Plant Growth in Two Acidic Soils Amended with Wallboard Waste

by

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(under the direction of William Paul Miller)

Fiberglass-faced wallboard consisting of gypsum, fiberglass, and urea formaldehyde is used in construction to form finish walls. Waste and cut-off gypsum based wallboard constitute 1.5 million Mg of construction waste per year and are readily amenable to on-site grinding in preparation for soil amendment. The objective of the study was to determine if fiberglass wallboard had any deleterious effect on growth or composition of agronomic crops. Application of three types of wallboard was made at three rates (11.2, 22.4, and 44.8 Mg/ha) to two soils (Cecil and Tifton) planted with two plants (wheat and sorghum) in a greenhouse evaluation. The biomass of both plants was unaffected by wallboard application, while soil pH and calcium concentration increased. Wheat tissue decreased in Mn, As, Ba and increased in Mo. Sorghum tissue decreased in K, Mg, Ba, and As. The application of fiberglass-faced wallboard was judged to have no negative effects under these conditions.

INDEXED WORDS: Waste Wallboard, Fiberglass, Urea Formaldehyde

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Construction and demolition companies have sought to reduce waste disposal costs from construction sites and potentially market pulverized wallboard at a minimal charge as a soil amendment. On-site or local re-use of pulverized wallboard should reduce construction costs with the prospects of improving soil conditions. Waste and cut-off gypsum-based wallboard constitute 1.5 million Mg of construction waste per year and are readily amenable to on-site grinding in preparation for soil amendment (EPA, 2009). The constituents of wallboard are gypsum ($CaSO_4 \bullet 2H_2O$) and facing material consisting of either paper or fiberglass and urea formaldehyde.

There have been studies on the benefits of waste wallboard as a soil amendment (Marvin, 2000; Carr and Munn, 2001; Townsend et al., 2001; Wolkoski, 2000). A majority of the waste wallboard is disposed of in Construction and Demolition (C&D) landfills where gypsum is anaerobically digested and hydrogen sulfide gas and metallic sulfide leachates are produced. Another disposal method is the incineration of wallboard which changes sulfate to sulfur dioxide gas; at high concentrations there is a reduction in the ability of alkaline scrubbers to deter acidic gases (Saludes et al., 2008). The production of these poisonous and environmental detrimental gases is a major issue with disposal methods of waste wallboard.

The issues attributed to paper-faced wallboard are the absorption of water and the production of mold. The production of mold indoors is a health hazard. A mold resistant wallboard was developed that has two fiberglass sheets instead of paper sheets. Paper-Faced wallboard has dominated the literature in regards to reuse of waste wallboard as an additive to arable land. The objective of this study is to evaluate fiberglass-faced wallboard as a potential environmentally benign soil amendment to arable land.

CHAPTER 2

REVIEW OF LITERITURE

A. GYPSUM AS A BUILDING AND WASTE MATERIAL IN CONSTURCTION

Wallboard Manufacture and Composition

The manufacturing of wallboard begins with the mining of gypsum after which impurities are extracted (shale and limestone). The gypsum is crushed and heated to create anhydrous calcium sulfate, also known as plaster of Paris. A lurry is created and molded between paper or fiberglass. Cutoff wallboard from construction sites is discarded into rollaway bins and typically placed into landfills (Townsend et al., 2001).

Construction and Demolition in the U.S.

Construction and demolition (C&D) waste is composed of construction waste, roadway waste, land-clearing debris, and inert debris waste. Construction debris is typically wood trimmings, wallboard, roofing material, and masonry debris. The demolition of buildings can generate 20 to 30 times the amount of construction waste per building compared to new construction. Wallboard in C&D waste stream can range from 4% to 76% depending on if the waste comes from construction, demolition or renovation projects (Townsend et al., 2001).

In the United States, the disposal of C&D waste is a costly process to execute and maintain. Some states require records of the amounts of C&D waste and the amounts of recovered materials that were reappropriated for other uses. In Table 1, the total amounts of C&D waste produced are shown, and the amounts of recovered waste by state are on average 48% (EPA, 2009). This is an impressive percentage that has the possibility of significant savings for the reuse of high imbedded energy materials. In Figure 1, there is a delineation of the constituents of C&D waste. Note that waste wallboard is the second largest percentage (27%) for new construction debris. C&D disposal and recovery can vary due to the fact that states define materials and govern the processes differently. It is estimated that there is 5.95 billion kg (6.56 million tons per year) of construction waste per year (EPA, 2009). Georgia has 44 C&D landfills and is the only state that counts unpermitted landfills, and it has 900 such sites (EPA, 1998).

Consequences of Wallboard Landfilling

The issues that are associated with the disposal of gypsum drywall in C&D debris include the transportation cost of materials to the landfill and the maintenance of ensuring the environmental integrity of the landfill and the hydrology in the vicinity.

The production of hydrogen sulfide gas is an environmental problem in C&D landfills. Hydrogen sulfide gas occurs when sulfate reducing bacteria act on sulfate. The generation of hydrogen sulfide is dependent on the concentrations of organic matter, concentration of dissolved oxygen in the leaching solution, the pH, and the temperature. Unlined landfills are subject to leaching of calcium sulfate by precipitation or groundwater intrusion. Aqueous sulfate leaching from landfills has the potential to exceed the groundwater protection standard for sulfate (Townsend et al., 2001).

LEED certification

The development of the trade mark Leadership in Energy and Environmental Design, known as LEED building certification, has provided an avenue for the transition to environmental benign buildings. Wallboard is incorporated in the LEED building certification, but first a discussion of the origins of LEED is necessary.

The U.S. Green Building Council (USGBC) created the LEED trade mark. LEED requirements for green building have seven measures, four categories of possible certification and the points related to those categories (Table 2). The point system is based on a possible 100 points (UGBC, 2011).

The USGBC touts the LEED certification is a competitive differentiator, for example, lowering operating costs by 13.6% for new construction projects and 8.5% for existing buildings. Also, the mitigation of indoor atmospheric contaminants can effectively attract potential investors. These benefits allow for owners to increase rental rates; on average the building rates increase by 10.9% for new construction and 6.8% for existing building renovation (USGBC, 2011).

The use of wallboard in new construction and renovation can provide points to LEED certification. There are 4 potential credits that apply to wallboard. They are as follows:

Construction Waste Management (MR Credit 2)

The construction waste management credit encourages the diversion of construction and demolition debris from disposal in landfills and incineration facilities. The credit also redirects recyclable recovered resources back to the manufacturing process and reusable materials to appropriate sites. If 50% of the construction waste is redirected to the appropriate facilities then 1 point is applied to the point system (USGBC, 2011).

Recycled Content (MR Credit 4)

The recycled content intends to increase the demand for building products that incorporate recycled materials, and thus reduces the impact from the extraction and processing of virgin materials. The recycled content value of a material assembly is determined by weight. The recycled fraction of the assembly is then multiplied by the cost of assembly to determine the recycled content value. The use of flue gas desulferization gypsum in wallboard is considered to be a recycled product since it is waste from coal production (USGBC, 2011).

Regional Materials (MR Credit 5)

This credit intends to increase demands for building materials and products that are extracted and manufactured within the region, and thus supporting the use of indigenous resources and reducing the environmental impacts resulting from transportation. The credit applies to manufactures that are within a 500 mile radius of the job site. If 10% of materials are considered to be regional materials, 1 point is accredited to the point system and if 20% then 2 points (USGBC, 2011).

