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Marcia LaCorbiniere-Jn-Baptiste

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By

Marcia LaCorbiniere-JnBaptiste

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ABSTRACT

EFFECTS OF GYPSUM, COMPOST AND COVER CROPS ON SOIL NUTRIENT AVAILABILIY, CRON YIELD AND QUALITY AND SOIL QUALITY

By

Marcia LaCorbiniere-Jn-Baptiste

The recent and growing interest in the use of gypsum ($CaSO_4 \cdot 2H_2O$) by Michigan farmers, and the lack of documentation on the effect of gypsum on Michigan soils, warrant investigation on its effect on various soil and plant growth parameters. This study investigated the effects of gypsum and its interaction with compost and cover crops on soil nutrient availability, yield and quality of sweet corn (*Zea mays var. rugosa*), and soil quality. The objective was to study the effects of gypsum alone, or combined with compost and cover crops on 1) extractable Ca and Mg, 2) sweet corn growth, yield and quality, and 3) soil quality. The treatment design involved three factors: gypsum application at 0 and 2.24 Mg ha^{-1}, poultry compost at 0 and 2.7 Mg ha^{-1}, and four cover crops, plus a no cover treatment. The four cover crops were oilseed radish (*Raphanus sativus*), oriental mustard (*Brassica juncea L*), red clover (*Trifolium pratense)*, and cereal rye (*Secale cereale*), or wheat (*Triticum aestivum*) and no cover. Corn was sown in the spring of each year and cover crops were sown in the spring of 2005 and both spring and fall of 2006. An early cover crop treatment was planted in early spring and a late cover treatment planted after sweet corn was harvested in the fall of 2006. The statistical model included the three factors and all interactions among them as fixed effects and replication as a random effect. Gypsum had minimal (positive) effect on extractable Ca in spring of 2007 but had a negative effect on extractable Mg in 2006 and 2007 (both spring and fall). Compost application increased Ca by up to 44% and resulted in significant transfer of extractable Mg to lower depths. Our results suggest that sweet corn has a higher demand for both Ca and Mg than the cover crops studied and that sweet corn requirement of Ca may be genetically/variety dependent. Cover crops may have potential to increase availability of both Ca and Mg ($\alpha = 0.05$) to soil. Gypsum application decreased both corn plant biomass at the V8 (8-leaf stage) growth stage and corn yield; had no effect on number of corn ears, and no combined treatment effect on number of corn ears per hectare. Cover crops affected the number of sweet corn ears only in 2006 ($\alpha = 0.05$). Both cover crops and compost had a positive effect on sweet corn growth, yield and quality. Gypsum had no effect on the quality components investigated. Compost application significantly enhanced aggregate stability and reduced bulk density over the three years of study. This increase corresponded with the active organic matter (AOM) test which showed a fair rating of soil quality compared to the non compost treatment. Generally there was no effect ($\alpha = 0.05$) of cover crops on the soil quality components studied. Mustard negatively influenced water stable aggregate (WSA), bulk density and nematode population. This study may have economic implications to Michigan and other farmers.

DEDICATION

This work is dedicated first to my husband for his unwavering support and love and for his dedication to the completion of my studies and research; my two sons- Ishmerai and Hasadiah for their patience, understanding and love.

Also, to the memories of my parents, Leonard and Flavienne LaCorbiniere and the memories of my four siblings, Peter, Nicholson, Gregory and Veronica.

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CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

One of the major issues dominating the global agenda for the agriculture sector over the past three decades is the need for sustainable production (management) systems (Bird, 2003). Prior to the dawn of agriculture, the hunter–gatherer lifestyle supported approximately 4 million people globally; modern agriculture now feeds over six billion people (Tilman et al., 2002). Yearly, global food crops have increased consistently throughout the 19^{th} and 20^{th} century, though at a more rapid rate during the latter (Krishna, 2002). Agricultural practices determine the level of food production and, to a great extent, the state of the global environment (Tilman et al., 2002) and consequently human health and wellbeing. Sustainability is a multifaceted concept, which ensures that management and use of natural resources does not diminish their capacities to meet economic, environmental, social and aesthetic needs and presents opportunities of present and future generations (Dalal et al., 2003). Agricultural sustainability therefore, envelopes environmental soundness, economic viability, social responsibility, service for the present and future generations, with emphasis on the welfare of all species of the biosphere (Allen et al., 1991). This sustainable view of agriculture presents a mandate for researches to reevaluate the agricultural practices which have adversely impacted the environment, and to adopt new management methods that will lessen potential risk to the environment and human health. Therefore, sustainable agricultural will be manifested only when farming practices seek to manage soils with an agro-ecological approach, since the most important link between agricultural productivity and agricultural sustainability is the health or quality of the soil (Gregorich, 1995, Cochrane, 2003). .

The concept of soil quality is not a new topic, having been used as early as the 1950s, especially by pedologists. Soil quality refers to a soil's capacity to perform specific functions. The term SQ envelopes both a soil's productive and environmental capabilities (Wander, et, al, 2002). Concerns with soil degradation worldwide, and the growing need for sustainable soil management in agro-ecosystems has renewed scientific attention to characterize soil quality (Carter, 2001; Sánchez-Marañón et al., 2002). Additionally, intensified crop production to meet world food demands, and the pressure on nonrenewable resources, have imposed a mandate for sustainable agriculture which has become a global agenda, as it offers long term focus for soil quality goals (Ditzler, et al., 2002; Sánchez-Marañón et al., 2002). In 1993, in an effort to assist with the conservation of natural resources and the environment, the United States Department of Agriculture (USDA), through the Natural Resources Conservation Service (NRCS) identified soil quality as an emphasis area, and established the Soil Quality Institute (SQI). The primary mission of the SQI is to develop and dissemination soil quality information and technology in cooperation with various partners (Ditzler, et al., 2002). A reduction in soil quality as a consequence of human activities can be defined as soil degradation (Cassman, 1999). Soil quality can be enhanced by the use of various soil amendments in crop production systems.

Soil Amendments

Soil amendments are added to improve soil status and can be either fertilizers, added for their nutrient values, or conditioners used for their beneficial impact on the biological, chemical and physical status of the soil, but have limited amount of nutrients. Soil amendments can be naturally occurring or synthetic, and either organic or inorganic. Since the 1950s soil conditioners have been used extensively in agriculture (Li et al., 2000). Soil amendments for the purpose of making nutrients available to crops and improving soil quality must be carefully examined. The misuse of soil amendments can result in adverse impacts on both crops and soils with consequences to environment and human health (Brown et al., 2004). Organic amendments include but are not limited to crop residues, green manures, and cover crops, food processing by-products, biosolids, sawdust and wood ash. Inorganic amendments include vermiculite, perlite, lime, gypsum, manures and compost. The most common form of soil amendment is granular inorganic fertilizer, NPK. Among those mentioned, gypsum, compost and cover crops are of interest here, and will be discussed further.

Gypsum as a soil amendment

Gypsum ($CaSO_4$–$2H_2O$) is a natural mineral and a source of readily available calcium (Ca) and sulphur (S) amendment that is sufficiently soluble to move rapidly into the soil when surface applied. Large quantities of gypsum are also produced by various processes. For example, phosphogypsum is the main byproduct of phosphoric acid production resulting from the mixing of phosphate rock with sulfuric acid (Soratto and

Crusciol, 2008; El-Mrabet et al., 2003; Hao et al., 2003; Zvomuya at al., 2005). Another type of gypsum, FGD (flue gas desulfurization), is a byproduct of the process which removes sulfur (SO_2) from the flue gas in coal-fired power plants for sulfur emissions reduction when coal is burned for energy (EPA, 2008; Chen et al., 2008; Punshon et al., 2001). FGD, commonly referred to as by-product gypsum contains less impurities than other commercially produced gypsum (EPA, 2008; Chen et al., 2008), and is of the identical chemical structure as mined gypsum (EPA, 2008). Gypsum (calcium sulfate dehydrate) contains 23- 32% Ca, 16-18 % S and 45-50% non-gypsum material and is a valuable input for rapidly replenishing the soil profile with Ca (Ritcher and Sunffer, 2002, Warncke, 2003, and Tisdale et, al, 1996).

Since the 1970s the benefits of gypsum on crop yield have been reported, particularly as they relate to amending sodic and acid soils. Throughout the world, extensive losses of topsoil and agricultural productivity from surface runoff is known to occur; this is caused mainly by low infiltration rate (IR) from surface seal due to falling raindrops (Yu, et, al. 2003, & Warrington et, al., 1990). Gypsum was found to reduce erosion rate by 50%, in infiltration and erosion studies done by Yu et al. Gypsum has been used extensively in reclamation of sodic soils with infiltration problems, to improve the soil physical conditions by promoting flocculation, enhancing aggregate stability, thereby increasing the infiltration rate. Norton (1997) reports that gypsum could reduce surface sealing and improves infiltration to reduce erosion. According to Libron et al., (2002), these observations had no scientific documentation or quantification to support the actual assembling of the soil particles at the aggregate level. However, in an experiment to study the effect of gypsum on aggregate size and geometry of three sodic soils under reclamation, Libron et al., reported that presence of gypsum in soil columns prevented the breakdown of aggregates in proportion to the amount of gypsum added. They found that the more gypsum added, the less break-down of aggregates.

In another study to examine the effect of various surface-incorporated amendments on plant growth in Ca and aluminum (Al) mobility in acidic mine spoil material, Willert and Stehouwer (2003) found the use of gypsum with or without other amendments only improved conditions for root growth in the amended layer, but not subsoil conditions. However, they found significant increase in extractable subsoil Ca in treatments that received gypsum or limestone or both. Reports have also indicated that P sorption capacity of soils can be increased by the addition of gypsum (Adler and Sibrell, 2003). Ritchey and Snuffer (2002) found that gypsum in the presence of dolomitic limestone improved yields, and gypsum alone negatively impacted soils and magnesium (Mg) concentrations, though yields were not depressed. In addition, plants in higher gypsum treatments had higher concentrations of P and K.

Management practices to ameliorate subsoil acidity by applications of gypsum have been widely applied. Gypsum application is known to increase exchangeable Ca, while reducing exchangeable Al; thus enhancing deep root exploration (Tomma et al., 1999; Reeve and Sumner, 1972). Recently, gypsum has been used as a source of Ca for developing peanut pods (Sumner, 1993). Gypsum has been shown to increase corn yield and that of other crops, alone, and combined with other soil amendments. Gypsum is a valuable input for rapidly replenishing the soil profile with Ca (Ritcher and Sunffer, 2002, Warncke, 2003, and Tisdale et, al, 1996); may alleviate hidden sulfur (S) deficiencies and consequently improve N uptake (Sheljazkov et al., 2006), resulting in increases in yields.

There are controversies over the actual benefits of gypsum in crop production, particularly in nutrient availability and soil quality aspects, and there seems to be limited documented research on the effect of gypsum in these areas. Ritchey and Snuffer (2002) reported that gypsum increased P and K uptake, whereas, Warncke (2003) reports that K uptake may be reduced by gypsum. Some researchers suggest that gypsum improves soil structure; others refute that. Scott (2004) contends that adding gypsum to sandy or non-sodic soils is a waste of money, and can result in negative impacts on plant, soil, and ecosystem health, by leaching aluminum and iron into ground water. What is apparent is that gypsum impacts different soils in different ways. The need for adopting sustainable agricultural systems has renewed interest in the use of gypsum as a soil amendment and therefore, the necessity and opportunities for research. Documented benefits of gypsum have been on soil conditions which are either limited, or non-existent in Michigan (Warncke and Dahl, 2004).

Compost as a soil amendment

Epstein (1997) defines composting as "the biological decomposition of organic matter under controlled, aerobic conditions to a humus-like stabled product. Animal manures are composted mainly for odor reduction, to reduce the incidence of contamination by pathogens, and the incidence of antibiotics entering surface waters from manure application (Dolliver et al, 2008; Davis et al., 2006). Additionally, composting allows for ease of handling, storage, transport of animal manures (Dolliver et al., 2008), and kills viable weed seeds (Eghball and Power, 1999; Larney and Blackshaw, 2003).

The use of compost as a soil amendment is as old as farming, and continues to be used to enhance soil quality. Several benefits of compost applications have been established, such as weed suppression and soil organic matter addition, nutrient cycling, and improved soil structure. The use of compost to manage nutrient inputs for crop production presents certain challenges (Singer et al., 2004). Much research in the uses of compost is being done to study the environmental implications of indiscriminate compost uses, particularly accelerated eutrophication of surface waters from high application of poultry and other manures (Preusch et al., 2002; Reddy et al., 2008; Singer et al., 2004). Compost (and manure) application to meet N for corn potentially increases soil levels of P (and other ions) because the N/P ratios of beef cattle feedlot manure and composted manures are significantly smaller than N/P uptake of most crops (Eghball and Power, 1999). Both organic and plant available forms of N (NO_3, NH_4) and P_2O_5 are found in compost (Eghball, and Power, 1999). Singer, et al., (2007) found that corn grown on compost treated plots accumulated more P (19 %) and K (21 %) than corn plants from non compost plots. Nutrients bound in organic forms, though lower than in raw manure and waste are slowly released, offering the benefit of nutrients being available long term.

Soil physical property is critical to soil health and its ability to support optimum crop production. Compost supplies organic matter to the soil, which improves soil structure, enhances water-holding capacity and aeration. Hudson (1994) reported that water-holding capacity more than doubles as soil organic content increases from 5 g/kg^{-1} to 30 g/kg^{-1}. Singer, et al. (2004), reported that soil organic matter content in compost plots was 63 g kg^{-1} compared with 56 g kg^{-1} in the no-compost plots from corn, soybean and wheat plots. Compost application rates were 61.6, 74.7, 54.1, and 22.3 Mg dry matter ha^{-1} in 1998, 1999, 2000, and 2001, respectively. An increase in organic matter and infiltration rate was reported by Butler and Muir (2006) from application of dairy compost. Compost application has also been found to decrease soil bulk density. Johnson et al., (2006) found decreases of up to 5.6 % with increased top-dressed application and Aggelides and Londra (2000) reported significant reductions of bulk density in clay and loamy soils of 17 % and 20 %, respectively. In a study to stabilize Loess-derived soils of the northern Paris basin, where soils are highly prone to degradation because of low clay and organic matter content, compost application caused a reduction in runoff and soil loss and improved the structural stability of seedbeds (Bresson et al., 2001).

Cover crops as soil amendments

Cover crops are plants grown primarily as ground covers to reduce erosion, cycle nutrients as green manures, add organic matter, suppress weeds and diseases and control the loss of nutrients through leaching (Mutch and Martin, 1998; Hutchinson McGiffen, Jr. 2000; Wang et al., 2008). All cover crops provide protection to the soil in the absence of cash crops. The cover prevents soil from being eroded by wind and the impact of rain drops. Additionally, runoff is controlled and infiltration is enhanced. The benefits of cover crops have been known for decades (Odland, and Knoblauch, 1938; De Bruin et al, 2005), and there is evidence of a growing interest in the use of cover crops as soil amendments to reduce the use of chemical inputs for economic reasons and environmental stewardship (Mutch and Snapp, 2003; Ngouajio and Mutch, 2004, 2004; Mutch, 2007). However, cover crops adoption in farming systems remains low. Only 11% of producers in the corn-belt used cover crops between 2001 and 2005, with others citing cost, lack of knowledge of cover crops, time consumption, among other reasons for not adopting (Singer et al., 2007; Mcdonald et al., 2008). The potential to improve soil quality, enhance soil fertility, and increase crop yields, are among the many reasons for using cover crops in farming systems, and also offers opportunities for scientific research (Ngouajio and McGriffen, 2002). The cover crops used in the this study were cereal rye, wheat, red clover, oriental mustard, and oilseed radish.

Cereal rye is commonly grown as a cover crop for its multiple functions in a cropping system. It is an excellent scavenger of residual NO_3-N. Kessavalou and Walters (1997), reported an average of 34 kg N Mg^{-1} of rye dry matter. Rye (and wheat) has the potential for reducing the leaching of nitrates (Kessavalou and Walters, 1997; Strock et al., 2004, De Briun et al., 2005; Duiker and Curran, 2005); is winter tolerant and can be planted late in fall (De Briun et al., 2005; Kessavalou and Walters 1997), making it a very attractive cover crop in the North-Eastern and Mid-western states (Ruffo et al., 2004; Duiker and Curran, 2005). However, cereal rye (and wheat), has the potential to reduce corn yield, because of N immobilization, and the alleleopathic phytotoxic compounds produced by these plants and their residues (Raimbault et al., 1990; Tollenaar, et al., 1993). Cereal rye and wheat reslease phenolic compounds such as ferulic acid (4-hydroxyl-3-methoxy-cinnamic acid), *p*-coumaric acid (4-hydroxycinnamic acid), and vanillic acid (hydroxybenzoic acid). These compounds inhibit the germination of some species of both monocot and dicot plants.

Oriental mustard and oilseed radish, both belong to the *Brassicaceae* family, and are attractive for their production of glucosinolates, which are secondary metabolites known for their activities on weeds, nematodes, and diseases (Snapp et al., 2005; Ngouajio and Mutch, 2004). Members of the *Brassicacea* family do not associate with arbuscular mycorrhizal fungi (AMF) to form mycorrhiza, which plays an important role in plant root development, nutrient availability (Wright, et al 1996). It is also important for the mobilization of certain nutrients, particularly, phosphorous and trace metals such as zinc and copper. Arbuscular mycorrhizal fungi produces glomalin – a soil glycoprotein (a glue) which contains about 30-40 % carbon, and may be responsible for soil clumping and carbon and nitrogen sequestration. In addition, reports relate glomalin to aggregate stability across a number of different soil types and management practices (Wright, 1996). Various researchers (Ryan, et al., 2001, Wright, et al., 2001, and Fraser et al., 2005) have documented significantly higher levels of mycorrhizal colonization and crop yield after, or in combination with AM forming plants, compared to *Brassica* plants which are non- AM compatible plants.

Brassica green manures and cover crops have the potential to provide biological control of several common soil pests, including soil borne diseases, nematodes, and weeds. Recent preliminary research involving the use of oriental mustard (*Brassica junica L*) as a soil biofumigant has been effective for the control of certain soil borne fungal diseases. *Phythium ultimim, Fusarium solani and Rhizocatonia solani* were suppressed by 67-100% and enhanced tubers and root health by 65 – 88% (Date and Snapp, 2004). These two different traits of *Brassica* present opportunities to obtain the benefits of *Brassicas* and avoid their potential negative impact on soil–plant continuum in cropping systems. Oilseed radish has a large, deep root system; is an excellent scavenger of nitrates, grows rapidly, and produces a large amount of biomass in a short time, making a good cover for wind erosion control. Oilseed radish established quickly and is tolerant to moderate drought. Additionally, the large roots create channels for improved aeration and infiltraton after decomposition (Ngouajio and Mutch, 2004).

Red clover, a legume, is an important forage crop in North America (Steiner and Aldermna, 1999), and is Michigan's most common cover crop, mostly grown in non-leguminous rotation systems (Mutch and Martin, 1998). It is attractive for its benefit in supplying nitrogen, ease of establishment, tolerance of seedlings to frost, and effective ground cover for reducing erosion (Mutch and Martin, 1998; Singer et al., 2005). Vyn et al., (2000) reported that presidedress NO_3–N concentrations were at least 24% higher after red clover, and that grain corn yield indicated enhanced N availability to corn than other cover crops studied. Winter wheat, which is grown in corn- soybean-wheat rotation (Kravchenko and Thelen, 2007), is being encouraged as an early spring forage (Thelen and Leep, 2006;) and as a good weed suppressor (Singer et al., 2007).

The growing interest in the use of gypsum by Michigan farmers (Warncke, 2003), and in cover crops for improving soil quality and nutrient enhancement (Mutch et al 2003, Snapp et al., 2005, and Ngouajio et al, 2003), warrants continued research in these areas. The main objective of this study was to investigate whether gypsum can be beneficial to cropping systems in Michigan, when applied alone, or in combination with compost and in association with cover crops. The study was a three part investigation to assess those treatment effects on 1) soil Ca and Mg availability, 2) sweet corn growth, yield and quality, and 3) soil quality of a Kalamazoo loam in southwest Michigan..

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CHAPTER 2

EFFECTS OF GYPSUM ALONE OR COMBINED WITH COMPOST AND COVER CROPS ON CALCIUM AND MAGNESIUM AVAILABILIY

ABSTRACT

Nutrient availability is viewed from both soil and plant perspectives. The recent and growing interest in the use of gypsum ($CaSO_4 \cdot 2H_2O$) by Michigan farmers, and the lack of documentation on the effect of gypsum on Michigan soils warrant investigation of its effect on various soil and plant growth parameters. This study investigated gypsum and its interaction with poultry compost and cover crops on extractable soil Ca and Mg. Sweet corn (*Zea mays var. rugosa*) was the index crop. The treatment design involved three factors: gypsum application at 0 and 2.24 Mg ha^{-1}, poultry compost, at 0 and 2.7 Mg ha^{-1}, and four cover crops plus a no cover treatment. The four cover crops were oilseed radish (*Raphanus sativus*), oriental mustard (*Brassica juncea L.*), red clover (*Trifolium pratense)*, and cereal rye (*Secale cereale*), or wheat (*Triticum aestivum*). The data presented here are for soil sampling for spring and fall of each of the three year (2005 and 2007) study. The statistical model included the three factors and all interactions among them as fixed effects, and replication as a random effect. Gypsum had no effect in 2006; minimal effect on extractable Ca only 2007, but had a negative effect on extractable Mg in 2006 and 2007 (both spring and fall). Compost application increased Ca by up to 44% and resulted in significant transfer of extractable Mg to lower depths. Our results suggest that sweet corn has a higher demand for both Ca and Mg than the cover crops studied Cover crops have potential to supply both Ca and Mg ($\alpha = 0.05$) to soil.

INTRODUCTION

Soil mineral resources are the key to optimal crop growth and harvest (Krishma, 2002), but are useless unless they are made available to plants when needed. Nutrient availability as defined by Bridgham et al., (2001), is the rate of replenishment (or the buffer capacity) of the dissolved inorganic nutrient pool. It is a function of soil chemical and mineralogical properties which control exchange reactions, nutrient concentration, nutrient diffusion, and mineralization (Sherrod et al., 2002). Reduction in yield potential due to mineral deficiency can vary widely from 20- 80 % of actual possible yield when balanced nutrition is unavailable to plants (Binkely and Vitousek, 1989). Nutrient availability can be viewed from a soil perspective and from the standpoint of plant productivity. From the soil perspective, the flux of nutrients from unavailable to accessible pools, represents the nutrient supply rate. From the plant productivity standpoint, individual plants or entire ecosystems can be affected by nutrient limitations (Binkely and Vitousek, 1989). Although nutrient availability is the most important aspect which influences crop productivity, quantifying available nutrients is a challenge because of the complexity of nutrient cycles and the limitations of methods for this purpose. Besides, the importance of individual pools and their transformation varies among nutrients (Bridgham et al., 2001). Soil nutrients are found in large numbers of pools that vary in availability to plants, and plants affect nutrient availability in a number of ways.

Total elemental composition of a soil is generally of little use in assessing the availability of these elements to plants. Example, the iron (Fe) and magnesium (Mg) deficiency in plants commonly occurs despite their relatively high levels in soils (McBride, 1989). Nutrient supply to plants in most part depends on the mobility of the ions and plant root density, and is most often limited by the availability of solutes rather than by root intrinsic absorption capacity. Hence, the limiting factor in the uptake of certain ions moving to the roots (as in non-mobile ions, such as phosphorus, P) is not usually due to the absorption ability of the roots, but the inability of ions to move to the roots. On the contrary, the absorption of mobile ions such as nitrates, may be limited by plant root ability to assimilate this element (Lavelle and Spain, 2001).

Many soils in which plants suffer from micronutrient deficiencies contain about 1,000 times the amount of the deficient element the crop needs (Leeper, 1985). The nutrient interaction within the soil-plant continuum is complex, and nutrient balances among both macro and micronutrients are essential; however, the latter is more difficult to maintain given that some of the plant enzyme systems dependent on micronutrients, require more than one element to function. For example, plants require both manganese and molybdenum for the assimilation of nitrates; some plants require both zinc and phosphorus for optimum use of manganese. Yet, other plants require sufficient amount of zinc for copper utilization which in turn is favored by adequate manganese (Brady and Weil 2002). Therefore, management programs must, in order to be cost effective, take into account the nutrient requirements of crops to be grown as well as the nutrient status of the soil (Warncke et al., 2004). Even the best methods cannot account for all the fluxes (Binkely and Vitousek, 1989). Consequently, any method for determining nutrient availability must be considered an index, since plant growth is an indirect measure of nutrient availability as it is a response to nutrient availability (Bridgham et al., 2001).

