs of the study, respectively, because germination was very low in both temperatures.

The plates were checked every day for eight days. Seeds and seedlings were placed into one of four categories: healthy germinated, unhealthy germinated, firm ungerminated, and unhealthy ungerminated.

Healthy germinated seedlings consisted of white hypocotyls with the radicle emerged and unblemished root hairs. The number of normal germinated seedlings was counted each day, and was removed after counting.

Seedlings were counted as unhealthy, germinated if the radicle and hypocotyl had emerged but the root hairs were brown and collapsed. Seedlings with water-soaked lesions on the stem or any that had wilted or fallen down were also put in this category. A white mycelium-like webbing was often found on and around the seedlings. Unhealthy, germinated seedlings were counted and removed on day 8.

The category firm, ungerminated seeds contained all seeds that never germinated but were also not unhealthy. Firm, ungerminated seeds were counted and removed on day 8.

Unhealthy, soft ungerminated seeds contained seeds that never germinated, and contained brown or soft insides. Soft, ungerminated seeds were counted and removed on day 8.

The total percent of seeds germinated, percent soft seed and unhealthy seedlings, percent of seeds that never germinated (firm, ungerminated) were recorded and the mean days to emergence (MDE) was calculated using the equation:

$$\text{Mean days to emergence} = \sum\left(\frac{D \times Em}{N}\right)$$

Where $D$ = the day number, $Em$ = the number of seedlings emerged that day, and $N$ = the total number of seeds emerged at 7 or 8 days. Germination index (GI) was also calculated using the equation:

$$\text{Germination index} = \sum\left(\frac{D \times Em}{n}\right)$$

Where $D$ = the day number, $Em$ = the number of seedling emerged that day, and $n$ = the total number of seeds planted.

The time it took for the treatments to reach 50% germination ($T_{50}$) was also calculated. The experiment was a randomized complete block, with blocks in time. It was repeated five times.

*Statistical analysis*

Results from analysis of variance using a fully-specified model statements in Proc GLM of SAS showed that the temporal replications could be combined since the interactive effects of repetition, soil, compost, and temperature were not significant. This analysis showed that treatment effects were consistent across experimental runs, so data from all runs were combined for analysis. Experimental conditions were consistent across temporal replications (See Figure 3.1). Data from all replications were combined and analyzed using analysis of variance, with effects considered significant when $p \leq 0.05$. Mean separation was performed using Fisher's Least Significant Difference. Contrasts were used to determine linear or quadratic relationships between variables.

## 3.4. RESULTS

In general, interactive effects were not significant, and if significant, followed no discernible pattern. Soil type affected final percent germination (FPG), though mainly at the higher temperatures (Table 3.1). Soil effects were significant at temperatures 16-25°C. Compost effects were significant at 19°C.

Soil did not affect mean days to emergence (MDE) (Table 3.2) at any temperature. Compost treatment did not affect MDE with an exception at 25°C.

Germination index (GI) was affected by soil and compost (Table 3.3). The soil main effect was significant at temperatures 16-22°C, while compost effects were significant at 10 and 25°C. Organically managed soil tended to lower germination index, while the paper control was higher than both compost treatments.

Time to 50% germination ($T_{50}$) was not affected strongly by soil or compost Table 3.4).There were two significant compost effects at 10 and 25 °C. Non compost-amended soils had the highest time to 50% germination.

At 10 and 13°C, germination variables (FPG, MDE, GI or $T_{50}$) were unaffected by soil management histories or compost applications (Tables 3.5 and 3.6).

At 16 and 19°C, the control plates had the highest FPG and GI, followed by the CNV soil history. The two organic history soils (ORG and OWC) were not significantly different from each other and were different than both the control and CNV treatments in FPG and GI. MDE and GI were not affected by soil or compost (Tables 3.7 and 3.8).

Control and CNV treatments were not significantly different with regards to FPG and GI at 22°C. These treatments had higher FPG and GI than the organically managed soils, which were also not significantly different from each other (Table 3.9). Again, MDE and $T_{50}$ were not affected by either soil or compost treatments.

At the highest temperature, 25°C, CNV treatments had the highest FPG and GI (Table 3.10). ORG, OWC and the control were not significantly different. MDE and $T_{50}$ were unaffected by soil management history. However, these variables were affected by compost. The control had the highest MDE and $T_{50}$, followed by compost-amended soil. Soils with no compost added had the lowest MDE and $T_{50}$.

FPG by day 7 or 8 varied with soil management history. In general, control plates had the highest germination, followed by conventional soil, then the two organic soils. For example, 50 of 50 seeds may have germinated in conventional soil whereas 35 of 50 germinated in organic soil. Regardless of compost treatments, ORG and OWC had significantly lower FPG than CNV (Figure 3.2).

Regardless of the total number of seeds of the 50 sown that germinated by day 7 (FPG), the percent of seed that germinated each day based on the number that germinated for the treatment overall (relative percent germination) was similar among soil types. This can be seen by comparing germination index (Figure 3.3) (a measure of absolute germination per day) with mean days to emergence (Figure 3.4) (a measure of relative germination per day). Time to 50% germination was also not strongly affected by any factors. Increases in temperature 10-25 °C tended to decrease absolute final germination percentages in organic soils. Highest final germination percentage was found in the control plates (containing paper) for temperatures 10-19 °C. For temperatures 21.5 and 25 C, conventional soils had the highest germination.

Soil and temperature effected FPG, MDE, GI and $T_{50}$ (Table 3.11)The effect of temperature on absolute final germination percentage was minimal in conventional soil. Lettuce seed did not germinate at 27 or 29 °C and declined in paper control plates at 21.5 and 25° C. Mean days to emergence was only affected by temperature (Figure 3.5). Higher temperatures tended to germinate more quickly and uniformly than lower temperatures. However, germination index was affected by both soil and temperature interactively (Figure 3.3). Germination index was similar in both organic soils (ORG and OWC) throughout all temperatures. Control plates had the highest germination index with regards to temperatures between 10 and 19 °C. At temperatures higher than that, CNV treatments were highest.

Time to 50% germination was significantly affected by soil and temperature. Blotter paper control plots had significantly lower days to 50% germination (Figure 3.6). An increase in temperature caused time to $T_{50}$ to decrease (Figure 3.7).

Soil and temperature affected all the classifications of seeds (i.e. unhealthy germinated or firm ungerminated) (Table 3.12). The percentage of firm and ungerminated seeds was generally constant throughout all temperatures and soil histories (Figure 3.8).

These seeds were affected strongly by soil and less so by compost or interactive effects (Table 3.13) at all temperatures except 10 °C. Temperature tended to increase the number of soft ungerminated seeds in the two organic histories. Soils with a conventional history were less affected, and control plates had no soft ungerminated seeds (Figure 3.9). The percentage of soft ungerminated seeds was affected by soil at all temperatures and by compost at 10 and 19 °C (Table 3.14). The percentage of healthy seedlings was similar to the FPG; soil affected healthy seedlings at temperatures 16-25 °C (Table 3.15). The number of unhealthy seedlings increased as temperature increased in both organic treatments. As with the soft ungerminated seeds, unhealthy seedlings had limited or no presence in conventional and control treatments (Figure 3.10). Seedlings classified as unhealthy were affected interactively by soil and compost at temperatures 13-19 °C (Table 3.16). Soil alone affected seedlings germinated at 22 and 25 °C.

In general, interactive effects were not significant, and if significant, followed no discernible pattern. Regardless of compost, as temperature increased the percentage of soft ungerminated seeds varied in an inverse, linear relationship with the FPG (Table 3.17).