Low-Emitting materials (IEQ Credit 4.6)

The credit intends to reduce the quantity of indoor air contaminants that are odorous, irritating and harmful to the comfort, and well-being of installers and occupants. Producers of the products that are considered to be low-emitting materials must have the GreenGuard indoor air quality certification. The criterion that must be meet by the products is as follows:

Total Volatile Organic Compound emissions (TVOC)………………………….. ≤ 0.5 mg/m^3

Formaldehyde emissions……………………………………………………….. ≤ 0.05 ppm

Total Aldehydes emissions………….…………………………………………. ≤ 0.1 ppm

(USGBC, 2011)

B. GYPSUM AS A SOIL AMENDMENT

Gypsum ($CaSO_4 \cdot 2H_2O$) is found worldwide and is typically found beneath rock deposits in marine salt domes (Havlin et al., 1999), and are formed from evaporating seawater in prehistoric sea beds. The deposited gypsum is mined for purposes such as manufacturing, industrial, and agricultural operations (Kessler, 1994). Gypsum is mined and goes through an extensive process where several additives are incorporated to ensure malleability in the processing and curing of wallboard (Havlin et al., 1999). The additives are not always apparent due to patent restrictions. Mined gypsum that is processed is either classified as calcined or uncalcined. Uncalcined gypsum is used in Portland cement manufacture, agriculture, and fillers in consumer products. Calcined gypsum has part of the water driven off and is used in the production of wallboard and plaster of Paris. Gypsum is naturally fire resistant which makes it a good building material (Townsend et al., 2001).

The addition of gypsum to arable land allows essential macronutrients Ca and S to be replenished and accumulate in plant tissue at high concentrations (1.5 to 35 g/ kg) (Sumner, 1986). Losses of Ca and S from the soil occur through leaching and crop removal. Ca is used in plants for cell division and cellular membrane function; S is used in plants to create amino acids and enzymes. Gypsum's chemical and physical properties make this compound a versatile tool in ameliorating soils. Gypsum has been known to ameliorate the dispersive properties of sodic soils and the acidity of sub-soils (Havlin et al., 1999).

Sodic soils

Excess Sodium (Na) creates chemical and physical problems, such as dispersive soil properties. Dispersion allows soils to be susceptible to erosion and develop compacted structure near the soil surface. The breakdown of soil aggregation leads to crusting, reduced water infiltration, runoff, and erosion. Declines in hydraulic conductivity result from as little as 5% Na, although the definition of sodic conditions is defined as Exchangeable Sodium Percentage (ESP) of 15% (Miller, 1987). The addition of calcium sulfate reacts with Na ion in the soil by the reaction, below (Havlin et al., 1999).

$$\text{Clay-2Na}^{+} + \text{Ca}^{2+} \rightarrow \text{Clay-Ca}^{2+} + 2\text{Na}^{+}$$

Sodium displaced from the soil can be leached from the profile by irrigation or rainfall. The calcium ion flocculates soil aggregates by virtue of being divalent and causes the diffuse double layers of clay to drawn together while exchangeable Na is replaced (Shainberg et al., 1989). Semiarid regions soils that possess dispersive properties often have an electric conductivity (EC_e: the conductivity of the solution extracted from a water-saturated soil paste) of < 4.0 ds/m, pH >8.5, and ESP >15.

Saline-Sodic

The sodic soils have dispersive properties and the saline soils have no physical issue. The saline-sodic soils have a range of both, depending on how much Na is in the soil. Saline-sodic is defined as electric conductivity of >4.0 (dS/m), pH <8.5, ESP >15, and soil physical condition is considered normal. Saline soils have excess soluble salts (Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, Na^+, Ca^{2+}, Mg^{2+}). Gypsum would not be an effective tool for ameliorating saline soils. But if there is a mixture of saline-sodic then gypsum can effectively deplete high Na content of the soil (Havlin et al., 1999).

Sub-soil Acidity

Sub-soil acidity is an issue in highly weathered soils due to the high phytotoxic levels of exchangeable Al and Mn. Additions of gypsum have been known to reduce exchangeable Al and increase root penetration. In most cases the high Al and Mn is associated with low levels of Ca (Korcak, 1993).

Sumner (1990) reported that an increase in root penetration into the subsoil and aggregate size resulted from application of gypsum (9 Mg/ha) after 48 months. Surface applications of calcium carbonate and gypsum showed that the Ca associated with the gypsum moved further through a soil column (Oxisol) than the Ca in the calcium carbonate (1500 mm of simulated rainfall) (Alva et al., 1991). Calcium carbonate treatments neutralized exchangeable Al in the top 30-cm of the profile, while the gypsum treatment reduced exchangeable Al throughout the profile. The gypsum treatment reduced exchangeable Al from 1.6 to 0.6 cmol (p+)/kg in the 0 to 10-cm horizon and from 1.9 to 1.5 cmol (p+)/kg in the subsoil. One hypothesized mechanism is the polymerization of Al by sulfate. Another mechanism suggested that the OH^- replaced by sulfate neutralized H^+ released through hydrolysis of Al (Pavan et al., 1987). Using computer modeling the addition of gypsum predicted a decrease in Al of 40% in the surface horizon to approximately 60% in the subsoil. The species of Al present was predominantly $AlSO_4^+$ and $Al(OH)_2^+$. The Ca species were largely Ca^{2+} and $CaSO_4$.The Al speciation of the drainage solutions were $Al^{3+,}$ $AlOH^{2+,}$ $Al(OH)_2^+$, and $Al(OH)_3$, accounting for 50, 25, 12, and 11% of the total, respectively. Gypsum additions contributed to 3% of the exchangeable Al being leached, but evidently a large proportion of the Al was polymerized into an insoluble form (Pavan et al., 1984).

Exchangeable Mg was reduced with the addition of gypsum. In one experiment, the untreated soil contained 0.55 cmol (p+) Mg/ kg whereas gypsum amended soil had approximately 0.10 cmol (p+) Mg/kg (Pavan 1984). The addition of dolomite and gypsum to neutralize exchangeable Al, while increasing the level of available Ca and Mg in the subsoil is a potential solution to this problem.

Calcium and Sulfur as a plant nutrient

Calcium (Ca) and sulfur (S) are essential plant macronutrients that are continually being extracted from the soil by plants. The availability of these nutrients ensures the vital functions such as protein synthesis, fruit maturation, and root development, among other functions.

Calcium (Ca) is a macronutrient that is essential for cell division and elongation. The deficiency of calcium results in a failure of the terminal buds of shoots and apical tips of roots to develop, halting plant growth. Calcium is essential in membrane structures and cellular diffusible compounds. The calcium improves NO_3^- uptake and provides some regulation of cation uptake, such as the uptake of K and Na (Havlin et al., 1999).

Calcium is generally immobile in the plant; the slow translocation of Ca in the phloem allows for a poor supply to fruits and storage organs. The translocation of Ca downward is also prevented which impedes the growth of roots in Ca-poor soil. The immobility of Ca is seen in the predictability of Ca deficiency in undeveloped root system. Deficiencies of Ca appear in corn as issues in emergence, unfolding of new leaves, and disorders in storage tissues. Calcium deficiencies in tomatoes result in blossom-end rot and bitter pit in apples (Havlin et al., 1999).

Sulfur is a vital element in the formation of proteins and acquisition of essential elements. Sulfur dioxide can be absorbed by plant leaves but high concentrations can be toxic, with typical S concentrations of within the leaves between 0.1 and 0.5%. Sulfate is reduced in the plant to S—S and –SH forms, but SO_4^{2-} also occurs in plant tissues and cell sap. Plant roots absorb S almost exclusively as sulfate (SO_4^{2-}). Plants may experience S deficiency in early growth stages until the root system can reach the subsoil. Plants with well-developed root systems are unlikely to have available sulfur shortages. S deficiencies in plants result in the accumulation of non-protein N in the form of NH_2 and NO_3. In S deficient vegetables NO_3^- accumulates in the leaf tissue affecting food quality. Similarly, ruminants require S from the plants they ingest for the rumen microorganisms that allow them to digest plant material. Rumen microorganisms need a N/S ratio from 9:1 and 12:1. Fertilizing with S to reduce the N/S ratio may be necessary for animal nutrition. Coenzyme A is dependent on S, which is involved in the oxidation and synthesis of fatty acids, amino acids, and the oxidation of intermediates of the citric acid cycle. Sulfur is also needed for the synthesis of chlorophyll and Fe-S proteins in the chloroplasts, called ferredoxins. Ferredoxin is a key component in the reduction of NO_2^-, SO_4^{2-}, and the assimilation of N_2 in root nodule bacteria, as well as, free-living N-fixing soil bacteria. The taste and smell of plants are dependent on S volatile compounds in mustard and onion families (Havlin et al., 1999).

