BUILDING SOIL FERTILITY USING SOIL AMENDMENTS

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ABSTRACT OF THE THESIS

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Soil amendments are organic and inorganic materials added to soil to improve it quality and chemistry for plants growth. Slag amendment is a material rich in silicon produced from manufactured steel. Effective utilization of organic amendments and slag builds soil fertility, improves plants resistance against disease, and it is important for sustainable agriculture. Greenhouse studies conducted at Rutgers University Vegetable Research Farm in East Brunswick, New Jersey from January 2013 to January 2014, compared various soil amendments for: (i) their ability to supply silicon for plants uptake, (ii) ability to suppress powdery mildew disease in pumpkin, and (iii) ability to neutralize soil acidity and raise soil pH. Sassafras siliceous, mesic, typical Hapludult sandy loam soil initial pH 5.1 was used to fill 2 gallon pots planted to pumpkin (Cucurbita pepo.). The soil was not amended for the control but amended with different types of soil amendments as liming materials. The amendments compared included agricultural limestone (calcite & dolomite), Calcium Magnesium Silicate (Agrowsil from Harsco Minerals), Calcium

Silicate (Wollastonite from R.T. Vanderbilt), Montana Grow, Glacier Rock Flour, Wood ash, Compost, and Cereal Rye/ Hairy Vetch cover crop. At the conclusion of the greenhouse experiment, some soil amendments were effective as liming materials and others had little effect on soil chemical properties. Calcite and dolomite, common agricultural liming materials increased soil pH by one fold than unamended and exchangeable Ca and Mg. Of the various non-carbonate amendments, CaMgSilicate (Agrowsil), Calcium Silicate (Wollastonite), and wood ash significantly increased soil pH similar to calcite and dolomite.

CaMgSilicate and calcium silicate amendments increased Soil test extractable Si levels by tenfold over unamended soil, calcite and dolomite. Si concentration in rye tissue was higher in CaMgSilicate plots (3.7 g/kg) than limestone plots (2.7 g/kg). Silicon level in pumpkin tissue was higher in calcium silicate (6575 mg kg^{-1}) than CaMgSilicate (4000 mg kg^{-1}). Calcium silicate delayed the onset of powdery mildew disease by 20 fold more than all amendments. The study found that calcium silicate and wood ash could be a useful alternative for limestone and calcium silicate may help protect pumpkin crops against disease.

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CHAPTER 1: Introduction and Literature Review of Soil Amendments

Liberia is within the tropical rain forest zone of sub-Saharan Africa. Liberia is about 43,000 square miles constitutes about 43 percent of the Guinea rain forest (Larbi, 2012). In Liberia, it rains nearly all year around. As a tropical country, the main soil order is oxisols (USDA Soil Classification). Oxisols, also known as latosols, are the most highly weathered soil order under the USDA soil classification system. Thus, many soils of Liberia are strongly acid, and deficient in many nutrients needed for sustainable crop production. As a nation, Liberia has much to gain by finding economic and sustainable ways of building up the fertility of its soils.

The first step in building soil fertility is to identify the extent to which soil acidity and nutrient deficiencies are limiting factors in crop production. According to Van der et al., (1999) "Law of the Minimum" the most severely deficient nutrient is the determining factor limiting crop yield. The most limiting nutrient deficiency can be corrected by adding it to the soil as fertilizer. With that deficiency corrected, the next most deficient nutrient now governs crop yield. Soil testing programs in combination with field and greenhouse research trials can identify these soil fertility-limiting factors. When P, K, Ca, Mg, S, or a micronutrient deficiency is identified, it can be supplied to the soil as fertilizer, compost, or other supplements. With the exception of N, which may be obtained from biological fixation, nutrients typically need to be imported from some outside resource to the soil. Ideally, some local resource material can economically supply the missing nutrient. When a given nutrient is severely limiting, it often must be imported from a distant source. However, once a nutrient has been imported and added to the locally deficient soils, it can be conserved and effectually recycled to minimize the need for further imports of the limiting nutrient.

Soil fertility and optimizing plant food can be an effective approach to preventing or at least suppressing plant disease (Huber, 1980). Adding silicon to soil has been shown effectively to reduce the incidence and severity of powdery mildew disease in several crops, including pumpkin (Elawad & Green, 1979; Epstein, 1994, Heckman, 2012). Silicon is the second abundance element to oxygen in the earth' (Nakata et al., 2008), 28% of the earth's surface (Rodrigues and Datnoff, 2005; Singer and Munns, 2005; Epstein, 1994), however, silicon is not considered an essential element for higher plant (Epstein, 1999; Datnoff et al., 2001; Nakata et al., 2008). Silicon, although not officially regarded as an essential plant nutrient, it is now recognized as a plant beneficial substance (AAPFCO, 2012). For the production of cucurbits, enhanced silicon food has been shown to suppress and delay the onset of powdery mildew disease (Menziesas et al., 1992; Bowen et al., 1992; Heckman et al., 2003). Silicon alleviates manganese and aluminum toxicity (Ma and Takahashi, 1990; Ma et al., 1997; Iwasaki et al., 2002). Furthermore, silicon taken up by plant forms a physical barrier that enhances plant resistance to plant disease (Ma and Yamaji, 2006; Fauteux et al., 2005; Ma, 2004).

Unlike Liberia major food crops grown are rice, cassava and corn and many other crops. Rice is the main staple food crop grown in Liberia. At low pH rice crop may not grow well in Liberia a problem experienced by many farmers contributing to low yield. Additionally, rice is very susceptible to blast fungal disease (Datnoff and Rodrigues, 2005). A study has shown that rice is very responsive to silicon uptake (Marscher, 1995; Datnoff et al., 2001; Takahashi et al., 1990). Onodera (1917) first observed the silicon psychopathologic effect, correlating decreased rice blast disease [causal agent, pyricularia grisea Sacc. = P. oryzae cavara (teleomorph: Magnaporthe grisea (Hebert) Barr)] (Onodera, 1917; Datnoff and Rodrigues, 2005). Silicon uptake in upland rice increases blast incubation time resulting in reduced conidia production and slowing progression of disease development (Seebold et al., 2001). Reductions in disease severity in rice with silicon uptake is not limited to rice blast but includes brown spot [causal agent Cochliobolus mityabeanus (Ito & Kuribayashi in Ito) Drechs. Ex. (anamorph Bipolaris oryzea (Breda de Haan) Shoemarker) (Datnoff et al., 1991). The concentration of silicon in rice vary based on cultivar, however, cultivars that accumulate higher silicon in leaf and stem tissue have shown reduced incidence of blast disease (Rabindra et al., 1981). Silicon uptakes in rice have shown to increased yield (Yoshida, 1981).

The continuous cropping, without crop rotation and returned of harvested nutrients results in depletion of soil fertility. In some instances, there is a need to use commercial fertilizers. However, the recycling crop residues and manures as compost or ash. Minimizes the need to purchase or import fertilizers (Heckman, 2013). Effective reuse of these local nutrient sources also may be more economically sustainable for Liberia.

1.1. Soil Amendments

Optimal production of crops requires a balance of nutrients in the soil. However, soil amendments may vary in content and their ability to supply plant available nutrients.

Selecting the right amendment and applying it in the appropriate number for the soil is necessary for sustainable use of local soil amendments.

Soil amendments may be classed into two general categories: Organic soil amendments and mineral soil amendments. Both types of amendments when applied to the soil supply valuable minerals that support plant and animal life.

Organic amendments tend to be bulky and hold relatively low contents of minerals. Examples include crop residues, manures, shade tree leaves, grass clippings, wood chips, and compost. Typically it is necessary to transport or handle substantial quantities of organic amendments to be able to supply a significant amount of plant available nutrients. Also, for most of the nutrients present in organic amendments require microbial activity and decomposition to become a plant available. This necessary process is referred to a mineralization. Besides the minerals supplied by these organic sources, the organic matter itself is valuable for building and maintaining soil organic matter content. A good level of organic matter is also important for feeding the soil food web and building overall soil health. Effective utilization of local organic amendments supports the law of return principle (Heckman, 2013).

Naturally occurring mineral amendments typical provide concentrations of nutrients such that there is less material to handle and transport. Examples include mined limestone (dolomite or calcite), Calcium Silicate (wollastonite), wood ash, rock phosphate, glacial rock flour, greensand, and others. Slag, although not a naturally occurring substance is a material rich in silicon that is produced in substantial amounts during the production of steel. The nutrients in these materials may be soluble and plant available or they may become only slowing available in the soil after a period of chemical and biological weathering.

Although these amendments are vital in building soil fertility they may sometimes contain levels of heavy metals, such as Pb, As, or Cd, which are of interest with respect to protecting the food chain for soil, plant, and animal health. Elevated levels of heavy metals may post long-term environmental health problems (Muse and Mitchell, 1995).