For a sustainable crop production management system nutrient removal must be offset by nutrient replacement to avoid soils being depleted of their fertility. When this relationship is not ideal, optimum productivity is not obtained, and there is potential for loss of nutrients to the environment, resulting in air, water and soil degradation, if replacement exceeds removal and need (Grant et al, 2002). A healthy soil will provide sufficient nutrients for growth and development of healthy crops with the ability to resist diseases. Many researchers have suggested that the liberal use of chemical fertilizers can decrease plant resistance to insect pest (Altieri and Nicholls, 2003). Soil nutrient availability has been found to affect both the amount of damage that plants receive from herbivores and the ability of plants to recover from herbivory (Myer, 2000). Altieri and Nicholls (2003) contend that, although more research is needed to investigate the effect of fertilization on plant resistance to diseases and herbivory, preliminary results indicates that nutritional imbalances in crops can make them more susceptible to insect disease pressures. In a 2-year study, Brodbeck et al. (2001) found significantly higher populations of the thrips *Frankliniella occidentalis* on tomatoes that received higher rates of N fertilization. Nutrient management for crop production requires knowledge of the growth and physiology of the crops to be grown and their nutrient requirement coupled with knowledge of the soils on which they grow. There is an intricate relation between nutrient management, the specific crops grown, and soil quality, where the latter can be positively or adversely impacted by the other parameters. The nutrients of interest in this study were calcium (Ca) and magnesium (Mg). In the past, researchers suggested a need for a specific Ca:Mg ratio necessary to facilitate uptake of other nutrients and for optimum plant growth and productivity (Bear and Toth, 1945; Sanik et al. 1952; McLean, 1977). This view promoted the "ideal balance ratio" (65% Ca, 10% Mg, and 5% K) for cation exchange capacity (CEC) and stipulated that plants cannot obtain optimum growth and yield outside of that ratio. Some research continues to promote the concept of the "ideal balance ratios" (Osemwota et al., 2007; Tisdale et al., 1999). The divergent view and research have established that no set "basic cation saturation ratio" exists to obtain optimum growth and yield, but supplying sufficient amounts of these nutrients regardless of ratios will result in optimum growth and yield; that is, the "sufficiency level of available nutrients" (SLAN) concept. Therefore, the Ca, Mg, and potassium (K) status and fertility can be maintained across a range of ratios for maximum plant productivity (Kopittke and Menzies, 2007, Favaretto, 2008; Mc Lean et al., 1983; Eckert and Mclean, 1981; Lanyon and Heald, 1982; Liebhardt, 1981). Calcium and Mg requirements vary for different crops, and under different soil conditions, specifically as they relate to soil pH (Favaretto et al, 2006; Sartain, 1993; Christenson et al., 1973). The objective of this phase of the study was to assess the effects of gypsum applied alone, or combined with compost and cover crops on soil Ca and Mg availability.

SITE DESCRIPTION AND EXPERIMENTAL DESIGN

A study was established at the Kellogg Biological Station in Kalamazoo County, South West Michigan, on a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalfs). The treatment design was a randomized, incomplete block design with four blocks in a 2x2x5 factorial. The designed was a type of split-split-split plot composed of the following three factors: gypsum with two levels (with and without), compost with two levels (with and without), and cover crops with five levels (four covers and a no cover). The layout of the design is illustrated in figure 2.1. Within each block, each gypsum level was randomly assigned to one 79.5 m x 5.3 m strip, and each compost level was randomly assigned to one 10.7 m x 13.3 m plot, resulting in three compost plots for each block with gypsum and no gypsum treatment. Each compost plot was split into three 10.7 m x 4.4 m sub-subplots. The assignment was such that every whole plot (compost level) had two subplots. Within each subplot were three sub- subplots with two cover crops and one with no cover. Each individual cover crop was randomly assigned to the sub-subplots; each with two gypsum sub-sub-subplots (5.3 m x 4.4 m). The system was managed in a cover crop-sweet corn rotation such that for each growing season both corn and cover crops were grown (Figure 2.1). A representation of block (rep) one for cover crops assignments is presented in figure 2.1.

MATERIALS AND METHODS

In 2005, two sets of cover crops were grown. One set included oilseed radish and mustard along with no-cover. The other set included cereal rye, red clover, and no-cover. In 2006, there was a two-phase planting of cover crops. One set of cover crop which included red clover, oilseed radish and mustard was the early phase. The second set was the same as the previous year with cereal rye being replaced by wheat (Figure 2.1b). No cover crop was grown in 2007 (Figure 2.1c). The planting schedule for cover crops and sweet corn is given in table 2.1. For each planting season, six rows of corn were planted in each sub-subplot about 0.76 m apart. In June of 2005 a 72 day maturing sweet corn variety (*Temptation*) was seeded on one whole plot (compost and no compost) and cover crops were grown on two whole plots (two composts; two non-composts). In 2006, sweet corn was grown on plots where cover crops were grown in 2005 and cover crops on sweet corn plots. An 82 day maturing sweet corn variety, *Serendipity* hybrid, was seeded at approximately 59,280 seeds/ha, and all cover crops were seeded at 28 kg ha^{-1} for each year. Planting of sweet corn was done on May 24th of 2006 which facilitated a two phase planting of cover crops. One phase (early) was planted in July and the second phase (late) in October, about one month after the sweet corn was harvested. Sweet corn grown on compost treated plots were harvested two days earlier (August 9th) than those on no-compost plots (August 11th). Adequate N can speed up the maturity of crops and permit an earlier harvest (Tisdale et al., 1999). In 2007, all plots were seeded with *BC 0805* sweet corn on May 18 and harvested August 10. Prior to seeding sweet corn and cover crops, gypsum and a poultry manure-oak leaves compost were incorporated at 2.24 Mg ha^{-1} and 2.7 Mg ha^{-1}respectively; N-P-K fertilizer was broadcasted at 0.2 Mg/ha^{-1} on plots not receiving compost treatments. The poultry compost contained approximately 4g/kg and 45g/kg of Mg and Ca respectively. The nutrient list and content of the poultry compost on a dry weight basis is presented in table 2. Gypsum was applied each year prior to planting; compost was applied only in the first year (2005) of this study, but had been applied to these same plots in the previous three years. Soil samples taken in the spring of 2005 prior to the application of this study reflects the crop treatments of the previous study. The previous crops were green bell pepper, cabbage and corn which followed cereal rye, red clover and no-cover crop. Each crop was grown on a compost plot, comprised of two levels (compost and no compost).

Soil Measurements

Soils were sampled at two depths; 0-10 cm (0-4") and 10-20 cm (4-8") with a 3 cm diameter soil probe, in spring, prior to planting, and fall after harvest. Six cores were taken from each gypsum treatment, giving four samples for each sub-subplot with either compost or no compost (Figure 2.1). Soil samples were air dried and ground to pass a 2.0 mm mesh. Extractable Ca, Mg, and K extracted with 1 *M* NH_4OAc at pH 7, as specified by the modified North Central Region -13 method described by Warncke and Brown (1998). This method involves a 1:10 soil to extracting solution ratio; 2g of soil and 20.0 ml extraction solution was used. The solution was shaken for 5 minutes at 200 rpm and the suspension filtered through Whatman No. 2 filter paper. The extractants were sent to the Soil Testing Laboratory (MSU), where K, Ca and Mg were measured by an atomic absorption spectrometer.

STATISTICAL ANALYSES

The data analysis was conducted in PROC MIXED (SAS Inc, 2002). The statistical model included the three studied factors; compost, cover crops and gypsum, and all the interactions among them as fixed effects, and replication as a random effect. The error terms used in this model associated with the strips were used to test the gypsum effect; errors associated with the plots were used to test the compost effect, and the interactions between strips and plots were used to test the gypsum plus compost interaction effect. Multiple comparisons among the various treatment means were conducted using t- tests when respective factors, interactions or slicing effects were found to be statistically significant at $\alpha = 0.05$.

RESULTS AND DISCUSSIONS

Residual effects on Calcium and Magnesium from prior treatments

In the spring of 2005 prior to the application of treatments for this study, soil samples collected reflected prior corn and cover crops treatments effects. ANOVA for significant treatment effects for Ca and Mg are presented in table 2.3 and means for extractable Ca and Mg are presented in tables 2.4, 2.5 and 2.6 respectively. The previous crops were sweet peppers, cabbage and corn which followed cereal rye, red clover and no-cover crop. In the spring the effects that were significant for Ca availability, were compost ($P < 0.001$), cover crops ($P \leq 0.01$), soil depth and the interaction of compost and depth ($P < 0.001$). Generally, mean Ca concentrations were highest following cabbage regardless of the previous cover crop, followed by corn, then sweet peppers. Compost application increased Ca concentrations by 35% (1200 mg/kg^{-1}) compared to no compost (891 mg/kg^{-1}) application. Extractable Ca was 10% higher at the 0-10cm depth (1086 mg/kg^{-1}) than the 10-20 cm depth (1005 mg/kg^{-1}). The mean of compost plus depth interaction was12% greater at the 0-10 cm depth than the 10-20 cm depth (Table 2.6). There was no difference in Ca between the two depths when compost was not applied.

The effects found to be significant for Mg were compost ($P < 0.001$), cover crops ($P < 0.001$), depth ($P < 0.01$), and the interactions of compost plus cover crops ($P < 0.01$) and compost plus depth ($P < 0.001$). Cover crop effects for Mg followed a similar pattern as Ca, with the greatest extractable Mg from cabbage plots followed by corn, then pepper, regardless of the preceding cover crop (Table 2.4). The mean for extractable Mg in the top 20 cm was 17 % greater for non compost treated plots (170 mg/kg^{-1}) the compost treatment (145 mg/kg^{-1}). The mean of extractable Mg for the 10-20 cm depth (153.9 mg/kg^{-1}) was 17% greater than 0-10 cm depth (131 mg/kg^{-1}). For the interaction of compost with cover crops, generally, the means for extractable Mg were greatest from cabbage plots followed by corn, then peppers irrespective of previous cover crop and compost treatment (Table 2.5). For the compost plus depth interaction, the greatest concentration of Mg was found in plots with no compost regardless of depth. When compost was applied, the Mg content of the 0-10 cm depth was 11 % greater than of the 10-20 cm depth (Table 2.6).

Treatment effects on exchangeable Ca concentration in soil

In 2005 cover crops were seeded about one month after corn, and incorporated two months after seeding (Table 2.1). For each growing season both corn and cover crops were grown on separate plots. Corn was grown on one compost plot (with a compost and non compost subplot), and cover crops were grown on two compost plots. (Figure 2.1). For post-harvest soil sampling in the fall of 2005 the effects that were found to be significant for extractable Ca, were crops ($P \leq 0.01$), compost ($P \leq 0.001$), depth ($P \leq 0.001$), the interactions of gypsum and depth ($P \leq 0.01$) and compost and depth ($P \leq 0.001$). ANOVA for soil Ca concentration as affect by cover crops and corn is presented in table 2.3. The mean of extractable Ca was similar for soils from all cover crops, which were no different from means for no-cover crop plots (Table 2.4: Figure 2.2). Soils from sweet corn plots had the lowest mean of extractable Ca (1081 mg /kg^{-1}); 9% less than no-cover crop (1180 mg/ kg^{-1}). This seems to indicate a higher Ca demand and removal from corn compared to the cover crops after cover crops were incorporated. There was no difference between the Ca in soils from no-cover and cover crops, indicating that cover crops did not supply nor sequester any significant Ca to soil after incorporation. Compost application increased soil Ca concentration (1374 mg/ kg^{-1}) by 38% compared to no compost (996 mg /kg^{-1}) and Ca was higher at the 0-10 cm (1247 mg/ kg^{-1}) by 11% than the 10-20 cm (1122 mg /kg^{-1}). From the interactions of compost plus depth, the mean of Ca was significantly greater at the 0-10 cm depth by 15% and 6 % than the 10-

20 cm depth from compost and non compost treated plots respectively (Table 2.7; Figure 2.6). At each depth the compost treatment had significantly higher Ca means than no compost. At the 0-10 cm depth, Ca from compost application was 44% (1469.8 mg $/kg^{-1}$) greater than the no compost application (1024.2 mg $/kg^{-1}$). Extractable Ca decreased with depth from both compost and non compost treated plots. However, compost application increased Ca in the 10-20 cm depth by 32 % compared to no compost, supporting other reports that compost and broiler liter enhances subsoil Ca (Zheljazkov , et al., 2006; Adeli et al., 2008). From the interaction of gypsum plus depth the mean of Ca was significantly greater at the 0-10 cm depth by 15% and 7 % than the 10-20 cm depth from compost and non compost treated plots respectively. There was no difference in Ca between the two depths from gypsum or non gypsum plot (Table 2.7).

The effects found to be significant for soil Ca concentration from soil sampled in both spring and fall of 2006 (Table 2.8) were compost ($P \leq 0.001$), crops ($P \leq 0.05 \leq 0.01$), depth ($P \leq 0.001$) and the interaction of compost plus depth ($P \leq 0.001$; $P \leq 0.01$). Corn was grown on the plots where the previous cover crops were grown in 2005. In the spring (2006) effects of the previous cover crops on soil Ca availability was as follows: mustard (1130 mg/kg^{-1}) = oilseed radish (1074 mg/kg^{-1}) ≥ cereal rye (1062 mg/kg^{-1}) = red clover (10286 mg/kg^{-1}). In the spring of 2006, the lowest soil extractable Ca was from corn plots (983 mg/kg^{-1}) which was significantly lower than no-cover crop (1072 mg/kg^{-1}), mustard and oilseed radish (Table 2.9; figure 2.2). Corn is among the crops with high calcium needs (Tisdale et al., 1999), and it seems to suggest that corn demand and removal of Ca was higher than for the other cover crops, as occurred in the fall of 2005. Additionally, there is more rapid cycling of nutrients from cover crops incorporated in the fall, opposed to corn. Sweet corn ears, which are a significant source of Ca were harvested and corn remaining stover takes much longer to decompose and cycle nutrients. In the fall of 2006 the means of extractable Ca for soils under crops was the reverse (from fall 2005) with the mean from corn plots significantly higher than the three cover crops grown; mustard, oilseed radish and red clover. The effect was as follows: corn (1114 mg/kg^{-1}) > mustard (1033 mg/kg^{-1}) = oilseed radish (1012 mg/kg^{-1}) = red clover (1010 mg/kg^{-1}). Compost application increased Ca availability by 35% and 37% in the spring (1214 mg/kg^{-1}) and fall (1204 mg/kg^{-1}) respectively compared to no-compost (902mg/kg^{-1} and 880.2 mg/kg^{-1}). The poultry compost used in this study was a significant source of Ca; it contained 45g/kg^{-1} Ca (Table 2.2). Other studies have found that poultry manures, and sludge significantly increased exchangeable Ca content compared to controls (Siddique and Johnson, 2003 Parsons et al., 2007); compost was found to significantly increase Ca > 55 % relative to the control (Eghball et al., 2002). In both spring and fall, Ca was significantly higher at the 0-10 cm depth than the 10-20cm depth by 11% and 12 % respectively. Extractable Ca for compost plus depth interaction followed a similar pattern in both spring and fall. The mean extractable Ca at the 0-10 cm depth was significantly higher than 10-20 cm for compost treatments; 1310 mg/kg^{-1} at 0-10 cm vs 1118 mg/kg^{-1} at 10-20 cm in the spring and 1290 mg/kg^{-1} vs 1118 mg/kg^{-1} in the fall. There was no difference in extractable Ca between the two depths when compost was not applied, and compost application had significantly higher available Ca than non compost plots at both depths (Table 2.10: Figure 2.6). Kingery et al., (1994) found that poultry liter and compost supplied significant amounts of K, Ca and Mg, and that extractable Ca was greatest at shallower depths. As much as 800 mg kg-^{1} more Ca was reported in the upper 15 cm of litter treated soils than non-littered soils.

Cover crops (late) were grown on plots where corn was harvested in the fall of 2005. For soil sampled in the spring of 2007 following early planted cover crops, the effects found to be significant for Ca availability were compost application ($P \leq 0.001$), depth ($P \leq 0.001$), the interaction of compost plus depth ($P \leq 0.001$), and gypsum plus depth ($P \leq 0.05$). Effects found to be significant following late planted cover crops were compost ($P \leq 0.001$), depth ($P \leq 0.001$), the interactions of compost and cover crops ($P \leq 0.05$) and compost and depth ($P \leq 0.001$). ANOVA of significant treatments for both spring and fall are presented in table 2.11; and means of treatment effects in tables 2.12, 2.13 and 2.14. Compost application increased Ca in soil by 37% compared to no compost regardless of cover crop planting time (Table 2.11: Figure 2.4). Means of extractable Ca were 11% (1026.3 mg/kg^{-1} vs 923.6 mg/kg^{-1}) and 9 % (1101 mg/kg^{-1} vs 1009 mg/kg^{-1}) higher at the 0-10 cm depth than 10-20 cm depth respectively following early and late planted cover crops (Table 2.12). Extractable Ca from the combined effect of compost and depth from spring sampling was greater at the 0-10 cm depth (1212 mg/kg^{-1}) by 17% more than the 10-20 cm depth (1040 mg/kg^{-1}) ; 44% and 29% greater at the 0-10 cm (841 mg/kg^{-1}) and 10-20 cm (808 mg/kg^{-1}) depths respectively, from compost compared to non compost plots, following early planted cover crops (Table 2.13). Following late planted cover crops the 0-10 cm depth was 13% (1297 mg/kg^{-1}) greater than the 10-20 cm depth (1147 mg/kg^{-1}). Following late planted cover crops, extractable Ca was 36% (1297 mg/kg^{-1} vs 905.6 mg/kg^{-1}) and 31 % (1147 mg/kg^{-1} vs 847) greater at the top 10 cm depth and 10-20 cm depth, respectively, from compost treatment than non compost. There was no difference between the two depths when compost was not applied.

From the gypsum plus depth combination extractable Ca was about 12% (1066 mg/kg^{-1} vs 943.5 mg/kg^{-1}) and (1146 mg/kg^{-1} vs 1026 mg/kg^{-1}) greater at the 0-10cm than the 10-20 cm following early and late early planted cover crop in both cases. There was no significant effect on Ca at the 10-20 cm depth from gypsum application, indicating that gypsum application did not enhance Ca in the 10-20 cm. The interaction of compost with cover crops affected Ca following late planted cover crops only. The effect was as follows: wheat (1298.2 mg/kg^{-1}) = red clover (1242 mg/kg^{-1}) = oilseed radish (1199 mg/kg^{-1}) ≥ mustard (1187.3 mg/kg^{-1}) = no-cover (1184 mg/kg^{-1}). There was no difference in Ca following cover crops when compost was not applied.

In the fall of 2007, significant effects (Table 2.11) for Ca availability following corn harvest, were gypsum ($P \leq 0.05$), compost ($P \leq 0.001$), depth ($P \leq 0.001$), and the interactions of compost plus depth ($P \leq 0.05$). When gypsum was applied Ca concentration in soil was 12% (1131 mg/kg^{-1}) higher than no gypsum application (1005 mg/kg^{-1}). Ca in soils to which compost was applied averaged 33% (1220 mg/kg^{-1}) greater than in non-compost treated soils (916 mg/kg^{-1}). At the 0-10 cm depth (1118 mg/kg^{-1}) available Ca was 10% greater than the 10-20 cm depth (1018 mg/kg^{-1}). Extractable Ca was 12% (1289 mg/kg^{-1} vs 1151 mg/kg^{-1}) and 9 % (948 mg/kg^{-1} vs 884 mg/kg^{-1}) higher at the 0-10cm depth than 10-20 cm depth from compost and none compost treated plots respectively (Table 2.12: Figure 2.6). Calcium was 36 % and 31% greater from compost than non compost treated plots, at the 0-10cm and 10-20 cm depth, respectively.

Treatment effect on exchangeable Mg concentration in soil

In the fall of 2005 the effects that were found to be significant for Mg availability, were cover crops ($P \leq 0.01$), depth ($P \leq 0.001$), the interactions of compost plus depth ($P \leq 0.001$), and cover crops plus depth ($P \leq 0.01$). ANOVA for treatment effect on extractable Mg for fall 2005 is presented in table 2.3. Extractable Mg was significantly different following the various cover crops and following corn. Mean soil Mg level from corn plots (179 mg /kg^{-1}) was 8% lower than the means of the various cover crops compared to no-cover (193 mg/ kg^{-1}). Among the cover crops only cereal rye and mustard were significantly different, with soil after mustard having 8% less Mg than soil after cereal rye (Table 2.4; Figure 2.3). This seems to indicate as in the case of Ca that corn has a higher demand for Mg, than the cover crops, and among the cover crops cereal rye had the lowest demand for Mg. The mean soil Mg at the 0-10 cm (197 mg /kg^{-1}) depth was greater than at 10-20 cm (188 mg /kg^{-1}) (Table 2.4).

Generally, the means of extractable Mg from the combined effects of compost plus depth were greater when no compost was applied and in that case there was no difference in Mg between the two depths. Extractable Mg was12 % greater at the 0-10 cm (193mg/ kg^{-1}) than the 10-20 cm (173 mg/ kg^{-1}) depth when compost was applied (Table 2.7). For the combined effect of cover crop plus depth the mean of extractable Mg was significantly lower from corn plots than the various cover crops, and there was no difference between the two depths. At 0-10 cm depth the mean from corn plots was (177 mg/ kg^{-1}) 14% less than no-cover (202 mg/ kg^{-1}). Among the cover crops, cereal rye resulted in the highest mean of Mg at the two depths, with the 0-10cm depth 12% greater than the 10-20 cm depth; there was no difference among the other cover crops compared to no- cover crop. Crops plus depth (0-10cm) combination effects were as follows: Cereal rye (213mg/kg^{-1}) ≥ no cover (202 mg/kg^{-1}) = oilseed radish (197 mg/kg^{-1}= red clover (197 mg/kg^{-1}) > corn (177 mg/kg^{-1}).

In the spring 2006 (Table 2.5) the effects found to be significant for Mg were compost ($P \leq 0.01$), the combined effects of gypsum plus depth and compost plus depth. When compost was applied, extractable Mg was 19% less (146 Mg/kg^{-1}) than non composed (174 mg/kg^{-1}) plots (Table 2.9). For the combined effect of compost plus depth, mean of Mg was greater when no compost was applied, regardless of depth. The means of Mg were 11% and 27 % greater at the 0-10cm depth and 10-20 cm depth respectively, when compost was not applied compared to compost treated plots (Table 2.10). When compost was applied Mg was 5% lower at the 10-20 cm (142 mg/kg^{-1}) depth than the 0-10 cm depth (149 mg/kg^{-1}). The mean of Mg for the combined effect of gypsum plus depth was greater at the 10-20 cm depth when gypsum was applied (163 mg/kg^{-1}) than the 0-10 cm depth (154 mg/kg^{-1}); there was no difference between the two depths from non gypsum plots (Table 2.10).

The effects found to be significant for soil Mg concentration from soil sampled in the fall of 2006 (Table 2.8) were compost ($P \leq 0.01$), crops ($P \leq 0.01$), depth ($P \leq 0.001$) and the interaction of compost plus depth ($P \leq 0.01$). Fall extractable Mg (2006) followed a similar pattern as Ca with the highest mean obtained from corn plots. The mean extractable Mg from corn plots was the greatest, and there was no difference among cover crop means. The effects were as follows: corn (151 mg/kg^{-1}) > red clover (145 mg/kg^{-1}) = mustard (142 mg/kg^{-1}) = oilseed radish (142 mg/kg^{-1}). The table means of treatment and interaction effect are presented in Tables 2.9 and 2.10 respectively. The mean of Mg concentration from compost was 18% less than non compost treated plots. Extractable Mg was greater in the 10-20 cm depth (153 mg/k^{-1}) than the 0-10 cm (140 mg/kg^{-1}) depth (Figure10). For the combined effect of compost plus depth, extractable Mg was greater from non compost plots than compost treatment regardless of depth, and greater within in the 10-20 cm depth (170 mg/kg^{-1}) than the 0-10 cm depth (148 mg/kg^{-1}), by 15% (Table 2.10).

For soil samples taken in 2007, ANOVA for extractable Mg is presented in table 2.11. Cover ($P \leq 0.01$), compost ($P \leq 0.01$), depth ($P \leq 0.01$) and the interaction of compost plus depth ($P \leq 0.01$) were the effects found to be significant for Mg from soil samples following early planted cover crops and. Mean of Mg concentration (Table 2.12: Figure 2.3) from red clover plots was 11% greater than both mustard (138 mg/kg^{-1}) and oilseed radish (138 mg/kg^{-1}). Compost application depressed soil Mg concentration by 23% (128 mg/kg^{-1}) compared to none compost (158 mg/kg^{-1}) plots (Table 2.12; Figure 2.5). From the interaction of compost plus depth, when no compost was applied, extractable Mg was 18% and 29% greater at the 0-10 cm and 10-20 cm depth respectively than compost treated plots, and 10% greater at the 10-20 cm depth than the 0-10 cm depth. There was no difference in Mg concentration between depths when compost was applied (Table 2.13).