Calcium: Soil

An adequate Ca concentration for crops in the soil solution is 15 ppm. When Ca concentrations are higher than needed for plant growth the uptake of Ca is unaffected since Ca uptake is determined genetically. The plants ability to absorb Ca is limited to only young root tips though the cell walls of the endodermis.

The soils chemical and physical properties determine the amount of available Ca within the soil solution. The total Ca supply within the soil will obviously effect the concentrations available to plants but soil pH can impede Ca uptake. Elevated levels of the hydrogen ion can impede Ca plant uptake and soils low in Ca may halt uptake all together. Another factor in the acquisition of Ca for plant growth is the cation exchange capacity (CEC). Soils that have low CEC are unable to withhold plant nutrients cations of particular concern are acidic sandy soils. Soil colloid type can affect the availability of Ca as well; for instance, 2:1 clays require higher concentrations of Ca than 1:1 clays for the proper availability to agronomic crops. For instance, proper Ca availability to plants in Montmorillonitic clays require >70% Ca while Kaolinitic clay able to provide adequate Ca at 40% to 50% Ca saturation (Havlin et al., 1999).

Calcium uptake can also be depressed due to the interactions with other ions in the soil solution. For example, interactions with NH_4, K, Mg, Mn, and Al depresses Ca uptake. Both Ca and Mg compete with K for entry into plants, thus, soils high in one or both of these cations may require high levels of K for satisfactory nutrition of crops. Higher ratio of Ca and Mg reduce K uptake into plants. As K is increased uptake of Ca and Mg would be reduced. K is more dependent on the concentration of Ca and Mg more than the total quantity of K present. On the contrary, Ca absorption is increased when plants are supplied with NO_3^-. A high level of NO_3^- nutrition stimulates organic anion synthesis and the results in accumulation of cations, particularly Ca (Havlin et al., 1999).

Leaching of plant nutrients is an agronomic concern as well as an environmental integrity concern. Ca is often the dominant cation in drainage waters, springs, streams, and lakes. Leaching ranges from 75 to 200 lb./acre/year. When leaching occurs Na is lost more readily than Ca due to charge and radii of the hydrated cation (Havlin et al., 1999).

Sulfur in soils

Sulfate (S) can account for up to one-third of the total S in subsoil, as a result of eluviation or leaching. Sulfur is present in the soil both organic and inorganic forms. In most non-calcareous surface soils 90% of S exists as organic forms. Inorganic forms are solution SO_4^{2-} , adsorbed SO_4^{2-}, insoluble SO_4^{2-}, and reduced inorganic S compounds. Adsorbed and solution SO_4^{2-} represent the readily available fractions of S utilized by plants (Havlin et al., 1999).

The roots absorb SO_4^{2-} by diffusion and mass flow. An S requirement for most crops is adequate at concentrations of 5ppm or more of SO_4^{2-} in soil solution. Most soils contain less than

10% of S as SO_4^{2-}. Seasonal and annual fluctuations in SO_4^{2-} occur due to environmental effects on the mineralization of organic S, down-ward and upward movement of soil solution, and uptake of plants. Thus, sulfate can be leached from the soil root zone but can be replaced by S amendments, precipitation, or irrigation waters. Leaching of S is least in acidic soils with high quantities of exchangeable Al^{3+}. Leaching losses of SO_4^{2-} are the greatest when monovalent ions (K+, Na+) dominate the soil solution, while divalent cations create the next highest leaching losses of SO_4^{2-}(Havlin et al., 1999).

Soils with high amounts of Al and Fe oxides can adsorb appreciable quantities of SO_4^{2-}, examples highly weathered soils (Ultisol: Red-Yellow Podzol and Oxisol: Latosol). Sulfate in these soils is plant available but not as rapidly as an S amended soil. The adsorption of SO_4^{2-} has been explained by several mechanisms. The absorption of sulfate by anion exchange can occur by the development of positive charges on Fe and Al oxides or clay edges (high absorption in kaolinitic soils). Subsoils tend to have higher sulfate absorption due to increases in clay and Fe-oxide contents. In addition, anion exchange capacity (AEC) increases with decreasing pH causing higher absorption of sulfate at low pH (< 5.5). Soil organic matter has amphoteric properties that can produce positive charges under certain conditions that cause absorption of sulfate in topsoil. The presence of anions can effect soil solution concentrations of sulfate as well; for instance, the phosphate ion will displace SO_4^{2-} . Chloride has little effect on SO_4^{2-} adsorption, as shown by the anion lyotropic series: $OH^- > H_2PO_4^- > SO_4^{2-} > C_2H_3O_2^- > NO_3^- = Cl^-$ (Havlin et al., 1999).

Flue Gas Desulfurization Gypsum

Gypsum board manufacturers are increasingly relying on byproduct gypsum from the flue gas desulfurization (FGD) of coal fired power plants. There are several uses for FGD gypsum (Figure 2), such as concrete products, structural fills, mining applications, waste stabilization, and agricultural application.

There are several types of gypsum that come from manufacturing production that can be used for the production of wallboard. The byproduct gypsum that is suitable for use in wallboard includes flue-gas desulfurization (FGD) gypsum, fluroogypsum, citrogypsum, and titanogypsum (from manufacturing titanium dioxide). Some types of gypsum are not used for the production of wallboard such as phosphogypsum because it might contain radon and radionuclides. Synthetic gypsum with potentially harmful materials is not used to manufacture wallboard. According to the ACAA (2009) report, 6,616,054 Mg of flue gas desulfurization gypsum was used in gypsum panel products and 256,406 Mg was used in agriculture.

When considering the application of FGD gypsum to arable land a review of the concentration of elements being applied must be considered. Miller (1995) refers to FGD gypsum as being 80% gypsum, with fly ash and unreacted lime existing in variable amounts. FGD may have high electrical conductivities (EC) due to the presence of soluble salts. FGD gypsum is known to have variable levels of trace contaminants due to aggregation with volatile elements within the desulfurization reactor. Potential contaminates in fly ash are Mo, Se, B, and As. Boron is often elevated in FGD gypsum. Mercury (Hg) concentrations in FGD gypsum are 2 mg Hg / kg in FGD gypsum. Of particular concern are the anionic contaminants (As, B, Mo, and Se) which have greater solubility in arable soils and potential phytotoxicity. These elements have the potential to adversely affect animals and humans by entering food streams or runoff into water supplies (Miller, 1995).

C. FACINGS AND ADDITIVES IN WALLBOARD

Research pertaining to wallboard recycling has been particularly focused on paper-faced wallboard; there is a lack of research on fiberglass-faced wallboard. Both paper and fiberglass-faced wallboard have a core of calcium sulfate composed of ether mined or flue-gas desulfurization gypsum. The components of the fiberglass facing are E-fiberglass (Table 6) and urea formaldehyde. In the following section a review of the applicability of fiberglass and urea formaldehyde as a soil amendment will be scrutinized, beginning with fiberglass.

Potential reactions and impacts of silicon additions to soils

Fiberglass comprises the second most prevalent component by mass in wallboard (97.73 g/m^2 or 2lbs/100 ft^2). The chemical composition of fiberglass can vary depending on the type. The fiberglass used in wallboard is called E-glass, the chemical composition and properties are presented in Table 6.