1.1.1 Wood Ash

Combustion of wood fiber results in a residue of mostly inorganic and some organic residue (Risse, 2013; Huang et al., 1992; Demeyer et al., 2001; Pitman, 2006; Vance, 1996). The nature of the wood fuel strongly influences the composition of wood ash (Arshad et al., 2012). Residues from the paper industry burn to produce different composition of ash than that obtained from bark-burning boilers or tree harvesting residue burns (Naylor and Schmidt, 1989; Campbell, 1990; Muse and Mitchell, 1995). Someshwar (1996) and Hakkila (1989) both showed that this mixed fuel, composed of paper-processing residues and waste wood results in highly variable ash chemistry. Elemental composition varies with the plant tissue included in the wood fuel (Arshad et al., 2012). For example, Hardwood produces more ashes than softwood, and bark and leaves produce more ashes then the inner woody part of the tree (Risse, 2013; Hakkila, 1989; Werkelin et al., 2005). Unlike decomposed remains of leaves, stems and green plants, burned wood ash does not contain nitrogen and sulfur (Darmrosch, 2012). However, it does provide phosphorus, potassium, calcium, boron and other elements taken up by growing plants (Demeyer et al., 2001; Darmrosch, 2012). Calcium and Si are the most abundant elements in bark ash (Werkelin et al., 2005). This composition gives an ash the properties similar to agriculture lime (Risse, 2013; Serup, 1999; Werkelin et al., 2005). A typical fertilizer grade for wood ash may be about 0-1-3 (N P K) (Naylor and Schmidt (1986).

Wood ash from untreated wood contains little elements that may pose environment concern (Risse, 2013). However, ash produced from industrial combustion systems may be subject to temperature combustion, cleanliness of the fuel wood, the collection area, and the process can have an effect on the nature of the ash (Etiegni and Campbell, 1991). Thus, wood ash composition can vary depending on the geographical area and the industrial processes (Risse, 2013; Misra et al., 1992). Studies have also shown that ash from burning trash, cardboard, coal or pressure treated, painted or stained wood may contain harmful substances (Scott, 2010; Martin, 2010). For example, ash containing boron can inhibit plant growth when present at excessive levels (Scott, 2010). A furnace temperature between 500 and 900°C is critical to the retention of nutrients, particularly potassium, and determines the concentrations of potentially toxic metals including aluminum in the ash (Etiegni and Campbell, 1991). Pitman (2005) looked at heavy metal and radionuclide and dioxin contamination of wood ash-based fertilizers and found minimal concentrations that would not likely affect ecosystem function. The effects of wood ash are primarily governed by application rate and soil type (Risse, 2013).

Wood ash is very alkaline and useful for raising soil pH (Darmrosch, 2012). Wood ash use is related to agriculture lime. The small particle size may bring about a more rapid pH change than that produced by agricultural limestone (Lerner, 2000). Furthermore, wood ash adjusts pH and supplies a substantial amount of several plant nutrients especially potassium (Arshad et al., 2012). Wood ash also contains silicon but the availability of this Si for plant uptake is unknown.

According to Risse (2013), Wood ash applied as liming material and fertilizer improves crops increase by decreasing the availability of heavy metals. He further states, “Wood ash provide calcium and magnesium to crops, and improves phosphorus availability." Even though, dolomite and calcite limestone are the most common agricultural liming materials; wood ash has many of the same beneficial effects. Wood ash use may replace many of the macro and micronutrients removed during plant growth and harvesting (Risse, 2013). Another benefit of wood ash is to supply calcium required by crops. Potassium, a nutrient quickly depleted by crops uptake, is supplied by wood ash, which protects plants from becoming weak and subject to disease (Martin, 2013; Hume, 2006). According to Martin (2013), most vegetable crops prefer a pH range of 6.0-7.5. He further said, “Potato is an exception growing best with soil pH 6.0-6.8 are subject to disease in neutral to alkaline soil." Studies have shown that wood ash as dust on cut potato seed prevents rot when planted (Martin, 2013; Hume, 2006). In addition tender plant such as basil, are subject to damage by cutworms, wood ash in planting soil deters this pest as well as slugs (Martin, 2013). Studies have shown that wood ash can be used to add nutrients to the compost when mix while building the pile (Scott, 2012).

Other studies have shown that wood ash sprinkled on lawns help grass and foster growth of clover. In addition, wood ash when applied as an ash tea on tomato may boost tomatoes fruiting (Damrosch, 2012). Other plants that may benefit from wood ash amendment include strawberries, plums, pears, and crabapples (Martin, 2013; Lerner, 2000). Exception to wood ash application benefits is acid loving plants such as rhododendrons, camellias, azaleas, junipers and conifers (Scott, 2010; Lerner, 2000; Hume, 2006). Decreased acidity and increased base cation saturation following use of loose wood ash have been frequently reported (Åbyhammar et al., 1994, Khanna et al. 1994; Bramryd and Fransman, 1995; Kahl et al., 1996; Rühling, 1996; Eriksson, 1998). Wood ash may also increase microbial activity in soil (Martikainen et al., 1994, Fritze et al., 1994, 1995).

Huang et al., (1992) reported that wood ash has a liming effect of between 8 and 90 percent of the total neutralizing power of calcium carbonate limestone and can increase plant growth up to 45 percent over traditional limestone. Some studies have reported detrimental effects from wood ash at extremely high application rates. These responses are explained by the drastic increase in soil pH that are beyond the plant optimal level and possible excess soluble salts. As long as soil pH is, maintain at the proper level, productivity will be enhanced by using wood ash as liming soil amendment (Risse, 2013).

1.1.2. Steel Mill Slag

Slag is a by-product of the process of steel production. Slag is essentially a group of compounds removed during the smelting process (Virgel et al., 1999). It can be a good source of plant available Si, Ca, and Mg, but it may also include other impurities such as metal oxides (Lisanti et al., 1976; Park, 2001). Some slags are further processed to remove impurities. Silicate-based slags are variable in composition and fineness. Finely ground, slag may be used as an alternative liming material (Park, 2001). However, before slags are used as soil amendments they must be analyzed for the presence of potentially hazardous material such as heavy metals.

1.1.3. Calcium Silicate (Wollastonite)

Wollastonite is named after the chemist and mineralogist William Hyde Wollaston (1766-1828). It is a calcium silicate mineral that may also contain small amounts of other elements, such as Mg, Fe, or Mn, substituting for Ca. Pure wollastonite is white. The mineral is mined from naturally occurring deposits in many countries around the world. In the USA, it is mined in from deposits in Upstate New York. Wollastonite, which is used in the manufacture of ceramics and numerous other products, is less well known as a soil amendment. When applied to the soil, wollastonite can neutralize soil acidity and supply plant available Ca and Si. Wollastonite obtained as a naturally occurring mined product and without any synthetic additives, may have find use in organic farming as an alternative to carbonated liming materials and as a source of Si.

1.1.4. Montana Grow

Montana Grow is a natural silicon fertilizer listed by OMRI for organic use. Montana Grow improves yield, suppress foliage disease and increase drought and salt resistance

(Montana.com).

1.1.5. Glacier Rock Flour

Glacial rock flour (known as glacial rock dust) is a natural mineral source of Si that provides mineral and trace element that improve soil quality and enhance plant growth (naturefootprint.com).

1.1.6. Compost

The complete recycling of all organic waste materials as a means of sustaining soil fertility is referred to as the law of natural return (Heckman, 2012). Plants extract nutrients from the soil during growth and development. Their wastes material may include a substantial amount of nutrients. Recycling wastes as compost, return nutrients to the soil originality.

The plant availability of Silicon from compost amendment soil has not been extensively investigated. When Si becomes crystallized inside plant tissues, as in phytoliths, its solubility tends to be limited. It is not known if the enhanced biological activity of the composting process can serve to increase Silicon availability from plant residues. Composting is a controlled decay of natural organic residues (Brady and Weil, 2008, p. 536). It transforms raw organic waste materials into biologically stable substance called humus (Brady and Weil, 2002, p. 363). According to the US Compost Council Fact sheet, compost is an excellent soil amendment. It further concludes that using compost as a soil amendment helps replenish nutrients in the soil.

Compost is an organic matter source. It can increase the soil chemical and physical properties. Moreover, encourages the biological activities of soil microbes (Brady and Weil, 2002, p. 516). Compost improves water retention in sandy soils. In addition, it promotes soil structure in clay soils by increasing the stability of soil aggregates (Brady and Weil, 2002, p. 516; Plaster, 1992, p. 210).

Adding compost improves the fertility of the soil. Additionally, compost increases the cation exchange capacity of low fertility soils. This enhances, soil water retention, nutrient absorption, and aeration (Brady and Weil, 2002, p. 516). Moreover, compost increases microbial activities and make them more active. Interestingly, the activeness of microorganism help suppresses some soil borne and foliar diseases.

Compost used as a soil amendment can stabilize soil acidity (Brady and Weil, 2002, p.516). On the other hand, materials that are not completely decomposed may be used as mulch. It further states that coarser composts are effective where conventional erosion control is not. In addition, coarse compost may serve as a mild herbicide.