Compost application ($P \leq 0.05$), depth ($P \leq 0.001$), and the interactions of both gypsum and compost plus depth ($P \leq 0.01$), were significant treatment effects following late planted cover crops. When compost was applied the mean extractable Mg (Table

2.10) was18 % (140 mg/kg^{-1}), less than the mean from non compost treated plots (166 mg/kg^{-1}). Extractable Mg at the 0-10 cm depth (148 mg/kg^{-1}) was less than in the 10-20 cm depth (157 mg/kg^{-1}). For the combined effect of gypsum plus depth, extractable Mg was 10 % greater at the 10-20 cm depth (156.0 mg/kg-1) than the 0-10 cm depth (142 mg/kg-1) from gypsum application (Figure 2.5). This extractable Mg at the 10-20 cm depth from applied gypsum was similar to extractable Mg when no compost was applied regardless of depth (Table 2.10). This seems to indicate a displacement of Mg from the exchange complex to lower soil depths when gypsum was applied. Other researchers have reported this effect of gypsum on Mg (Peregrina et al., 2008; Ritchey et al., 2004; Toma et al. 1999; Sumner, 1993). Evidence of the preference for Ca over Mg on the soil exchange sites is frequently demonstrated (DeSutter et al., 2006; Bladel et al., 1980; Cutin et al., 1998). Extractable Mg was greater from non composted plots than compost plots by 15% and 22 % at the 0-10 cm and 10-20 cm depth respectively. When no compost was applied, the 10-20 cm depth was 9% (172 mg/kg^{-1}) greater in extractable Mg than the 0-10 cm (159 mg/kg^{-1}) depth (Table 2.13). The observed greater extractable Mg when no compost was applied and within the 10-20 cm depths from compost application is evidence of Mg displacement by Ca from compost application as seen to occur when gypsum was applied. There is limited focus/research on soil available/extractable Mg and Ca, with relation to soil amendments, including compost.

Only corn was grown on all plots for the 2007 growing season. For post harvest soil sampling, the effect found to be significant for extractable Mg were compost ($P \leq 0.01$), depth ($P \leq 0.01$) and the interactions of gypsum plus depth ($P \leq 0.01$) and compost plus depth ($P \leq 0.01$). When compost was applied, Mg was depressed by 22% compared to non compost application; a similar pattern as the two previous growing seasons. Mean of Mg was greater (Table 2.12; Figure 2.7) for 10-20 cm depth (154 mg/kg^{-1}) than the 0-10 cm depth (147 mg/kg^{-1}). Mean of Mg for the combined effects of gypsum plus depth was greater by 9 % at the 10-20 cm depth (150.9 mg/kg^{-1}) than the 0-10 cm depth (138 mg/kg^{-1}). At the 0-10 cm depth, extractable Mg when gypsum was applied was 13% less than non gypsum treatment, and there was no difference between the gypsum and non gypsum treatments at the 10-20 cm depths (Table 2.14).

SUMMARY AND CONCLUSION

Compost increased extractable Ca by up to 38% within the top 20 cm depth compared to control plots. Extractable Ca levels within the 0-10 cm depth ranged from 42-44 % greater from compost plots compared to non compost plots. Evidence of enhanced Ca from increases of 28% - 31% within the 10-20 cm depths was observed, but no significant difference in the three year study or between spring and fall of each year. Conversely, compost application resulted in Mg displacement of up to 18% from the top10 cm depth. The decrease of up to 29 %, of Mg in the10-20 cm depth from compost application is evidence of Mg displacement by Ca below the 10-20 cm depth. Generally, Mg levels were greater by 23 % when compost was not applied.

Gypsum's influence on extractable Ca was minimal, with 6% and 15% increases within the top 10 cm depth in 2005 (fall) and 2007(spring) respectively, and 12% in the top 20 cm depth in 2007 (fall). Gypsum application did not enhance Ca levels within in the 10-20 cm depth. Evidence of Mg displacement by Ca from gypsum application was observed in the top cm depth. These decreases were observed in 2006 (spring) and 2007 (spring and fall) within ranges of 8-13% %. There were no changes in Mg levels from non gypsum plots.

In the fall of 2005 significantly lower soil Ca levels from corn plots than all the cover crop plots, seemed to indicate a greater Ca need and removal by corn than the cover crops studied. In spring of 2006, Ca from corn, cereal rye and red clover plots were similar, but significantly lower than the other cover crops, which may be due to slower rates of nutrient cycling. Significantly higher soil Ca levels from corn plots than cover crops in fall 2006 and from corn plots in the previous year may be due to the difference in sweet corn varieties grown. Calcium uptake is genetically controlled (Tisdale et al., 1999), and corn hybrids vary in their efficiency to utilize and mobilize nutrients (Hatlitligil, et al., 2005; Heckman et al., 2006). Generally, Mg concentration in corn plots remained the same, but the Mg in cover crop plots decreased over time. One explanation is a decrease in biomass production, which would in turn decrease the amount of nutrients for cycling. Some of the cover crops in this study may have potential as sources of soil Mg and Ca in cropping systems.

Table 2.1. Planting schedule for cover crops and sweet corn (2005-2007)

	2005		2006				2007	
	Planting	Harvest	Planting	Harvest	Planting	Harvest	Planting	Harvest
Cover crops			----- Early-----		----late-----			
Mustard	7/29	10/11	7/11	10/05	9/01	10/05		_
Oilseed radish	7/29	10/11	7/11	10/05	9/01	10/05		_
Red clover	7/29	_	_	5/4	9/01	_		4/30
Cereal rye	7/29	_	_	‡5/4	_	_	_	_
Wheat	_	_	_	_	9/01			4/30
Sweet corn								
Temptation	6/30	8/09	_	_	_	_	_	_
Serendipity	_	_	5/24	8/11	_	_	_	_
BC805	_	_	_	_	_	_	5/18	8/10

Table 2.2. Nutrient composition of poultry compost

Nutrients	%	g/kg^{-1}
Nitrogen	0.9	9.1
Sulfur	0.2	1.6
Phosphorous	0.6	6.1
Potassium	0.4	4.0
Magnesium	0.4	4.0
Calcium	4.5	45.1
Sodium	0.2	2.0
Zinc	0.02	0.2
Manganese	0.1	0.6
Iron	0.6	6.3
Copper	0.002	0.02
Aluminum	0.6	6.2

Poultry compost was applied only in spring of 2005 at 2.7 Mg/ha^{-1} Values are given on a weight basis

Table 2.3. Statistical significance of gypsum, compost, depth and cover crops, and corn effects on Ca and Mg for the spring 2005 pre-treatment soil sampling

	Sources	2005			
		Ca		Mg	
Spring		F-value	P-Value	F-value	P-Value
	Gypsum	0.02	ns	0.05	ns
	Compost	79.55	***	65.43	***
	Gyp*comp	0.02	ns	0.05	ns
	Crops	2.57	**	11.87	***
	Gyp*crops	0.02	ns	0.04	ns
	Comp*crops	1.73	ns	2.66	**
	Gyp*comp*crops	0.02	ns	0.04	ns
	Depth	25.32	***	10.65	**
	Gypsum*depth	0.09	ns	0.08	ns
	Comp*depth	13.96	**	13.34	***
	Gyp*Comp*depth	0.09	ns	0.08	ns
	crops *depth	1.19	ns	1.20	ns
	Gyp* crops *depth	0.08	ns	0.07	ns
	Comp* crops *depth	0.40	ns	0.33	ns
	Gyp*comp* crops *depth	0.08	ns	0.07	ns
Fall					
	Gypsum	0.26	ns	3.41	ns
	Compost	57.94	***	4.45	ns
	Gyp*comp	0.03	ns	0.28	ns
	Crops	3.40	**	3.80	**
	Gyp* crops	1.55	ns	0.44	ns
	Comp* crops	2.27	ns	1.09	ns
	Gyp*comp* crops	0.21	ns	0.04	ns
	Depth	50.95	***	11.53	***
	Gypsum*depth	7.03	**	2.38	ns
	Comp*depth	14.88	***	34.38	***
	Gyp*Comp*depth	0.02	ns	1.74	ns
	Crops*depth	1.39	ns	3.38	**
	Gyp* crops *depth	1.59	ns	0.56	ns
	Comp* crops *depth	0.78	ns	0.91	ns
	Gyp*comp* crops *depth	0.16	ns	0.28	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P < 0.001$
ns Not significant at α=0.05 Abbrev: Gyp = gypsum; comp = compost

Table 2.4. Effects from gypsum, compost, depth, cover crops and corn on mean soil extractable Ca and Mg in the top 20 cm for 2005 soil sampling

	Spring 2005			Fall 2005	
Treatments	Ca	Mg	Treatments	Ca	Mg
	---------- mg/kg^{-1}	----------			
Cereal rye-B	1164a	184a	Corn	1081b	179c
Red clover-B	1124a	175a	No cover	1180a	193ab
No-cover -B	1075ab	176a	Mustard	1257a	190b
Cereal rye-C	1084ab	157b	Oilseed radish	1187a	193ab
Red clover-C	1050abc	152b	Red clover	1180aa	196ab
No-cover -C	1071ab	154b	Cereal rye	1223a	205a
Cereal rye-P	945.0c	141c	-	-	-
Red clover-P	958bc	143bc	-	-	-
No-cover -P	942c	138c	-	-	-
Compost	1200a	145b	-	1374a	183a
No compost	891b	170a	-	996b	202a
Gypsum	-	-	-	1199a	201a
No gypsum	-	-	-	1171a	184a
Depth 0-10cm	1086a	131b	-	1247a	1975a
Depth 10-20 cm	1006b	154a	-	1123b	188b

Means within the same column and groups followed by the same letters are not significantly different at α=0.05

Abbrev. B- cabbage; C- corn; P- green bell pepper, followed by cereal rye (grain cover crop); red clover (legume); no-cover crop

Table 2.5. Effects from compost by previous crop on mean extractable soil Mg. Spring 2005

	Previous crops and cover crops								
	Cabbage			Corn			Pepper		
Crops*compost	BG	BL	BN	CG	CL	CN	PG	PL	PN
	---------------------------- Magnesium mg/kg^{-1} --------------------------								
Compost	174bc	167bc	145d	142de	141de	150d	127e	134e	129e
No compost	193a	184b	207a	172bc	162c	157cd	155d	151d	146d
Stdr		18			17			18	

Means within rows and columns followed by the same letters are not significantly different at α=0.05

The cash crops were followed by cereal rye (grain cover crop); red clover (legume); No cover crop
Abbrev. B- cabbage; C- corn; P- green bell pepper; C- cereal rye; L- Red clover; N-no cover

Table 2.6. Effects from compost plus depth interaction on mean extractable Ca and Mg for spring 2005

	Ca		Mg	
Compost*depth	Compost	No compost	Compost	No compost
	--------------------mg/kg^{-1}		-------------------	
0-10 cm	1270a	902c	153a	169a
10-20 cm	1130b	880.c	138b	170a
Stdr	79		17	

Means within groups followed by the same letters are not significantly different at α=0.05

Table 2.7. Effects from treatment interactions on mean extractable Ca and Mg in Fall 2005

	Ca		Mg	
Compost*depth	Compost	No compost	Compost	No compost
	-------------------------	mg/kg^{-1}	-------------------------	
0-10 cm	14708a	1024c	193a	200a
10-20 cm	1278b	967d	172b	205a
Stdr	97		16	

	Ca		Mg	
Gypsum*depth	Gypsum	No gypsum	Gypsum	No gypsum
0-10 cm	1284a	12108a	203a	190a
10-20 cm	1114b	1132b	199a	178a
Stdr	97		16	

Magnesium

Crops *depth	No cover	Mustard	O/radish	R/clover	C/rye	Corn
	--------------------Magnesium	mg kg^{-1} ---------------------				
0-10 cm	202ab	192b	197b	197b	213a	177.0c
10-20 cm	185c	188bc	189bc	195b	196b	180c
Stdr	16	16	16	16	16	16

Means within the same rows followed by the same letters are not significantly different at α=0.05

O/radish = oilseed radish
R/cover = red clover
C/rye = Cereal rye

Table 2.8. Statistical significance of gypsum, compost, depth, corn and cover crops effects on Extractable Ca and Mg

	2006			
Sources	Ca		Mg	
Spring	F-value	P-Value	F-value	P-Value
Gypsum	0.99	ns	0.03	ns
Compost	69.60	***	13.23	**
Gyp*comp	0.39	ns	1.52	ns
Crops	2.69	*	0.58	ns
Gyp*Crops	0.24	ns	0.50	ns
Comp*crops	1.80	ns	0.15	ns
Gyp*comp*crops	0.06	ns	23.00	ns
Depth	50.96	***	3.48	ns
Gypsum*depth	1.93	ns	6.36	**
Comp*depth	22.93	***	26.47	***
Gyp*Comp*depth	0.05	ns	0.85	ns
Cover*depth	0.11	ns	0.86	ns
Gyp* crops *depth	0.07	ns	0.10	ns
Comp* crops*depth	0.45	ns	0.24	ns
Gyp*comp* crops*depth	0.07	ns	0.11	ns
Fall				
Gypsum	0.8	ns	1.95	ns
Compost	173.3	***	25.28	**
Gyp*comp	0.03	ns	0.06	ns
Crops	6.34	**	5.28	**
Gyp*crops	0.12	ns	0.02	ns
Comp*crops	0.56	ns	0.09	ns
Gyp*comp*cover	0.06	ns	0.07	ns
Depth	28.69	***	18.43	***
Gypsum*depth	0.48	ns	0.76	ns
Comp*depth	7.38	**	10.58	**
Gyp*Comp*depth	0.02	ns	0.05	ns
Cover*depth	0.01	ns	0.26	ns
Gyp*crops*depth	0.03	ns	0.12	ns
Comp*cover*depth	0.05	ns	0.13	ns
Gyp*comp*crops*depth	0.05	ns	0.04	ns

* $P \leq 0.05$

** $P \leq 0.01$

*** $P \leq 0.001$; ns Not significant at α=0.05 Abbrev: Gyp = gypsum; comp = compost

Table 2.9. Effects from gypsum, compost, depth and cover crops on mean extractable Ca and Mg in the top 20 cm.

	Spring 2006		Fall 2006	
Sources	Ca	Mg	Ca	Mg
	------------------------g/kg^{-1}------------------------			
Corn	982.5b	154.8a	1113.5a	156a
Cover crops				
Mustard	1130a	164a	1033b	142b
Oilseed radish	1074a	159a	1012b	142b
Red clover	1028ab	158a	1010b	145b
Compost	1214a	146b	1204a	134b
No compost	902b	174a	880b	159a
Gypsum	1077a	159a	1053a	143a
No gypsum	1039a	160a	1031a	150a
Depth 0-10cm	1116a	158a	1099a	140b
Depth 10-20 cm	1000b	162a	985b	153a

Means within columns and groups followed by the same letters are not significantly different at $\alpha = 0.05$

Table 2.10. Effects from gypsum*depth and compost*depth on mean extractable Ca, and Mg for 2006.

Spring 2006 Gypsum*depth	Ca Gypsum	Ca No gypsum	Mg Gypsum	Mg No gypsum
	---------------------mg/kg^{-1}		------------------------	
0-10 cm	1145a	1086a	154b	161a
10-20 cm	1008b	993b	164a	160ab
Stdr	66		18	

2006 Compost*depth	Ca Compost	Ca No compost	Mg Compost	Mg No compost
	-------------mg/kg^{-1}		-----------	
Spring				
0-10 cm	1310a	921c	149c	1661b
10-20 cm	1118b	883c	142.2d	181a
Stdr	66		18	
Fall				
0-10 cm	1290a	908.	132c	148b
10-20 cm	11189b	852c	135c	170a
Stdr	66		16	

Means within rows and groups followed by the same letters are not significantly different at α= 0.05

Table 2.11. Statistical significance of gypsum, compost, depth, corn and cover crops on extractable Ca and Mg for 2007.

Sources	2007			
	Ca		Mg	
Spring	F-value	P-Value	F-value	P-Value
	-------------Early------------			
Gypsum	0.59	ns	0.16	ns
Compost	61.96	***	60.72	***
Gyp*comp	0.08	ns	0.55	ns
Cover	0.18	ns	6.53	**
Gyp* cover	0.09	ns	0.27	ns
Comp* cover	1.10	ns	1.90	ns
Gyp*comp* cover	0.50	ns	0.13	ns
Depth	128.53	**	11.00	**
Gypsum*depth	4.85	*	1.94	ns
Comp*depth	58.35	***	9.21	**
Gyp*comp*depth	1.56	ns	0.57	ns
Cover*depth	0.38	ns	0.04	ns
Gyp* cover *depth	1.15	ns	1.81	ns
Comp* cover *depth	1.69	ns	0.14	ns
Gyp*comp* cover *depth	1.74	ns	2.49	ns
	--------------Late-------------			
Gypsum	1.05	ns	0.54	ns
Compost	123.66	***	8.87	*
Gyp*comp	0.38	ns	0.27	ns
Cover	0.18	ns	0.76	ns
Gyp* cover	0.15	ns	0.24	ns
Comp* cover	2.72	*	0.74	ns
Gyp*comp* cover	0.22	ns	0.14	ns
Depth	36.66	***	21.2	***
Gypsum*depth	3.17	ns	5.83	*
Comp*depth	14.07	***	5.85	*
Gyp*comp*depth	0.36	ns	0.89	ns
Cover*depth	0.15	ns	1.25	ns
Gyp* cover *depth	0.26	ns	0.58	ns
Comp* cover *depth	0.35	ns	0.57	ns
Gyp*comp* cover *depth	0.11	ns	0.33	ns
Fall				
Gypsum	12.66	*	2.78	ns
Compost	219.92	***	16.79	**
Gyp*comp	0.76	ns	0.00	ns
Depth	33.58	***	7.94	**
Gypsum*depth	3.77	ns	7.99	**
Comp*depth	4.66	*	14.53	**
Gyp*Comp*depth	1.49	ns	0.45	ns

* $P \leq 0.05$

** $P \leq 0.01$;

*** $P \leq 0.001$; ns Not significant at α=0.05 Abbrev: Gyp = gypsum; comp = compost

Table 2.12. Effects from gypsum, compost, depth and cover crops on mean extractable Ca and Mg (2007).

2007	Spring Early		Spring Late		Fall Late	
Sources	Ca	Mg	Ca	Mg	Ca	Mg
			mg/kg^{-1}			
No Cover	_	_	1042a	150a	_	_
Wheat	_	_	1068a	157a	_	_
Mustard	977a	138b	1062a	155a	_	_
Oilseed radish	966a	138b	1055a	149a	_	_
Red Clover	982a	153a	1048a	153a	_	_
Compost	1126a	128b	1222a	139b	1220a	136b
No compost	824b	158a	888b	166a	916b	167a
Gypsum	1005a	141a	1086a	149a	1131a	145a
No gypsum	945a	145a	1024a	156a	1005b	157a
Depth 0-10 cm	1026a	139b	1101a	148b	1119a	147b
Depth 10-20 cm	924b	147a	1009b	157a	1018b	154a

Mean within the columns and groups followed by the same letters are not significantly different at $\alpha = 0.05$

Table 2.13. Effects from treatment interactions on mean extractable Ca, and Mg (2007).

	Ca		Mg	
Compost*depth	Compost	No compost	Compost	No compost
Spring	------------------- mg/kg^{-1}		-------------------	
Early				
0-10 cm	1212a	841c	128c	150b
10-20 cm	1034b	808c	128c	159a
Stdr	78		19	
Late				
0-10 cm	1297a	906c	138c	159b
10-20 cm	1147b	870c	141bc	172a
Stdr	70		17	
Fall				
0-10 cm	1289a	948c	138c	158b
10-20 cm	1151b	884d	134c	173a
Stdr	57		18	

	Ca		Mg	
Gypsum*depth	Gypsum	No gypsum	Gypsum	No gypsum
Spring	------------------- mg/kg^{-1}		-------------------	
Early				
0-10 cm	1067a	986b	136a	142a
10-20 cm	944bc	903c	146a	147a
Stdr	85		17	
Late				
0-10 cm	1146a	1057a	142b	154a
10-20 cm	1026a	992a	156a	158a
Stdr	74		17	
Fall				
0-10 cm	1198a	103b	138b	157a
10-20 cm	1063b	972c	151a	157a
Stdr	59		18	

Means within the same columns and rows followed by the same letters are not significantly different at α=0.05

Table 2.14. Effects from compost and cover crops on mean extractable soil Ca for spring 2007

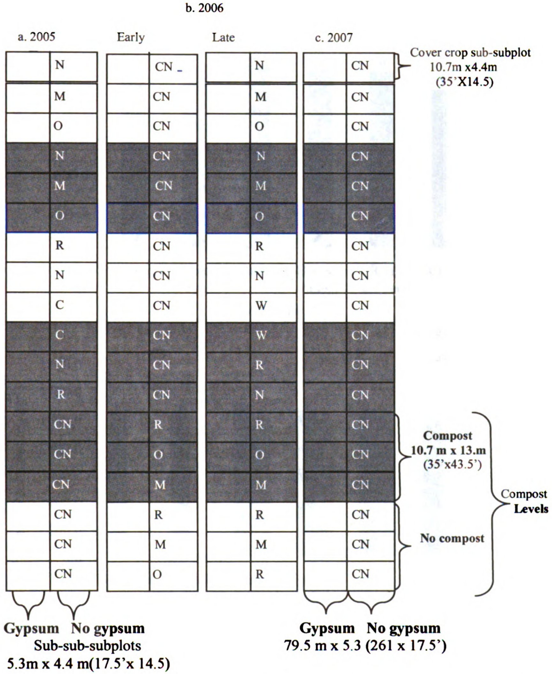
	Spring 2007				
Cover*compost	N	W	M	O	R
Early	------------------------------mg/kg^{-1}	----------------------------			
Compost	-	-	1104a	11278a	1146a
No compost	-	-	849b	8.4b	819b
Stdr	-	-	80	80	80
Late					
Compost	1184b	1298a	1187b	1198ab	1242ab
No compost	899c	839c	937c	911c	854c
Stdr	75	77	77	77	77

Means within the same columns and groups followed by the same letters are not significantly different α=0.05

Abrev:N = no-cover; W= wheat; M= mustard; O = oilseed radish; R= red clover

FIGURES

Figure 2.1. Representation of a typical block of the experiment design.



Abbrev.: N= No cover; C= Cereal rye; W= Wheat; R= Red clover; O= Oilseed radish; M=Mustard; CN= Corn

Figure 2.2a. Effect of cover crops and corn on extractable Ca, 2005 and 2006.

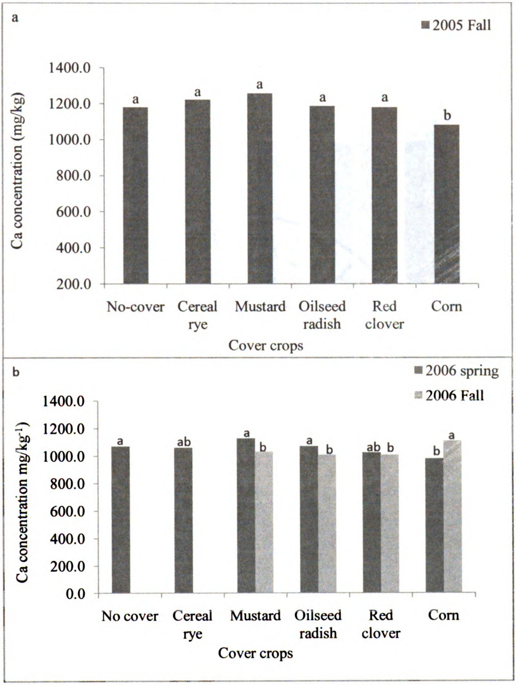


Figure 2.2b. Effect of cover crops and corn on extractable Ca, 2007.

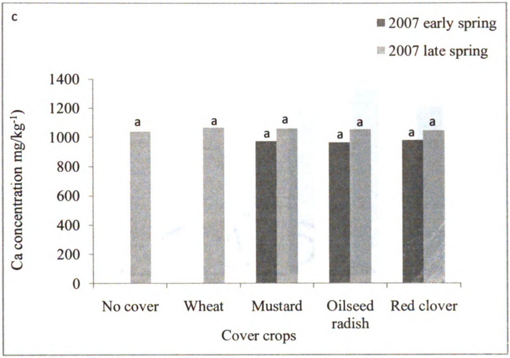


Figure 2.3a. Effect of cover crops and corn on extractable Mg 2005, and 2006

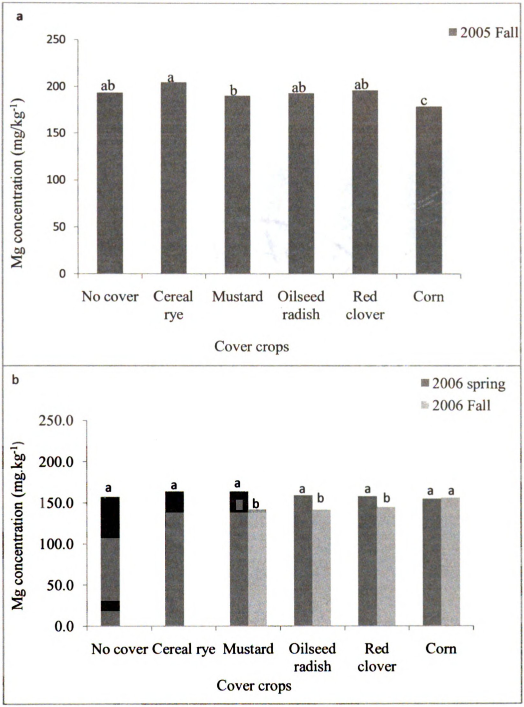


Figure 2.3b. Effect of cover crops and corn on extractable Mg 2007

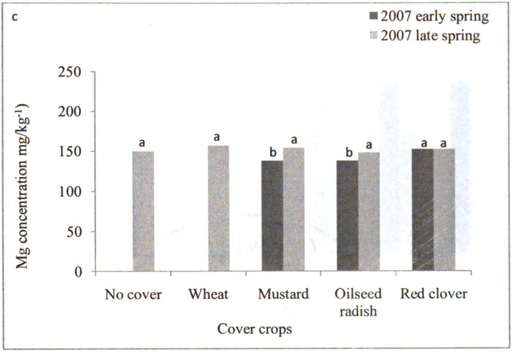


Figure 2.4. Effect of compost and gypsum on extractable Ca.