## 3.5 DISCUSSION

It is unlikely that the poor germination in the greenhouse experiment and reduced germination in this experiment were due to using an immature compost. Immature composts typically contain phytotoxic compounds such as short chain organic acids, soluble salts or excessive amounts of $NH_3$. Allelopathic compounds can also be present. However, these compounds are destroyed within the first few weeks of composting (Chen and Inbar, 1993). The compost used in this experiment was composted for 14-16 weeks, which makes it unlikely that it was immature. There was also no odor associated with the compost, which is typically a characteristic of immature compost (Sullivan and Miller, 2001).

Certain composts have the ability to suppress specific soil borne diseases. Which diseases are suppressed are a function of the type of compost applied and the pathosystem. For example, composts from horse and green manures suppressed *Verticillium dahlia* in eggplant, but increased numbers of *Cylindrocladium spathiphyllum* in spathiphyllum systems (Termorshuizen et al., 2006). In a study done with 36 different composts, only 44% of composts tested effectively suppressed *Pythium* spp. damping off. Damping off due to *Rhizoctonia solani* was actually increased in 44% of the composts (Scheuerell et al., 2005). It is possible that the dairy compost we used was not suppressive to the particular organism that caused the unhealthy seed/seedlings. Overly cured (more than 130 days) composts can also have reduced suppressiveness to *Sclerotium rolfsii*. As the compost cured, the pH increased. However, the percentage of the medium that is the compost has to be higher than 20 % (Hoitink et al., 1993). This is true for soilless mixtures (i.e. peat). In field soils, the amount needed for suppression is not well defined, and may be significantly higher. This could explain why the compost had no effect on the amount of unhealthy seeds and seedlings.

The number of unhealthy seeds/seedlings was highest in the organically managed soils, contrary to the literature (Bulluck et al., 2002; Drinkwater et al., 1995; Ryan, 1999; Workneh and van Bruggen, 1994). However, it is noted that organic soils tend to be more biologically active then their conventional counterparts (Carpenter-Boggs, 2000; Condron, 2000; Drinkwater et al., 1995; Fließbach et al., 2007; Mäder et al., 2002; Ryan, 1999; Reganold et al., 1993;) which may have contributed to the activity of disease causing organisms. The soils that were removed from the conventional fields had been cropped to potato which had been protected with synthetic fungicides These chemicals may have persisted in the soil. While the organic field was also cropped to potato, synthetic disease controlling agents were not used, and allowable substances may not have been as effective at control, thus allowing disease causing organisms to flourish in the soil. In addition, lettuce seeds have a flattened, elongated shape. Flattened seeds do not persist as long as rounded seeds in the seed bank, which may indicate they are more susceptible to predation, including attack by microorganisms (Thompson et al., 1993).

High organic matter content can influence the amount and type of microbes living in the soil. The addition of organic matter through the addition of compost or manures can increase the number or activity of the microbial biomass (Bulluck et al., 2002; Carpenter-Boggs et al., 2000; Gunapala and Scow, 1998) by providing a food and habitat source. In general, warmer, moister soils with higher organic substrates tend to have higher amounts of microbial biomass (Dalal, 1998; Gunapala and Scow, 1998). Increased moisture, due to a higher water holding capacity could also be responsible for increased levels of microorganisms (Dalal, 1998). Increase moisture due to rain or higher temperatures are not likely to have caused differences between the organic and conventional soils used, since they originated from the same area. Since the organically managed soils that were used in this experiment (ORG and OWC) had a higher percentage of carbon, this could affect the microbial community.

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| Final % Germination | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Temperature (°C) | | | | | |
| source | df | 10 | 13 | 16 | 19 | 22 | 25 |
| Soil (S) | 2 | ns | ns | *** | *** | *** | *** |
| Compost (C ) | 1 | ns | ns | ns | * | ns | ns |
| S x C | 2 | ns | ns | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.1. Analysis of variance for the influence of soil management history and compost on final percent germination in lettuce seeds germinated at six different temperatures on a thermogradient table.

| Mean days to emergence | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Temperature (°C) | | | | | |
| source | df | 10 | 13 | 16 | 19 | 22 | 25 |
| Soil (S) | 2 | ns | ns | ns | ns | ns | ns |
| Compost (C ) | 1 | ns | ns | ns | ns | ns | * |
| S x C | 2 | ns | * | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.2. Analysis of variance for the influence of soil management history and compost (C) on mean days to emergence in lettuce seeds germinated at six different temperatures on a thermogradient table.

| Germination index | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Temperature (°C) | | | | | |
| source | df | 10 | 13 | 16 | 19 | 22 | 25 |
| Soil (S) | 2 | ns | ns | *** | *** | *** | ns |
| Compost (C ) | 1 | * | ns | ns | ns | ns | * |
| S x C | 2 | ns | ns | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.3. Analysis of variance for the influence of soil management history and compost (C) on germination index in lettuce seeds germinated at six different temperatures on a thermogradient table.

| | | $T_{50}$ | | | | | |
|---|---|---|---|---|---|---|---|
| | | Temperature (°C) | | | | | |
| source | df | 10 | 13 | 16 | 19 | 22 | 25 |
| Soil (S) | 2 | ns | ns | ns | ns | ns | ns |
| Compost (C ) | 1 | * | ns | ns | ns | ns | * |
| S x C | 2 | ns | * | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.4. Analysis of variance for the influence of soil management history and compost (C) on time to 50% germination in lettuce seeds germinated at six different temperatures on a thermogradient table.

| Source | $n^w$ | final % germ. | mean days to emerg. | germ. index | time to 50% germ. |
|---|---|---|---|---|---|
| Soil | | | | | |
| Conventional | 10 | 76.8 a | 10.9 a | 6.0 a | 6.1 a[y] |
| Organic | 10 | 88.4 a | 11.6 a | 6.9 a | 6.0 a |
| Amended Org. | 10 | 82.6 a | 13.0 a | 6.3 a | 6.3 a |
| Control | 3 | 99.3 a | 5.4 a | 9.4 a | 9.4 a |
| Compost applied? | | | | | |
| Yes | 10 | 78.3 a | 12.7 a | 6.8 b | 5.9 a |
| No | 10 | 86.9 a | 11.1 a | 6.0 b | 6.2 a |
| Control | 3 | 99.3 a | 5.4 b | 9.4 a | 4.7 a |

Table 3.5. Effect of soil and compost on germination parameters in lettuce seeds germinated at 10°C on a thermogradient table.

$n^w$ = number of data points used in statistical analysis of individual main effects.
[y] Numbers in the same main effect followed by the same letter are not significantly different according to Fisher's least significant difference test at $\alpha = 0.05$ ($LSD_{0.05}$).

| Source | $n^w$ | final % germ. | mean days to emerg. | germ. index | time to 50% germ. |
|---|---|---|---|---|---|
| Soil | | | | | |
| Conventional | 10 | 83.6 a | 6.2 a | 9.7 a | 3.9 a[y] |
| Organic | 10 | 79.6 a | 6.4 a | 9.0 a | 3.9 a |
| Amended Org. | 10 | 78.4 a | 7.0 a | 8.6 a | 4.0 a |
| Control | 3 | 99.3 a | 3.3 a | 15.2 a | 2.8 a |
| Compost applied? | | | | | |
| Yes | 10 | 11.2 a | 6.8 a | 9.2 a | 3.9 a |
| No | 10 | 81.3 a | 6.3 a | 8.9 a | 4.0 a |
| Control | 3 | 99.3 a | 3.3 a | 15.2 a | 2.8 a |

Table 3.6. Effect of soil and compost on germination parameters in lettuce seeds germinated at 13°C on a thermogradient table.