Accordingly, the benefits of compost as a soil amendment is convincing. One can say recycling waste products has sustained and multiples influence soil fertility. In addition, frequent use may reduce the need for inorganic fertilizer (Hackman, 2012).

1.2. Soil Amendments and pH Adjustment

Soil pH is the measure of how acidic or basic a soil is (Brady and Weil, 2008, p. 535). Soil acidity or alkalinity (soil pH) is important because it influences nutrient uptake by plants (Brady and Weil, 2002, pp. 363-64). A soil pH between 0-7 is acidic while the pH range 0f 7-14 is alkaline or basic and pH 7 is neutral (Plaster, 1992, p. 210).

Most nutrient plants are optimally available at soil pH 6.0 to 7.5. Below pH 6.0, nutrients like N, P, and K are less available (Plaster, 1992, p. 210). Above pH 7.5, Fe, Mn and other micro-elements are less available (Brady and Weil, 2002, p.364). However, soil pH is influenced by environmental factors, rainfall, vegetation, and temperature (Havlin et al., 1999, pp. 41- 45). Tropical region with high rainfall promotes soil acidification. Region with low rainfall are associated with a near neutral pH levels while arid regions tend to be alkaline (Brady and Weil, 2002, 364). Studies have shown that most crops grow in slightly acid to neutral pH (6.0-7). Some exceptions are crops such as potatoes, blueberry, and azalea. Tomato does well in moderately acid soil (Risse, 2013).

One way to optimize an acid or alkaline soil conditions is by using soil amendments (Davis and Whiting, 2013). Wood ash, limestone, and slags are examples of amendments used to increase soil pH. Nitrogen fertilizers containing ammonium cause soil acidification.

According to Ohno et al., (1990) wood ash as a soil amendment is an alternative liming agent. The calcium carbonate equivalent of wood ash was reported to be 26-59 percent, indicating its effectiveness as liming material relative to calcite. Risse (2013) also reported that recycling wood ash has a liming effect of between 8-90 percent of the neutralizing powers of limestone and can increase plant growth up to 45 percent over the traditional limestone. Wood ash dissolves more quickly than limestone and raises the soil pH faster (Rise, 2013). However, the spread of wood ash in excessive amounts may increase soil pH above the optimum 6.5-7.0. A pH above the optimum adversely affects plant growth (Risse (2013).

According to Heckman (2012), calcium silicates applied as a liming material has a neutralizing acidity power similar to calcium carbonates. He demonstrated this by applying calcium silicate on an acid soil, and found that pH increased as much as with agricultural limestone. Chichilo (1963) also report that silicon application as liming material has the same effect as limestone. Several laboratory and field experiments have shown that silicon fertilization is more effective than liming for reducing aluminum toxicity (Matichenkov and Calvert, 1999).

Calcite and dolomite are the most common liming material used in soil amendments (Havlin et al., 1999, p. 57). It is used to correct soil acidity. Calcite (calcium carbonate) is a more frequently used than dolomite (calcium magnesium carbonate) (Brady and Weil, 2002, p. 394). However, dolomite is used only when the soil is deficient in magnesium. Studies have shown that limestone slowly raises soil pH and may have a long-term impact on the soil pH (Brady and Weil, 2008, Havlin et al., 1999; Gardiner and Miller, 2008).

1.3. Silicon as a Beneficial Substance

Silicon (Si) is the second most abundance element to oxygen in the earth's crust (Nakata et al., 2008). Silicon forms 28% of the earth's surface (Rodrigues & Datnoff, 2005; Elawad & Green, 1979; Singer & Munns, 2005; Epstein, 1994). Despite the abundance of Si, it is not considered an essential element for higher plants (Datnoff et al., 2001; Nakata et al., 2008). However, its beneficial effects have been reported on a wide variety of crops. Silicon concentrations in plants vary (Elawad & Green, 1979; Epstein, 1994). Studies show that monocots are higher accumulator than dicots (Rodrigues & Datnoff, 2005; Jones & Handreck, 1967; Epstein, 1999; Rodrigues et al., 2001; Nishimura et al., 1989). According to studies, crops such as rice, wheat, sugar cane, cucumber and barley are responsive to silicon, (Marscher, 1995; Datnoff et al., 2001; Takahashi et al., 1990).

More than 60 plant elements are present in soils and are classified as essential, useful or toxic elements (Marschner, 1995). Silicon is classified as a useful element. Essential elements are those required by all plants for growth and development (Brady and Well, 2002, p. 638).

The beneficial effects of Si are characterized by helping plants to overcome various stresses including biotic and abiotic stresses (Epstein, 1999; Richmond and Sussman, 2003; Ma, 2004; Ma and Yamaji, 2006). For example, Si increases the resistance of plants to fungi, insect pests, lodging, and drought stresses (Datnoff et al., 2001). Furthermore, Si alleviates mineral stresses such as Mn toxicity, Al toxicity, and P deficiency (Ma and Takahashi, 1990; Ma et al., 1997; Iwasaki et al., 2002). High deposition of Si in tissues forms a physical barrier that enhances the strength and rigidity of the tissues (Yoshida et al., 1962;

Ma and Yamaji, 2006). Soluble Si played an active role in enhancing host resistance to plant diseases by stimulating some defense response mechanism(s) (Fauteux et al., 2005, Ma, 2005; Laing et al. 2008). According to Epstein, (1999) Si is the only element that in high levels of accumulation does not damage plants.

Silicon fertilizers are available in liquid and solid form and the liquids offer the rapidest response (Virta, 2001; Mamedov and Belov, 1956). Interestingly, Calcium carbonate chemically interacts with the silicon to form calcium silicate (Summer et al., 2006; Maxim et al., 2008, Yu et al., 2010). Silicon is in rock mineral and fertilizers and rock phosphate. However, this is not the plant available form of the mineral. Silicic acid (H4SiO4) is the plants absorbed form in soil solution (Faure, 1991; Langmuir, 1997). Additionally, rice hull ash and wheat straw are good sources of silicon after harvest (Katha et al., 2011) Potassium silicate and sodium silicate are liquid form of silicon. They are used as a foliar supplement in greenhouse and field experiments (Belanger et al., 1995; Kamenidou et al., 2006; Menezies et al., 1992; Rodrigues et al., 2009). Studies have shown that crops such as cucumber, rice, wheat and barley are responsive to Si uptake (Marscher, 1995; Datnoff et al., 2001; Takahashi et al. 1990). Studies have shown Rice (Oryza Sativa) as high silicon accumulator (Ma and Takahashi, 2002; Ma et al. 2005; Ma, 2005; Huang, X. et al., 2012; Sommer, 1926). This accumulation agreed with reduced rice blast disease (Oryzae Cavara: magnaportha grisea (Hebert) (Rodrigues et al., 2003; Datnoff and Rodrigues, 2005; Onodera, 1917). Seebold et al., (2001) reported that calcium silicate use on upland rice reduced conidia growth by a delayed development of fungal blast disease. Si has proved effective against brown spot (Cochliobolus Miyabeanus), stem rot (magnaportha salvinii

Cattaneo), and the sheath blight (Thanatephorus cucumeris) (Rodrigues et al., 2003; Datnoff et al., 2001; Datnoff et al., 1991, Elawad and Green, 1979). Previous studies indicate Si increases resistance of rice to borers (Winslow, 1992). The increase in yield of rice with Si reported (Snyder et al. 1986; Datnoff et al., 1992; Korndorfer et al., 1999). Provance-Bowley et al., (2010) focused her study on how wheat and Kentucky bluegrass responded to Si supplements in New Jersey soil. She found that Si fertilization could be cost efficient and environmentally sound despite research on crop response is limited in temperate region. Silicon treatment of soil used to grow pumpkin plant has shown improved leaf retention, disease resistance and increased yield (Heckman, 2013).

1.4. Limestone as soil amendment

Calcite and dolomite are usually mined from naturally occurring marine deposits. These minerals are commonly used in agriculture as liming materials. Both supply Ca, but dolomite supplies Mg along with Ca (Brady and Weil, p. 394). Limestone vary in composition and purity. Pure calcium carbonate is used as a standard (Calcium carbonate equivalent, CCE) to compare the ability of different liming materials to neutralize soil acidity (Havlin et al. 1999, p. 56). Depending on purity, dolomite liming materials may have a CCE greater than 100% but they are typical less reactive in soil and slower to raise soil pH (Havlin et al., 1999, p. 56). Fineness of limestone influences the rate of response (Havlin et al., 1999, p.57).