Studies on the degradation of fiberglass in an agricultural setting are nonexistent. The studies that have been completed that are applicable to this study are the additions of soluble silica in agricultural environments. The climatic regime over which soluble silica is available determines the benefit or determent of the element. For instance, in arid and semi-arid regions siliceous hardpans develop but in sub-tropical regions the addition of silicon fertilizers has provided agronomic benefits.

The geographic areas that are high in silica are arid regions or areas that have freshly deposited volcanic ash. Correspondingly, the areas with low levels of silica are highly weathered soils comprised primarily of Fe and Al (Oxisols), or soils developed from low silicon parent material (National Academy Sciences, 1973). Silicon is the second most abundant element in the earth’s crust. Inert quartz or crystalline silicates represent most of the Si-rich compounds within the soil. Typically silica concentrations in clay soils are 200 to 350 g Si/kg and in sandy soils 450 to 480 g Si/kg but only a fraction is biological available (Matichenkov and Calvert, 2002). The concentration of silica in the soil is dependent on pH, degree of weathering, temperature, and iron and aluminum oxides surface area. Amorphous silica has a solubility of 60 to 70 mg/ kg (National Academy Sciences, 1973).

Plant Silicon

Silicon substances that are physically and chemically active are monosilicic acids, polysilicic acids, and organosilicon compounds (Matichenkov and Calvert, 2002). Plants and microorganisms absorb silica solely as monosilic acid that is available in the soil solution (National Academy Sciences, 1973).

Silica has been found to be vital in some species (reed canary grass, coastal Bermuda grass, and tall fescue) (Van Soet and Jones, 1964). As mentioned earlier the utilization of Si differs with each agronomic plant; for instance, potatoes removes 50 to 70 kg Si/ha, cereal grains 100 to 300 kg Si/ha, and sugarcane removes 500 to 700 kg Si/ha. Si fertilizers have improved the vegetative growth, fruit, and grain production in rice (Oryza sativa L.), barley (Hordeum vulgare L.), wheat (Triticum vulgare Vil), corn (Zea mays L.), cucumber (Cucumus sativa L), tomato (Lycopersicon esculentum Mill), citrus (Citrus taitentis Risso) and sugarcane (Matichenkov and Calvert, 2002).

Silica reduction in digestibility

An increase in plant silica has been attributed to a decrease in digestibility by ruminates. The forms of silica that are able to be metabolized include polymeric silicic acid (opal) deposition in cell walls and organic linkages of soluble silica. The cell wall silica functions, in part, by adding structural strength and has been associated with deterring rice diseases (Van Soet and Jones, 1968).

Silica slag improved P availability

Biogeochemically active substance rich in silicon have a high adsorption capacity for anions and can reduce P leaching by 30 to 90%. The application of silica slag helped reduce P leaching and possible pollution in sandy soils due to low retention. Sandy soils have low retention because of, the lack of alumino-sliicates and metal-oxide clays and the lateral P transport within the E horizon due to seasonal water table. The silicon rich compounds can adsorb mobile P and allow them to stay plant-available forms. Increased P availability was noted in the addition of silica slag in the positive effect on Bahiagrass root system (Van Soet and Jones, 1968)

Urea Formaldehyde

Urea Formaldehyde (UF) is used as a binder in fiberglass-faced wallboard as an adhesive to provide structure for the fiberglass strands. The reaction of urea and formaldehyde is fundamentally a two-step, alkaline methloation and acid condensation. The process of methylolation is the addition of formaldehyde (2 to 3, in theory 4) to one molecule of urea termed methyloureas. Each methyloation has its own rate constant (K) and is responsible for the low resistance against hydrolysis and consequent formaldehyde emission. Formaldehyde emission results from slight hydrolysis of weakly bonded formaldehyde. The formation of UF is dependent on the Formaldehyde-Urea molar ratio. The type of bond development depends on the conditions in the acid condensation process. Low temperatures and slightly acidic pH favor the formation of methylene ether bridges (CH_2-O-CH_2) and higher temperatures and lower pH lead to the more stable methylene (CH_2) bridge. Ether bridges can rearrange to methylene bridges by splitting off formaldehyde. The acid condensation step and the alkaline methloation step are performed at the same high molar ratio (F/U= 1.8 to 2.5). UF that has lower F/U molar ratio showed better resistance to hydrolytic stability (Hse and Higuchi, 2010; Abdullah and Park, 2009). Resins today have a lower content of formaldehyde and therefore emit less formaldehyde. The difference between urea formaldehyde resins with high and low contents of formaldehyde is the content of free formaldehyde and the degree of crosslinking in the cured network. The degree of crosslinking (formaldehyde) is directly correlated to the molar ratio of the two components. The ideal linear UF chain has a molar ratio of 1.0, with no ether bridges, no unreacted branch-site methylol groups, and no free formaldehyde. In practice, this calculation is not exact. In essence, the higher the F/U molar ratio, the higher the content of free formaldehyde within the resin. The formaldehyde content of unmodified UF resin is 0.1% at F/U=1.1 and 1% at F/U=1.8 (Dunky, 1998).

Microbial biomass and activity

The dissolution of UF in the soil is dependent on various bacterial species to metabolize UF to inorganic forms. Soil microorganisms (bacteria and fungi) were found to grow effectively on UF (Mohn, 1997) and the application of UF increases in microbial activity and the production of CO_2 in UF-treated soil. Furthermore, the delay in the mineralization of UF has been attributed to low microbial activity, low temperature (14 ^{o}C), and the increase in pH (Aarino et al., 1996). Formaldehyde degradation has been related to the growth of a pink-pigmented facultative methylotrophic bacteria belonging to the genus Methylobacteriaceae. Methylotrophic bacteria belong to a group of microorganisms with an efficient metabolic pathway for using single carbon compounds (C1 compounds) as their energy source (Maiuta et al., 2009).

Mycorrhizal infection is known to aid plants in the acquisition of essential nutrients that would be otherwise unavailable to the limited plant root system. Adversely affecting this beneficial agronomic fungus with applications of UF would not be advisable. Fortunately, mycorrhizae fungi infection was not affected by the addition of UF. The use of Nitroform (Urea Formaldehyde slow-release fertilizer) at high concentrations did not impede the capacity of mycorrhizal fungi infection of pine seedlings (Aarino and Martikainen, 1995).

Urea is typically used as an N fertilizer but is plagued with the lack of efficiency due to volatilization, leaching, denitrification, and immobilization. A slow-release N fertilizer would alleviate the issues associated with urea by releasing N on a schedule that would be appropriate for plant uptake (Aarino and Martikainen, 1995).

Aarino (1996) sought to improve the synchrony of the availability and uptake of N fertilizer in 50-y-old coastal Douglus-firs with the use of slow-release N fertilizers, such as urea formaldehyde. The UF-treated soils were found to liberate NH_4^+ from UF at a slow rate. The first weeks of incubation the exchangeable NH_4^+ pool was very low in the UF-treated soils. At the 6th-week of the experiment NH_4^+ increased in the UF-treated soils and increased until a plateau occurred at week 45. The addition of NO_3^- was negligible and considered to be the same for all treatments. Urea formaldehyde increased microbial N. The tree crops incorporated the applied N at a range of 5-20%. UF amended soils had the highest amount of N within soil residue. Aarino (1996) concludes that UF was complexed into humic material.

In a similar study UF was provided for barley as an N source. In a two season growing period UF provided higher grain and straw than control in the first vegetation period. The second growing period gave similar results for grain production. According to the author the utilization of ^{15}N was low in the grains and stems of barley. Consequently, the soils that had been fertilized with UF-polymers had higher amounts of N incorporated into the plant. The author concludes that the addition of UF provided more soil available N but not as direct N suppliers (Sotiriou,et al. 1986). Soils treated with UF had a high soluble organic N (atom% ^{15}N). The extracted organic N (50%) originated from the water-soluble fraction of UF, which consists of free urea and short chain polymers of methylene urea. When the UF was applied the atom% ^{15}N excess increased and was constant for the duration of the experiment (Aarino et al., 1996).