$n^w$ = number of data points used in statistical analysis of individual main effects.
[y] Numbers in the same main effect followed by the same letter are not significantly different according to Fisher's least significant difference test at $\alpha = 0.05$ ($LSD_{0.05}$).

| Source | $n^w$ | final % germ. | mean days to emerg. | germ. index | time to 50% germ. |
|---|---|---|---|---|---|
| Soil | | | | | |
| Conventional | 10 | 89.0 b | 4.8 a | 13.2 b | 2.9 a |
| Organic | 10 | 63.8 c | 4.4 a | 6.6 c | 2.8 a |
| Amended Org. | 10 | 65.4 c | 14.6 a | 9.4 c | 3.1 a |
| Control | 3 | 99.3 a | 3.0 a | 16.6 a | 2.5 a |
| Compost applied? | | | | | |
| Yes | 10 | 73.9 a | 4.8 a | 10.6 a | 3.0 a |
| No | 10 | 71.6 a | 11.2 a | 10.9 a | 2.9 a |
| Control | 3 | 99.3 a | 3.0 a | 16.6 a | 2.5 a |

Table 3.7. Effect of soil and compost on germination parameters in lettuce seeds germinated at 16°C on a thermogradient table.

$n^w$ = number of data points used in statistical analysis of individual main effects.
[y] Numbers in the same main effect followed by the same letter are not significantly different according to Fisher's least significant difference test at $\alpha = 0.05$ ($LSD_{0.05}$).

| Source | $n^w$ | final % germ. | mean days to emerg. | germ. index | time to 50% germ. |
|---|---|---|---|---|---|
| Soil | | | | | |
| Conventional | 10 | 84.0 b | 5.5 a | 14.5 b | 2.6 a |
| Organic | 10 | 57.8 c | 4.0 a | 10.1 c | 4.4 a |
| Amended Org. | 10 | 52.4 c | 4.3 a | 9.1 c | 2.8 a |
| Control | 3 | 98.7 a | 2.7 a | 21.4 a | 1.9 a |
| Compost applied? | | | | | |
| Yes | 10 | 67.2 a | 4.2 a | 11.0 a | 2.6 a |
| No | 10 | 62.3 a | 5.0 a | 11.5 a | 2.6 a |
| Control | 3 | 98.7 a | 2.7 a | 21.4 a | 1.9 a |

Table 3.8. Effect of soil and compost on germination parameters in lettuce seeds germinated at 19°C on a thermogradient table.

$n^w$ = number of data points used in statistical analysis of individual main effects.
$^y$ Numbers in the same main effect followed by the same letter are not significantly different according to Fisher's least significant difference test at $\alpha = 0.05$ ($LSD_{0.05}$).

| Source | $n^w$ | final % germ. | mean days to emerg. | germ. index | time to 50% germ. |
|---|---|---|---|---|---|
| Soil | | | | | |
| Conventional | 10 | 87.4 a | 2.8 a | 20.1 a | 1.7 a |
| Organic | 10 | 57.2 b | 2.8 a | 12.8 b | 1.8 a |
| Amended Org. | 10 | 58.8 b | 2.9 a | 13.0 b | 1.8 a |
| Control | 3 | 76.0 a | 3.5 a | 17.8 a | 1.9 a |
| Compost applied? | | | | | |
| Yes | 10 | 67.3 a | 3.0 a | 15.7 a | 1.7 a |
| No | 10 | 68.3 a | 2.7 a | 14.9 a | 1.8 a |
| Control | 3 | 76.0 a | 3.5 a | 17.8 a | 1.9 a |

Table 3.9. Effect of soil and compost on germination parameters in lettuce seeds germinated at 22°C on a thermogradient table.

$n^w$ = number of data points used in statistical analysis of individual main effects.
$^y$ Numbers in the same main effect followed by the same letter are not significantly different according to Fisher's least significant difference test at $\alpha = 0.05$ ($LSD_{0.05}$).

| Source | | $n^w$ | final % germ. | mean days to emerg. | germ. index | time to 50% germ. |
|---|---|---|---|---|---|---|
| Soil | | | | | | |
| | Conventional | 10 | 86.8 a | 3.0 a | 19.2 a | 1.8 a |
| | Organic | 10 | 55.0 b | 3.1 a | 12.4 b | 1.9 a |
| | Amended Org. | 10 | 43.4 b | 2.9 a | 9.5 b | 1.8 a |
| | Control | 3 | 56.0 b | 3.6 a | 13.0 b | 1.6 a |
| Compost applied? | | | | | | |
| | Yes | 10 | 62.5 a | 3.4 ab | 14.4 a | 1.7 ab |
| | No | 10 | 60.9 a | 2.6 b | 13.3 a | 2.0 a |
| | Control | 3 | 56.0 a | 3.6 a | 13.0 a | 1.6 b |

Table 3.10. Effect of soil and compost on germination parameters in lettuce seeds germinated at 25°C on a thermogradient table.

$n^w$ = number of data points used in statistical analysis of individual main effects.
[y] Numbers in the same main effect followed by the same letter are not significantly different according to Fisher's least significant difference test at $\alpha = 0.05$ ($LSD_{0.05}$).

| source | df | total germ. % | mean days to emer. | germ. Index | time to 50% germ. |
|---|---|---|---|---|---|
| Soil (S) | 2 | *** | *** | *** | *** |
| Temp. (T) | 5 | *** | *** | *** | *** |
| S x T | 10 | *** | ns | *** | ns |

Table 3.11 Effect of soil management history and temperature on various germination parameters.

| Source | df[z] | Germ. % | Firm Ungerm. % | Unhealthy Seed % | Unhealthy Seedling % |
|---|---|---|---|---|---|
| Soil (S)[y] | 3 | *** | ns | *** | *** |
| Temperature (T)[x] | 5 | *** | *** | *** | *** |
| S x T | 15 | *** | *** | *** | *** |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.12. Effect of soil management history (S) and temperature (T) on the percentage of healthy and soft ungerminated seeds and seedlings.

[Z] df = degrees of freedom
[y] Conventional, Organic, Amended Organic, Control
[x] 10, 13, 16, 19, 22, 25 °C

| | | Temperature (°C) | | | | | |
|---|---|---|---|---|---|---|---|
| source | df | 10 | 13 | 16 | 19 | 22 | 25 |
| % Firm | | | | | | | |
| Soil (S) | 2 | ns | ** | *** | *** | *** | *** |
| Compost (C ) | 1 | ns | ns | * | ns | ns | ns |
| S x C | 2 | ns | * | ns | ns | ns | ns |
| % Soft | | | | | | | |
| Soil (S) | 2 | * | * | *** | *** | *** | *** |
| Compost (C ) | 1 | ** | ns | ns | * | ns | ns |
| S x C | 2 | ns | ns | ns | ns | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.13. Analysis of variance for the influence of soil management history (S) and compost (C) on the percentage of two categories of ungerminated lettuce seeds imbibed at six different temperatures on a thermogradient table.

| | | Temperature (°C) | | | | | |
|---|---|---|---|---|---|---|---|
| source | df | 10 | 13 | 16 | 19 | 22 | 25 |
| % Healthy[z] | | | | | | | |
| Soil (S) | 2 | ns | ns | *** | *** | *** | *** |
| Compost (C ) | 1 | ns | ns | ns | ns | ns | ns |
| S x C | 2 | ns | ns | ns | ns | ns | ns |
| % Unhealthy[y] | | | | | | | |
| Soil (S) | 2 | ns | *** | *** | *** | *** | *** |
| Compost (C ) | 1 | ns | ns | * | ns | ns | ns |
| S x C | 2 | ns | * | * | * | ns | ns |

***,**,*,ns – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.14. Analysis of variance for the influence of soil management history (S) and compost (C) on the percentage of two categories of germinated lettuce seedlings at six different temperatures on a thermogradient table.