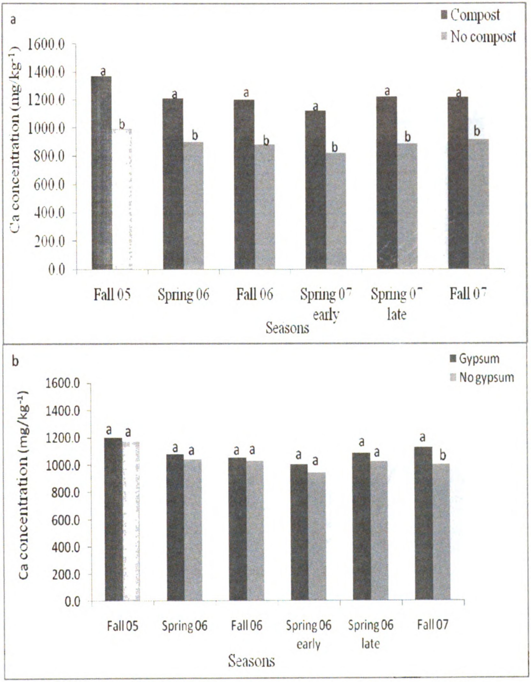


Figure 2.5. Effect of compost and gypsum on extractable Mg.

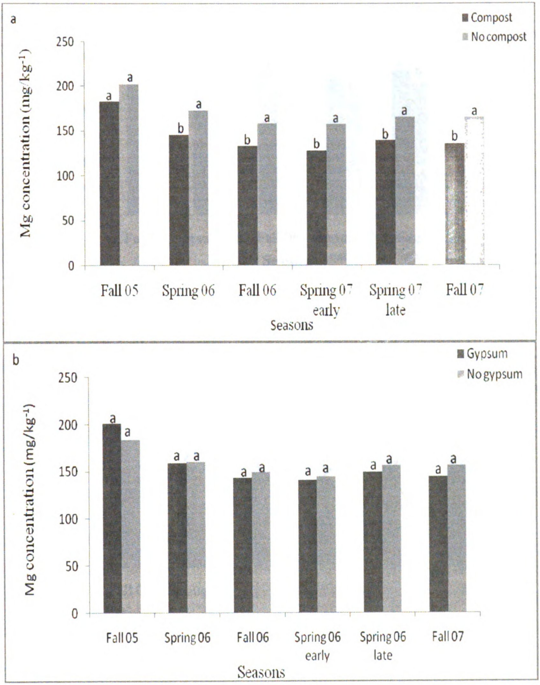


Figure 2.6. Effect depths on extractable Ca.

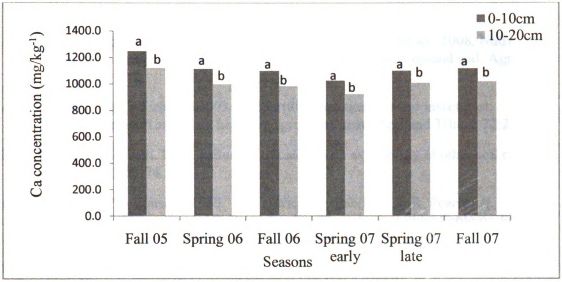
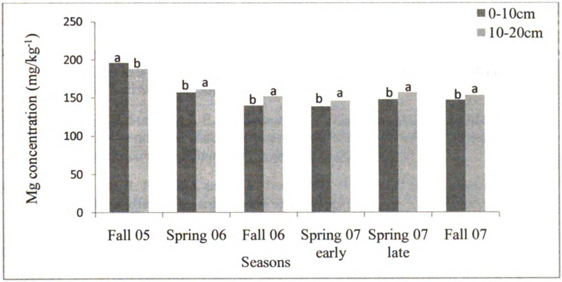


Figure 2.7. Effect depths on extractable Mg.



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CHAPTER 3

EFFECTS OF GYPSUM ALONE OR COMBINED WITH COMPOST AND COVER CROPS ON CORN YIELD AND QUALITY

ABSTRACT

This phase of the study investigated gypsum and its interaction with compost and cover crops on growth, yield and quality of sweet corn (*Zea mays var. rugosa*). The treatment design involved three factors: gypsum application at 0 and 2.24 Mg ha^{-1}, poultry compost, at 0 and 2.7 Mg ha^{-1}, and four cover crops plus a no cover treatment. The four cover crops were oilseed radish (*Raphanus sativus*), oriental mustard (*Brassica juncea L.*), red clover (*Trifolium pratense)*, and cereal rye (*Secale cereale*), or wheat (*Triticum aestivum*). Sweet corn was sown in the spring of each year and cover crops in the spring of 2005 and both spring and fall of 2006. The data presented here are for two years (2006 and 2007) of a three year study. Gypsum application decreased both corn plant biomass at the V8 growth stage and corn yield; had no positive effect on the total number of marketable corn ears per hectare either alone or combined. Gypsum plus compost interaction reduced corn yield per hectare when red clover was the previous crop. Cover crops affected the number of sweet corn ears per hectare in 2006 ($\alpha = 0.05$). Both cover crops and compost had a positive effect on sweet corn growth, yield and quality.

INTRODUCTION

Gypsum has been shown to increase corn yield and other crops when applied alone, and combined with other soil amendments. These yield increases have been observed mostly when subsurface acidity was treated with gypsum in highly weathered soils of the southeastern USA (Sumner et al., 1986; Tomma et al., 1999) and that of tropical and subtropical soils which are highly leached and variable charged which impedes root penetration (Reeve and Sumner, 1970; Hammel et al., 1985. Sumner et al., (1986) reported increased yield in alfalfa (*Medicago sativa L.*) in the southeastern USA due to improved root development as a consequence of improved physical condition in the subsoil. Yield increases by corn (20-50%) and alfalfa % in response to gypsum were shown to be directly correlated to improved water extraction from the subsoil through decreased Al toxicity to roots, throughout a sixteen year study in Georgia (Tomma et al., 1999). Similarly, significant improvement in corn and soybean yields reported by Hammel et al., (1985) was due to increases in Ca levels and a consequent decease in Al toxicity which allowed for deeper penetration and root proliferation and increased water uptake from the subsoil. Gypsum is a valuable input for rapidly replenishing the soil profile with Ca (Ritchey and Sunffer, 2002; Warncke, 2003 and Tisdale et al., 1996); may alleviate hidden sulfur (S) deficiencies and consequently improve N uptake (Sheljazkov et al., 2006), resulting in increases in yields. Sulfur deficiency frequently encountered in alfalfa management was corrected with addition of gypsum, and resulted in a slight yield increase in soybean (*Glycine max* L.), and up to 40% increase in alfalfa (Chen et al., 2005) in Ohio. Also, clay-textured soils amended with gypsum, were shown to increase sugar yields of ratoon sugarcane in Louisiana (Breithaupt et al., 1991).

Reports of responses from compost application to soil nutrient and soil physical properties are abundant in the literature, but information on compost effect on crop growth and yield is limited. Singer et al., (2004) found significant increases in soil P and organic matter when compost was applied to soybean plots and increases in both corn and soybean yield. In a two year study to assess the effects of compost and tillage on corn growth and nutrient accumulation in corn grain, Singer et al., (2007) also found increases in P (19%) and K (21%) from compost application compared to non compost in corn. Bow et al., (2008) reported increases in both grasses and legumes from compost application due to increase soil P levels.

Traditionally, cover crops are used for erosion control (Andraski and Bundy 2005 Zheng et al., 2004; Kessavalou and Walters. 1999) and weed and disease suppression (Snapp et al., 2005; Ngouajio and Mutch, 2004, Date and Snapp, 2004), through alleopathy. Although a considerable amount of research into the benefits of cover crops have been done in recent years, the adoption of cover crops in crop production systems is still low. Several studies have documented both beneficial and unfavorable reports of their uses. For example, yield increases of corn grain following winter rye (*Secale cereale* L.) have been observed by Moschler et al.,1976; Andraski and Bundy, 2005 and Clarke et al., 2007 and also, following winter killed oat (*Avena sativa* L.) and triticale (x *Triticosecale* Wittmack) compared to control (Clarke et al., 2007). Conversely, Mcdonald et al., (2008) reported significant decreases (5 to 22%) in corn grain yield following winter rye, winter wheat (*Triticum aestivum* L.), and triticale compared to control plots. Hively and Cox (2001) reported significantly lower corn grain yields following annual rye plots compared to control plots, and interceeding red clover and chickling vetch did not affect corn yield when corn was planted at various densities (Baributsa et al., 2008). Additionally, a significant delay in soybean pod maturity and a decrease in dry matter were observed following winter rye compared to control plots (Westgate, et al. 2005). When soybean was interceded with rye, yield was greatly reduced due to moisture stress (Thelen et al., 2004). In a study to investigate N availability to corn in south-central Ontario, Vyn et al., (2000) found corn grain yield responses to red clover substantially enhanced available N, but oilseed radish, oat, and rye cover crops did not. In order to obtain the benefits from cover crops for subsequent cash crops, continued research is needed for the suitability of the various cover crops within specific cropping systems in all aspects of production.

Taking into account the lack of information on the use of gypsum in Michigan cropping systems and the limited documentation on compost and cover crop with regards to crop growth and quality aspects, this study assessed the response of sweet corn growth (and development) yield and quality to gypsum, and the synergistic effects with poultry compost and the various cover crops studied.

MATERIALS AND METHODS

Site description and experimental design are explained in chapter two (p. 22). Description of treatments and plot layout are given in the materials and methods of chapter two (p. 23).

Sweet Corn Measurements

Plant stand, plant height, and whole corn plant samples were taken at the 8^{th} leaf stage, about one month after sowing each year. Three corn plants were randomly selected from each of two rows in each gypsum treatment, giving two samples per subplot; a gypsum and a non-gypsum sample. Chlorophyll meter readings (CMRs) were taken when tassel emerged with a Minolta SPAD (soil-plant analysis development) chlorophyll meter (Spectrum Technologies, Inc., Plainfield, IL). Readings were taken on 20 randomly selected uppermost fully developed leaves, midway between the leaf tip and base and between the leaf margin and mid-rib, as described by Zhang et al., 2008, Varvel et al., 2007; and Shanahan et al., 2001. Corn ears were harvested from 3.05 m (10ft) of the two middle rows from each subplot, and each gypsum treatment. All harvested corn ears from each gypsum treatment were sorted into marketable and non marketable ears, and weighed. From the marketable ears, ten were randomly selected, and their (combined) weights, lengths and diameters measured.

Nutrient analysis

Five of the ten husked ears were selected and 7.6 cm mid-section sample taken for nutrient analysis. All plant tissues were dried at 60 ^{O}C for 72 hrs, then ground with a Wiley Mill and sent to A & L Great Lakes Laboratory Inc., Fort Wayne, Indiana for total nutrient analyses. The nutrients analyzed were nitrogen (N), sulfur (S), phosphorus (P), potassium (K), sodium (Na), boron (B), zinc (Zn), manganese, (Mn), iron (Fe), copper (Cu), aluminum (Al), magnesium (Mg), and calcium (Ca) (A&L Great Lakes Lab., Inc).

RESULTS AND DISCUSSIONS

Treatment effects on Sweet Corn Growth and Development

For both 2006 and 2007, visual observations made up until visible tassel, corn plants following oilseed radish had the darkest green color followed by mustard, then corn followed by red clover. Corn which followed cereal rye or wheat was less green in color (or similar) than corn which followed no- cover crop treatments. This was especially noticeable in the plots where compost was applied, although compost interaction with cover crops was not statistically significant ($P>0.05$) for CMRs. The degree of greenness generally reflects the level of nitrogen available in the soil for plant uptake. ANOVA and means for CMRs are presented in tables 3.1 and 3.2 respectively. CMRs were taken about the time of tassel emergence (VT) but prior to silking (RI). Only cover crops influenced CMRs for corn plants. Results of CMRs in 2006 showed significant differences ($P \leq 0.01$) among cover crop treatments in the following order: cereal rye (55.5) = Oilseed radish (55.1) = red clover (55.1) = mustard (54.6) > no cover (53.3). CMRs indicate the relative amount of chlorophyll in plant leaves; readings are in SPAD units and are dimensionless (Zhang et al., 2008). In 2007 when corn followed early planted cover crops, means of CMRs for red clover was significantly higher (47.7), than for corn after oilseed radish (45.5) or mustard (42.6). Visual observations for corn which followed late planted cover crops in 2007 were similar to the visual observations in 2006, and CMRs in 2007 were reflective (numerically) of the visual observations. The order of CMRs readings in corn following late cover crops were: oilseed radish (43.8) = Mustard (43.7) = red clover (43.1) = wheat (42.5) > no cover (41.0). CMRs following cereal rye were expected to be similar or less than corn following no cover crops. It was not expected that the CMRs of corn following cereal rye (2006) would be similar to CMRs of corn following other cover crops particularly for oilseed radish and mustard, since visual observations indicated that the color intensity (greenness) was lowest for corn following cereal rye. CMRs for cereal rye were expected to be similar or less than corn following no cover crops. The reason for the disparities between visual observations and CMRs could be due to: 1) Immobilization and mineralization time for the cereal rye was different from the other cover crops. This is because mineralization occurred much later in the season for cereal rye than mustard and oilseed radish which were winter killed. Conversely, red clover (and other leguminous cover crops) can fix atmospheric N which can increase available N during decomposition (Kuo and Sainju, 1998). During the early stages of the corn growth since cereal rye was incorporated in the early spring, N immobilization exceeded N mineralization while the residue was being decomposed. Net N immobilization generally occurs for the first couple months after winter cereal cover crops are incorporated (Snapp et al., 2005; Malpassi et al., 2000). Vyn et al., (2000) also found low spring concentrations of NO_3-N following annual rye indicating a low N availability to succeeding corn compared to other cover crops and no-cover crop treatment. During the decomposition of crop residue, N immobilization can reduce soil N (NH_4^+ and NO_3^-) concentrations to very low levels (Tisdale et al., 1999). 2) When mineralized N was made available from cereal rye later during the growing season, this resulting in higher CMRs for corn than from the other cover crops. 3) It is also possible for corn following cereal rye to have higher levels of chlorophyll and N concentration than the other cover crops. This is because cereal rye (or wheat) killed in the early spring while still young has lower biomass than if killed after reaching or approaching physiological maturity, but will have higher N concentration and a low C/N ratio (Reiter et al., 2008). Young cereal rye plants have a C/N ratio of 14:1 compared to cereal rye at mid-boot which is 40:1(Boswith, 2006). The C/N ratios for oilseed radish, red clover, and mustard are 28:1, 21:1 (Vyn et al., 1999) and 26:1 respectively. Additionally, rye has shown superior ability to scavenge residual soil N than some cover crops (Ranells and Waggner 1997; Shipley et al., 1992).

In 2006 cover crops ($P \leq 0.001$), compost ($P \leq 0.001$) and the combined effects of compost and cover crops ($P \leq 0.05$) significantly affected corn height at the V8 stage. ANOVA and means of plant height are presented in tables 3.2, 3.3 and 3.4. Plant height was greatest when corn followed oilseed radish (70.3 cm) and mustard (68.7); there was no significant (Figure 3.2a) difference between red clover (60.2 cm) and no-cover (59.6 cm). Cereal rye had the lowest mean compared to no-cover (57.1 cm). In 2007, there was no difference in mean height when corn followed early planted cover crops. Mean plant height when corn followed late cover crops (Figure 3.2b) was higher from oilseed radish (62.3 cm) and mustard (62.0 cm) than red clover (58.5 cm), and wheat (54.2 cm). Plant height in no-cover plots (61.0cm) was similar to that following oilseed radish and mustard. More vigor and growth from these cover crop treatments can be directly related to their capacities to cycle N to the surface soil. Oilseed radish has a deep root system and is an excellent scavenger of nitrates; produces a large amount of biomass in a short time (Ngouajio and Mutch, 2004). Collins et al., (2007) reported 36 kg N ha^{-1} from decomposition of mustard residues from a study to evaluate N cycling from mustard cover crops to potato. In both years, corn following cereal rye (2006) and wheat (2007) had the lowest mean heights even compared to no-cover.

Compost application increased plant height in 2006 ($P < 0.001$) and in 2007 ($P \leq 0.01$) from early cover crops; both compost ($P \leq 0.01$) and cover crops ($P \leq 0.001$) influenced height of corn following late planted cover crops (Figure 3.3a; tables 3.2, 3.3, and 3.4). When compost was applied in 2006, plant height increased by 19 % (47cm) compared to no-compost treatment (39.5 cm). In 2007, plant height from compost treatment was 12 % greater (63 cm) than no-compost (56 cm). Compost treated plots developed tassels much earlier than no-compost (Figure 3.4a and 3.4b), and sweet corn from compost treated plots were harvested two days before non compost treated plots because of earlier maturity. Singer et al., (2004), reported that soil organic matter content in compost plots was 63 g kg^{-1} compared with 57 g kg^{-1} in the no-compost plots. Organic matter enhances soil physical properties and water holding capacity, consequently affecting crop growth and development. Corn plants growing in compost treated soil accumulated more P and K than plants growing in non compost soils (Singer et al., 2007). Table 3.5 shows that corn plots accumulated more Ca, P and K from compost soils than from compost treated soils. Adequate P in the early stages of plant growth is important for development of productive parts. K is vital for activation of enzymes which are abundant in meristematic plant tissues where rapid cell division occurs and primary tissues are formed. Tisdale et al., (1999) reported more advanced development of small grains receiving P, compared to control.

When compost and cover crops interacted, the greatest effect on plant height was from compost application with oilseed radish (74 cm) and mustard (72 cm), followed by red clover (68 cm), then cereal rye (65 cm). There was no statistical difference in plant height between cereal rye and no-cover (66 cm). Gypsum application had no effect on plant height in both years (Figure 3.3b). Corn grown on gypsum plots regardless of compost treatments developed tassels later than no-gypsum plots. However, no-gypsum plots which were compost treated developed tassels earlier than gypsum plots which had no compost applied. Trends for soil available P from Mehlich-3 anaylsis indicated that P concentrations were lower for gypsum than non-gypsum treated plots, although differences were not significant. Gypsum supplies additional Ca to the soil, which may result in phosphorous (P) being less available for plant growth at the critical early stages of development. Gypsum application was found to reduce dissolved reactive P (DRP) concentration by converting readily desorbable soil P to less readily soluble Ca-P compounds (Favaretto, et al., 2006; Stout et al., 2000). It seems that delayed tassel development of corn from gypsum treated plots may be a consequence of reduced P availability at the critical growth stage, or rather more P available from compost treatments when no gypsum was applied which resulted in earlier tassel development.

Only cover crops and compost influenced whole plant biomass at the V8 stage in both years. ANOVA and means of plant biomass are presented in tables 3.2 and 3.3. Cover crops significantly affected plant biomass in 2006 (P<0.001) and in 2007($P \leq$

0.05) when corn followed late planted cover crops. Mean for corn plant biomass at the V8 stage in 2006 were as follows: oilseed radish (0.68 Mg/ha^{-1}) = mustard (0.64 Mg/ha^{-1}) > red clover (0.51Mg/ha^{-1}) = no-cover (0.50 Mg/ha^{-1}) = cereal rye (0.44 Mg/ha^{-1}). Mean weight for corn plant biomass where cover crops were incorporated in 2006 (Figure 3.5a) were significantly higher than for 2007 (Figure 3.5b). One reason for this difference in biomass may be higher temperatures in 2007 than 2006 which resulted in drier soil conditions that affected growth at early stages of growth. In 2007 mean for plant biomass when corn followed oilseed radish and mustard, were similar to no-cover; wheat had the lowest mean. There was no significant difference among means of plant biomass following early planted cover crops, mostly because early cover crops did not include no-cover treatment and cereal rye or wheat.

Compost application had a positive effect on whole plant biomass for both years (Figures 3.6a). The mean from compost treatment was 26% greater than no-compost in 2006 ($P \leq 0.001$). When corn followed early planted cover crops in 2007 ($P \leq 0.001$) the mean of plant biomass from compost application was 48% higher than no-compost application, and 45 % higher following late cover crops ($P \leq 0.01$) . This is noteworthy, since NPK fertilizer was applied to no-compost plots. Other studies have reported increased biomass yield due to residual plant-available N provided by compost (Lynch et al., 2004; Tejada and Gonzalez, 2006), when compost alone was applied compared to controls. Still other studies have reported unexplained yield increases from compost application. In a study comparing compost treatments with tillage management, Singer et al., (2007) reported greater yield responses from no-till. There was no apparent reason for this, since the data suggested that N was not responsible. Although gypsum application did not significantly affect plant biomass (Figures 3.6b); numerically, corn plant biomass from gypsum application was 9% lower than no-gypsum in 2006. In 2007 mean of corn plant biomass from gypsum application was 14% lower than no-gypsum, following early cover crops (Table 3.2). This trend was not statistically significant and was not observed in 2007 following late cover crops.

Nutrient (Ca, Mg, N, P and K) concentrations of plant biomass were significant for gypsum, compost and the combined effects of gypsum and compost, and of compost and cover crops. Effects of the various treatment factors (ANOVA) on whole plant nutrient concentrations are presented in Table 3.5a and 3.5b; their means in Tables 3.6 and 3.7. In 2006, mean of Ca concentration in corn biomass was 7 % higher for compost (3.6 g/kg^{-1}) than no-compost (3.4 g/kg^{-1}) application. In 2007, Ca was 11% higher with compost than no-compost when corn followed early planted cover crops and 6 % higher when corn followed late planted cover crops. Cover crops significantly ($P \leq 0.001$) influenced Ca concentration of plant biomass in 2006. Red clover incorporation resulted in the highest Ca concentration (3.7 g/kg^{-1}); mustard was the lowest (3.2 g/kg^{-1}), compared to no-cover (3.5g/kg^{-1}). When corn followed early planted cover crops in 2007, the order of effect was: red clover (4.52 g/kg^{-1})> mustard (4.0 g/kg^{-1}) = oilseed (4.0g/kg^{-1}). No cover crop effect was observed following late planted cover crops in 2007. Gypsum significantly affected Ca concentration in plant biomass only in 2006 and 2007 when corn followed late planted cover crops. Calcium concentration was 8% higher (4.3 g/kg^{-1}) from gypsum application compared to no-gypsum (3.9 g/kg^{-1}). Faveratto et al., (2008) reported higher Ca concentrations in corn shoots when gypsum was applied compared to control plots.

Magnesium concentration was significantly affected in both years by compost and cover crops and in 2007 by the combined effect of compost and cover crops (Tables 3.5a and b, 3.6 and 3.7). Magnesium concentration of corn plant biomass was significantly depressed when compost was applied, a direct opposite to the effect on Ca concentration in plant biomass. Compost application resulted in 23% decrease of Mg compared to no-compost in 2006, and similar decreases in 2007 when corn followed both early and late planted cover crops. The combined effect of compost and cover crops had a significant effect on Mg following early planted cover crops (Table 3.7). When compost was applied compared to no compost application, corn following red clover had the largest decrease in Mg (1.2 g/kg^{-1}), followed by mustard (0.8 g/kg^{-1}), then by oilseed radish (0.5 g/kg^{-1}). The application of both gypsum and compost resulted in increased Ca and decreased Mg concentrations; conversely, when neither compost nor gypsum was added, Mg concentration in plant biomass increased. Magnesium and Ca existence in plant tissue is sensitive in relation to each other. Too much of one results in the reduction and possibly, an insufficiency of the other (Vitosh et al., 1994; Faveratto et al., 2008).