Liming acid soils is associated with numerous agronomic benefits. Firstly, limestone application to acid soil raises the pH (Collier, 1984; Havlin et al., 1999, p. 54-55; Brady and Weil, 2002, p. 394). An increase pH decreases the amount of aluminum and other toxic minerals in soil solution. At low pH aluminum and other elements are harmful to plants (Havlin et al., 1999, p. 60; Brady and Weil, 2002, p. 388-390). Secondly, limestone provides calcium or magnesium in the soil that are deficient of such nutrient. For example, sandy soil may have magnesium shortage (Plaster, 1992, p. 210; Brady and Weil, 2002, p. 404-406) and at low pH Phosphorus is insoluble and rarely available to plant (Havlin et al., 1999, p. 175-76). According to agronomists, limestone use as an amendment increases phosphorus availability by raising soil pH (Follett et al., 1981; Risse, 2013). By applying limestone changes the condition. Biological activities are enhanced by raising soil pH (Plaster, 1992, p. 210). At low pH, some microorganism might not function properly (Brady and Weil, 2002, pp. 391-92). For example, nitrogen fixation bacteria may not perform at low pH (Gardiner and Miller, 2008, pp. 149-155). Thus, nitrogen mineralization and nitrification are enhanced.

1.5. Objectives

The objectives of the study are: (i) Evaluate liming materials and soil fertility amendments for acid soils and their impact on soil fertility (ii) Evaluating the effectiveness of silicon amendment as a disease suppressive agent to powdery mildew. And, a parallel objective is to introduce the requisite skills in soil chemistry, soil amendments, plant food into Liberia to increase crop yields.

1.6. Summary

In summary, soil amendments are important in the lives of soils and plants. When recycled into useable forms it has similar benefits as inorganic fertilizers. The use of soil amendments improves soil textures and chemistry while minimizing the impact on the environment. The some soil amendments are more affordable, manageable, and economical for farmers in developing countries while others are expensive.

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Chapter Two: Finding Effective Soil Amendments for Supplying Silicon and Suppressing Powdery Mildew Disease on Pumpkin

2.1 Introduction

Pumpkin (Cucurbita pepo.) is an important crop in New Jersey for roadside markets and “entertainment type farming." However, pumpkin can also be a challenging crop to grow because of the impact of powdery mildew disease. Powdery mildew [Podosphaera (sect. sphaerotheca) xanthii (castagne) U. Braun & N. shishkoff (also known as spaerotheca) Fusca (Fr) S. Blumer and S. Fuliginea (schlechtend.Fr) Pollacci] is an important disease of the cucurbit crops throughout the United States (Zitter et al., 1996). The pathogen may overwinter on crop debris, however, in most years, the pathogen is wind dispersed into northern regions from the Southern States each production season (Zitter et al., 1996). The pathogen typically infects older leaves and stems first causing premature loss of foliage resulting in a reduction, in yield as the size and number of fruit decrease (Mossler and Neshem, 2003; Zitter et al., 1996). There are many ways to calculate disease on affected leaf area of plant. Disease severity, usually defined as % (area) of disease tissue present on affected plant, is another measure, particularly for evaluation of foliar diseases where the amount of disease present on the plant may be correlated to yield loss estimate (Sparks et al., 2008).

On many farms, weekly fungicide applications are used to control this disease. Costs of fungicides, time measuring the disease, equipment, and labor greatly contribute to the cost of production. Furthermore, frequent application of the same fungicide enables disease organisms to develop resistance to the chemical.

Soil fertility and optimizing plant food can be an effective approach to preventing or at least suppressing plant disease (Huber and Datnoff, 2002). Adding silicon to soil has been shown effectively to reduce the incidence and severity of powdery mildew disease in many crops, including pumpkin (Elawad & Green, 1979; Epstein, 1994, Heckman, 2012). Silicon is the second abundance element to oxygen in the earth' (Nakata et al., 2008), 28% of the earth's surface (Rodrigues and Datnoff, 2005; Singer and Munns, 2005; Epstein, 1994), however, silicon is not considered an essential element for higher plant (Epstein, 1999; Datnoff et al., 2001; Nakata et al., 2008). Silicon, though not officially regarded as an essential plant nutrient, it is now recognized as a plant beneficial substance (AAPFCO, 2012). For the production of cucurbits, enhanced silicon food has been shown to suppress and delay the onset of powdery mildew disease (Menziesas et al., 1992; Bowen et al., 1992; Heckman et al., 2003). Studies have shown that silicon alleviate manganese, aluminum toxicity and phosphorous deficiency (Ma and Takahashi, 1990; Ma et al., 1997; Iwasaki et al., 2002). Furthermore, silicon taken up by plant forms a physical barrier that enhances plant resistance to plant disease (Ma and Yamaji, 2006; Fauteux et al., 2005; Ma, 2004; Laing et al., 2008).

The natural form of calcium silicate is wollastonite (Virta, 2001, Maxim and McConnell, 2005; Maim et al., 2008). It Pulverized form is considered the best of Si (Park, 2001). An alternative to wollastonite is calcium silicate slag, by-product of iron and steel manufacturing (Virgel et al., 1999). Montana Grow is a natural silicon fertilizer listed by OMRI for organic use. Montana Grow improves yield, suppress foliage disease and enhance drought and salt resistance (Montana.com).

Glacial rock flour (known as glacial rock dust) is a natural mineral source of Si that provides mineral and trace element that improve soil (naturefootprint.com). In addition, rice and wheat are cereal crops that are responsive to silicon uptake. Rice husk and wheat straw ash are natural waste source of silicon (Kavitha et al., 2011). Although a silicon fertilization typically does not completely prevent the disease, may where soils are amended with silicon, fewer applications of fungicides will be needed. Reduced amounts of spraying, as guided by an integrated pest management program, could increase the profitability of pumpkin production.

To use a soil fertility approach for disease management most efficiently, one need to know which sources are most effective at supplying silicon. Since the study on pumpkin yield and disease response to amending the soil with silicon was conducted, potentially new industrial sources silicon amendment have become available. Also, certain types of naturally occurring waste materials contain silicon and are potential sources in need of investigation.

Wood ash, crop residues, and compost are examples of materials that may supply silicon. Silicon taken up by plants may convert to crystals or phytoliths of very low solubility (Fauteux et al., 2005, Ma, 2004; Laing et al. 2008). Thus, the cycling of silicon through the soil plant environment after having been accumulated in plants may be very slow.

2.2 Objectives

The objectives of the greenhouse study is to: (i) compare different soil amendments as to their ability to supply silicon for uptake by pumpkin plants, (ii) to determine how the amendments change the chemistry and fertility of the soil, (iii) to compare experience of the amendments to neutralize soil acidity and raise soil pH, (v) to compare amendments for the ability to suppress powdery mildew disease, (iv) to evaluate certain natural waste materials as possible sources of plant available silicon, (vi) To assess silicon sources that may be approved for use in certified organic crop production.

2.3 Hypothesis

Use of soil amendments will improve soil fertility, plant nutrition and reduce disease.

2.4 Material and Methods

A rye hairy vetch cover crop was seeded in September 2012 on field plots at the Rutgers Snyder Research and Extension Farm near Pitstown, NJ for the purpose of investigating responses of various crops to silicon. The treatment plots were established in 2000 when they had been amended with equal application rates of agricultural limestone or a commercial silicon fertilizer. Harsco Metals & Minerals manufactures this recycled steel slag by-product. It is primarily composed of silicates of Ca and Mg, which for the purposes of this article will be called CaMgSilicate. Previous research had demonstrated that CaMgSilicate functions like a liming material and supplies plant available Ca, Mg, and Si to the soil with residual benefits to crops lasting many years (Heckman et al., 2003). CaMgSilicate has a Si concentration of 39.3% and its calcium carbonate equivalent (CCE) rating is 93%. Agricultural liming materials, consisting of calcite and dolomite, with near matching CCE ratings were applied to the unamended or control plots to achieve the same soil pH level and approximately the same percent Ca and Mg saturation levels of the soil colloid. A total Si of 8953 kg/ha was applied from periodic applications over the years from 2000 to 2012.

The rye hairy vetch cover crop was harvested with a sickle bar mower 2 inches above the soil surface on 21 May 2013 from 36 sq. ft. sections obtained from the centers of 20 x 30 ft. plots. The experimental design was a randomized complete block with nine replications of the two treatments. The cover crop fresh biomass was weighed in the field. Rye and hairy vetch plants samples were separately collected, dried at 700^0 C for 48 h, ground, and mixed, and a subsample sent to the lab for tissue analysis. A Thomas Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ) was used to grinding the plant samples to pass a 2-mm sieve. The ground rye plant tissue, which contained minimal amounts hairy vetch, was used as a soil amendment in the following greenhouse experiment.

Two greenhouse experiments were conducted using sassafras; sandy loam, siliceous, mesic, typical Hapludult soil which had a history of no chemical fertilizer or pesticide inputs for many decades. Thus, no substances on the prohibited list would prevent this land from being transitioned into certified organic farming. Immediately before soil collection this field at the Rutgers University Vegetable Research Farm in East Brunswick, NJ, the surface 15 cm was tilled using rotary tiller. The collected soil was sieved through a 2mm screen removing stones and plant residues.