[z] Healthy germinated seedlings = white hypocotyls, radicle emerged, unblemished root hairs.
[y] Unhealthy germinated seedlings = brown, collapsed root hairs, water-soaked lesions, wilted or fallen down.

| Soil | Soil temperature (°C) | Germination (%) | Unhealthy seed/seedling incidence (%) |
|---|---|---|---|
| Conventional | 13 | 85 | 7 |
| | 15 | 89 | 8 |
| | 17 | 83 | 12 |
| | 21 | 87 | 7 |
| | 23 | 86 | 10 |
| Linear contrast | | NS | NS |
| Organic | 13 | 80 | 18 |
| | 15 | 67 | 31 |
| | 17 | 58 | 35 |
| | 21 | 56 | 34 |
| | 23 | 56 | 33 |
| Linear contrast | | *** | ** |
| OWC | 13 | 80 | 15 |
| | 15 | 67 | 29 |
| | 17 | 53 | 38 |
| | 21 | 57 | 34 |
| | 23 | 45 | 42 |
| Linear contrast | | *** | *** |

***,**,*,NS – represents significance at the 0.001, 0.01, and 0.05 probability level or non-significant

Table 3.15. Interactive effect of temperature and soil on seed germination and unhealthy seed/seedling incidence.

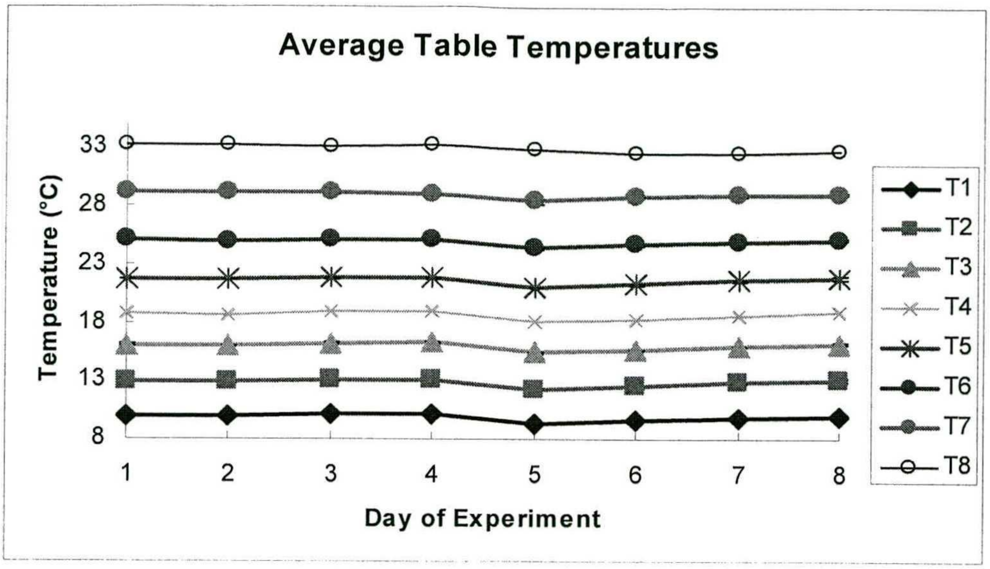


Figure 3.1. Average thermogradient table temperatures. Values are the means of five measurements. T1 was set at 10° C, T2, 13°, T3, 16°, T4, 19°, T5, 22°, T6, 25°, T7, 29°, T8 was set at 32° C

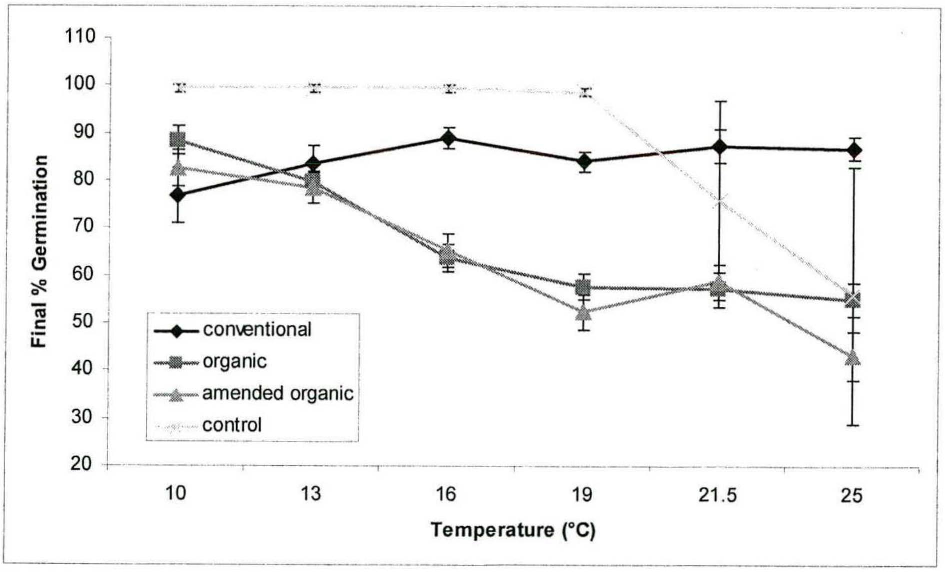


Figure 3.2. Interactive effect of temperature and soil treatment on final percent germination. Error bars are ± standard error of the mean.

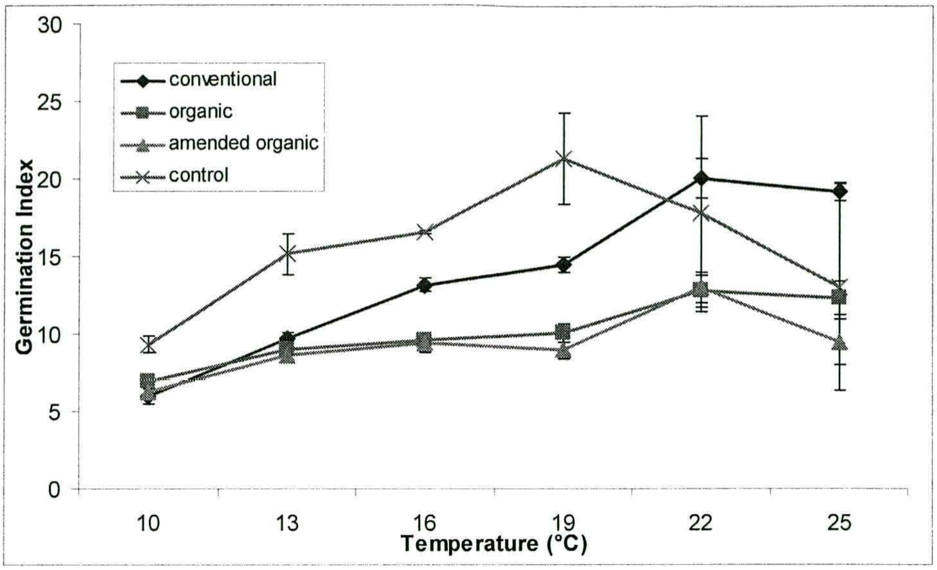


Figure 3.3. Effect of temperature on germination index on paper and in three different soil management histories. Germination index = Sum of ((Day*number of seedlings emerged that day)/Total number of seeds planted).