Soil pH

The release of N in UF treated soils is optimium at a soil pH of 6 than pH 5 or pH7. The study of 20 soils having a pH values ranging from 3.9 to 7.8 found a highly significant negative correlation between soil pH and rate of accumulation of inorganic N (NO_3^- and exchangeable NH_4^+). The rate of N released observed in the most acid soil was 8 to 15 times higher than the rate observed in alkaline soils. N release was about one-third greater in a soil at pH 6.7 than 5.5 (Tlustos 1992). After mineralization of UF the soil pH increased in both untreated (4.4- 6.5) and UF-treated soils (4.5-6.1) (Aarino et al., 1996) (Table 3).

Rate of degradation of UF

Urea formaldehyde resin is considered to be 100% water insoluble and a comparison of a closely related chemical, Ureaforms (a slow-release N fertilizer) is necessary to gain perspective of UF rate of degradation in the soil.

UreaForms are composed of methylene urea polymers that have various molecular weights, and is formed by an acid-catalyzed reaction. The varying molecular weights give rise to differing solubility. Tlustos and Blackmer (1992), report data on water soluble, water insoluble, hot water soluble, and hot water insoluble fractions; for a comparison to the UF resin found in fiberglass-faced wallboard this study will review the hot water insoluble fraction (HWIS). In a study done on 6 different Mollisols the average HWIS N over a 60 day period was .061 mg N/kg d. The rates of release of N from the HWIS fraction ranged from <0.001 to 0.2 mg N/ kg/ d with a distinct trend for rates of release to decrease with increase in soil pH. The production of NO_3^- was favored with increasing pH and in the HWIS fraction (pH 5 to pH 8 slop of -0.07 (r^2=0.67). HWIS fractions release N at negligible rates in soils near or above neutrality (Tlustos and Blackmer, 1992).

HWIS fraction is considered to be inactive in soils. The hot water soluble (HWS) fraction contains polymers of intermediate length; N in this fraction is reported to be slowly nitrified over periods of an equivalent of 6 months. The rate of N release observed in most acid soil was 8 to 15 times higher than alkaline soil. The rate of N release was one-third greater in a soil at pH 6.7 than 5.5 (Table 3). There is always the possibility of free formaldehyde in the system; reactive formaldehyde is toxic to plant growth (Sotiriou,et al. 1986). However, the low molar ratios of UF resin ensure low amounts of free formaldehyde and no adverse plant interactions due to free formaldehyde have been recorded (Table 7).

Turf grass

There are many variations of UF, one of them being urea formaldehyde resin foam (UFRF). The water holding capacity of UFRF is 57% (v/v), weight 18-30 kg/m3, which is reported to have benefits of a period of 20 yrs. The increase in water holding capacity was shown to decreased hardness, air-filled porosity, saturated hydraulic conductivity, and increased seed germination rate in sandy profiles. Soils amended with UFRF raised the moisture content by 2% (w/w) than control. UFRF increased tuff biomass in winter but no difference was noticed in summer or spring. The increase in biomass was attributed to the N released from the UFRF (6 g/m2/yr). UFRF did increase root biomass and root architecture (Nektarios et al., 2004).

Hydrocell (Urea formaldehyde resin foam) is a soil amendment. The product improved sapling leaflet at the 30% (v/v) treatment. Improvements were recorded in F.schottiana saplings in the sand and loam soils but clay soils did not shown improved data (Chan and Joyce, 2007).

Soil Stabilization

The use of UF has been used to improve soil aggregate stability, water infiltration, limit water adsorption, soil erosion, evaporation, and water seepage. Sandy soils have been aggregated by the use of UF resins with cross-linking agents in order to prevent the UF resins from leaching through the sand. UF (without cross-linking agent) provided an unconfined compressive strength of 1.30 and 2.50 (N/mm^2) at a dose % by weight of sand 10 and 20, respectfully (Lahalih 1998). The application of UF at varies rates (g/kg) has been attributed to the increase of water stable aggregates (%), coefficient of infiltration (mm/min), decrease in bulk density (g/cm^3), and the percentage difference as compared to control. Wu et al. (2010) extrapolated appropriate concentrations, to reduction in amounts of sediment and runoff.

D. WALLBOARD USE AS A SOIL AMENDMENT

As mentioned earlier in the paper, there has been extensive research on paper-faced wallboard and a lack of research on fiberglass-faced wallboard. Wallboard recommendations for application to arable land are currently available for paper-faced wallboard. For instance, the University of Georgia recommends 11.2 Mg/ ha (5 tons/acre) in the Piedmont, Mountains, and Ridge and Valley regions. Their recommendations for the Coastal Plain is 2.2 Mg/ha (1 ton /acre) (Gaskin et al., 2009). Burger (1993) reported that applications of paper-faced wallboard typically have fallen between 17.9 Mg/ha and 49.3 Mg/ha (8 and 22 tons per acre, respectively). The variation in recommended application rates varies with soil in relation to the chemical and physical properties of the soil. Though the soils have varying properties the wallboard chemical properties can vary as well. The chemical analysis of paper-faced wallboard and agricultural gypsum from past research is provided in the Table 8. All materials have appreciable concentrations of Ca, S, Mg, and K

Agronomic crops interaction with applications of wallboard

In consideration of the effects of wallboard on elemental concentrations in soils, wallboard amendments have the potential to alter plant elemental concentrations. The research done on wallboard has covered a variety of agronomic plants (corn, bunch collards, bravo cabbage, butter crunch lettuce, china blue chinese cabbage, clover, alfalfa, and wheat). The interactions observed have varied from increase in productivity, increase in essential elements, decreases in elemental concentrations and phytotoxicity.

Wallboard has high concentrations of Ca and S, and an increase in these elements in plant tissue grown on amended soils has been noted (Burger, 1993; Wolkowski, 2000; Townsend, 2001). For instance, Ca increased 3.2 and 8.4 times in plots receiving low and high (24.6 Mg/ha and 49.3 Mg/ ha) applications of wallboard compared to control (Burger, 1993). Sulfur concentrations increased with an increase in rate of wallboard and gypsum fertilizer (Wolkowski, 2000). Corn grain production was substantially increased by 26% and 25% on plots receiving low and high applications of wallboard, respectively, compared to control. The higher yields were hypothesized to be a result of higher Ca, Mg, and S in the soil solution (Burger, 1993). Similarly, corn ear leaf nutrients were compared to critical values and an increase of Mg corn ear leaf concentrations resulted from the addition of wallboard Mg. Magnesium concentrations in the added wallboard were 22 g/kg. Magnesium was found to be 2.7 times higher in plots receiving the high application (49.3 Mg/ha) of drywall relative to control. Agricultural gypsum applications resulted in Mg concentration of soil being 1.7 times higher than plots receiving the low application (24.6 Mg/ha) of drywall (Burger, 1993).

A similar study reviewed the effects of wallboard as an agricultural amendment on several agronomic plants, such as bunch collards, bravo cabbage, butter crunch lettuce, and china blue chinese cabbage (Townsend, 2001). The field trail consisted of 6 treatment rates (0, 1.1, 2.2, 5.4, 11, 22 Mg/ha) in a Lakeland fine sand. The plant tissue analysis of the collard plant showed that boron levels increased as the rate of application of wallboard increased but were within the plant sufficiency ranges (25-50 ppm). Boron is used in paper-faced wallboard as a flame retardate and is not inherent in mined gypsum. Applications of 10 Mg/ha of wallboard would supply 0.43 kg B/ ha, which is 25% of the agronomic recommendation for this nutrient. Yearly soil test should monitor the concentrations of these elements to provide essential plant nutrients without becoming phytotoxic.