The first greenhouse trial was conducted in the spring and resulted in the absence of a powdery mildew inoculum. The expectation was that the disease would be present. It is suspected the disease was absent because there were no inoculums present in the greenhouse. Seven different amendments as listed in (Table 1) were compared to the unamended control. Treatments were replicated four times in a completely randomized design. Before seeding all pots received Perdue AgriRecycle's microSTART60 (3-4-5), an OMRI listed product, at the rate of 40 g/kg of soil. CaMgSiO3 (Agrowsil TM Harsco's calcium and magnesium) silicon-based fertilizer a by-product from stainless steel manufacturer now called (CrossR Over, Harsco 2012), Wollastonite a natural mined calcium magnesium silicate alternative to Agrowsil (Harsco.com) and Montana grow a natural commercial Si fertilizer (Montana.com) all OMRI listed for Organic use. Glacier rock dust a natural mineral product by glacier action provides silicon and trace element to the soil (naturefootprint.com). All of the amendment treatments was mixed into the soil at a rate 90 g/kg of soil. Eight pumpkin seeds of Howden variety – a susceptible cultivar (Wyenandt et al., 2008) were planted on the same day as the fertilizer and liming materials were added to the soil. After seedling emergence, they were thinned to two plants per pot. Pots were watered as necessary, to keep the soil moist. Above ground biomass was obtained by sampling at seventy (70) days after planting for tissue analysis by collecting the plant material above the third node.

All plant samples were dried at 700 C for 48 hours and weighed. The samples were grinded in a Wiley mill to pass a 1-mm sieve. The samples were analyzed for mineral nutrients using inductively coupled plasma (ICP) emission spectroscopy after samples were digested with nitric acid and hydrogen peroxide (Luh Huang and Schulte, 1985). The silicon concentration was determined using the method of Elliott and Snyder (1991). The second greenhouse experiment was conducted using the most of the same methods as used in the first experiment. The treatment list included more amendments as listed in Table 3. Also in this second experiment pumpkin plants growing in plots already infected with powdery mildew were moved into the greenhouse and placed on an adjacent bench. These infected plants were first grown outdoors during the late summer months to capture a natural infection of powdery mildew. Pumpkin was seeded in six liters experimental pots containing 11 kg (22.3 lbs) of soil on Oct. 25, 2013. The few plants that did grow were pulled up and new pumpkin (Howden cultivar) seeds were planted on Nov. 15, 2014. When powdery mildew lesions appeared the number of lesions per the two plants in each pot was counted on 15-21 Dec. 2013 (four days) with two days interval of counting. Once the disease became more severe a visual percentage estimation of leaves that were infected with powdery mildew was determined for 7 days. The area under the disease progress curve (AUDPC) was calculated as the trapezoid method, to discretize the time variable (hours, days, months or years) and calculate the average disease intensity between each pair of adjacent points (Madden et al., 2007).

A composite soil sample representing each treatment was collected by taking a soil core from each pot replicate on 10 Jan 2014. Soil pH was measured using a 1:1 soil volume to water ratio, soil organic matter content was measured by the loss on ignition method (Storer, 1984). The Mehlich-3 soil test method was performed following Recommended Soil Test Procedures for the Northeast (Sims and Wolf, 1995). Bray II test method was used to determined P level. Soil tests for Si were performed using the method of Korndorfer et al. (2001). All extractions were analyzed by ICP.

Experimental data was subjected to analysis using the T test (least significant digits LSD) and REGWQ procedure of SAS (SAS Institute, 1999-2000, Cary, N.C.) to determine differences in yield and treatment, disease severity, and plant tissue analysis. Correlation analysis in Excel was used to examine the relationship between soil tests Si, plant tissue Si and disease or yield measurements.

2.5. Results and Discussion

2.5.1. Cover Crop Biomass

The spring cover crops biomass yields, from limestone and CaMgSilicate amended plots harvested at Rutgers Snyder Farm, were similar on limestone and CaMgSilicate amended plots (Table 1). The biomass consisted of mostly cereal rye and a very small fraction of hairy vetch. Samples of rye plant tissue were found to have concentrations of 2.7 g/kg of Si when collected from the limestone plots and 3.7 g/kg when collected from the CaMgSilicate plots (Table 1). The concentrations of silicon in collected hairy vetch samples were very low and apparently below the detection limit of the laboratory method used to measure the element. Based on the concentrations of silicon in the rye tissue and the biomass one could estimate that about 13 lbs/acre of Si was taken up from the limestone plots and 18 lbs/acre from the CaMgSilicate amended plots. These two different types of rye (Normal Rye versus Si Enriched Rye) were used as soil amendments in the following greenhouse experiment.

2.5.2. Soil Properties

At the conclusion of the greenhouse experiment, or six weeks after the soils were amended, it is apparent that some of the amendments were effective as liming materials and others had little impact on soil chemical properties (Table 5).

Both calcite and dolomite, common agricultural liming materials, behaved as expected and increased soil pH and exchangeable Ca and Mg. Carbonate liming materials react slowly in soil over a period of months or even years depending on particle size (Brady and Weil, 2002, p.394, Havlin et al., 1999, p. 57). Both of these carbonate liming materials increased soil pH to a more desirable range for pumpkin but the dolomite less so than the calcite. As expected, dolomite, which is less soluble (Havlin et al., 1999, p. 59), did not increase soil pH to the same level as calcite within the timeframe of this study.

Of the various non-carbonate amendments, only CaMgSilicate, Calcium (Wollastonite), and wood ash were found to be reasonably effective as alternative liming materials. Wood ash, which contains oxides of base cations, reacts rapidly to neutralize soil acidity and increase soil pH. Compared to all other soil amendments, wood ash achieved the highest soil pH level. Wood ash moderately increased Ca and Mg exchangeable levels and very strongly raised K to a level (12% exchangeable) that may be considered excessive. An exchangeable K level of about 5% is considered an adequate fertility level (Brady and Weil, 2008).

With regards to raising soil pH and supplying Ca and Mg, Wollastonite behaved much like calcite limestone. In this same regard, CaMgSilicate behaved much like dolomite limestone. Thus, both Wollastonite and CaMgSilicate are effective liming materials. On soils with a low Mg fertility status, CaMgSilicate would be the preferred amendment to meet the need for this nutrient. Amendment of this soil with rye cover crop residue, glacial rock flour, or compost did little to change soil chemical properties.

Extractable Si soil test levels was done using the acetic acid process, were Si increased by more than tenfold over unamended soil by the CaMgSilicate and Wollastonite amendments. Glacial rock flour and wood ash increased extractable Si levels to a lesser extent. Other amendments exhibited little impact of on soil test extractable Si. Most surprisingly, Montana grow that is marketed as a Si soil amendment had very little impact on Si soil test level.

2.5.3. Plant Tissue Mineral Analysis

Concentrations of N and P were not influenced by soil amendment, but concentrations of different K, Ca, Mg, and Na was impacted in many cases. The major cations in plants are well known to compete for uptake (Brady and Weil, 2002, p. 343). Thus, when anyone of these cations is supplied to the soil in abundance, the uptake of those in relatively lower supply tend to be depressed. This antagonism among cations was illustrated in the tissue study response to dolomite limestone. This amendment, which is rich in Mg, tended to suppress an uptake of K and Mg. Calcite and Wollastonite which are especially rich in Ca tended to suppress Mg uptake.

Montana Grow, glacial rock flour, both types of cover crop residues, and compost all tended to improve K uptake while depressing Ca uptake. Results seem to suggest that these amendments be providing ample K such that it may be competing with uptake of other cations.

Micronutrient availability is often influenced by liming and elevations in soil pH. The effect of soil reaction was clearly reflected in the reduced tissue concentrations of Mn, Zn, Cu, and Al (Tables 5 and 4). In the case of Mn, the soil amendments which were shown to be effective as liming materials, reduced tissue concentrations from what may be considered excessive levels to normal levels (Marschner, 1995).

Silicon in the plant tissue varied among treatments from the lowest concentration to the highest by a factor of more than ten. The concentration of Si was increased to the highest level by amending the soil with calcium silicate (Wollastonite). CaMgSilicate also increased the concentrations of Si but not as efficiently as with calcium silicate (Wollastonite).

Besides the limestone, the soil amendments that did not increase Si uptake included Montana Grow, Wood ash, GRF, Cover Crop residues, and Compost. Application of calcite limestone tended to decreased Si uptake. The reason for this is unclear since dolomite limestone did not have this effect. The concentration of Si in the plant tissue increased in relation to increasing levels of acetic acid extractable Si (Fig. 1).

2.5.4. Powdery Mildew Disease

As Si level, increased in the plant the incidence and severity of powdery mildew disease decreased (Fig. 2). Pumpkin plant dry matter yield and Si concentration in the plant tissue, however, exhibited only a weak positive relationship (Fig. 3).

In the first week, during the onset of the disease, the Wollastonite treatment consistently ranked as having the fewest number of powdery mildew lesion on its leaves (Table 2a). The compost treatment tended to have the most lesions.