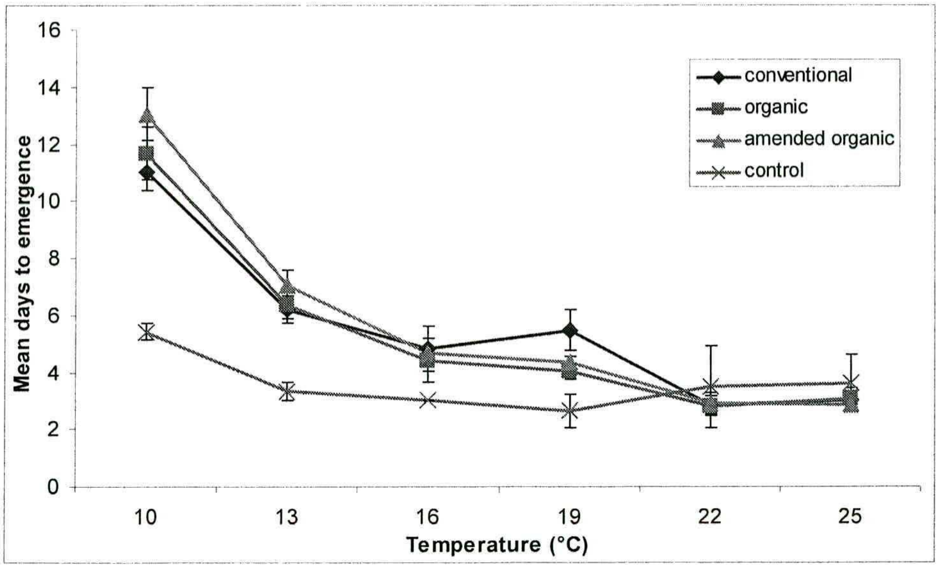


Figure 3.4. Effect of temperature on mean days to emergence on paper and in three different soil management histories. Mean days to emergence = Sum of ((Day*number of seedlings emerged that day)/Total number of seeds emerged).

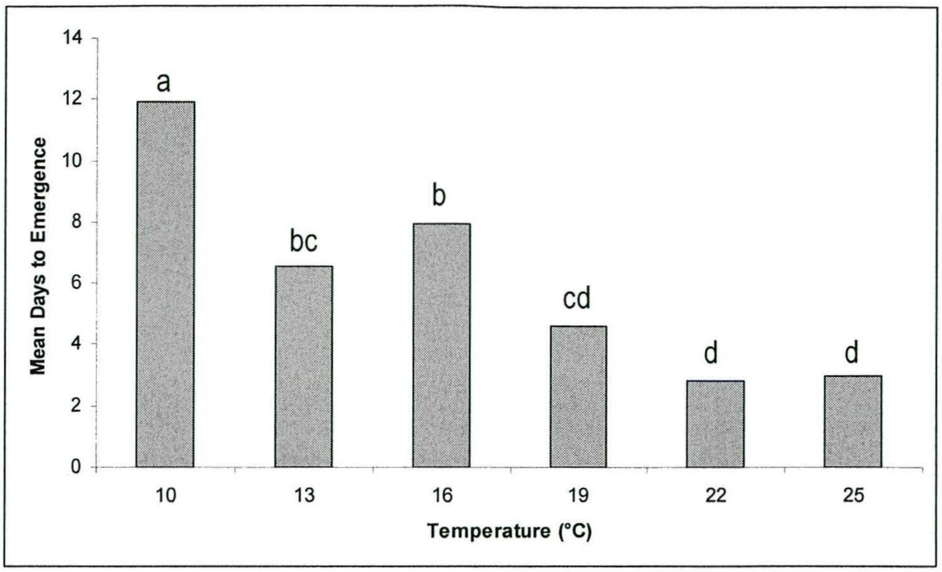


Figure 3.5. Effect of temperature on mean days to emergence averaged over all treatments. Mean days to emergence = Sum of ((Day*number seedlings emerged that day)/Total number emerged). Columns with the same letter are not significantly different at the $\alpha \leq 0.05$ level.

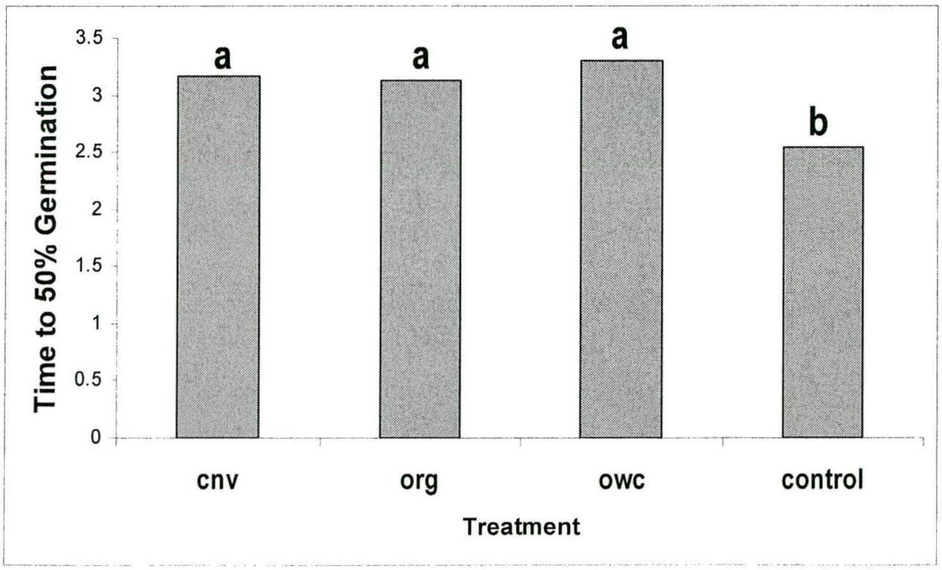


Figure 3.6. Effect of soil treatment on the time to 50 % germination averaged over all temperature treatments. Columns with the same letter are not significantly different at the $\alpha \leq 0.05$ level.

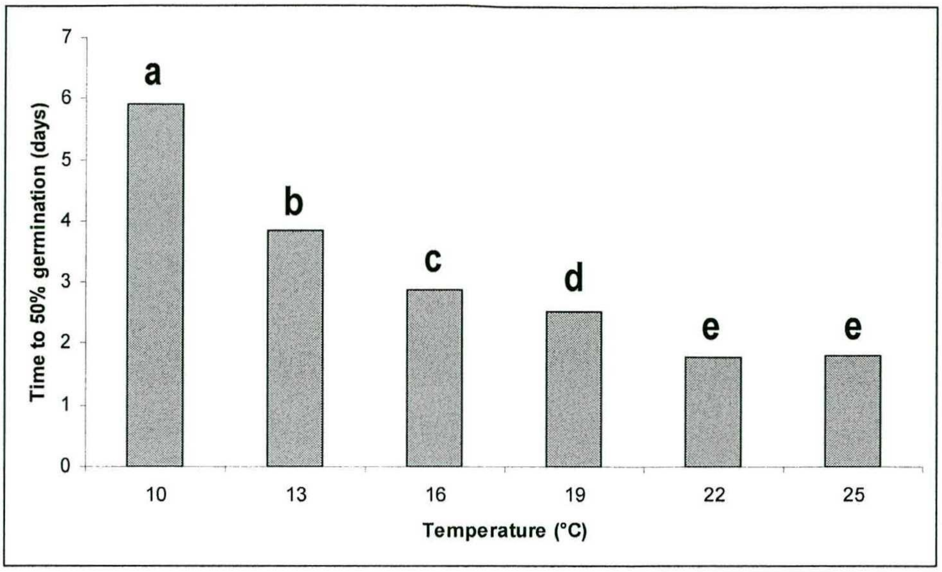


Figure 3.7. Effect of temperature on the time to 50% germination averaged over all soil treatments. Columns with the same letter are not significantly different at the $\alpha \leq 0.05$ level.