Nitrogen concentration in corn biomass was enhanced by the effects of cover crops ($P \leq 0.001$), and the interactions of cover crops and compost ($P \leq 0.001$) in 2006 (Tables 5, 6 and 7). The order of cover crop effects were: oilseed radish (25.6g/kg) > red clover (24.1g/kg) = cereal rye (23.9g/kg) > mustard (22.0g/kg) = no cover (21.9g/kg). A similar trend was observed in 2007 ($P \leq 0.001$), when corn followed both early and late cover crops. The combined effects of compost and cover crops were significant in 2006 ($P \leq 0.001$) and following late cover crops in 2007($P \leq 0.05$). The mean of N concentration in plant biomass when cover crop plots received compost application in

2006 (Table 3.7) was highest following cereal rye and red clover (25.0 g/kg^{-1}), followed by oilseed radish (24.0g/kg^{-1}), then mustard (20.9g/kg^{-1}) which was similar to no-cover (21.5g/gk^{-1}). When corn followed late cover crops, application of compost to no-cover plots increased N concentration by 10% compared to no-cover plots without compost. There was no difference among other compost-cover crop interactions. Gypsum application had no effect on N concentration of plant biomass in 2006 but had a significant negative ($P \leq 0.05$) effect in early 2007. When corn followed early cover crops in 2007, gypsum decreased N by 6%, but had no effect with late cover crops. There was a significant effect from the combined application of gypsum and compost on N content of plant biomass only from early planted cover crops in 2007. There was a 10% decrease in N when gypsum was applied to no-compost plots compared to compost plots when neither gypsum nor compost was applied. No gypsum effect on N content of plant biomass was observed when corn followed late cover crops (Table 3.5b).

Phosphorous concentration in plant biomass was influenced by cover crops in 2006 ($P \leq 0.05$) and 2007 ($P \leq 0.001$), and by compost in 2006 ($P \leq 0.01$). In 2006, when corn was grown on oilseed radish plots, P concentration of plant biomass was the lowest (3.0 g/kg^{-1}); there was no difference among the other cover crops compared to no-cover (3.5g/kg^{-1}). The highest mean of P in 2007 from early planted cover crops, was for corn grown on red clover plots (3.9 g/kg^{-1}); there was no significant difference between oilseed radish (3.5 g/kg^{-1}) and mustard (3.4 g/kg^{-1}). A similar trend was observed in 2007 (as 2006) when corn followed late planted cover crops; oil seed radish resulted in the lowest P (3.9 g/kg^{-1}), and there was no difference among the other cover crops including no-cover (4.3 g/kg^{-1}). When compost was applied in 2006, biomass P increased by 11 %

compared to no-compost application. There was no compost effect in 2007 and gypsum had no effect on P concentration of plant biomass. Singer et al, (2007) reported that corn plants growing in compost treated soil accumulated more P and K than plants growing in no-compost soils. Cover crop effect on P was generally the direct opposite of N. Mustard and oilseed radish, resulted in the highest N concentrations, with no difference between wheat, and no-cover (Table 3.6).

Effects found to be significant for K concentration in corn biomass were compost ($P \leq 0.05$) in 2006 and 2007, and cover crops ($P \leq 0.001$) in 2007. Compost application increased K by 8% compared to no-compost in 2006. When corn followed late planted cover crops, K was increased by 8%, but no compost effect was observed following early planted cover crops in 2007. Cover crops had no significant effect on K concentrations in 2006 ($P > 0.05$), but influenced K in 2007 ($P \leq 0.001$). When corn followed early planted cover crops, the highest K concentration was following oilseed radish (46.4 g/kg^{-1}), followed by mustard (44.1 g/kg^{-1}), then red clover (37.8 g/kg^{-1}). There was no significant difference in K when corn followed late cover crops (Table 3.6). There is limited information in the literature on effect of these soil amendments on corn whole plant nutrient concentration; most studies focus on soil nutrient status, and treatment effect on soils.

Treatment Effects on Sweet Corn Yield

In 2005, corn yield data was not meaningful due to heavy infestation by European corn borer. ANOVA and means for corn yield in 2006 and 2007 are presented in Tables 3.8 and 3.9 respectively. Only cover crops significantly ($P > 0.01$) affected the number of marketable corn ears in 2006. Oilseed radish resulted in the highest number of total marketable ears per hectare; cereal rye was the lowest, and similar to no-cover (Figure 3.7a). There was no significant difference ($P > 0.05$) in number of ears from early or late treatments of similar cover crops (mustard, oilseed radish and red clover) (Figure 3.7b). Overall, there was no significant difference in the percentage of marketable corn ears among cover crops (Table 3.9). Generally, the number of corn ears was higher in 2006 than 2007 across cover crop treatments, partly due to lower plant densities in 2007. Cereal rye (2006) and wheat (2007) generally resulted in the lowest corn yield (and biomass), even compared to no-cover. We hypothesize that, this was due partly to N immobilization (Tollenaar et al., 1993; De Bruin, 2005), which reduced available N for plant growth. Also, lower growth, development and corn yield can be caused by rye and wheat through alleopathy from phytotoxic compounds secreted by the roots, or produced by decomposition of their residues (Tollenaar et al., 1993; and Raimbault, 1990). Ear weights were not significantly affected by treatments in 2006.

In 2007, only compost had a positive significant effect ($P \leq 0.01$) on ear weights. When corn followed late cover crop treatments, mean weight of corn ears was 11.78 Mg/ha^{-1} for compost and 9.49 Mg/ha^{-1} for no-compost. There was no effect from the early planted cover crops. Singer et al, (2004) reported that compost increased wheat yield numerically by 5% and 4% (2001 and 2002), though differences were not statistically significant. They also reported increased yield in field corn by 6% (2000), 8% (2001), and 13% (2002), from compost, compared to no-compost treatments. Dorivar et al., (2008) reported significantly higher grain yields in field corn from poultry compost compared with control plots, and Endale et al., 2008, reported 18% yield increase in field corn from compost compared to mineral fertilizer. Neither gypsum nor any of the combined treatments affected number of marketable corn ears. Number of marketable corn ears though not statistically significant, was numerically higher for no-gypsum plots than gypsum treated plots for both years. There was a 4% increase in 2006; 6% and 5% increases from early and late cover crops in 2007 respectively when gypsum was not applied compared to gypsum application (Table 3.9).

Treatment Effects on Sweet Corn Quality

The quality of sweet corn was evaluated by the physical measurements of weights, lengths and diameters, and the nutrient concentrations of 10 randomly selected corn ears (combined). ANOVA and means for treatment effects on physical measurements of sweet corn ears are presented in Tables 3.10 and 3.9 respectively. In 2006 lengths and weights were significantly affected by both cover crop incorporation ($P \leq 0.001$) and compost application ($P \leq 0.05$) but there was no treatment effect on ear diameter ($P > 0.05$). Effect of cover crops on means of combined lengths of the ten corn ear were as follows: cereal rye > red clover= no cover> mustard =oilseed radish (table 3.9). Generally, means for lengths of corn ears follow a similar pattern with corresponding ear weights. Corn ear lengths and weights were inversely correlated with the plant densities of corn and the number of corn ears following respective cover crops (Tables 3.2 and 3.9). Compost application significantly increased both lengths ($P \leq 0.05$) and weights ($P \leq 0.01$) of corn ear in 2006. When compost was applied, corn ears were longer (by 4 cm) and heavier (by 0.2 kg), than no-compost. In 2007, lengths, weights and diameters were significantly influenced by compost and cover crops. When corn followed early planted cover crops only compost ($P \leq 0.01$) application was significant for corn ear weights ($P \leq 0.01$); both compost ($P \leq 0.01$) and cover crops ($P \leq 0.05$) were significant for corn ear diameter. Mean corn ear weight was 5% higher and diameter was 4 % higher when compost was applied, compared to no-compost. Mustard cover crop (46.9 cm) resulted in the largest diameter mean followed by red clover (46.5 cm), then oilseed radish (45.6 cm) when corn followed early cover crops. When corn followed late planted cover crops, means of lengths ($P \leq 0.01$), weights ($P \leq 0.001$) and diameters ($P \leq 0.01$) were significantly higher from compost application compared to no-compost. Cover crops influenced corn ear weight and diameter, but had no significant ($P > 0.05$) effect on length. The order of effect on mean corn ear weight from late cover crops was: Oilseed radish (2.03 kg) kg) = no cover (2.02 kg) mustard (1.94 kg) = red clover (1.92kg) ≥ wheat (1.88 kg). Cover crops (late) except wheat, resulted in an increase in ear diameter, compared to no-cover.

Generally, mean corn ear lengths were higher across treatments in 2006 than 2007, but diameter means were greater in 2007 than 2006. The growing season in 2007 was hotter and drier, which may have caused a reduced number of kernels per row, consequently reduced ear lengths. Kernels per row can be strongly influenced by severe stress such as drought conditions occurring about two weeks prior to pollination (Janes and Rosati, 2002). Low soil moisture can result in low K availability to plant roots because diffusion and mass flow are responsible for most of the K adsorbed by plants. Potassium also provides most of the osmotic pull drawing water into plant roots.

Potassium can be available, but if soils are to dry, K can become positionally unavailable. When this happens many plant physiological processes are impacted, including the development of meristematic tissues where cell division takes place (Tisdale, et al., 1999).

Concentrations of Ca, Mg, N, P, and K of the corn ears were determined. ANOVA for treatment effect on nutrient concentrations in corn ears is presented in Table 3.11a and 3.11b, and means of nutrient concentrations from the various treatment factors and their interactions are presented in Tables 3.12, 3.13a and 3.13b, respectively. In 2006, Ca concentration in corn ears was affected only by compost ($P \leq 0.05$) and the combined effect of gypsum and compost ($P \leq 0.05$). Compost application increased Ca concentration in corn ears (0.17 g/kg^{-1}) by 31% more than no-compost (0.13 g/kg^{-1}). When both compost and gypsum were combined, Ca concentration (0.21 g/kg^{-1}) was 75% higher than gypsum application alone (0.12 g/kg^{-1}), 50% higher than compost application alone (0.14 g/kg^{-1}) and 50 % higher from plots where neither gypsum nor compost (0.14 g/kg^{-1}) was applied (Table 3.13b). This may indicates a synergic effect between gypsum and compost for enhanced Ca accumulation in sweet corn ears. No treatment factor had an effect on Ca concentration in corn ears in 2007.

In 2006 (Table 3.11b), N was influenced by gypsum ($P \leq 0.05$), cover crops ($P \leq 0.001$), and the combined effect of compost and cover crops ($P \leq 0.01$). When gypsum was applied, mean N concentration (15.1 g/kg^{-1}) was decreased by 3.3% compared to no gypsum (15.6 g/kg^{-1}). There was no gypsum effect on corn ear N concentration in 2007. Cover crops effect on N concentration of corn ears in 2006 was as follows: oilseed radish (15.7 g/kg^{-1}) = mustard (15.7 g/kg^{-1}) $\geq$ cereal rye (15.4 g/kg^{-1}) $\geq$ red cover (15.1g/kg^{-1}) =

no cover (15.0 g/kg^{-1}). There was no significant difference among cover crop treatment on N concentration of corn ears in 2007. The combined effect of compost and cover crops on N concentration in corn ears was significant ($P \leq 0.01$) in 2006. The highest increase was observed from compost interaction with cereal rye (7.4%), followed by mustard and oilseed radish (4%), then red clover, which was similar to no-cover (14.9g/kg^{-1}) plots when compost was applied (Table 3.13b). Only compost application influenced N concentration of corn ears in 2007 when corn followed early planted cover crops, with a 5% increase compared to no compost. There was a significant ($P \leq 0.05$) three way interaction among compost, gypsum and cover crops when corn followed late cover crops in 2007 (Table 3.13b).

Means of N concentration were similar when either compost (19.2 g/kg^{-1}) or gypsum (19.1 g/kg^{-1}) was applied to red clover plots. When both compost and gypsum were applied to plots following red clover, N concentrations remained the same as red clover plots with neither compost nor gypsum applied (18.0 g/kg^{-1}); a 6.4% less N (Table 3.13b). It appeared that interaction of gypsum and compost with red clover exhibited a negative effect on N concentration in corn ears. Legumes generally have a relatively high S requirement (Mckell et al., 1971; (Sathyamoorthi et al., 2007) for the formation of nodules and nitrogen fixation (Vitosh et al., 1994; Tisdale et al., 2005). Compost application potentially increases soil levels of P (Eghball and Power, 1999). In a study to evaluate the effect of S and P on mung bean, Aulahk and Pasricha (1977) reported an antagonistic relationship between S and P uptake and utilization especially when applied together. This may explain the reason for the decrease in N concentration in corn ears, when compost and gypsum interacted with red clover. The effect of compost application to no-cover crop plots was similar to the effect of gypsum plus compost application (18.7 g/kg^{-1}), but significantly higher (7.5 %) than gypsum application alone to the no-cover crops (17.4 g/kg^{-1}). There was no significant difference between gypsum application alone (17.4 g/kg^{-1}) and when both gypsum and compost were not applied (17.8 g/kg^{-1}). No significant compost by gypsum three-way interaction was observed with wheat and mustard.

Phosphorous concentration in corn ears was influenced only by cover crop treatments in 2006 ($P \leq 0.05$), and their effects followed a similar trend to N concentrations. Mustard (3.4 g/kg^{-1}) and oilseed radish (3.5 g/kg^{-1}) resulted in the highest increases in P concentration which were significantly higher than following red clover (3.3 g/kg^{-1}) and cereal rye (3.5 g/kg^{-1}). Corn ear P concentration following cereal rye and red clover were not different from no-cover crop (3.3 g/kg^{-1}). Potassium was only influenced by cover crops ($P \leq 0.001$) in 2006 and the combined effect of compost and cover crops ($P \leq 0.01$) when corn followed early planted cover crops in 2007 (Table 3.12). The effect of cover crops on K followed an opposite trend to their effects on N and P. The mean corn ear K concentration (Table 12) following oilseed radish (10.6 g/kg^{-1}) and mustard (10.7 g/kg^{-1}) were the lowest; following no-cover crop (11.1 g/kg^{-1}) was the highest, followed by cereal rye (11g/kg^{-1}), then red clover (10.9 g/kg^{-1}). When corn followed early planted cover crops (2007), the corn ear K means following mustard (9.5 g/kg) and oilseed radish (9.6 g/kg-1) were 9% and 6% higher respectively, when combined with compost than their means with no compost applied. The mean ear K following red clover combined with compost was 5% lower than no-compost (Table 3.13a).

SUMMARY AND CONCLUSION

This study indicates that, cover crops and compost alone or combined, have potential to increase the quality and yield of sweet corn. Oilseed radish and mustard offer great potential for increases in sweet corn yield and ear quality. Cereal rye and winter wheat are not good choices for improving yield. There is indication that combining gypsum and compost application can have a negative interaction effect on sweet corn yield when red clover is the previous crop. In some cases, gypsum applied alone and in combination with compost and various cover crops used in this study had a negative effect on corn growth, yield and/or quality. Generally, sweet corn yield was lower when gypsum was applied alone or in combination with cover crops or compost. If the desired benefit is for increasing yield and improving quality, the use of gypsum was not beneficial in sweet corn production on a Kalamazoo sandy loam. Long term studies are necessary to investigate the effect of gypsum on crop yield for different soils across Michigan and elsewhere.

Table 3.1. Statistical significance of gypsum, compost and cover crops for CMRs in 2006 and 2007

	2006		2007			
Sources of variations	F-value	P-value	F-value	P-value	F-value	P-value
2006			Early		Late	
Gypsum	1.47	ns	0.55	ns	0.55	ns
Compost	3.11	ns	0.90	ns	3.89	ns
Gypsum * compost	0.32	ns	0.97	ns	0.20	ns
Cover	4.72	**	38.04	***	6.17	***
Gypsum * cover	0.13	ns	1.68	ns	1.16	ns
Compost * cover	0.38	ns	1.35	ns	0.73	ns
Gypsum * cover * compost	1.09	ns	0.01	ns	0.41	ns

** $P \leq 0.01$
***$P \leq 0.001$
ns Not significant at α=0.05

Table 3.2. Effects of plant compost, gypsum and cover crops on corn density, height, biomass, and CMRS, concentration (V8) for 2006 and 2007

Treatment	Plant density	Plant height	Corn Biomass	CMR
	Plants/ha^{-1}	cm	Mg/ha^{-1}	Reading
2006				
No cover	74915c	57b	1.00b	53.3c
Mustard	75992b	69a	1.28a	54.6a
Oilseed radish	76207a	70a	136a	55.1a
Red clover	71040b	60b	1.03b	55.1a
Cereal rye	67596c	57c	0.88c	55.5a
Compost	72332a	69a	1.28a	54.4a
No compost	74054a	56b	0.94b	55.1a
Gypsum	73193a	63a	1.06a	55.0a
No Gypsum	73193a	63a	1.16a	54.5a
	----------Early----------			
2007				
Mustard	52527a	61a	0.37a	42.6c
Oilseed radish	53388a	62a	0.43a	45.5b
Red clover	50589a	59a	0.42a	47.7a
Compost	53818a	63a	0.52a	45.0a
No compost	50589a	56b	0.30b	45.6a
Gypsum	51666a	61a	0.38a	45.5a
No Gypsum	52742a	60a	0.44a	45.0a
	----------Late----------			
No cover	52742a	62a	0.40a	41.0c
Mustard	53388a	62a	0.43a	43.7a
Oilseed radish	53603a	62a	0.41a	43.8a
Red clover	51235a	59b	0.37ab	43.1ab
Wheat	51450a	54c	0.33b	42.5ab
Compost	51666a	62a	0.43a	43.3a
No compost	53173a	58b	0.34b	42.3b
Gypsum	52096a	59a	0.39a	43.0a
No Gypsum	52957a	61a	0.39a	43.0a

Means within the same column and groups followed by the same letters are not significantly different α=0.05 .

Table 3.3. Statistical significance of gypsum, compost and cover crops, on corn plant height, biomass and corn ears

Sources of variations	2006 F-value	2006 P-value	2007 F-value	2007 P-value	F-value	P-value
Plant height(V8)			**Early**		**Late**	
Gypsum	0.01	ns	0.05	ns	0.13	ns
Compost	70.53	***	41.52	***	15.10	**
Gypsum *x compost	2.77	ns	0.08	ns	0.76	ns
Cover	34.80	***	0.42	ns	10.18	***
Gypsum * cover	0.68	ns	0.52	ns	0.64	ns
Compost * cover	3.28	*	0.92	ns	1.54	ns
Gypsum * cover *compost	0.14	ns	0.71	ns	1.23	ns
Plant Biomass (V8)			**Early**		**Late**	
Gypsum	6.34	ns	0.94	ns	0.00	ns
Compost	72.08	***	29.57	***	16.11	**
Gypsum * compost	2.05	ns	0.08	ns	0.86	ns
Cover	27.55	***	0.81	ns	2.50	*
Gypsum * cover	1.28	ns	0.23	ns	0.36	ns
Compost * cover	0.93	ns	0.10	ns	1.98	ns
Gypsum * cover * compost	0.03	ns	0.10	ns	0.97	ns
Corn Ears			**Early**		**Late**	
Gypsum	1.04	ns	0.11	ns	0.14	ns
Compost	0.61	ns	0.23	ns	2.68	ns
Gypsum * compost	0.00	ns	0.14	ns	0.16	ns
Cover	3.98	**	0.55	ns	0.85	ns
Gypsum * cover	0.12	ns	0.25	ns	0.17	ns
Compost* cover	0.60	ns	0.12	ns	0.52	ns
Gypsum * cover * compost	0.70	ns	0.23	ns	0.31	ns

*$P \leq 0.05$
**$P \leq 0.01$
***$P \leq 0.001$
ns Not significant at $\alpha=0.05$

Table 3.4. Effect of combined interactions of compost and cover crops on mean corn height

	Treatments	N	C/W	M	O	R
2006		---------------------------cm-------------------------				
	Compost	66b	65b	72a	74a	69ab
	No compost	53c	42d	66b	67b	54c
2007		-----------------Early------------------				
	Compost	-	-	66a	66a	63ab
	No compost	-	-	56b	57b	54b
		-----------------Late--------------------				
	Compost	64a	54c	65a	64a	61a
	No compost	60b	55c	59b	61ab	56bc

Means within the same treatments groups followed by the same letters are not significantly different at α=0.05

Abrev.: Abrev.: N= No cover; C=Cereal rye; W= Wheat; M= mustard; O= Oilseed radish; R= red clover

Table 3.5a. Statistical significance of gypsum, compost and cover crops on Ca and Mg concentration of Corn plant biomass (V8 stage)

Treatments	Ca		Mg	
2006	F-value	P-value	F-value	P-value
Gypsum	8.88	*	0.15	ns
Compost	26.04	**	121.54	***
Gypsum* compost	4.53	ns	0.97	ns
Cover	9.43	***	3.11	*
Gypsum*cover	0.25	ns	1.90	ns
Compost*cover	1.07	ns	0.87	ns
Gypsum*cover*compost	1.13	ns	0.51	ns
2007		----------------Early--------------		
Gypsum	4.71	ns	1.38	ns
Compost	24.28	**	22.46	**
Gypsum* compost	3.46	ns	0.19	ns
Cover	16.41	***	40.83	***
Gypsum*cover	0.08	ns	0.72	ns
Compost*cover	0.47	ns	0.32	*
Gypsum*cover*compost	0.54	ns	0.30	ns
		-----------------Late---------------		
Gypsum	9.96	*	1.69	ns
Compost	6.08	*	31.31	**
Gypsum* compost	1.95	ns	0.55	ns
Cover	1.07	ns	2.97	*
Gypsum*cover	0.36	ns	1.39	ns
Compost*cover	0.97	ns	1.07	ns
Gypsum*cover*compost	0.73	ns	0.70	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05

Table 3.5b. Statistical significance of gypsum, compost and cover crops on nutrient concentration of plant biomass (V8 stage)

Treatments	N		P		K	
2006	F-value	P-value	F-value	P-value	F-value	P-value
Gypsum	2.21	ns	0.67	ns	0.00	ns
Compost	1.02	ns	18.41	**	8.18	*
Gypsum* compost	2.21	ns	2.05	ns	0.30	ns
Cover	11.70	***	3.11	*	2.01	ns
Gypsum*cover	0.50	ns	2.00	ns	0.35	ns
Compost*cover	5.69	***	1.14	ns	0.86	ns
Gypsum*cover*compost	0.45	ns	1.40	ns	0.50	ns
2007		-------------------Early----------------				
Gypsum	14.40	*	0.03	ns	0.04	ns
Compost	4.25	ns	2.56	ns	0.21	ns
Gypsum* compost	6.70	*	1.53	ns	0.52	ns
Cover	51.46	***	16.95	***	23.17	***
Gypsum*cover	0.21	ns	0.68	ns	1.08	ns
Compost*cover	1.06	ns	0.28	ns	1.18	ns
Gypsum*cover*compost	0.37	ns	0.12	ns	1.17	ns
		--------------------Late-----------------				
Gypsum	1.52	ns	3.83	ns	0.09	ns
Compost	1.23	ns	0.81	ns	6.84	*
Gypsum* compost	0.12	ns	0.00	ns	0.33	ns
Cover	6.24	***	1.65	ns	1.43	ns
Gypsum*cover	0.62	ns	0.64	ns	1.20	ns
Compost*cover	2.53	*	0.75	ns	2.27	ns
Gypsum*cover*compost	0.90	ns	0.66	ns	0.26	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05

Table 3.6. Means of corn plant nutrient concentration as affected by the various treatment factors at the V8 growth stage

	Treatment	Ca	Mg	N	P	K
2006				g/kg^{-1}		
	No Cover	3.5b	2.7bc	21.9c	3.5a	43.5ab
	Mustard	3.2c	2.6c	22.0c	3.4ab	41.9ab
	Oilseed radish	3.4b	2.8ab	25.6a	3.1c	42.2ab
	Red Clover	3.7a	2.9a	24.1b	3.4ab	43.0ab
	Cereal rye	3.6ab	2.8ab	23.9b	3.3abc	45.6a
	Compost	3.6a	2.4b	23.3a	3.5a	45.0a
	No Compost	3.4b	3.1a	23.7a	3.2b	41.5b
	Gypsum	3.6a	2.7a	23.8a	3.4a	43.3a
	No gypsum	3.4b	2.8a	23.2a	3.3a	43.2a
				Early		
2007	Mustard	4.0b	3.1b	27.8b	3.4b	44.1a
	Oilseed radish	3.8b	2.9c	32.0a	3.5b	46.4a
	Red clover	4.5a	4.0a	34.2a	3.9a	37.8b
	Compost	4.4a	3.0b	30.8a	3.6a	43.0a
	No Compost	3.9b	3.8a	31.9a	3.7a	42.32a
	Gypsum	4.3a	3.2a	30.3b	3.6a	42.6a
	No gypsum	4.0a	3.4a	32.3a	3.7a	42.9a
				Late		
	No Cover	4.2a	3.1b	25.4c	4.3a	42.3a
	Mustard	4.0ab	2.8c	28.5a	4.1ab	42.5a
	Oilseed radish	4.0ab	3.1b	27.6ab	4.0b	43.8a
	Red Clover	4.2a	3.2a	26.9b	4.0b	40.6a
	Wheat	4.1ab	3.0b	26.4bc	4.2a	41.7a
	Compost	4.2a	2.6b	27.2a	4.1a	43.8a
	No Compost	4.0b	3.5a	27.6a	4.0a	40.5b
	Gypsum	4.26a	3.0a	26.4a	4.0a	42.4a
	No gypsum	3.92b	3.13a	27.4a	4.2a	42.2a

Means within the same columns and group followed by the same letters (within treatment groups) are not significantly different at α=0.05)

Table 3.7. Effects of gypsum, compost, cover crop interaction on N and Mg concentration on mean plant biomass at the V8 stage

Compost*cover crop	N	C/W	M	O	R
			Nitrogen		
			-----g/kg^{-1}-----		
2006					
Compost	21.5cd	25.0b	20.9d	24.0b	25.0b
No Compost	22.3cd	22.3cd	23.1bc	27.2a	23.1bc
2007			---Early---		
Compost			26.8a	31.5a	34.2a
No Compost			28.8a	32.5a	34.3a
			---Late---		
Compost	26.7ab	26.2ab	28.2a	27.4a	27.5a
No Compost	24.0b	26.6b	28.8a	27.8a	26.2ab
			Magnesium		
2006					
Compost	2.35a	2.41ab	2.3ab	2.5ab	2.4ab
No Compost	3.05a	2.41a	2.9a	3.1a	3.3a
2007			---Early---		
Compost	_	_	2.7c	2.6d	3.4b
No compost	_	_	3.5b	3.1bc	4.6a
			---Late---		
Compost	2.7ab	2.5ab	2.5ab	2.8ab	2.7ab
No Compost	3.5b	3.5b	3.2ab	3.4ab	3.7a

Gypsum*compost	Compost	No Compost
	Nitrogen	
2006		
Gypsum	23.3a	24.3a
No gypsum	23.3a	23.1a
2007	---Early---	
Gypsum	30.4b	30.2b
No gypsum	31.1b	33.6a
	---Late---	
Gypsum	26.6a	26.3a
No gypsum	27.8a	27.1a

Means within the same groups followed by the same letters are not significantly different at α=0.05

Abrev.: Abrev.: N= No cover; C=Cereal rye; W= Wheat; M= mustard; O= Oilseed radish; R= red clover

Table 3.8. Statistical significance of gypsum, compost and cover crops, on number and weights of sweet corn ears for 2006 and 2007

Sources of variations	2006 F-value	2006 P-value	2007 F-value	2007 P-value	2007 F-value	2007 P-value
Number of Ears			---Early----		----Late----	
Gypsum	1.04	ns	0.11	ns	0.14	ns
Compost	0.61	ns	0.23	ns	2.68	ns
Gypsum*compost	0.00	ns	0.14	ns	1.06	ns
Cover	3.98	**	0.55	ns	0.85	ns
Gypsum *cover	0.12	ns	0.25	ns	0.17	ns
Compost*cover	0.60	ns	0.12	ns	2.52	ns
Gypsum *cover *compost	0.70	ns	0.23	ns	0.31	ns
Ear Weights			----Early----		-----Late-----	
Gypsum	0.63	ns	0.60	ns	0.85	ns
Compost	5.07	ns	3.45	ns	14.90	**
Gypsum *compost	0.21	ns	0.01	ns	1.42	ns
Cover	2.35	ns	0.32	ns	1.82	ns
Gypsum*cover	0.16	ns	0.38	ns	0.30	ns
Compost *cover	0.45	ns	0.02	ns	2.27	ns
Gypsum*cover *compost	0.34	ns	0.62	ns	0.08	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05

Table 3.9. Effect of gypsum, compost and cover crops on yield and quality. Yield is presented in percentage of marketable ears, weight and number of ears. Quality is presented in lengths, diameter and weights of ten selected husked ears.