2.5.5. Statistical analysis

Variances in plant minerals, powdery mildew lesion, and silicon uptake were analyzed separately during each growing period. The methods were analyzed using Ryan-Einot Gabriel-Welsch F procedure (REGWQ) of Statistical Analysis Software (SAS Institute, 1997). The pumpkin dried matter yield were analyzed by Fisher's Least Significant difference test (LSD) at alpha level of 0.05. Statistical test was not used to analyze soil samples due to composite samples collection. All treatments means were analyzed across the different soil amendments. Soil amendments were considered significant among treatment means using the REGWQ F procedure.

2.6. Summary

Findings from the field experiment revealed that rye was an accumulator of Si in its plant tissue but hairy vetch does not. The rye grown on the Si enriched field soil contain about a third more Si than the rye grown on unamended soil. The additional Si added to the soil in the rye residue did not significantly increase Si uptake into the pumpkin plant tissue.

Within the time frame of this experiment, there was no indication that amending soil with Si enriched rye residue was of any help in suppressing powdery mildew disease.
This study confirmed that both Wollastonite and CaMgSilicate are effective liming materials and effective sources for plant available Si. CaMgSilicate provides a balance of Ca and Mg for acid soils that need to be supplied with both nutrients whereas Wollastonite supplies Ca but very little Mg. However, of these two Si sources, Wollastonite tends to be better for enhancing Si uptake by pumpkin plants and for offering protection from powdery mildew disease than CaMgSilicate.

Montana Grow, Wood ash, GRF, Rye Crop residue, and Compost did little to improve Si uptake or suppress powdery mildew disease on pumpkin. However, wood ash increased soil pH and supplied more potassium than Ca and Mg. For agronomical practices, wood ash may serve as alternative liming material for limestone with a considerable economic benefit for poor farmers in developing countries. Especially so in developing countries where resource poor- farmers lack purchasing power of fertilizers and limestone. Organic growers need to check with their certified before applying questionable amendments to their certified farmland. The one OMRI listed product in this study, Montana Grow, might superficially appeal to organic growers. Although it may have other merits not discovered in this study, Montana Grow was not shown to be effective as a source of plant available Si. Nor was it shown to be useful as a liming material. The practical findings from this research suggest that organic growers use Calcium Silicate (wollastonite) as a soil amendment and liming material to achieve multiple benefits for pumpkin production. Multiple benefits such as, reduced onset of powdery mildew disease, increased crop yield, and improved soil quality and overall health of the plant by providing silicon to the soil.

The use of Calcium Silicate (Wollastonite) on the pumpkin crop may be a better value than limestone in that it has more benefits than limestone. Calcium Silicate (Wollastonite) benefits improve soil chemistry, reduce powdery mildew disease, and supply silicon to the soil and increase crop yield. Whereas, the help of limestone is improved soil chemistry.

Besides the initial pumpkin crop, there may be residual benefits from the applied Si to other crops following the crop rotation. However, long term study would be needed to flush out such benefits. In addition, the greenhouse trial had gradient flaw using complete randomized design. There was short period of day light. There is a need to conduct future studies using complete randomized block design during long period of day light.

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Table 1. Rye cover crop fresh biomass matter yield, silicon concentration and estimated silicon uptake.

Treatment	Rye Fresh Matter	Si conc.	Estimated Si Uptake
	---- lbs acre-1------	-----g kg-1------	----- lbs acre-1-----
Limestone	24,840	2.7	13.4
CaMgSiO3	23,908	3.7	17.7
		P>F	
Treatment	0.48	0.017	------

A rye cover crop planted in field after amending soil with limestone and CaMgSiO3 shows no significant different in plant biomass yield. Tissue analysis shows higher Si concentration in Cover crop amended Plot than Limestone.

Table 2. Pumpkin plant yield, and powdery mildew disease lesion and Area under the Disease Progress Curve in response to soil amendments.

Treatment	Yield	15 Dec	17 Dec	19 Dec	21 Dec	
	-- g pot^{-1}	----------------------Lesion----------------------				-AUDPC--
Control	123ba	41bac	66bac	83a	106bdac	444bac
Calcite	143ba	25bac	47dc	83a	140bac	425bac
Dolomite	127ba	17bc	40dc	75ba	148ba	394bdac
AgrowSil	180a	23bc	47bdc	71ba	98bdac	364bdac
Wollastonite	159ba	10c	22d	41b	62d	198d
Montana Grow	100b	21bc	43dc	67ba	94bdc	333dc
Wood Ash	165b	19bc	42dc	73ba	136bac	385bdac
GRF	94b	28bac	50bdc	75a	114bdac	391bdac
CR/CaCO3	116ba	24bac	47dc	69ba	94dc	350bdc
CR/CaSiO3	153ba	45ba	75ba	103a	150a	548ba
Compost	107ba	54a	84a	105a	132bac	562a
			Pr >F			
Treatment	0.005	0.001	0.02	0.18	0.05	0.08

CR/$CaCO_3$= Cover Crop (RYE & Hairy vetch) Calcium Carbonate, CR/$CaSiO_3$= Cover Crop (RYE & Hairy vetch) Calcium silicate, GRF=Glacier rock Flour, AUDPC= Area under Disease Progress Curve. Treatment with the same letter is not significantly difference.

Table 3a. Pumpkin plant tissue analysis after amending soil pots in a greenhouse trial in 2014.

Treatment	Si	N	P	K	Ca	Mg	Na
	Mg kg^{-1}	------------------------- g kg^{-1} -------------------------					
Control	2021cd	55.5a	5.3a	72.5ba	38.9d	9.8c	4.7bac
Calcite	612d	54.0a	4.7a	58.1b	66.7a	11.5c	5.1bac
Dolomite	2318c	59.9a	4.8a	58.2b	50.9c	18.0a	5.9a
Agrowsil	4007b	53.5a	5.1a	64.9ba	55.2bc	14.4b	5.4bac
Wollastonite	6575a	50.7a	5.0a	62.7ba	63.8ba	7.1d	5.1bac
Montana Grow	2131cd	52.9a	5.4a	72.3ba	39.1d	9.8c	5.1bac
Wood Ash	1300cd	49.2a	5.3a	69.5ba	62.1ba	10.6c	5.8ba
GRF	2389cb	52.8a	5.0a	71.2ba	35.6d	9.9c	4.6bc
CR/CaCO3	1696cd	57.4a	6.1a	76.7a	37.9d	9.8c	5.1bac
CR/CaSiO3	2052cd	54.0a	5.8a	78.0a	41.4d	10.2c	4.4c
Compost	2070cd	54.1a	5.5a	73.1ba	39.2d	10.2c	4.8bac
				Pr >F			Pr >F
Treatment	0.0001	0.31	0.09	0.009	0.001	0.001	0.001

$CR/CaCO_3$= Cover Crop (Rye & Hairy Vetch) Calcium Carbonate

$CR/CaSiO_3$=Calcium Silicate

GRF=Glacier Rock Flour

Treatment with the same letter is not significantly different.

Plant tissue micronutrients analysis continue as Appendix G (p. 52)

Table 4a. Chemical properties of the soil after Pumpkin plant harvest on Jan. 2, 2014.

Treatment	CEC	pH	OM	Si	P	S	Ca	Mg	K	Na	Ca	Mg	K	Na
	$Cmol_c kg^{-1}$	%		ppm	------------------ mg kg^{-1} -----------------						----------- % ----------			
Control	16	4.5	5.5	13	118	86	654	107	336	181	21.0	5.6	5.4	4.9
Calcite	14	6.3	5.5	25	166	50	1685	206	319	171	61.0	12.0	5.9	5.4
Dolomite	14	6.0	5.7	29	128	90	1290	376	326	186	46.0	22.0	5.9	5.7
AgrowSil	15	5.9	5.4	159	122	69	1548	299	304	186	50.0	16.0	5.0	5.2
Wollastonite	13	6.2	5.8	156	82	57	1766	93	221	156	67.0	5.9	4.3	5.2
Montana Grow	17	4.3	5.3	15	75	68	650	94	275	155	19.0	4.7	4.2	4.0
Wood ash	15	6.5	5.7	60	179	90	1742	207	689	223	58.0	11.0	12.0	6.5
GRF	16	4.6	5.3	94	107	65	736	111	338	165	23.0	5.8	5.4	4.5
CR/$CaCO_3$	15	4.9	6.0	14	145	67	770	119	428	179	26.0	6.7	7.4	5.3
CR/$CaSiO_3$	16	4.7	5.6	13	132	70	754	115	414	190	23.0	5.9	6.6	5.1
Compost	17	4.7	5.5	24	127	80	818	125	406	191	24.0	6.1	6.1	4.9

CR/$CaCO_3$= Cover Crop (Rye & Hairy Vetch) Calcium Carbonate,
CR/$CaSiO_3$= Cover Crop (Rye & Hairy Vetch) Calcium Silicate
GRF=Glacier Rock Flour
OM=Organic Matter
CEC=Cations Exchange Capacity
Chemical properties of soil continued as Appendix F: (p.52)