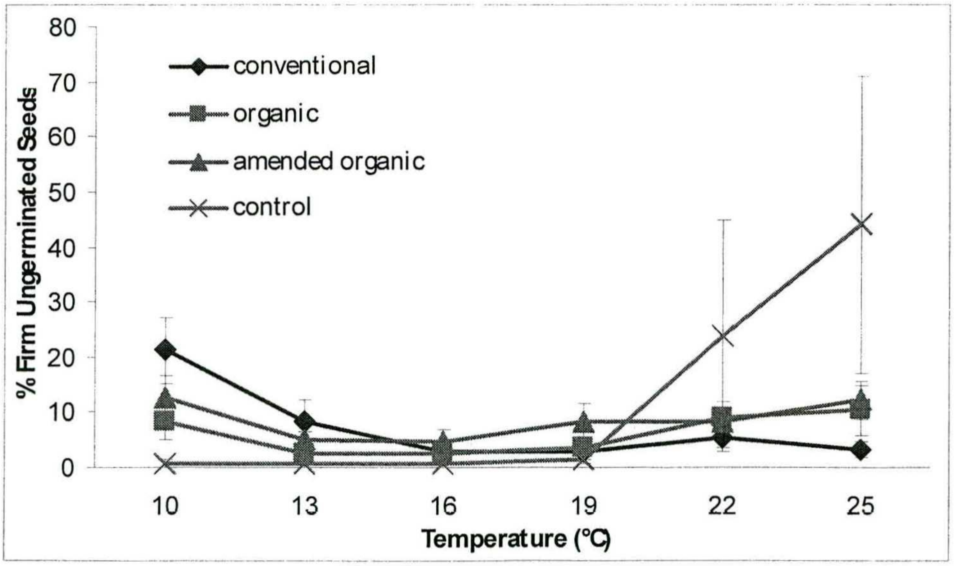


Figure. 3.8. Effect of temperature on the percentage of firm, ungerminated seeds in a paper control and three soil management histories. Values were collected at the end of a 7 or 8 day period. Values are the averages of all compost treatments.

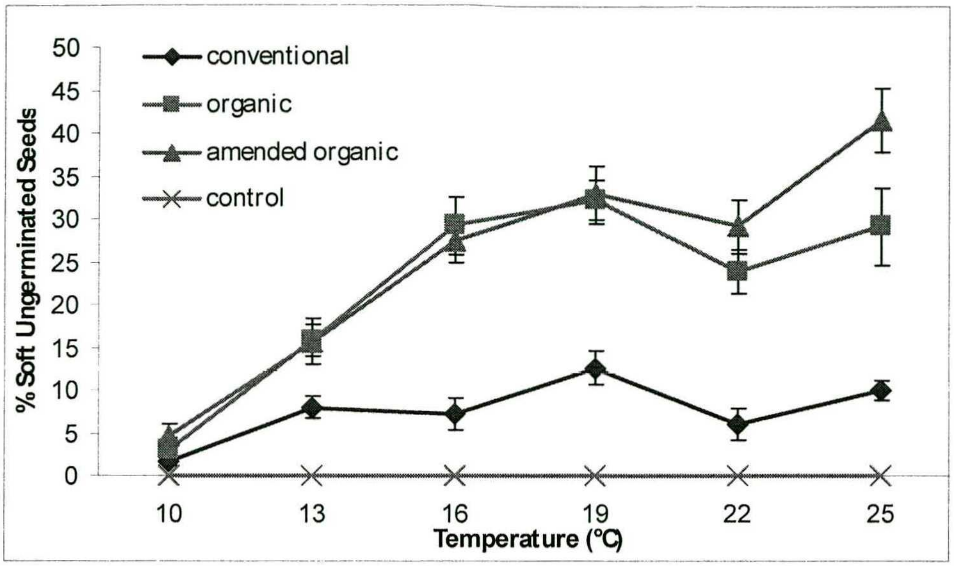


Figure 3.9. Temperature and soil effects on the percentage of soft ungerminated seeds at the end of 7 or 8 days. Error bars = ± standard error of the mean. Values within soils are averaged across all compost treatments.

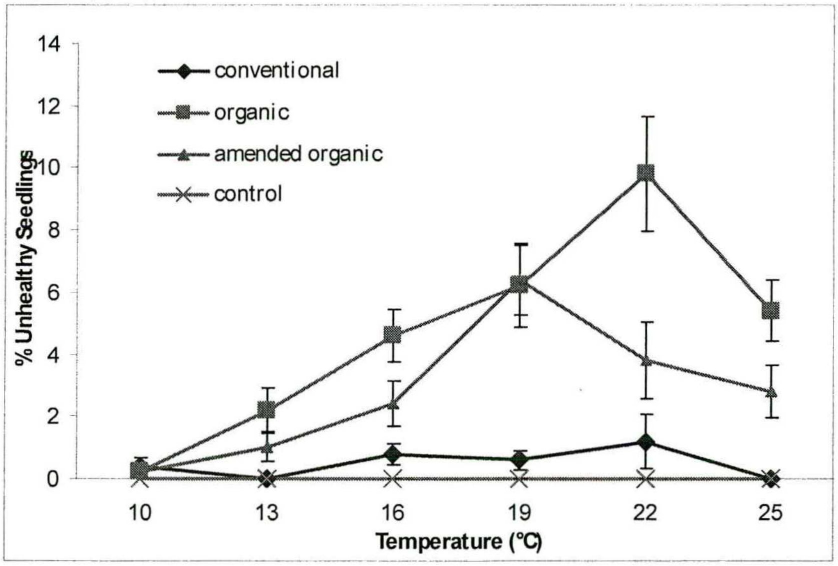


Figure 3.10. Effect of temperature on the percentage of unhealthy seedlings in a paper control and three soil management histories. Values were collected at the end of a 7 or 8 day period. Values are the averages of all compost treatments.

## 4.1 GENERAL DISCUSSION

Organic and conventional systems differ in their respective production methods. Although both systems have the same goal (successfully and profitably producing a crop), they use different methods to reach that objective. These differences in methods can lead to differences in the soil physical, chemical and biological characteristics. These differences can range from the belief that organic foods, lacking chemical pesticides, fertilizers and herbicides are healthier for human consumption (Harper and Makatouni, 2002; Raab and Grobe, 2005), to the belief that by using less chemicals, organically produced goods are better for the environment (Davies et al., 1995; Hutchins and Greenhalgh, 1997; Tregear et al., 1994). By using compost, it is possible to change the flavor of certain foods (Wszelaki et al., 2004). By changing the soil in which plants are grown, it is possible to change how the plants germinate and grow.