		Yield			Quality		
		Marketable corn ears			Diamter	Length	Weight
	Treatment	Dozens/ha^{-1}	Mg/ha^{-1}	Percentage		---cm----	kg
2006							
	No cover	4541bc	13.59a	81a	41a	203b	1.91b
	Mustard	4967ab	15.20a	82.a	42a	199c	1.93b
	Oilseed radish	5079a	15.72a	83a	42a	199c	1.99b
	Red clover	4967ab	15.97a	85.a	41a	203b	1.93b
	Cereal rye	4294c	15.10a	83.a	41a	208a	2.15a
	Compost	4711a	15.84a	82a	42a	204a	2.08a
	No compost	4828a	14.39a	85a	41a	201b	1.88b
	Gypsum	4693a	14.85a	84a	42a	203a	1.96a
	No gypsum	4846a	15.38a	83a	41a	202a	2.00a
2007							
			---------Early---------				
	Mustard	3677a	11.40a	90a	47a	173a	2.01a
	Oilseed radish	3509a	11.00a	89a	46ab	175a	1.97a
	Red clover	3576a	11.00a	85a	45b	175a	1.92a
	Compost	3610a	12.00a	90a	47a	173a	2.05a
	No compost	3565a	10.50a	85a	45b	175a	1.88b
	Gypsum	3475a	11.00a	87a	46a	174a	1.94a
	No gypsum	3699a	11.52a	87a	47a	173a	1.99a
			---------Late---------				
	No cover	3458a	10.61a	83a	46a	173a	2.02a
	Mustard	3486a	10.74a	84a	46a	172a	1.94ab
	Oilseed radish	3475a	10.93a	83a	46a	180a	2.03a
	Red clover	3318a	10.24a	83a	46a	173a	1.92ab
	Wheat	3172a	9.23ab	84a	45b	179a	1.88b
	Compost	3486a	11.16a	86a	47a	181a	2.06a
	No compost	3278a	9.57b	81a	45b	170b	1.85b
	Gypsum	3297a	10.01a	83a	46a	174a	1.96a
	No gypsum	3468a	10.66a	84a	46a	175a	1.96a

Values within the same columns and groups followed by the same letters are not significantly different at α = 05

Table 3.10. Significance of gypsum, compost and cover crops on sweet corn ear lengths, weights and diameter

	2006		2007			
Sources of variations	F-value	P-value	F-value	P-value	F-value	P-value
Lengths			----Early----		----Late----	
Gypsum	0.18	ns	0.25	ns	0.49	ns
Compost	11.35	*	1.79	ns	28.15	**
Gypsum*compost	0.75	ns	0.99	ns	1.39	ns
Cover	9.34	***	0.53	ns	2.29	ns
Gypsum * cover	0.16	ns	1.37	ns	1.30	ns
Compost* cover	0.89	ns	0.54	ns	0.82	ns
Gypsum *cover *compost	1.25	ns	0.81	ns	0.69	ns
Weights						
Gypsum	0.14	ns	1.29	ns	0.05	ns
Compost	22.60	**	18.38	**	52.73	***
Gypsum *compost	0.25	ns	1.24	ns	0.21	ns
Cover	3.98	**	1.84	ns	3.80	**
Gypsum * cover	0.28	ns	0.70	ns	0.39	ns
Compost *cover	0.38	ns	1.28	ns	0.59	ns
Gypsum*cover*compost	0.37	ns	0.08	ns	0.24	ns
Diameters						
Gypsum	0.04	ns	1.84	ns	0.88	ns
Compost	1.91	ns	25.91	**	26.54	**
Gypsum *compost	0.92	ns	3.48	ns	0.02	ns
Cover	0.31	ns	3.51	*	4.35	**
Gypsum *cover	0.12	ns	0.39	ns	0.51	ns
Compost *cover	0.64	ns	0.63	ns	0.23	ns
Gypsum * cover * compost	0.93	ns	0.05	ns	0.13	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05

Table 3.11a. Statistical significance of gypsum, compost and cover crops on nutrient concentration of corn ears.

	Ca		Mg	
Treatments	F-value	P-value	F-value	P-value
2006				
Compost	6.12	*	0.77	ns
Gypsum* compost	6.89	*	0.63	ns
Cover	1.26	ns	0.30	ns
Gypsum*cover	0.53	ns	0.43	ns
Compost*cover	0.07	ns	0.40	ns
Gypsum*cover*compost	0.58	ns	0.78	ns
2007		----------**Early**----------		
Gypsum	3.71	ns	0.00	ns
Compost	0.49	ns	0.13	ns
Gypsum* compost	2.07	ns	0.13	ns
Cover	0.33	ns	2.64	ns
Gypsum*cover	0.06	ns	0.59	ns
Compost*cover	1.67	ns	1.41	ns
Gypsum*cover*compost	2.84	ns	0.58	ns
		----------**Late**----------		
Gypsum	0.03	ns	2.00	ns
Compost	0.14	ns	0.03	ns
Gypsum* compost	0.02	ns	0.06	ns
Cover	0.93	ns	0.10	ns
Gypsum*cover	1.98	ns	2.05	ns
Compost*cover	0.41	ns	0.21	ns
Gypsum*cover*compost	0.58	ns	1.54	ns

* $P \leq 0.05$
** $P \leq 0.01$,
*** $P \leq 0.001$,
ns Not significant at α=0.05

Table 3.11b. Statistical significance of gypsum, compost and cover crops on nutrient concentration of corn ears.

	N		P		K	
Treatments	F-value	P-value	F-value	P-value	F-value	P-value
2006						
Gypsum	9.49	*	4.90	ns	0.22	ns
Compost	0.06	ns	1.42	ns	0.22	ns
Gypsum* compost	0.95	ns	0.00	ns	0.19	ns
Cover	5.80	***	3.15	*	6.72	***
Gypsum*cover	0.13	ns	0.46	ns	0.54	ns
Compost*cover	4.58	**	0.58	ns	1.28	ns
Gypsum*cover*compost	1.00	ns	0.23	ns	0.39	ns
2007			-----------------Early--------------------			
Gypsum	1.88	ns	0.45	ns	0.01	ns
Compost	10.05	*	5.11	ns	4.25	ns
Gypsum* compost	1.00	ns	0.00	ns	0.27	ns
Cover	2.76	ns	0.34	ns	0.55	ns
Gypsum*cover	2.11	ns	0.40	ns	0.71	ns
Compost*cover	1.55	ns	1.86	ns	7.41	**
Gypsum*cover*compost	1.67	ns	0.59	ns	0.95	ns
			-------------------Late------------------			
Gypsum	1.07	ns	0.22	ns	0.51	ns
Compost	4.91	ns	3.89	ns	3.78	ns
Gypsum* compost	0.55	ns	0.13	ns	0.09	ns
Cover	1.69	ns	0.58	ns	0.08	ns
Gypsum*cover	0.76	ns	2.61	ns	0.65	ns
Compost*cover	1.54	ns	0.47	ns	0.76	ns
Gypsum*cover*compost	2.73	*	1.90	ns	1.56	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05

Table 3.12. Means of nutrient concentration of corn ears as affected by gypsum, compost and cover crops

Treatment	Ca	Mg	N	P	K
2006			g/kg^{-1}		
No Cover	0.15ab	1.20a	15.0b	3.3b	11.1a
Mustard	0.13b	1.24a	15.6a	3.40a	10.7bc
Oilseed radish	0.14ab	1.23a	15.7a	3.5ab	10.6c
Red Clover	0.15ab	1.24a	15.1b	3.3b	10.9ab
Cereal rye/wheat	0.19.a	1.22a	15.4ab	3.3b	11.0a
Compost	0.17a	1.21a	15.4a	3.3a	10.7a
No Compost	0.13b	1.24a	15.4a	3.3a	10.8a
Gypsum	0.17a	1.23a	15.1b	3.3a	10.9a
No gypsum	0.14a	1.22a	15.6a	3.4a	10.8a
2007			Early		
Mustard	0.11a	1.24a	18.2a	3.5a	9.2a
Oilseed radish	0.12a	1.29a	18.7a	3.6a	9.3a
Red clover	0.13a	1.29a	18.9a	3.6a	9.3a
Compost	0.12a	1.27a	19.1a	3.7a	9.43
No Compost	0.11a	1.27a	18.1b	3.5a	9.1a
Gypsum	0.13a	1.27a	18.8a	3.6a	9.3a
No gypsum	0.11a	1.27a	18.4a	3.7a	9.2a
			Late		
No Cover	0.11a	1.27a	18.2a	3. 6a	9.2a
Mustard	0.13a	1.27a	18.7a	3.5a	9.3a
Oilseed radish	0.10a	1.26a	18.4a	3.6a	9.2a
Red Clover	0.12a	1.27a	18.5a	3.6a	9.3a
Cereal rye/wheat	0.13a	1.25a	18.1a	3.5a	9.3a
Compost	0.12a	1.26a	18.8a	3.6a	9.3a
No Compost	0.11a	1.26a	18.4a	3.5a	9.2a
Gypsum	0.12a	1.25a	18.5a	3.5a	9.2a
No gypsum	0.11a	1.27a	18.2a	3.6a	9.3a

Means within the same columns and treatment groups followed by the same letters are not significantly different

Table 3.13a. Effects from treatment interaction on Ca, N and K concentration in corn ears

	Nitrogen				
Compost*cover	N	C	M	O	R
2006	-----------------------------g/kg^{-1}------------------------				
Comp	14.9b	16.0a	15.5ab	15.6ab	15.0b
No comp	15.1b	14.9b	15.7a	15.8a	15.3b
2007	Early				
Comp			18.9a	19.2a	19.1a
No comp			17.6a	18.2a	18.7a
	Late				
Comp	18.7a	18.1a	18.9a	18.6a	18.5a
No comp	17.6a	17.9a	18.4a	18.0a	18.6a
			Potassium		
2006					
Comp	11.0a	11.1a	10.7a	10.4a	10.9a
No comp	11.8a	10.8a	10.7a	10.7a	10.8a
2007					
Comp			9.5a	9.6a	9.0b
No comp			8.8c	9.1b	9.5a
Comp	9.4a	9.3a	9.5a	9.52a	9.3a
No comp	9.1a	9.3a	9.0a	9.01a	9.35a

	Calcium	
Gypsum*compost	Gypsum	No gypsum
2006		
Compost	0.21a	0.14b
No compost	0.12b	0.14b
2007	----------Early---------	
Compost	0.15a	0.12a
No compost	0.12a	0.11a
	---------Late---------	
Compost	0.12a	0.12a
No compost	0.12a	0.11a

Means within rows and groups followed by the same letters are not significantly different α=0.05)

Abrev.: N= No cover; C=Cereal rye; M= mustard; O= Oilseed radish; R= Red clover

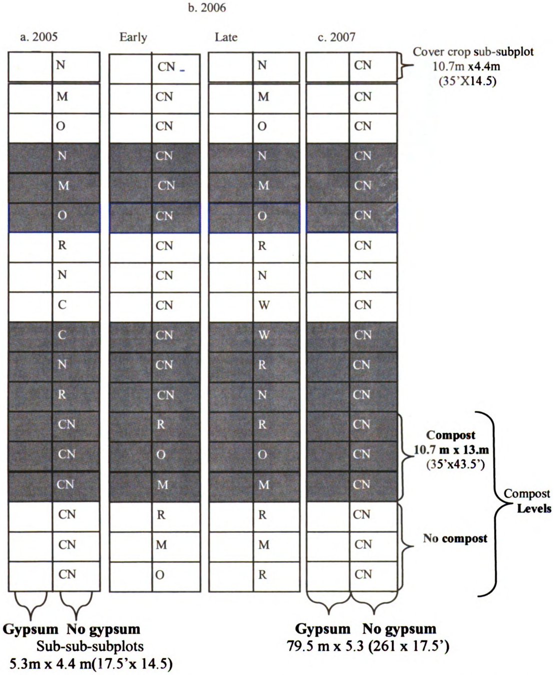
Table 3.13b. Effects from treatment interaction on N concentration in corn ears.

	Gypsum		No gypsum	
Gyp*comp*cover	Compost	No compost	Compost	No compost
2006	-------------------g/kg^{-1}--------------------			
No cover	14.5a	15.1a	15.1a	15.1a
Mustard	15.5a	15.4a	15.5a	15.5a
Oilseed Radish	15.6a	15.5a	15.6a	16.1a
Red clover	14.8a	14.9a	15.1a	15.7a
Cereal rye/Wheat	15.7a	14.5a	16.3a	15.0a
2007	---------------------Early---------------------			
No cover				
Mustard	19.3a	17.6b	18.6ab	17.5b
Oilseed Radish	19.0a	18.2b	19.4a	18.1b
Red clover	20.0a	18.8ab	18.2a	18.6ab
Cereal rye/Wheat				
	----------------------Late----------------------			
No cover	18.7a	17.4b	18.7a	17.8b
Mustard	19.4a	18.3ab	18.4ab	18.5a
Oilseed Radish	18.8a	18.5ab	18.7a	17.6b
Red clover	18.0b	19.2a	19.1a	17.9b
Cereal rye/Wheat	18.4ab	18.2ab	17.9b	17.6b

Means within columns and groups followed by the same letters are not significantly different (α=0.05)

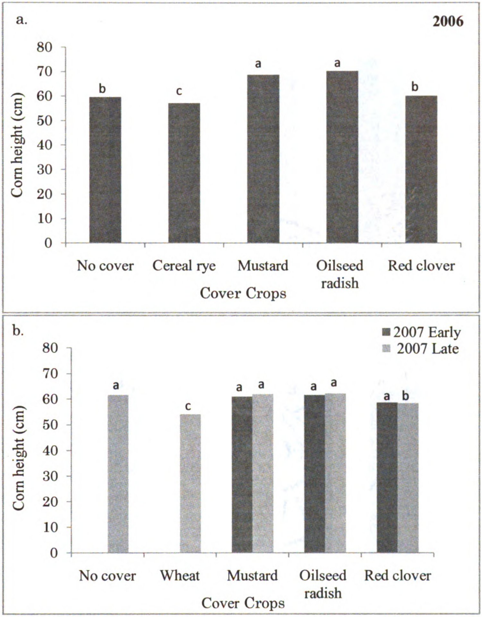
FIGURES

Figure 3.1. . Representation of a typical block of the experiment design.



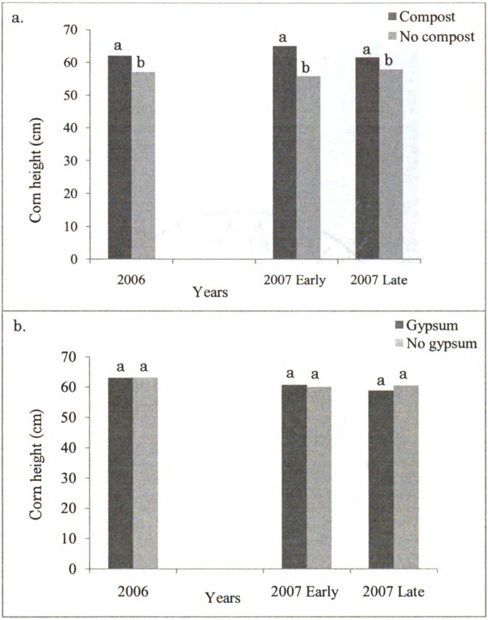
Abbrev.: N= No cover; C= Cereal rye; W= Wheat; R= Red clover; O= Oilseed radish; M=Mustard; CN= Corn

Figure 3.2. Effects of cover crops on corn height, 2006 and 2007..



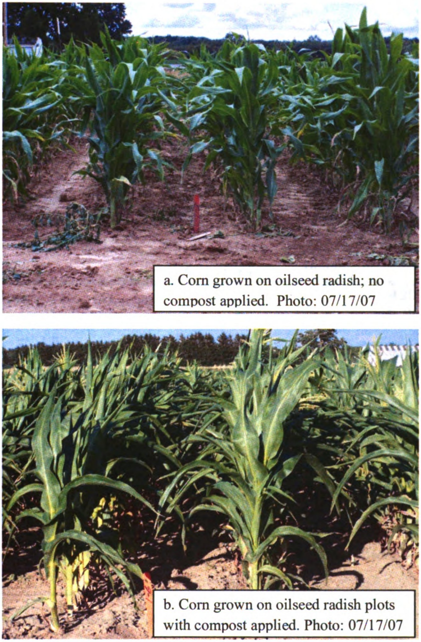
Mean comparisons in 2007 are by cover crop planting time

Figure 3.3. Effect of compost and gypsum on corn height, 2006 and 2007.



Mean comparisons in 2007 are by cover crop planting time

Figure 3.4. Corn growth and development as affected by compost application.

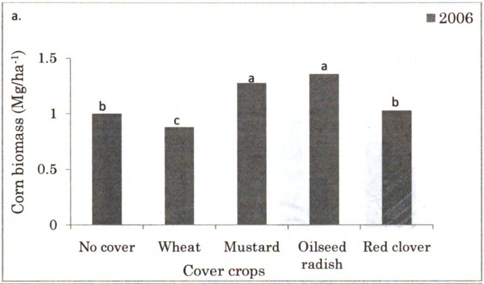


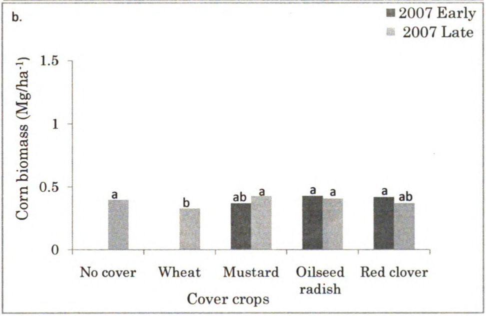
a. Corn grown on oilseed radish; no compost applied. Photo: 07/17/07

b. Corn grown on oilseed radish plots with compost applied. Photo: 07/17/07

Images in this dissertation are presented in color

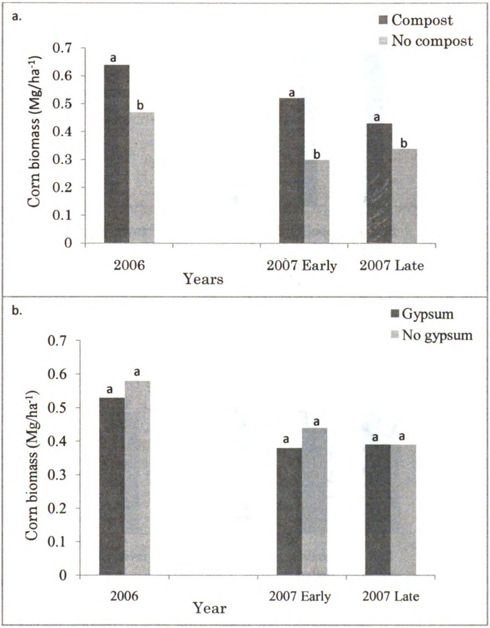
Figure 3.5. Effects of cover crops on whole corn biomass at the V8 Stage, 2006 and 2007.





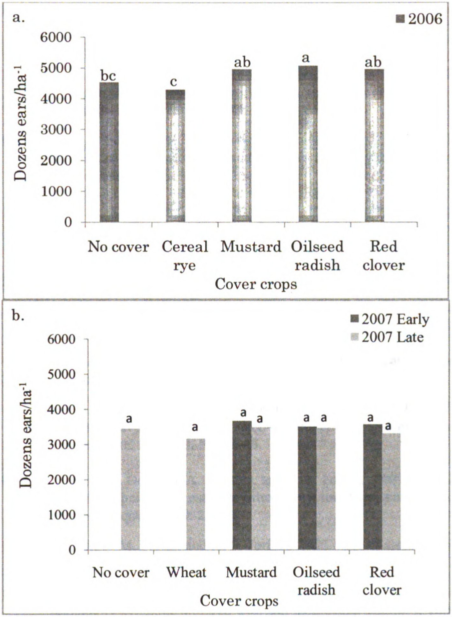
Mean comparisons in 2007 are by cover crop planting time

Figure 3.6. Effects of compost and gypsum on whole corn plant biomass at the V8 Stage, 2006 and 2007.



Mean comparisons in 2007 are by cover crop planting time

Figure 3.7. Effect of cover crops on corn yield, presented in number of corn ears.



Mean comparisons in 2007 are by cover crop planting time

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CHAPTER 4

EFFECTS OF GYPSUM ALONE OR COMBINED WITH COMPOST AND COVER CROPS ON SOIL QUALITY

ABSTRACT

Water stabled aggregate (WSA), bulk density, microbial biomass and nematode population, along with the simplified active organic matter (AOM) test were used to determined soil quality. The treatment design involved three factors: gypsum application at 0 and 2.24 Mg ha^{-1}, poultry compost, at 0 and 2.7 Mg ha^{-1}, and four cover crops plus a no cover treatment. The four cover crops were oilseed radish (*Raphanus sativus*), oriental mustard (*Brassica juncea L*), red clover (*Trifolium pratense)*, and cereal rye (*Secale cereale*), or wheat (*Triticum aestivum*). Soil samples were taken the spring and fall of each of the three years (2005- 2007). The statistical model included the three factors and all interactions among them as fixed effects, and replication as a random effect. Gypsum did not improve any soil quality component investigated. Compost application significantly enhanced aggregate stability and decreased bulk density over the three year study. These increases corresponded with the AOM test which showed a fair rating for the soil quality compared a poor rating for the non compost treatment. Generally there was no positive effect (α =0.05) of cover crops on the soil quality components studied. Mustard negatively influenced WSA, bulk density and nematode population.