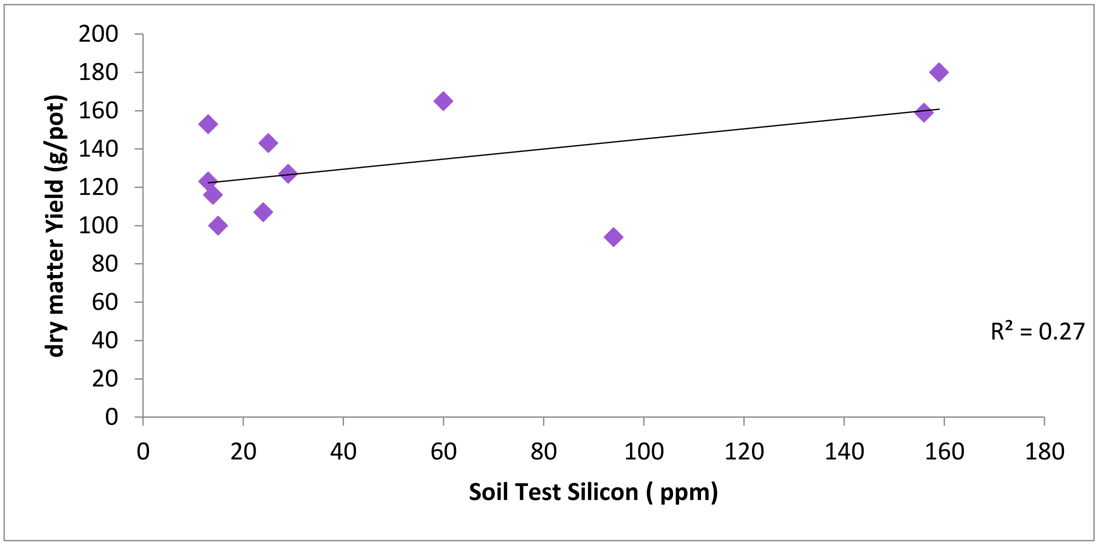


Fig. 1. Relationship between pumpkin dry matter yield and Soil Test Silicon.

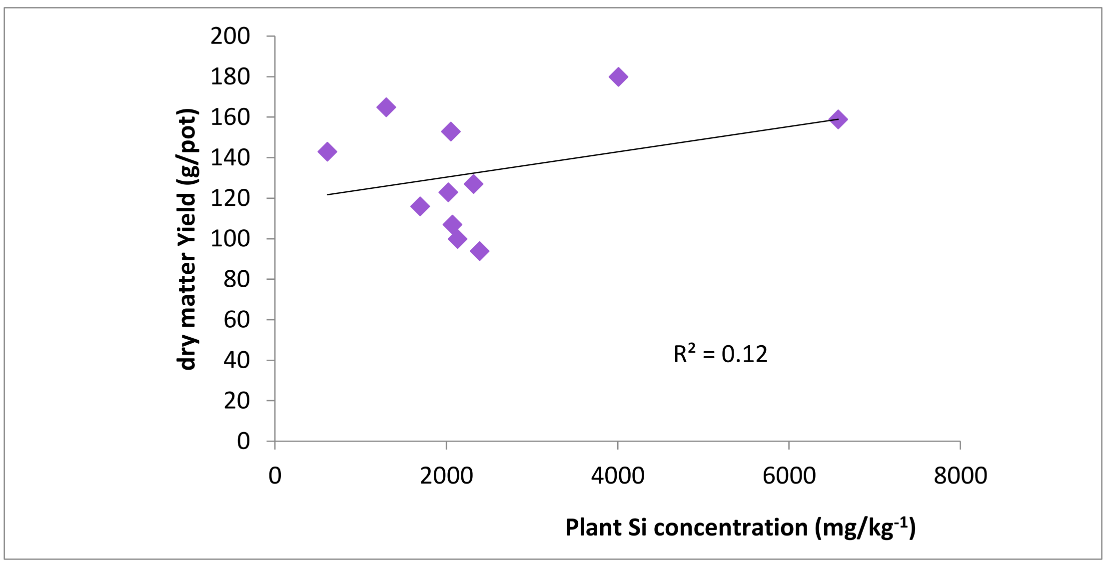


Fig. 2. Relationship between pumpkin dry matter yield and Silicon concentration in plant tissue.

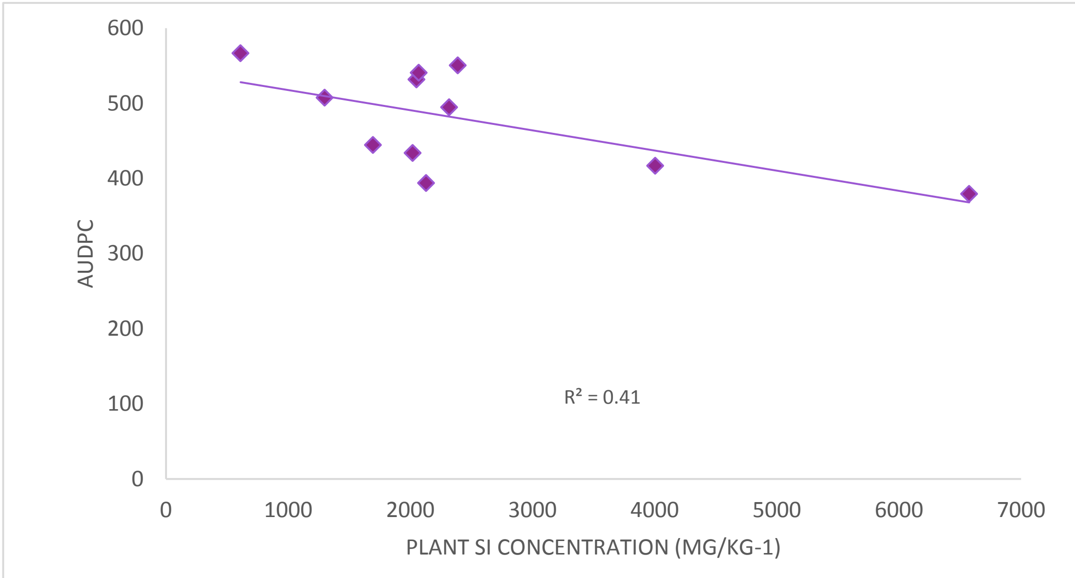


Fig. 3. Relationship between powdery mildew and Silicon concentration in plant.

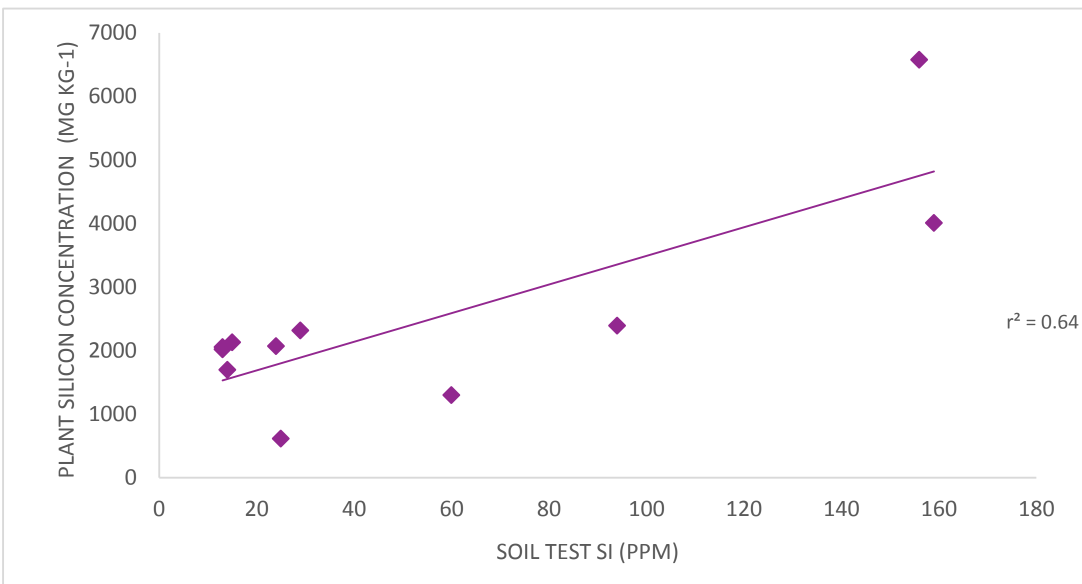
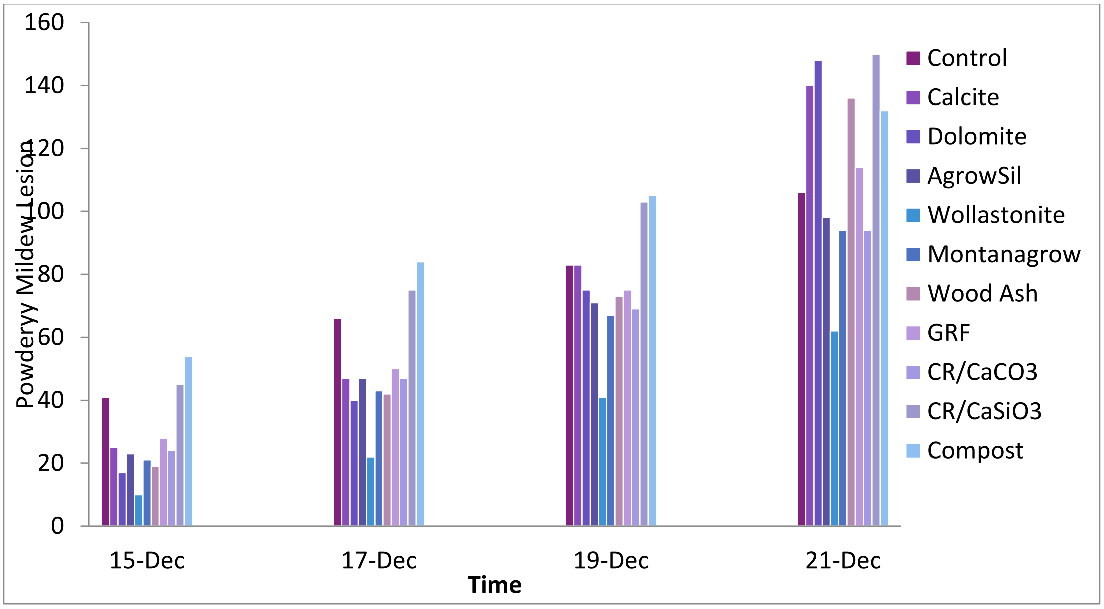