The EPA (1993) noted that the application of wallboard to agriculture systems would not exceed EPA 503 rules of metal loading limits for many years at reasonable application rates. In a related study, phytotoxicity was evident in Dixie crimson clover and Osceloa white clover. The yellowing of the leaves and marginal burning was only visible at 22 Mg/ha, the highest rate (Townsend, 2001).

The application of wallboard results in the addition of high concentrations of Ca and SO_4 which invariably causes elemental interactions within the soil. The over-application of gypsum can adversely affect crop growth due to the negative effects of some of these interactions. Gypsum is a soluble salt; the added Ca^{2+} is likely to replace other exchangeable cations. A decrease in elemental concentrations in plant tissue and soil extracts has been recognized in previous studies (Burger, 1993; Korcak, 1993; Wolkowski, 2000). Additions of calcium sulfate have been known to cause leaching of Mg and K from the root zone. The depletion of Mg and K from the root zone with the applications of gypsum can have severe consequences, particularly on sandy soils. Soils with higher cation exchange capacities (CEC) will be affected less due to the ability to maintain ions on exchange sites (Shainberg et al., 1989). For instance, in one study soil Mg decreased in multiple locations even though 9 kg of Mg were applied for every Megagram of waste wallboard applied. The presumption was that Ca displaced Mg from the sampled zone (top 0.15 m). Soil test Mg in Spooner soil (Cress sl Typic Dystrochrepts) had decreased at high application rates (36 Mg/ha) in the last two years of the experiment. Mg had decreased so much that there was a possibility of deficiency of Mg in crops. Though Mg was affected by influx of Ca, other were are not affected. Wolkowski (2000) found that over 3 seasons of application of waste wallboard on 4 soils the effects of wallboard treatments on P, K, B, Zn, and Mn were inconsequential.

A reduction of N in the corn ear leaf was noted in both high and low wallboard treatments in comparison to agricultural limestone and control. Burger (1993) suggests that there was a “dilution effect” because the increase grain production required more N which was mobilized N from the leaves. Sodium reduction in corn leaf nutrients was also noted presumably from the additions of $CaSO_4$; potassium was also reduced in soil solution (Burger, 1993).

The interaction between $CaSO_4$ and heavy metals was identified in corn ear leaf concentrations. Barium in corn ear leaf samples was lowered below the detection limit (< 1.0 mg/kg) in agricultural gypsum and low and high wallboard treatments (Burger, 1993). This could be due to elemental competition between Ca^{2+} and Ba^{2+}. Similarly, Cr^{2+} was decreased. Another possible reason for the decreases in Ba^{2+} and Cr^{2+} is that leaching of SO_4^{-2} enhanced leaching of those elements (Burger, 1993).

In another study, forage Mg concentrations were reduced at higher applications rates (Wolkowski, 2000). Results were considered to be due to competition at the root surface. Forage Mg concentrations were lowered below what is considered sufficient (<3.0 g/kg) for alfalfa but several sites showed low levels for all treatments of wallboard (Wolkowski, 2000). In terms of animal health, grass tetany can develop in ruminants that feed on forages low in Mg (Korcak, 1993).

The application of gypsum to a Tifton loamy sand soil when growing peanuts showed greater leaching of Mg and K compared to sandy clay loam soils (Alva et al., 1991). An increased percent pod rot and decrease in percent of sound mature kernels and yield has been associated with high concentrations of Mg and K in the fruiting zone (0 to 8 cm of topsoil). Ca is required for peanut pod development and Ca must be absorbed directly from the soil solution within the fruiting zone. The vital period of Ca absorption for peanut fruit development is 15 to 35 days after pegs enter the soil. Application of gypsum is recommended in Georgia if Mehlich 1 Ca is less than 560 kg/ha in the fruiting zone sampled 10 to 14 d after planting.

Application of Wallboard to arable lands.

The practical application of wallboard to agricultural fields can be inconsistent due to wind drift. The wallboard is pulverized before application so that the fine particles are able to dissolve quickly and become incorporated into the soil. A sieve test can be conducted on the pulverized wallboard to determine the dominate particle sizes that were effected by wind drift (Table 5). When pulverized wallboard was applied under mild breeze conditions; these conditions affected the consistency of field applications. A standard lime spreader had difficulty spreading pulverized wallboard. The author suggests that a blending of pelletized fertilizer with the fine particles of pulverized wallboard would result in improved distribution. The incorporation of pulverized wallboard into pellets would increase the ability to spread efficiently (Wolkowski, 2000).

E. OBJECTIVES

The objective of the studies proposed here was to clarify the overall suitability of ground waste fiberglass-faced wallboard as a soil amendment for general agricultural use. The long-term benefits of gypsum applications for plant growth have been extensively demonstrated in the literature (Shainberg et al., 1989), and are not investigated here. Rather, experiments were designed to use agronomic plants to assess any potential negative impacts of such applications (made at recommended rates or higher). A finding of “no effect” based on the observed growth response was taken as an indication of “no environmental effect”.

Table 1: Total amounts of C&D waste disposed and recovered by state (EPA, 2009).

State	Disposed (lbs.)	Recovered (lbs.)	Recovery Rate
Florida	5,277,259	1,998,256	
Maryland	1,913,774	2,270,100	
Massachusetts	720,000	3,360,000	
New Jersey	1,519,783	5,582,336	
North Carolina	1,844,409	20,002	
Utah	1,054,296	46,461	
Virginia	3,465,548	95,131	
Washington	1,780,356	2,640,560	
Total	17,575,425	16,012,846	48%

Table 2: LEED measures, categories of certification, and the point system of certification (UGBC, 2011)

Measures	Categories	points
Sustainable sites	Certified	40-49
Water Efficiency	Silver	50-59
Energy and Atmosphere	Gold	60-79
Materials and Resources	Platinum	≥ 80
Indoor Environmental Quality		
Innovation in Design		
Regional Priority		

Table 3: pH increase in UF additions to Douglus-fir field experiment (Aarino et al. 1996)

Incubation time	24H	1 wk	6 wk	15wk	45wk	54 wk
UF	4.5	4.6	5.1	5.7	6.1	5.7

Table 4: Chemical Composition of Flue-gas desulfurization gypsum (ACAA, 2009)

Major elements % dry wt.	
P	<0.1-0.2
K	0.1
Ca	21.0-23.5
Mg	0.02-0.2
S	16.6-18.6
Si	0.07
Al	0.03-0.2
Minor elements mg/kg dry wt.	
B	75
Mo	1.3
Cu	8
Zn	36
Ni	9.7
Pb	<0.1
Cd	0.01
Cr	10
Se	0.3
Hg	0.01-0.4
As	3.1

Table 5: Sieve test on pulverized wallboard with particle size and percentages (Wolkowski, 2000)

Particle size	Percentage
8 mm	71%
20 mm	61%
60 mm	40%
100 mm	24%

Table 6: Composition and properties of E-fiberglass (Milewski and Katz, 1987)

Chemical Properties of E glass			
Chemical Composition %		Chemical resistance - 14 mm fiber: % weight loss after 1 hr boil in	
SiO_2	52 to56	H_2O	1.7
CaO	16 to25	1.04 N H_2SO_4	48.2
Al_2O_3	12 to16	0.1 N NaOH	9.7
MgO	0 to5	Physical Properties	
B_2O_3	5 to 10	Specific gravity (bare fiber)	2.52 to 2.61
TiO_2	0 to 1.5	Pristine tensile strength, psi	500,000
Na_2O	0 to 2	Tensile elastic modulus, psi	10,500,000
K_2O_3	0 to 2	Elongation at 72 ^{0}F, %	3 to 4
Fe_2O_3	0 to 0.8	Poisson's ratio	0.22
ZnO	-	Thermal Properties	
SO_3	-	Softening Point, ^{o}F	1540 to 1555
F_2	0 to 1.0	Coefficent of thermal expansion - in/in/ ^{o}F x 10 -7	28 to 33
Optical properties		Specific heat at 72 ^{0}F [(k) BTU-in/hr/ft^{2}/ ^{0}F	7.2
Index of refraction	1.55 to 1.56 (a 550 nm)	BTU/lb/ ^{0}F	0.197
Electrical Properties			
Dielectric constant, 72 ^{o}F, 106 Hz	6.1 to 6.7		
Loss tangent, 72 ^{o}F, 106 Hz	0.001		