INTRODUCTION

Among the many factors for consideration in addressing management practices for sustainable agriculture is soil quality (SQ). The concept of soil quality is not a new topic, having been used as early as the 1950s especially by pedologists. However, it has been viewed with a different approach – the ecosystem concept – since the late 1980s (Lal, 1998) when addressing sustainability issues and is considered a key element of agricultural sustainability (Carter, 2001). Concerns with soil degradation and the growing need for sustainable soil management in agro-ecosystems has renewed scientific attention to characterize soil quality (Carter, 2001). Soil quality refers to a soil's capacity to perform specific functions and includes both a soil's productive and environmental capabilities (Wander et al., 2002). Hence, with respect to agricultural production, SQ is a soil's ability to sustain agricultural productivity (Johnson et al., 1997 and Lal, 1998). If an agricultural system is unsustainable it is due in part to decline in SQ over time (Lal, 1998). A reduction in soil quality due to human activities can be defined as soil degradation (Cassman, 1999).

Soil quality has two aspects – its inherent and dynamic properties. Its inherent properties are a function of its geology, acted upon by intrinsic factors, such as climate, topography and hydrology. It is mainly static; showing little change over human time scales. Hence, each soil has an inherent capacity to function; for example, a loamy soil has a higher inherent water holding capacity than a sandy soil. Dynamic properties on the other hand, can change over short time periods, and examples are as soil macroporosity, structure and soil organic matter (SOM) content (Carter, 2002). Though a loamy soil has an inherently higher water holding capacity, under certain management practices, this capacity can become limited due to compaction, reduced aggregate stability and other factors (Maushbach, 1996). The focal point for assessment of SQ (also referred to as soil health) in agricultural production is soil dynamic properties, which are greatly influenced by agronomic practices (Lal,1998; Rachman, 2003; Moebius-Clune, 2008). Although SQ cannot be measured directly, its capacity to function is reflected in many measurable soil (quality) indicators and is a combination of physical, chemical, and biological aspects that are reflective of soil processes and management practices (Detzler and Tugel, 2002; Schindelbeck,et al., 2008). Therefore, due to a soils' multifaceted nature, SQ determination requires that biological, physical, and chemical attributes of a soil be considered simultaneously (Wander and Bollero, 1999; Brejda, et al., 2000).

Physical attributes of SQ are those qualities that are derived from primary and secondary soil particles, and void pore spaces between then. These attributes facilitate functions such as soil capacitance (ability to store and transmit liquid and gases), soil strength, and their interactions (Topp et al., 1997). The chemical properties of soil function are to provide nutrients for crop growth. A soil's chemical properties include but not are limited to cation exchange capacity (CEC), electrical conductivity (EC), exchangeable sodium percentage (ESP), organic matter (OM) content, mineralogy, and soil pH (Heil and Sopsito, 1997). The biological aspects of soil quality include the living organisms and their derivatives; those components and processes related to soil organic matter cycling. Examples of these are total carbon, total nitrogen, microbial biomass, enzyme activities (Gregorich et al., 1997), arbuscular mycorrhiza (AM) fungi, and glomalin. Presumably, glomalin a newly discovered insoluble soil glycoprotein, is produced by the arbuscular mycorrhizal fungi (AMF) which grow symbiotically on plant roots. Glomalin contains about 30-40 % carbon, and may contribute to clumping (Wright et al., 1996). Such finding warrants the inclusion of glomalin in studies regarding SQ. Glomalin may be an important specific cementing agent involved in the process of aggregation (Wright et al., 1996; Wright and Upadhyaya, 1996). The soil quality indicators studied were organic matter, aggregate stability, bulk density, microbial biomass and nematode population.

Organic matter

Soil organic matter is made up of humic substances and biochemical compounds, such as peptides, proteins, polysaccharides, and sugars, which are derived from decomposed animal and plant residues. Organic matter influences biological and chemical properties of the soil (Pierzynski et al., 2000; Sparling et., al 2006), resulting in an array of benefits that enhance soil quality. Most recently, organic matter has been promoted as having both direct and indirect impact on environmental quality (Sparling et al., 2006; Carter, 2000; Pullman, 2000) and global climate through carbon sequestration (Lal, 2001). Addition of organic matter improves soil structure, increases cation exchange capacity, buffering capacity against pH change, the soil's chelating ability, and supplies C and energy sources for microorganism (Pierzynski et al., 2000; Sparling et al., 2006). A linear positive relationship has been established by researchers between organic matter and soil quality (Jansen, et al 1997) where a decline in organic matter correlates with a decline in soil quality, and vice versa. The active portion of soil organic matter is the most important component indicator of soil quality, because of the susceptibility to further decomposition (Islam and Wright, 2003)

Soil aggregation and aggregate stability

A soil aggregate is an assemblage of particles of various sizes, shapes, orientations, and chemical composition, which contains amorphous substances, particularly OM, attached to the mineral grains – flocculation plus cementation (Hillel, 2004). Factors affecting the process of soil aggregation are biotic, abiotic and environmental; also, chemical, biological and physical (Marques et al., 2004). Aggregation is important because it increases the macroporisity of soils, thereby facilitating gas exchange, infiltration, percolation, seedling emergence and root exploration. Hence, soil aggregation is a particularly good indicator of management practices' influence (Nissen and Wander, 2003), and a major factor for assessing SQ (Marques et al., 2004). Soil aggregation process is a means to both conserve and protect SOM and allow the stored OM to function as a reservoir of plant nutrients and energy (Carter, 2002). Soil aggregate stability is a measure of a soil's vulnerability to externally disruptive forces, as it expresses the resistance of aggregates to breakdown when subjected to potentially disruptive forces (Hillel, 2004). Although soil aggregate formation and aggregate stability have been hypothesized as being crucial in SQ and productivity, yet many questions still exist with regards to the processes by which aggregates are formed and stabilized. Tisdall and Oades (1982), contend that though polysaccharides play an important role in soil aggregate formation and stability, they are not involved with stabilizing large aggregates but only those less than 50 µm in diameters, and have less importance with soils high in OM.

Aggregate stability has been strongly correlated with soil OM, and decreases in OM have been shown to correspond with decreases in aggregate stability, upon cultivation (Chen et al., 2000). Soil organic matter compounds were generally believed to bind the primary particles in the aggregate, physically and chemically, and this in turn, increases the stability of the aggregates and limits their breakdown during the wetting process. McLauchlan and Bailey (2004) found positive relationships which indicated that labile soil organic carbon, (SOC_L) increased with total soil organic matter (SOC_T). Gale et al., (2000) contends that little is known about the dynamics of the particulate organic matter (POM) fraction or its role in aggregate formation. However, recent investigations have demonstrated that soil aggregate formation, stability and soil tilth are directly influenced by the presence of glomalin, which is a glycoprotein produced in abundance by AM fungi (Wright et al., 1996; Wright et al., 1998, wright et al., 1999). Glomalin and its relation to soil aggregate stability, influence of plant roots and other soil interactions aspects, needs further investigation (Wright et al., 2001).

Bulk density

A soil's bulk density is the ratio of the soil's solid weight to its bulk volume, is inversely related to its porosity, and is an indicator of a soil's compaction. Bulk density ranges from 1.2 g/cm^{-3} in loamy soils to 1.6 $g\ cm^{-3}$ in sandy soils depending on a number of factors including, texture, structure and degree of compaction (Blake and Hartge, 1986; Carter and Ball, 1993; Hillel, 2004; Lampurlanés and Martínez, 2003; Assouline, 2006). Compaction influences the physical, chemical and biological processes of a soil through infiltration, evaporation, seedling emergence, root penetration and development, among others. Increases in bulk densities can occur from both natural processes such as root penetration, shrink -swell cycles and artificial processes such as humans and tractor movement (Assouline, 2006). As the soil becomes compressed from the weight of humans and farm vehicles, soil pores are reduced and bulk density increases. Bulk density has also been shown to have strong correlations with organic matter, decreasing as organic carbon increases (Alexander, 1980). Generally, bulk density increases with depth because of reduced soil pores due to reducd organic matter, root penetration, and aggregation in the subsoil. The ability of a soil to offer structural support, water solute and air movement impact the soil's health (Brady and Weil 2002; Kuykendall, 2008); hence, bulk density measurements is a useful indicator of the physical component of soil and ecosystem functioning, and impacts both the biological and chemical properties. Measurements of bulk density can be done through various methods- the core (cylinder), clod, excavation and radiation methods.

Microbial biomass and Nematode population

Soil microorganisms play an important function in maintaining soil quality because they play a central role in the decomposition of organic matter and the cycling of nutrient. (Parkinson and Paul, 1982; Anderson and Domsch, 1985; Dick 1992; Byre et al., 2003) and bacterial polysaccharides may enhance soil aggregation. Although microbial biomass is only approximately 1-3 % of organic carbon (Anderson and Domsch, 1989; Gregorich et al., 1997), the fast turnover time gives microbial biomass its central role in nutrient cycling (Suman et al., 2006; Gregorich et al., 1997). For this reason, soil microbial population has been widely used as a useful indicator of soil quality (health). Soil microbial biomass is sensitive to an array of ecological factors, including temperature, soil structure, plant communities and moisture levels, which make it a good indicator of soil quality (Suman et al., 2006). Microorganisms inhibit soil pore spaces (Brye et al., 2003); consequently, soil aggregation and bulk density as affected by management practices will impact the microbial community. Bacteria and fungi are the major components of the soil microbial biomass (Byre et al., 2003; Parkinson and Paul, 1982), and their combined population represents a large fraction of the total microbial biomass. Therefore management practices will reflect the population ratio of soil fungi and bacteria. Soil that are less intensely managed are dominated by fungi, while more intensely managed soils are dominate by bacteria (Bardgett et al., 1999).

Soil microfauna which includes nematodes are major determinants of soil processes that affect soil fertility and soil structure. Therefore their abundance, diversity and activities are useful indicators of soil quality (Gregorich et al., 1997). Nematodes are threadlike, un-segmented worms that are ubiquitous in every ecological niche, and are the second most abundant soil faunal group in terms of numbers and biomass after protozoa. Of the more than 10,000 described species, the vast majority are predators on bacteria and fungi living in soils and water – fresh and marine (Gundy, 1982). Some nematodes are defined by humans as beneficial to the soil environment and plant health while others are not. Plant parasitic nematodes are pathogens that may cause yield and quality losses for many vegetable and field crops where suitable management practices are not in place. For example, lesion nematodes (*Pratylenchus* spp.) have approximately 400 different crop and weed species that serve as hosts, and root-knot nematodes (*Meloidogyne* spp.) can reduce production for more than 2000 species of plants, including forage crops, small grains, fruits, vegetables, field crops, nursery crops, turfgrasses, and weeds. (Kratochvil et al., 2004). Several management practices for the control of plant parasitic nematodes have been utilized. These include crop rotation, the use of resistant cultivars, green manure crops, organic soil amendments, among others (Johnson and Motsinger, 1990; Kratochvil et al., 2004).

Due to a soil's multifaceted nature, SQ determination requires that biological, physical, and chemical attributes of a soil be considered simultaneously. Therefore, we investigated the effects of the various treatments applied in this study (gypsum poultry compost, and the various cover crops) on several quality parameters (physical and biological) - bulk density, aggregate stability, active organic matter, nematode population and microbial biomass.

MATERIALS AND METHODS

Site description and experimental design are explained in chapter two (p. 22). Description of treatments and plot layout are given in the materials and methods of chapter two (p. 23).

Soil Measurements

Active organic matter: a simple soil quality test

Soil samples for organic matter determination were sub-samples from soils used for nutrient analysis. Soils samples from a depth of; 0-10 cm (0-4") taken with a 3 cm diameter soil probe, in the fall of 2007 after sweet corn harvest. Six cores were taken from each gypsum treatment, giving four samples for each sub-subplot with either compost or no compost. Soil samples were air dried and ground to pass a 2.0 mm mesh. Samples were sent to the Agricultural Research and Development Center at Ohio State University for soil quality analyses. Active organic matter (AOM) was used as a measure of soil quality with the "Simple Soil Quality Test" developed by Dr. Rafiq Islam of Ohio State University. The method employed the use of potassium permanganate (KMnO4) which preferentially oxidizes the active fraction of soil organic matter. The soil quality is based on the degree of color loss from the purple solution which can be determined on a pre-established index. As the soil quality improves, the purple color decreases. This method is used to determine both the AOM and available nitrogen in the soil (Islam and Sandermeirer, 2003; Weil et al., 2003; Islam, 2008).

The test is based on the premise that active soil organic matter (SOM) is the most important component of, and most widely accepted soil quality indicator. Soil (OM) has no definite chemical composition; therefore, soil organic carbon (SOC) which is the dominant component of SOM is more commonly measured (Weil et al., 2003). Air dried soil (5 g) was shaken for about 2 minutes in 20.0 ml KMnO4 solution (0.2M KMnO4 in 1M calcium chloride, $CaCl_2$, adjusted to pH to 7.2) with 2.0 ml of 0.1M sodium hydroxide. The $CaCl_2$ serves to stimulate soil flocculation and settling to speed the clearing of the supernatant. The mixture was allowed to settle for 10 minutes. An aliquot (1.0 ml) of the supernatant was transferred to in a test tube and placed in a Hach, single parameter, portable colorimeter (550 wavelength) to obtain the absorbance reading. This wave length was adopted because it always "resulted in the lowest slope and highest regression coefficient (Weil et al., 2003)." The absorbance reading was used to estimate soil quality (Tabhe 4.1); both active organic matter (AOM) and the soil available N (Table 4.2b). These values can checked against the color chart developed for the quick field test for soil quality (Tables 4.3a and 4.3b). The lighter the color of the supernatant, the greater the active organic matter content of the soil, and the better the soil quality.

Bulk density and aggregate stability

Soils were sampled with a coring tube (cylinder) driven in the soil with a drop hammer, as described by Blake and Hartge, 1986. The coring tube was 7.6 cm diameter (3.0") x 7.6cm high (3.0"); a total volume of 344.6 cm^3. Care was taken to avoid compressing the soil in the cylinder to preserve the structure. Soil samples were taken in the fall of 2005 from no-cover crop plots, and in the spring (2006 and 2007) from all cover crop plots (including no-cover), prior to planting of cover crops and corn on all plots. Weights of soil samples were recorded prior to and after drying. Weights were taken about three times, until weights became stable, then bulk densities were calculated. Units are presented in g/cm^3.

$$\textit{Bulk density } (\rho_b) = \textit{Wt soil}_{(g)} / \textit{Total volume}_{(\mathrm{cm3})}$$

Aggregate stability measurements were made from soil cores used for bulk density measurements. Soil samples were remoistened with a low pressure mist of deionized water, gently crumbled and air dried. Each sample was sieved into six size fractions (<1, 1–2, 2–4, 4–6.3, 6.3–9.5, and >9.5 mm), using stacked sieves and a catch pan. The samples were shaken for1 minute with a Tyler Coarse Sieve mechanical shaker (Mentor, OH) and stored at room temperature in tightly sealed plastic containers. The 6.3 to 9.5 mm fraction size aggregates were used to determine water-stabled aggregation using a portable rainfall simulator designed at Cornell University (Ogden et al., 1997; van Es et al., 1991; Moebius et al., 2007). The apparatus was set up as described by Moebius et al., 2007 (Figure 4.2). The rainfall simulator was hanged above the sieve stand, and filled with deionized water up to 43 cm. Single layers of aggregates (30 g sample) were spread on a 4-mm mesh sieve placed 0.5 m below the 0.25m diameter rainfall simulator and calibrated to deliver 1.0 J of energy over a 300 –s (5 min) period to each sample (set of aggregates). An automatic shut-up valve allowed the water to stop flowing after 5 minutes. The rainfall simulator was refilled after every 300-s to maintain the flow rate which is a function of the hydraulic head. This calculation was based on the flow rate, which was 0.6 kg (605 ml) for 300-s (5 min).

$$KE = \frac{1}{2}\, mv^2, \text{ where } V = \sqrt{2gh}$$

$$KE = \frac{1}{2}\ (0.6 \text{ kg x } 3.1\text{m/s})$$

$$KE = 0.6 \text{ x } 3.1/2 = 0.93 \sim 1.0 \text{ J}$$

For each sample processed, the slaked soil material which fell through the sieve was collected in a pre-weighed 1000 ml beaker, dried and weighed. Stones and other solid materials were also weighed and the water stabled aggregate (WSA) fraction was calculated from the equation below. The respective variables, W_{total}, W_{stable}, W_{slaked}, and W_{stones}, are the dry weights of the total aggregates tested, the stabled aggregates that remained on the sieve, aggregates slaked through the sieve and the stones (Moebius et al., 2007).

$$WSA = W_{stable} / W_{total}, \text{ where}$$

$$W_{stable} = W_{total} - (W_{slaked} + W_{stones})$$

Microbial biomass

For microbial biomass determination, soil sampling was done in the fall of 2006 and spring and fall of 2007. The cover crop treatments selected for microbial biomass measurements were cereal rye/ wheat, mustard and no-cover crop. Soils were sampled at two depths; 0-10 cm (0-4") and 10-20 cm (4-8") with a 3 cm diameter soil probe, and stored in 15°C. Ten cores were taken from each gypsum treatment, giving four samples for each sub-subplot with either compost or no compost (Figure 4.2). The chloroform-fumigation–incubation method described by Parkinson and Paul, 1982; Horwath and Paul, 1994 was employed. The soil samples were passed through a 6.35mm sieve to remove roots and stones. Two replicated sets (one for fumigation, one control set) of 40 g soil from each treatment and depth were weighed into a 50 ml beaker. Each replicated set was placed in a large vacuum desiccator lined with moist tissue paper to protect samples from drying. A few zeolites granules were placed in a 100 ml beaker with 50-ml alcohol-free chloroform ($CHCl_3$) placed in a desiccator for fumigation. Samples were evacuated four times until $CHCl_3$ boiled vigorously, allowing 2 minutes for the last boiling. The valves on the desicators with fumigated samples and controls were closed and desicators kept in darkness for 18-24 at 25°Ch. The moist paper and $CHCl_3$ were removed and the desicator evacuated 8 times for three minutes allowing air to circulate through after each evacuation. This allowed for removal of residual $CHCL_3$ from the soil samples. Each fumigated sample was inoculated with approximately 1 g of its corresponding unfumigated sample and thoroughly mixed. All samples, (fumigated and unfumigated) were adjusted to 55% of the soil's water holding capacity then placed in a 1-L air-tight sealed mason jar lined with moist paper and incubated for 10 days in darkness. A septum was inserted in the cover of each mason jar to accommodate the extraction of CO_2. After the incubation period CO_2 measurements were made using an Infrared Gas Analyzer (Analytical Development Co Ltd, Series 225, Mk3).

This process is based on the premise that the respiration rate of the soil prior to fumigation is greater than the rate immediately after fumigation, and that a temporary flush of CO_2 occurs after the fumigant is removed. The flush of CO_2 is largely the result of the decomposition of microbial cells killed by the fumigation process. Hence it has been proposed that a measure of the CO_2 evolved is the approximate size of the soil microbial biomass (Parkinson and Paul, 1982). After the incubation period measurements of CO_2 evolved were measured using a CO_2 infrared gas analyzer. The micorbial biomass of each sample calculated using the following:

Total microbial biomass $B = F/K$, where $K = 0.41$, where

$$B = \frac{CO_2\text{-C evolved from fumigated soil - } CO_2\text{-C evolved from non-fumigated soils } (F)}{\text{Fraction of biomass C mineralized to } CO_2 \text{ over 10-day incubation period } (K)}$$

Nematode population

Soil sampling was done in the spring and fall of 2007. The cover crop treatments selected were red clover, mustard and no-cover crop. Ten cores were taken from each gypsum treatment, giving two samples for each sub-subplot with either compost or no compost (Figure 4.1). Soils were sampled at approximately 20.0 cm depth (8") with a 3 cm diameter soil probe, and stored at 15°C. The nematode extraction and counting was done by the Michigan State University (MSU) Nematology Laboratory using the centrifugal-flotation technique (Jenkins, 1964). Nematodes were identified at 40 to 60x magnification and the number of nematodes was expressed per 100 cm^3 soil basis. The nematode population reported in this study were for two plant parasitic nematodes; the lesion (*Tylenchorhynchus* sp), lesion (*Pratylenchus* sp), and bacterial feeders which are beneficial nematodes. The stunt nematodes are ecto-parasites while the lesions nematodes are endo-parasites.

RESULTS AND DISCUSSION

Active organic matter Tests

Soil samples for active organic matter (AOM) determination were from soils collected after corn harvest in the fall of 2007. ANOVA and means for treatment effects are presented in tables 4.1 and 4.2. Significantly different effects for active organic matter were found only from compost treatments ($P < 0.01$). Compost application resulted in a fair rating for soil quality compared to poor soil quality when no compost was applied (Tables 4.2). These ratings correspond with low (> 0.25 – 0.50) and extremely low (> 0 – 0.25) absorbance readings respectively, from the color chart (Tables 4.3a and 4.3b). For soils rated with a poor quality, the AOM range is 0- 448kg/ha-1 (>0 - 400 lbs/a); for soils rated fair the range is 488gk/ha^{-1} – 896 kg/ha^{-1} (>400 - 800 lbs/a). Neither gypsum nor previous cover crop affected AOM. According to Islam, this method of evaluating soil quality is not only inexpensive but also simple and requires little time to measure. Because soil organic matter is widely accepted as the most sensitive indicator of soil quality, measuring the active fraction of organic matter gives early indication of the soil's response to management practices which impacts soil quality (Álvaro-Fuentes et al., 2008; Islam, 2008; Franzluebbers et al., 2000; Wander and Bollero, 2000). Among the various treatment applied in this study, compost had the biggest influence on corn yield and all quality components measured, on bulk density, WSA and extractable and Ca and Mg.

Bulk density effects

For soils sampled in 2005 (no cover crop plots), there were no significantly different effects when either compost ($P > 0.9$) or gypsum ($P > 0.4$) was applied. ANOVA and the table of means are presented in Tables 4.4 and 4.5; Figure 4.3. The bulk densities for soils from both compost and gypsum treated plots were 1.50 g/cm^3 with or without treatments. Effects found to be significant in 2006 and 2007 were cover crops and compost (Table 4.4). In 2006, compost application ($P \leq 0.01$) resulted in a lower (4%) bulk density (1.40 g/cm^3) than non compost plots (1.46 g/cm^3), and a 7 % decrease compared to compost treatment in 2005. In 2007 bulk density from compost treated plots was 3.5 % lower (1.43 g/cm^3) than non compost plots (1.48 g/cm^3). Other studies have shown improved bulk densities from compost application. Johnson et al., (2006) reported 5.6% lower bulk density from composted dairy manure, compared with the control within one year. Spargo et al., (2006) also found significant improvement from both composted and non composted poultry litter applied to silt-loam soils. As much as 19.7% and 16.7 % reduction in bulk density was observed from application of town-waste compost to loamy and clay soil respectively (Aggelides and Londra, 2000).

Cover crop treatment effects for 2006 were as follows: Mustard (1.46g/cm^3) = oilseed radish (1.44 g/cm^3) $\geq$ red clover (1.42g/cm^3) = cereal rye (1.42g/cm^3) = no-cover (1.41g/cm^3). The bulk density of soils from mustard plots was 4 % greater than soils from no-cover crop plots. There was no difference in bulk density among red clover, cereal rye and no-cover crop plots (Table 4.5; Figure 4.4a). This result seems to suggest that mustard negatively affects soil bulk density. Cover crop effects for 2007 showed significant differences in bulk densities in soils from both early and late planted cover crops. Generally, wheat and red clover resulted in lower bulk densities than mustard and oilseed radish. The effects from early planted cover crops were as follows: Mustard (1.52 g/cm^3) = oilseed radish (1.48 g/cm^3) $\geq$ red clover (1.46g/cm^3). The effects from late cover crops were: oilseed radish (1.47 g/cm^3) = no-cover (1.45 g/cm^3) = mustard (1.43g/cm^3) > wheat (1.42g/cm^3) > red clover (1.41 g/cm^3). The bulk density of soils from late planted mustard and red clover plots were 6% and 4 % lower than these early planted cover crops respectively, but their bulk densities were not significantly different from soils in no-cover plots (Table 4.5; Figure 4.4b). A possible contributing factor to the higher bulk densities of mustard and oilseed radish, which is consistent for both years, is that *brassica* cover crops do not form mycorrhizae. Possibly, as a result soil aggregation was negatively influenced and consequently, bulk density increased. Various researchers (Ryan et al., 2001; Wright et al., 2001, and Fraser et al., 2005) have documented significantly higher levels of mycorrhizal colonization and crop yield after, or in combination with AM forming plants, compared to *Brassica* plants. Bulk densities of soils from red clover and wheat were also generally lower than mustard and oilseed radish, but not significantly. During the growing periods, large amounts of organic materials are exuded from roots of cover crops plants (Goodfriend et al., 2000). The roots of winter cover crops remain active during the winter and continue growth in spring, as opposed to cover crops that are winter killed such as mustard and oilseed radish. There was no difference in soil bulk densities between early or late planted oilseed radish plots.