Fig. 4. Relationship between Silicon concentration in plant tissue and soil test extractable

Fig. 5. Soil amendments effect on the incidence and severity of powdery mildew disease lesion over time.



Appendices A. Soil Test Mehlich 3 Cations on CEC Amendments Added at 10.57 mg/ha (4.72 TA)

Amendments	pH	Calcium	Magnesium	Potassium
		----------------------mg ha^{-1}	--------------------------	
Control	5.1	29	8	4
Calcite	6.4	55	14	4
Dolomite	6.3	44	21	3
Wood Ash	6.6	55	10	7
G. Rock Flour	4.8	27	7	3
AgrowSil	6.4	55	18	3
Wollastonite	6.1	52	8	4
Montana Grow	5.0	33	8	4

Appendices B. Silicon and Cations Analysis in Pumpkin Vine Tissue with Amendments Spring 2013.

Amendments	Silicon	Calcium	Magnesium	Potassium
	-------------------------- g kg-1	----------------------------		
Control	1.20 cbd	21.7 bc	6.9 cd	37.4 ab
Calcite	0.62 cd	31.0 abc	6.5 cd	34.7 bc
Dolomite	0.48 d	32.2 ab	10.9 a	28.3 d
Wood Ash	1.65 cbd	36.5 a	7.1 cd	31.6 cd
G. Rock Flour	1.05 cbd	20.0 c	7.2 cd	42.6 a
AgrowSil	2.33 b	28.4 abc	8.3 cd	31.1 cd
Wollastonite	5.63 a	34.4 a	5.7 d	28.7 d
Montana Grow	1.82 cd	39.2 a	9.8 ab	39.2 ab

Appendices C: Pumpkin vine yield and powdery mildew as affected by amendment application Area under the Disease Progress Curve Summer 2013.

Treatment	23 Dec	25 Dec	27 Dec	28 Dec	30 Dec	31 Dec	2 Jan	
	----------	----------	----------	%	----------	----------	----------	--AUDPC--
Control	61a	22cd	40bc	51ba	52a	57b	85a	434edfc
Calcite	28ba	46a	53a	61a	64a	67ba	81ba	567a
Dolomite	14b	31cb	46ba	56ba	58a	63ba	86a	495ebdac
AgrowSil	60a	28cb	39bc	43bc	53a	59ba	81ba	417edf
Wollastonite	40ba	17d	32c	43bc	50a	55b	72ba	379.8f
Montana Grow	31ba	17d	32c	40c	50a	62bc	76ba	394ef
Wood Ash	40ba	31cb	45ba	56ba	62a	66ba	81ba	508bdac
GRF	39ba	33cb	53a	63a	66a	71ba	85a	551a
CR/CaCO3	44ba	27cbd	39bc	49bac	55a	60ba	76ba	445ebdfc
CR/CaSiO3	18b	30cb	47ba	60a	67a	74a	60b	532bac
Compost	17b	34b	51ba	62a	64a	74a	82ba	541ba
				Pr > F				
Treatment	0.12	0.003	0.006	0.02	0.12	0.19	0.52	0.003

CR/CaCO3= Cover Crop (RYE & Hairy vetch) Calcium Carbonate,
CR/CaSiO3= Cover Crop (RYE & Hairy vetch) Calcium silicate,
GRF=Glacier rock Flour,
AUDPC= Area Under Disease Progress Curve. Treatment with the same letter is not significantly different.

Appendices D. Portable X-Ray Fluorescence Chemical Analysis of Calcium Silicate

Principles-Hazardous Component	Percent	AGGIH Threshold Limit Volume (Unit)	OSHA PEL
AgrowSil () Non-Hazardous		N/A	
Calcium	30% (typical)	10 mg/m^2 ($CaCO_3$) 5 mg/m^2	15 mg/m^2 ($CaCO_3$) 5 mg/m^2 (resp)
Magnesium	7% (typical)	10 mg/m^2 total particulates	5 mg/m^2 (resp)
Silicon	12% (typical)	10 mg/m^2 total particulates 5 mg/m^2 (resp)	15 mg/m^2 (total) 5 mg/m^2 (resp)
Manganese	1% (typical)	0.2 mg/m^2 dust	5 mg/m^2
Aluminum	3% (typical)	10 mg/m^2 dust 5 mg/m^2	15 mg/m^2 (total) 5 mg/m^2 (resp)
Iron	4% Typical)	5 mg/m^2 dust	10 mg/m^2
Chromium	0.2% (typical)	0.5 mg/m^2 metal	1 mg/m^2
Sulfur	0.2% (typical)	5.2 mg/m^2 (SO_2)	13 mg/m^2
Titanium	0.5% (typical)	10 mg/m^2 (TO_2)	15 mg/m^2
Nickel	0.04%(typical)	0.05 mg/m^{2}metal	1 mg/m^2

Calcium Silicate analysis using the Portable X-Ray Fluorescence of heavy metal content. National Conservative Reserve Services.

Appendix E. Pictures soil and colors of various of Soil Amendments

Soil **Calcite** **Dolomite** **Wood ash**

G. Rock Flour **AgrowSil** **Wollastonite** **Montana Grow**

Appendix F. (Table 4b). Chemical properties of the soil after Pumpkin plant harvest on Jan. 2, 2014.

Treatment	B	Fe	Mn	Cu	Zn	Al
	mg kg^{-1}					
Control	0.63	228	68	7.1	11.0	1023
Calcite	0.81	214	36	8.6	13.0	816
Dolomite	0.75	218	39	8.1	10.0	910
Agrowsil	0.66	191	40	7.4	10.0	835
Wollastonite	0.63	221	30	6.7	8.2	777
Montana Grow	0.53	214	71	6.2	8.8	987
Wood Ash	1.0	188	41	8.8	14.0	821
GRF	0.64	237	69	7.3	12.0	986
CR/CaCO3	0.73	211	71	7.4	14.0	969
CR/CaSiO3	0.64	220	63	7.5	14.0	1020
Compost	0.74	267	91	7.7	14.0	1059

CR/$CaCO_3$= Cover Crop (Rye & Hairy Vetch) Calcium Carbonate
CR/$CaSiO_3$= Cover Crop (Rye & Hairy Vetch) Calcium Silicate
GRF=Glacier Rock Flour

Appendix G. (table 3b) Pumpkin plant tissue analysis after amending soil pots in a greenhouse trial in 2014.

Treatment	B	Mn	Zn	Cu	Fe	Al
	ppm					
Control	46bdc	2765ba	191a	12ba	89a	38a
Calcite	47bdac	146e	66c	11b	91a	14d
Dolomite	52ba	345e	69c	11b	90a	11d
Agrowsil	45dc	284e	168b	11b	86a	11d
Wollastonite	43d	268e	69c	12ba	97a	17dc
Montana Grow	49bac	3053a	179ba	13a	90a	33ba
Wood Ash	47bdac	114e	57c	12ba	103a	18dc
GRF	44dc	2390bcd	168b	13a	95a	26bc
CR/CaCO3	47bdac	2028cd	197a	13a	98a	32ba
CR/CaSiO3	52a	1933d	181ba	13a	92a	30b
Compost	44dc	2465bc	168b	13a	99a	30ba
			Pr >F			
Treatment	0.03	0.0001	0.001	0.01	0.69	0.001

CR/$CaCO_3$= Cover Crop (Rye & Hairy Vetch) Calcium Carbonate
CR/$CaSiO_3$=Calcium Silicate
GRF=Glacier Rock Flour
Treatment with the same letter is not significantly different.