Organically managed soils are measurably different from conventionally managed soils. Organically managed soils tend to have a higher organic matter content, (Bulluck et al., 2002; Cardelli, 2004; Drinkwater, et al., 1995), a lower bulk density (Condron, 2000; Reganold et al., 1993) and a higher water holding capacity (Pimentel et al., 2005). In addition, cation exchange capacity (Bulluck et al., 2002; Herencia et al., 2007; Schjønning et al., 2002) and nutrient levels may differ (Melero et al., 2006; Warman, 1998). Beneficial organisms, ranging from spiders and earthworms, (Carpenter-Boggs, 2000; Ryan, 1999) to disease-suppressive bacteria (Fließbach and Mäder, 2000; Schjønning et al., 2002) and mycorrhizal fungi (Mäder et al., 2002; Pimentel et al., 2005). are present in organic soils in larger amounts compared to conventional.

Seed germination and subsequent seedling growth is a critical time for the crop. If seeds do not germinate and grow quickly and uniformly, crop value can be reduced (Couture et al., 2004; Pavek and Thornton, 2005; Weidong et al., 2004; Weiner et al., 2001).

Our results strongly suggest that seedlings as early as 14 days, are affected by the type of soil management history. Generally, seedlings grown in organic treatments or seedlings grown with the addition of compost were largest. Seedlings at later stages of growth (such as 35 or 50 days after planting) are more strongly affected by soil history and compost.

Although seedlings grown in organically managed soils were larger than their conventional counterparts, the same pattern did not hold true for the germination studies. In general, conventionally managed soils had higher germination compared to the organically managed treatments. Organic treatments also had higher numbers of soft ungerminated seeds and seedlings.

The results for the seedling experiment are similar to other reports (Clark et al., 1999; Dick and McCoy, 1993; Drinkwater, et al., 1995; Roe, 1998, 2001). The soils with composts incorporated tended to have more nutrients in them compared to unamended soils of either type. However, the differences between both soil treatments were present whether both were unamended or amended. No nutrient was low enough to imply a deficiency. This suggests that it is not only the nutrient content influencing the seedlings, but another factor such as increased water access, or the presence of beneficial bacteria or arbuscular mycorrhizae.

The results from the seed germination experiment are not similar to the literature. Typically, diseases are reduced in organic systems due to the increases in beneficial microorganisms (Bulluck et al., 2002; Drinkwater et al., 1995; Ryan, 1999; Workneh and van Bruggen, 1994). It is possible that the organically managed soils were simply infested with a disease-causing organism.

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## APPENDIX A

## TABLES AND FIGURES

| Soil Type | pH | P (ug/ g) | K (ug/ g) | Ca (ug/ g) | Mg (ug/ g) | CEC (meq/ 100g) | % N. | % C. | soluble. salts (mmhos/ cm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Spring Experiment | | | | | |
| CNV-NC | 5.1 | 85 | 164 | 677 | 161 | 12.3 | 0.10 | 1.0 | 0.2 |
| CNV-C | 5.7 | 99 | 466 | 1081 | 300 | 12.7 | 0.18 | 1.7 | 0.6 |
| ORG-NC | 5.6 | 51 | 154 | 1009 | 176 | 10.5 | 0.11 | 1.0 | 0.3 |
| ORG-C | 5.9 | 105 | 597 | 1326 | 283 | 14.1 | 0.22 | 2.4 | 0.7 |
| | | | | Fall Experiment | | | | | |
| CNV-NC | 5.6 | 53 | 111 | 908 | 240 | 10.5 | 0.10 | 0.8 | 0.2 |
| CNV-C | 6.1 | 121 | 299 | 1285 | 361 | 12.6 | 0.19 | 1.7 | 0.5 |
| ORG-NC | 6.0 | 53 | 156 | 1134 | 231 | 10.4 | 0.16 | 1.3 | 0.3 |
| ORG-C | 6.3 | 88 | 372 | 1326 | 318 | 10.2 | 0.23 | 2.1 | 0.5 |
| OWC-NC | 6.4 | 76 | 429 | 1313 | 302 | 10.2 | 0.20 | 1.8 | 0.4 |
| OWC-C | 6.5 | 165 | 942 | 1674 | 431 | 14.4 | 0.31 | 3.0 | 0.7 |

Table A.1. Soil characteristics in the Spring and Fall experiment. Values are the average of two samples. Soil analyzed at the Service Testing and Research Lab at the OARDC, Wooster, OH.

CNV-NC, CNV-C, ORG-NC, ORG-C, OWC-NC, OWC-C are conventional soil with no compost added, conventional soil, 15% compost by volume added, organic soil with no compost added, and organic soil with 15% compost by volume added, historically amended organic soil with no compost added, and historically amended organic soil with 15% compost by volume added.

| Compost | pH | P (ug/g) | K (ug/g) | % Solid | % N | % C | C:N | $NH_3$-N (µg/g) | $NO_3$-N (µg/g) | Soluble Salts (mmhos / cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Spring | 7.4 | 5393 | 15983 | 34.1 | 4.0 | 46.1 | 11.4 | 225.4 | 981.6 | 4.4 |
| Fall | 7.0 | 4458 | 22002 | 39.0 | 3.6 | 38.4 | 10.6 | 30.4 | 2548.1 | 9.1 |

Table A.2. Compost characteristics in the Spring and Fall experiments. Values are the average of two samples. Compost analyzed at the Service Testing and Research Lab at the OARDC, Wooster, OH.

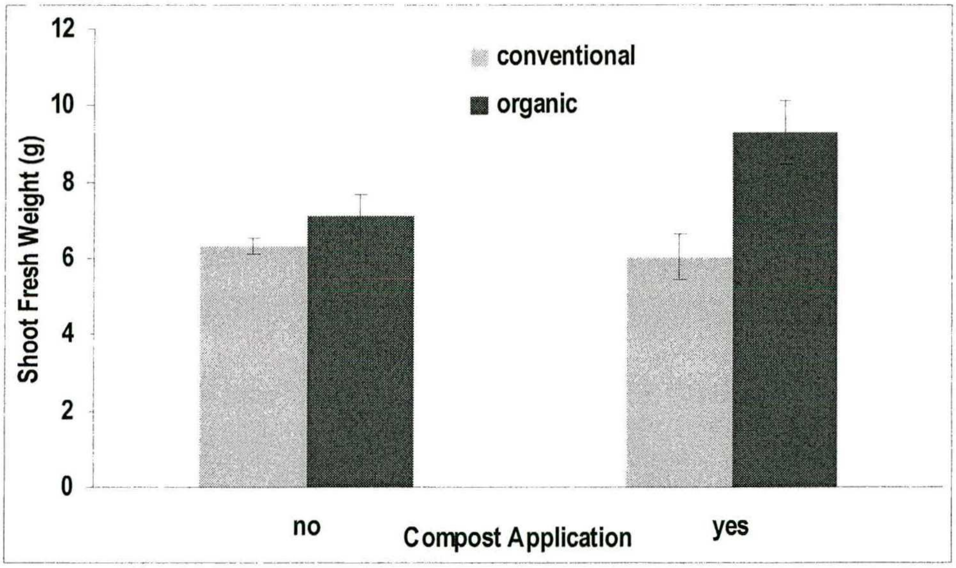


Figure A.1 Interactive effect of soil management history and compost on shoot fresh weight in 35 DAP sweet corn seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