Treatment Effects on WSA

In the fall of 2005 aggregate stability samples were taken only from no cover plots with both gypsum and compost treatments. In 2006, and 2007, aggregate stability measurements were done on soil from selected cover crop treatments (mustard, cereal rye/wheat, and no-cover crop), with and without gypsum and compost. There was no significant treatment effect on aggregate stability in 2006 ($P > 0.05$). The effects found to be significant for increased water stable aggregation (fraction size 6.3 to 9.5 mm) in 2007 were compost ($P \leq 0.05$) and cover crops ($P \leq 0.05$). ANOVA and table of means for treatments effects on aggregate stability are presented in Tables 4.6 and 4.7. Compost application increased aggregate stability by 21.5 % compared to non compost treatment. The statistically significant difference observed with cover crops was between early and late planted mustard. There was a 29 % decrease in stabled aggregates when mustard was planted early compared to late planted mustard. The non- AM forming relationship of *brassicas* negatively influences soil aggregation (Ryan et al., 2001, Wright et al., 2001; and Fraser et al., 2005). There was no significant difference in water WSA from soils in late planted mustard, and wheat when compared to no-cover crop plots. Generally, higher percentages of stabled aggregates were found in cover crop plots than no-cover plots although the differences were not statistically significant for either year.

Effects on Microbial Biomass Carbon and nematode population

For microbial biomass determination, soil sampling was done in the fall of 2006 and spring and fall of 2007. The soil samples selected for microbial biomass measurements were from cereal rye/wheat, mustard, no-cover crop and corn plots. Soils were sampled at two depths; 0-10 cm (0-4") and 10-20 cm (4-8"). In the fall of 2006 (Table 4.8 and 4.9), the effects found to be significant for soil microbial biomass (or the CO_2 evolved) were depth ($P \leq 0.05$) and the interaction between crops and depth ($P \leq 0.05$). Microbial biomass was 34% greater at the 0-10 cm (91 mg/kg^{-1}) depth than the 10-20 cm (68 mg/kg^{-1}) depth (Table 4.10). For the crop plus depth interaction (Table 4.11), microbial biomass in the top 10 cm depth of corn plots was 79% (104 mg/kg^{-1}) greater than the 10-20 cm (58 mg/kg^{-1}). Below the 10 cm depth microbial biomass decreased significantly under corn but did not change under mustard within the top 20 cm depth. In the spring and fall of 2007, the only factor with significantly different microbial biomass was depth ($P \leq 0.001$). In the top 10 cm depth of the soil, microbial biomass was 43 % (82 mg/kg^{-1} vs 58 mg/kg^{-1}) and 29% (74 mg/kg^{-1} vs 57 mg/kg^{-1}) greater than the 10-20 cm for spring and fall respectively (Table 10). It was expected that microbial activities would decrease with depth which is consistent with other findings that as organic matter decrease within the subsoil, so does the microbial activities. However, it was also expected that microbial biomass would increase with cover crop treatment when compared to no-cover crop or fallow (Mendes et, al 1999; Upendra et al., 2005), which was not the case here.

Soil sampling for nematode population count was done in the spring and fall of 2007 from red clover, mustard and no-cover crop plots of both compost and gypsum treatments. Samples were taken at the 0-20 cm (8") depth. For both parasitic nematodes stunt, and lesion), the effects found to be significant (Table 4.12) was cover crops ($P=$ 0.001 and ($P<0.0001$). Neither gypsum nor compost significantly influenced nematode population. Although studies have reported antagonism between the lesion nematodes and poultry litter (Kratochvil et al., 2004), this evidence was not observed with this study. Significantly greater numbers of both stunt and lesion nematodes were found in plots of early planted mustard compared to late planted mustard, early and late planted red clover. An increase of 281 % (77 per100 cm^3) and 264% (50 per100 cm^3) in stunt and lesion nematodes were found in mustard plots compared to no-cover (20.2 and 13.0 per100 cm^3) respectively. This may suggest that mustard potentially serve as a host to both stunt and lesion nematodes, and early planting provide an extended energy source encouraging the population to build compared to late planted mustard. There was no difference in the stunt nematode population among no-cover crop, late planted mustard, early and late planted red clover plots. However, the lesion nematode population was significantly lower (45%) in early planted (7 per100 cm^3) than late planted (11 per100 cm^3) red clover plots (Table 4.13). Taylor and Queensberry (1999) reported on documented research findings that red clover is a good host of the lesion nematode. The results suggest that early planting of red clover may potentially suppress the lesion nematode. Only compost significantly influenced bacterial feeders ($P \leq 0.0001$). When compost was applied bacterial feeders increased by 43% (371 cm^3 soil) compared to non compost treatment (258.8). Among the nematodes counted bacterial feeders dominated (Table 4.13), indicating a high bacterial population (Goodfriend et al., 2000). The literature is scarce on the subject of cover crops influence on nematode population.

SUMMARY AND CONCLUSIONS

Active organic matter (AOM) is widely accepted as the most sensitive indicator of soil quality. At the end of the three year study, measurements of AOM from the *simplified soil quality test* showed enhanced soil quality from poor to fair which was influenced by compost application. The first year following the application of the poultry compost a 7 % decrease in bulk density was observed. Neither gypsum nor cover crops affected soil AOM. A 4% and 3.5% decrease in bulk density was observed from compost plots in 2006 and 2007 respectively, compared to non compost treated plots. Generally, cereal rye and wheat resulted in higher percentages of stabled aggregates than mustard and red clover. Mustard negatively influences soil aggregation when planted early. The percentage of stable aggregates increased over time with application of compost which is consistent with the AOM soil test. Although microbial biomass was not significantly (α=0.05) different between compost and non compost treatments numerically, compost treatment showed greater microbial activity, suggesting that compost has the potential to enhance microbial activity in soil. Microbial activity in corn plots was greater within the top 10cm depth and decrease significantly in the 10-20 cm depth, but in mustard plots there was no decrease in microbial activity within the top 20 cm depth. The cover crops planting time influenced the population of both parasitic nematodes, but had no effect on the beneficial nematodes. When compost was applied bacterial feeders were significantly increased. The evidence in this study seem to suggest that mustard increases the population of both stunt and lesion nematodes if planted early in the season and red clover planted early in the season may reduce the lesion nematode population.

Table 4.1. Statistical significance of gypsum and compost on active soil organic matter for fall 2007

Fall 2007

	Active carbon	
Sources	F-value	P-value
Gypsum	6.5	ns
Compost	125.3	**
Gypsum*compost	1.3	ns

** $P \leq 0.01$; ns Not significant at α=0.05

Table 4.2. Effects from gypsum and compost on active soil organic matter (fall 2007).

	Fall 2007	
Sources	Active SOM	Soil quality rating
	---mg/kg---	
Compost	658a	Fair
No compost	567b	Poor
Gypsum	636a	Poor
No gypsum	585a	Poor

Mean within columns and groups followed by the same letters are not significantly different at α= 0.05.

Table 4.3a. Soil quality field chart

Extremely low	Low	Low	High
Poor	Fair	Good	Excellent
>0 – 0.25	>0.25 – 0.50	>0.50 – 0.75	>0.75 - 1.0
Soil quality index scale			

Table 4.3b. Soil quality, active organic matter (AOM), and available N color chart

Poor Soil quality	Medium soil quality	Good soil quality	Excellent soil quality
> 0 to 400 AOM lbs/A	> 400 to 800 AOM lbs/A	> 800 to 1600 AOM lbs/A	> 1600 AOM lbs/A
> 0–12 lbs Available N/A	> 12–26 lbs Available N/A	> 26–40 lbs Available N/A	> 40 lbs Available N/A

Tables above show color comparison of $KMnO_4$ solution after shaking with soil

Table 4.4. Significant effects of gypsum, compost and cover crops on bulk density

	Bulk density					
	2005		2006		2007	
Sources	F-value	P-value	F-value	P-value	F-value	P-value
Gypsum	0.89	ns	0.54	ns	0.09	ns
Compost	0.00	ns	27.50	**	18.92	**
Gyp*comp	0.38	ns	0.03	ns	0.00	ns
Cover	-	-	2.45	*	3.73	**
Gyp*cover	-	-	0.37	ns	0.45	ns
Cover*comp	-	-	1.81	ns	0.75	ns
Gyp*cover*comp	-	-	0.45	ns	0.46	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05
Abbrev: Gyp = gypsum; comp = compost

Table 4.5. Effects from compost, gypsum and cover crop on mean bulk density

	Bulk density			
	2005	2006	2007	
Sources			Early	Late
		-------------g/cm^3 -----------		
Mustard	-	1.46a	1.52a	1.43bc
Oilseed radish	-	1.44ab	1.48ab	1.47b
Red clover	-	1.42b	1.46b	1.41c
cereal/wheat	-	1.42b	N/A	1.42c
No cover	-	1.41b	1.45bc	
Compost	1.50a	1.40b	1.43b	
No compost	1.50a	1.46a	1.48a	
Gypsum	1.50a	1.42a	1.46a	
No gypsum	1.50a	1.43a	1.45a	

Mean within columns and groups followed by the same letters are not significantly different at α= 0.05 (2005 and 2006), and mean within group (early and late) followed by the same letters are not significantly different at α= 0.05 (2007)

Table 4.6. Statistical significance of gypsum, compost, depth and cover crops on soil WSA determined by the rain simulator method (2005-2007)

Sources	Fall 2005		Spring 2006		Spring 2007	
	Aggregate Stability					
	F-value	P-value	F-value	P-Value	F-value	P-value
Gypsum	0.00	ns	0.29	ns	2.11	ns
Compost	1.22	ns	2.76	ns	9.26	*
Gyp*comp	0.97	ns	0.46	ns	0.27	ns
Cover	-	-	2.21	ns	3.31	*
Gyp*cover	-	-	1.37	ns	0.74	ns
Comp*cover	-	-	0.02	ns	0.56	ns
Gyp*comp*cover	-	-	0.34	ns	1.27	ns

* $P \leq 0.05$
** $P < 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05

Table 4.7. Effects from gypsum compost depth and cover crops on mean WSA determined by the rain simulator method (2005-2007)

Sources	Fall 2005	Spring 2006	Spring 2007
	Aggregate Stability		
	----------------------%----------------------		
Mustard	-	27a	
Early	-	-	31b
Late	-	-	40a
Rye/wheat	-	34a	42a
No Cover	-	27a	38a
Compost	24a	32a	42a
No compost	24a	27a	34b
Gypsum	27a	30a	35a
No gypsum	27a	30a	40a

Means within the same column and groups followed by the same letters are not significantly different at α=0.05

Table 4.8. Statistical significance of gypsum, compost, depth, cover crops, and corn on soil microbial biomass (MB) for fall 2006.

Fall 2006		
	Microbial Biomass	
Sources	F-value	P-value
Gypsum	0.50	ns
Compost	3.50	ns
Gyp*comp	0.71	ns
Crops	0.02	ns
Gypsm*crops	0.82	ns
Comp*crops	0.11	ns
Gyp*comp*crops	0.14	ns
Depth	7.70	*
Gypsum*depth	0.59	ns
Comp*depth	0.00	ns
Gyp*Comp*depth	0.56	ns
crops *depth	6.27	*
Gyp* crops *depth	1.06	ns
Comp* crops *depth	0.89	ns
Gyp*comp* crops *depth	0.30	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns Not significant at α=0.05

Abbrev: Gyp = gypsum; comp = compost

Table 4.9. Statistical significance of gypsum, compost, depth, corn and cover crops effects on microbial biomass.

	2007	
	Microbial Biomass	
Sources	F-value	P-Value
Spring		
Gypsum	0.29	ns
Compost	3.28	ns
Gyp*comp	0.06	ns
Cover	1.56	ns
Gyp*cover	0.18	ns
Comp*cover	0.89	ns
Gyp*comp*cover	0.30	ns
Depth	60.38	***
Gypsum*depth	0.88	ns
Comp*depth	2 13	ns
Gyp*Comp*depth	0.04	ns
Cover*depth	0.37	ns
Gyp*crops*depth	0.30	ns
Comp*cover*depth	0.22	ns
Gyp*comp*crops*depth	1.26	ns
Fall		
Gypsum	1.24	ns
Comp	0.37	ns
Gypsum*comp	0.55	ns
Depth	42.99	***
Gypsum*depth	0.03	ns
Comp*depth	0.04	ns
Gyp*Comp*depth	0.52	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$; ns Not significant at α=0.05

Abbrev: Gyp = gypsum; comp = compost

Table 4.10. Effects from gypsum, compost, depth, cover crops and corn on mean microbial biomass (fall 2006)

Sources	Microbial biomass Fall 2006	Spring 2007	Fall 2007
	------------------------mg/kg^{-1}	-------------------------	
Corn	82a	-	-
Cover Crops			
Mustard	79a	-	-
Early	-	64a	-
Late	-	71a	-
Wheat	-	72a	-
No cover		72a	-
Compost	89a	69a	68a
No compost	71a	71a	64a
Gypsum	76a	62a	70a
No gypsum	84a	66a	62a
Depth 0-10 cm	91a	82a	74a
Depth 10-20 cm	68b	58b	57b

Means within the same column and groups followed by the same letters are not significantly different at α=0.05

Table 4.11 Effects from interactions of corn and mustard plus depths on mean microbial biomass; fall 2006

Crops *depth	Microbial Biomass Corn	Mustard
	-------mg/kg^{-1}	--------
0-10 cm	104a	80ab
10-20 cm	58b	78ab
Stdr	7	12

Means within the same column followed by the same letters are not Significantly different at α=0.05

Table 4.12. Statistical significance of gypsum, compost and cover crops effects on nematode population

	Nematode population					
	Stunt		Lesion		Bacterial feeders	
	F-value	P-value	F-value	P-value	F-value	P-value
Spring 2007						
Gypsum	1.86	ns	0.30	ns	1.71	ns
Compost	2.60	ns	2.46	ns	5.87	*
Gyp*comp	1.83	ns	0.89	ns	0.33	ns
Cover	6.11	***	12.98	***	0.88	ns
Gyp*cover	0.25	ns	1.50	ns	0.35	ns
Comp*cover	2.05	ns	0.13	ns	0.49	ns
Gyp*comp*cover	0.72	ns	0.42	ns	0.78	ns
Fall 07						
Gypsum	0.01	ns	0.75	ns	0.18	ns
Compost	0.01	ns	4.62	ns	0.03	ns
Gyp*comp	1.58	ns	0.08	ns	2.03	ns

* $P \leq 0.05$
** $P \leq 0.01$
*** $P \leq 0.001$
ns No significant at α=0.05

Abbrev: Gyp = gypsum; comp = compost

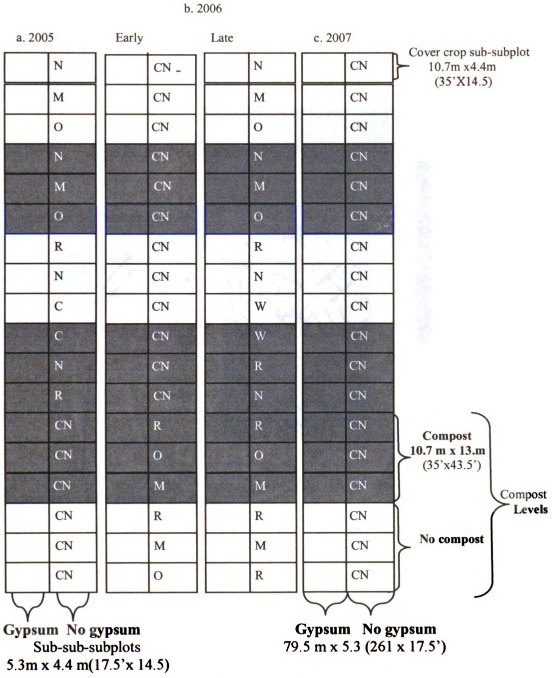
Table 4.12. Effects from gypsum, compost and cover crops on nematode community (Measures on a 100 cm ^{3} soil basis)

	2007					
	Nematodes					
	Stunt†		Lesion†		Bacterial Feeders‡	
Sources	Spring	Fall	Spring	Fall	Spring	Fall
	----------------------100cm^3 (soil)--------------------					
Mustard						
Early	77a	-	50a		299a	-
Late	11b	-	22b		337a	-
Red clover						
Early	21b	-	7c		257a	-
Late	33b	-	11b		388a	-
No cover	20b	-	13b		293a	-
Compost	25a	32a	25a	27a	371a	275a
No compost	40a	32a	17a	18a	259b	284a
Gypsum	26a	32a	23a	24a	285a	269a
No gypsum	39a	33a	19a	21a	345a	290a

Means within the same columns and groups followed by the same letters are not significantly different at α=0.05

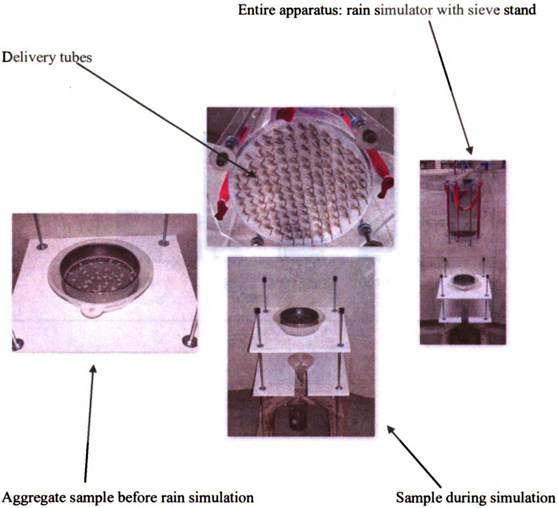
†Plant parasitic nematodes
‡Beneficial nematodes

Figure 4.1. . Representation of a typical block of the experiment design.



Abbrev.: N= No cover; C= Cereal rye; W= Wheat; R= Red clover; O= Oilseed radish; M=Mustard; CN= Corn

Figure 4.2. Rain simulator



Images in this dissertation are presented in color

Figure 4.3. Effect of compost on bulk density, 2005 - 2007

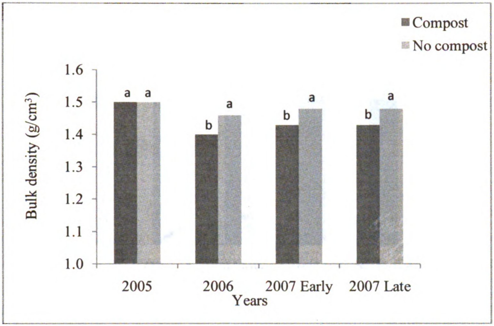


Figure 4.4. Effect of cover crops on bulk density, 2006 and 2007

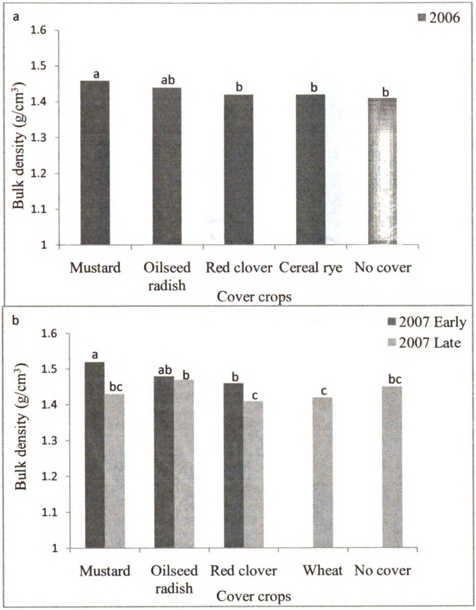


Figure 4.5. Effect of compost on water stable aggregates (WSA) 2005 -2007,

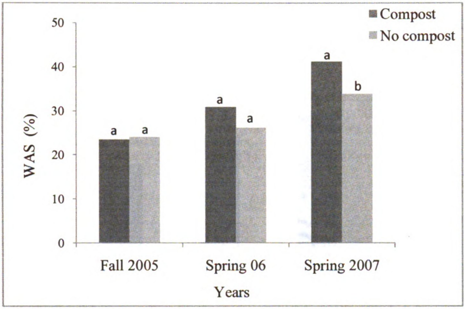
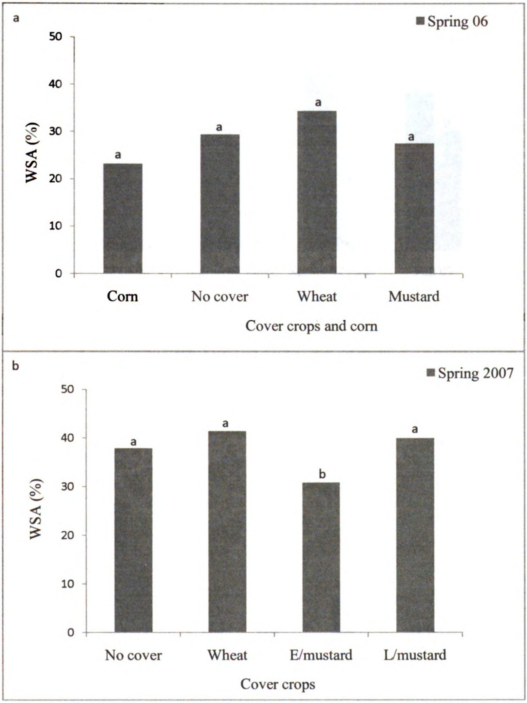


Figure 4.6. Effect of corn and cover crops on water stable aggregates (WSA)



Abbrev.: E = Early planted cover crops; L = Late planted cover crops

Figure 4.7. Microbial biomass with reference to soil depth, 2006 and 2007.

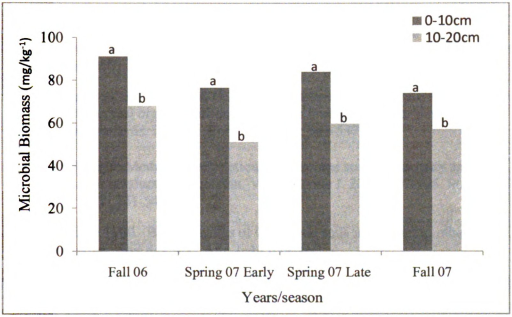
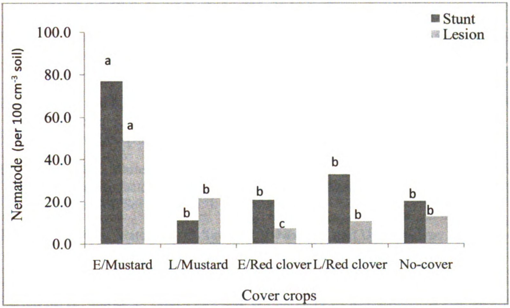


Figure 4.8. Effect of cover crops on nematode population, 2006 and 2007.



Abbrev.: E = Early planted cover crops; L = Late planted cover crops

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GENERAL CONCLUSIONS AND RECOMMENDATIONS

It is apparent that gypsum impacts different soils in different ways. This research provided critical information for gypsum effects on a Kalamazoo sandy loam. When gypsum was applied ($2.24 Mg/h^{-1}$) applied Ca was four times that applied through compost ($2.24 Mg/h^{-1}$), yet extractable Ca from gypsum treated plots was not different from non-gypsum plots for all years. Generally, gypsum did not increase the soil extractable Ca. Compost increased extractable Ca by up to 38% within the top 20 cm depth compared to control plot. Therefore, in a Kalamazoo sandy loam, gypsum application is not recommended if the intended benefit is to increase Ca. Additionally, according to Warncke, (2003), soil test levels at and above 35 ppm and 350 ppm for Mg and Ca respectively are adequate for optimum production on sandy textured soils.

This study showed, that both cover crops and compost, alone or combined, have potential to increase the quality and yield of sweet corn. Sweet corn yield was generally lower when gypsum was applied alone or in combination with cover crops or compost and in some cases, gypsum applied alone and in combination with compost and cover crops had a negative effect on corn growth, yield and/or quality. If increasing yield and improving quality is the intended benefit, gypsum may not be an economical choice for a Kalamazoo sandy loam.

If one desires to improve soil quality, gypsum application is not a good choice of amendments, but compost application showed evidence of reducing bulk density over time. Some of the cover crops show potential to reduce bulk density and increase aggregate stability over time especially if planted later in the season. A mustard (late) cover crop reduced WSA and seemed to be a good host for both the stunt and lesion nematode, especially when planted early. The latter observation contradicts the common view and documented research that *Brassica* cover crops suppress nematode population.

Further research to study the benefit of gypsum across Michigan is recommended, since farmers have interest in its use. Such studies can be developed collaboratively with other research institution across the north central regions due to the growing interest in gypsum in these regions also. Secondly, building on this study (long term) would be a good way forward especially to investigate the status of the Ca as affected by gypsum application. Where did all that Ca go? In this study, soil samples were taken within the top 20 cm depths and only one rate of gypsum was used. Sampling lower depths and applying more than one rate of gypsum would give a better understanding of the gypsum effects. Thirdly, I would also recommend complete designs that would accommodate all cover crops in each block and for each season. This would allow for a better assessment of cover crops effects on the following cash crops. Finally, a good addition to this study would be to investigate the effect of the various treatments on glomalin. Several reports on glomalin indicate a positive relationship with increases in soil gomalin and improved soil quality, especially as it relates to soil aggregate formation. Studies have also linked low glomalin levels and corresponding poor soil quality with *Brassicas*.