Table 7: Urea Formaldehyde resin formed at varying pH and subsequent formaldehyde emission (Hse and Higuchi, 2010)

UF resin (pH)	Molar ratio F/U	Formaldehyde emission (mg/L)
UF-1.0	1.3	0.93
UF-4.5	1.3	4.84
UF-5.0	1.3	6.64
UF-1.6	1.3	10.8
UF-0	1.3	5.00

Table 8: Elemental analysis of wallboard and agricultural gypsum

	Wallboard					Gypsum	
	1	2	3	4	5	4	5
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
N	1,500	280	.	.	.	.	.
S	176,000	133,821	.	116,000	164,000	132,000	276,000
Ca	230,000	160,360	4120	260,000	228,000	220,000	212,000
Mg	74,000	8,475	340	22,000	5,500	32,000	1,900
K	1,000	<62	159	500	500	1500	100
Na	161.2	.	.	200	900	100	1000
Mn	114.4	45	9.56	.	150	.	50
P	85.5	<22	43	200	300	40	200
B	48.1	42.5	.	.	20	.	95
Zn	40.2	11.5	1.48	.	19.5	.	8.2
Cr	21.7	11.6	.	59	18.8	.	11.6
Cu	10.3	7.1	0.16	.	12.2	.	8.1
Pb	3.6	15.6	.	.	28.2	.	.
Hg	1.2		.	26	<0.01	.	.
Fe	.	858	.	.	2410	.	805
Al	.	295	.	.	1,320	.	190
Cd	.	3.1	.	.	1	.	1
Co	.	9.2	.	.	4.8	.	4.9
Cl	.	194	.	.	.	.	.
Mo	.	2.7	.	.	.	.	.
Ni	.	20.1	.	.	6.7	.	1
Li	.	<2.5	.	.	.	.	.
As	.	<28	.	.	6.7	.	0.45
Se	.	<19	.	.	.	.	.
Ba	.	.	.	19.7	29.6	.	9.4

References: Colum 1- Carr and Munn, 2001; Colum 2- Wolkowski, 2000 ; Colum 3- Townsend, 2001; Colum 4- Burger, 1993; Colum 5-Gaskin, 2009, "." Indicates missing data or below detection limits.

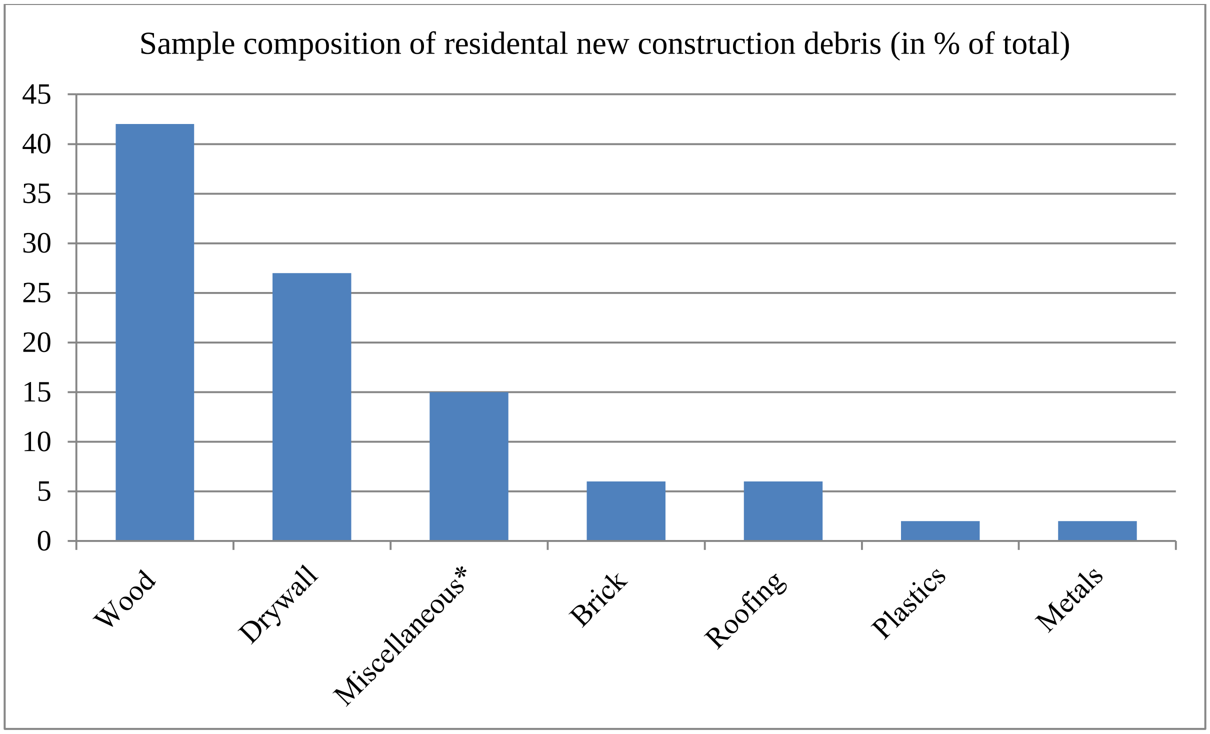

Figure 1: Sample composition of residential new construction debris (EPA, 2009).

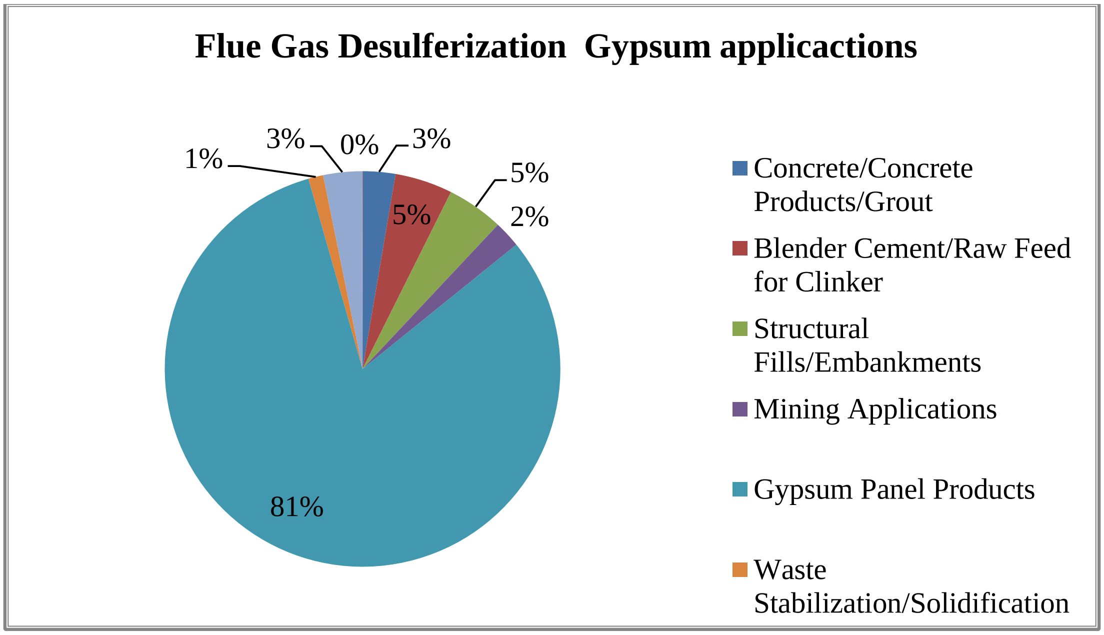

Figure 2: Flue gas desulfurization gypsum applications percentage by category (ACAA, 2009).