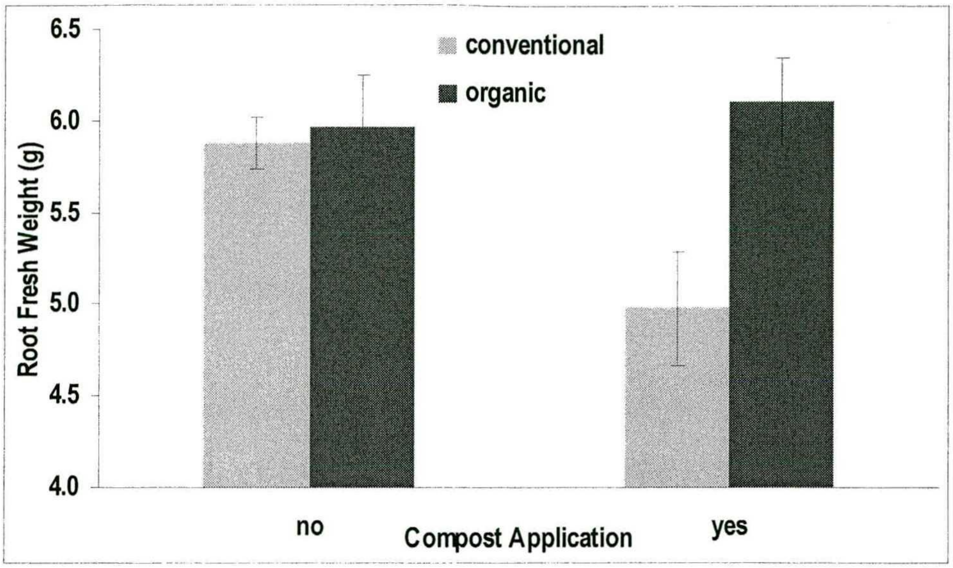


Figure A.2. Interactive effect of soil management history and compost on root fresh weight in 35 DAP sweet corn seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

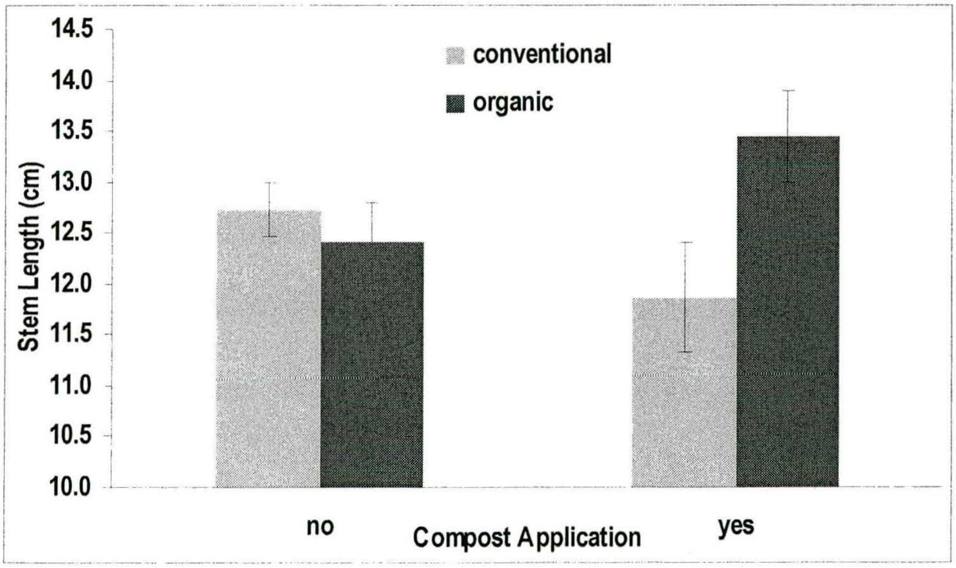


Figure A.3. Interactive effect of soil management history and compost on stem length (cm) length in 35 DAP sweet corn seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

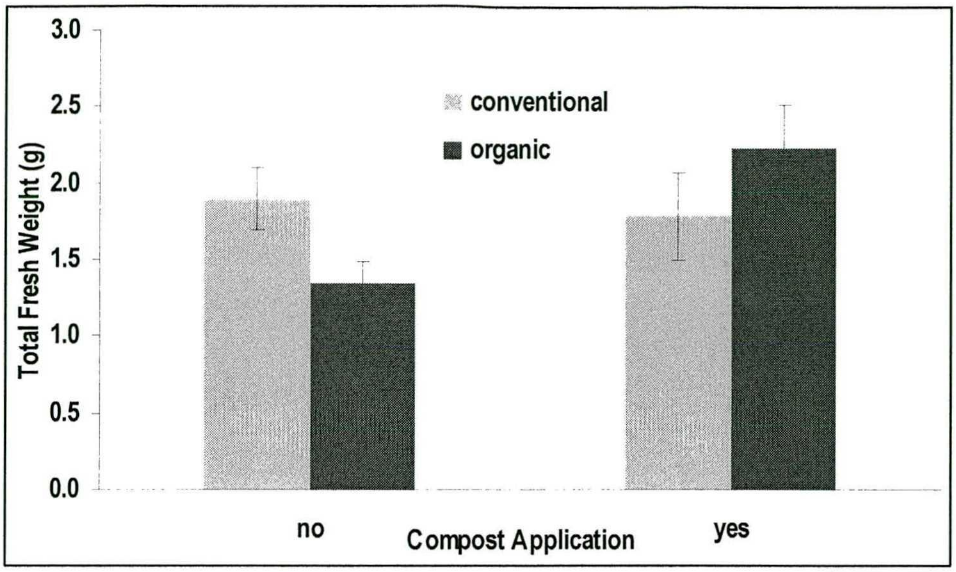


Figure A.4. Interactive effect of soil management history and compost on total fresh weight in 14 DAP tomato seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

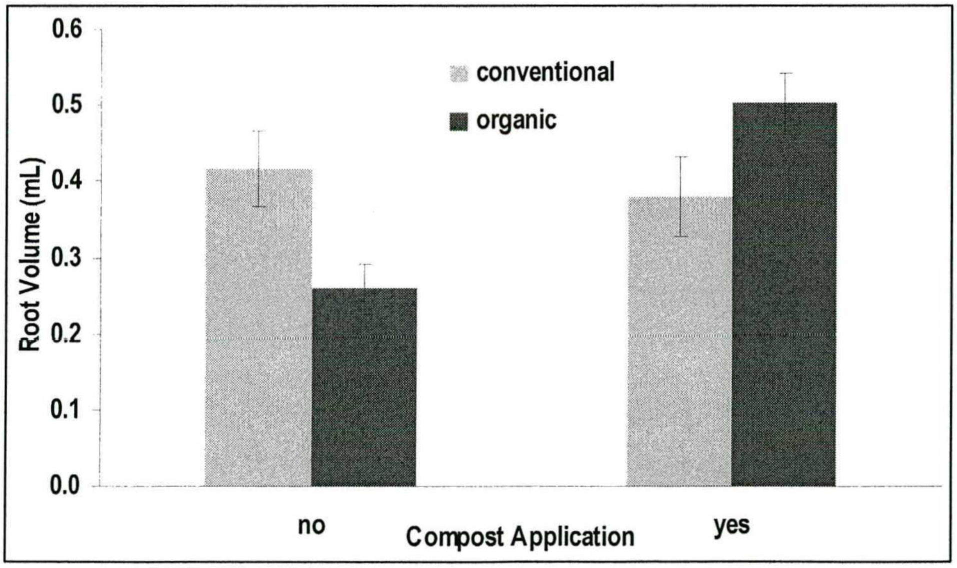


Figure A.5. Interactive effect of soil management history and compost on root volume in 14 DAP tomato seedlings. Each bar is the mean of 8 values. Error bars are the standard error of the mean.

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