CHAPTER 3

MATERIALS AND METHODS

To test the effects of wallboard on agronomic systems, a controlled environment test (greenhouse) was performed using two soils, two crop species, and four types of amendments applied at three rates. Control treatments included no amendment added and treatment with agricultural gypsum added at the three rates.

Soils

A Cecil and Tifton soil were used in the experiments. The Cecil was sampled from a cultivated field at the Plant Sciences Farm in Oconee Co., GA from the 0-10 cm depth; the soil is classified as the Cecil series (fine, kaolinitic, thermic Typic Kanhapludults). The Tifton soil was a loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) sampled from 0-10 cm depth from a continuously cultivated field at the Coastal Plain Experiment Station in Tifton, GA. The soils were chosen because they represent the majority of arable land in the State of Georgia. The Cecil series represents the northern half of the state and the Tifton represents the southern.

Soil particle size analysis

Soils were weighed (50 g) into 500 mL vessels with 15 mL of 10% sodium metaphosphate, and diluted with 425 mL of DI water. The soils were then shaken on low on a reciprocal shaker for 24 hours. The dispersed soils were then poured into 1 liter cylinders and diluted with DI water to the 1 liter mark. The suspensions were mixed and after 40 seconds a reading was taken with a hydrometer. The next day (15 hrs.) another reading was taken. The results are shown in Table 11.

Soil fertilization

Soil tests were performed for fertilizer requirements using the Mehlich 1 method at UGA cooperative extension soil testing laboratory. Recommendations (Table 10) showed the need for P and K additions to the two soils. The soils were initially amended based on soil test recommendations with soluble P and K salts, and N additions were made to all treatments based on crop requirements. The pH values were within the desired range (6.0 to 6.5).

Wallboard Amendments

Three types of wallboard were tested: conventional paper-faced wallboard, the proprietary GP Dens-Glass fiberglass-faced wallboard, and an unspecified mix of paper-faced and fiberglass-faced material. The paper-faced wallboard and mixture wallboard had been stored in outside facilities with no cover from the elements for an undisclosed amount of time. Both the paper-faced wallboard and mixture wallboard were moist upon delivery, and were air-dried prior to processing. The wallboards were ground in a Thomas-Wiley Laboratory Mill Model 4 and screened to <2mm. The portion of wallboards that did not go through the screen was pulverized with Spex 8000 mixer mill and then homogenized into the screened wallboard. The screened wallboards were homogenized to allow for uniform sampling.

Greenhouse Experiment on Plant Growth

The plant cultivars sorghum (SS 800) and wheat (AGS 2031) were grown on the two soils mentioned previously. For each soil/plant combination (two soils x two species), there were five treatments: control (unamended), commercial gypsum, paper-faced wallboard/fiberglass-faced wallboard mixture, paper-faced wallboard, and fiberglass-faced wallboard. The wallboard types were applied at rates of, 11.2, 22.4, and 44.8 Mg/ha; refer to Table 14 for U.S. Ton equivalents. There were 13 total treatments in the experiment, in two soil series, two crops, and three replications for 156 total observational units.

Each pot (3.75 L) was filled with one of the two soils. The soil was amended with waste wallboard according to the rates and type, and then incorporated at a depth of 8 cm to resemble field conditions. An equivalent of 5 cm of water was applied prior to planting and allowed to percolate through the soil and freely drain from the pot. The application of water was to simulate the application of wallboard prior to planting.

The sorghum and wheat were planted on March 20, 2010. The plants were then thinned to 8 wheat plants per pot and 3 sorghum plants per pot on April 8, 2010. The plants were fertilized with a full recommended portion of N-P-K on April 20, 2010 (Table 14) to supplement growth and replace leached nutrients. A half portion of the recommended plant fertilizer was applied on April 29, 2010 and then again on May 15, 2010. Plants were watered daily as needed during the growth period.

Sorghum was harvested on June 1, 2010 and placed in paper bags. The bags were then placed in a BlueM Power-O-Matic 60 dryer, at 60^0 C. The sorghum was cut above advantigious roots (Figure 3). Dead leaves that were slightly attached were discarded and were not incorporated into the biomass weights. The sorghum total dry biomass was weighed and then pulverized with a Thomas-Wiley Laboratory Mill Model 4. The plant matter was ground for a second time with the Spex 8000 mixer/mill in preparation for elemental analysis of the plant matter.

The wheat was harvested on June 7, 2010 and processed similarly to sorghum. All plant matter was included the wheat biomass at approximately 2mm height above the soil surface (Figure 4).

Elemental analysis of plant tissue

Approximately 0.09 g of air dried samples were weighed to four significant digits into sealable teflon microwave digestion vessels. Five mL concentrated trace metal grade nitric acid was introduced and the samples allowed to pre-digest for 30 min. Vessels were then tightened by hand and microwaved for 20 min at 400 w. After cooling, 10 mL of deionized (DI) water was added and the vessels weighed for dilution calculation. This digestion method exceeded the specifications of US EPA method 3050 (USEPA, 1993). Two to three blanks were included in each set of 12 vessels sent through the microwave to monitor background levels.

Analysis was performed by ICP MS (Inductively coupled plasma mass spectroscopy: PerkinElmer ICP-MS model- ELAN 9000). The plant tissue analysis covered the elements of importance. The isotopes of elements evaluated in the ICP were: : ^{135}Ba, ^{137}Ba, ^{111}Cd, ^{75}As, ^{52}Cr, ^{53}Cr, ^{35}Cl, ^{31}P, ^{23}Na, ^{24}Mg, ^{39}K, ^{43}Ca, ^{11}B, ^{27}Al, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{63}Cu, ^{65}Cu, ^{66}Zn, ^{68}Zn, ^{98}Mo, ^{95}Mo, ^{206}Pb, ^{207}Pb, and ^{208}Pb. Various standards were used to validate ICP calibration including, utilization of scandium, rhodium and germanium as internal standards. Three calibration standards were used (1, 100, and 500 ppb) that contained each of the analytes. One quality control check was included during each run which consisted of a different standard made up by a different person. Digestion blanks were measured initially and replications done at the end of the run to assess precision. Background levels or the concentration level in digestion blanks was subtracted from the sample concentrations. Concentrations in mg/kg were computed by using the dilution multiplier which was the volume of the sample divided by the sample weight. The sample volumes were determined by the microwave vessel weight subtracted from the vessel weight after digestion. Detection limits were computed by multiplying the detection limit by the average dilution factor of all the samples.

Soil extractions were done by shaking 5 g in 30 mL of Mehlich-1 extractant for 5 minutes on an Eberbach model 6000 reciprocating shaker. Filtration was performed with Whitman #1 paper. Soil extractions were analyzed on the ICP. The elements that were analyzed were: ^{135}Ba, ^{137}Ba, ^{111}Cd, ^{75}As, ^{52}Cr, ^{53}Cr, ^{35}Cl, ^{31}P, ^{23}Na, ^{24}Mg, ^{39}K, ^{43}Ca, ^{11}B, ^{27}Al, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{63}Cu, ^{65}Cu, ^{66}Zn, ^{68}Zn, ^{98}Mo, ^{95}Mo, ^{206}Pb, ^{207}Pb, and ^{208}Pb. The standards and calibration of the ICP were the same as in the plant digestions.

Gypsum and wallboard materials used were analyzed using the same procedure as for plant tissue.

Soil pH and electrical conductivity determination after growth period

The soil pH was determined using a. Fisher Scientific accumet AB15 Basic pH meter Twenty g of air dried soil was added to a vessel and then 40 mL of deionized water was added to the air dried soil and left to equilibrate for 10 minutes. The Fisher Scientific conductivity meter(S/N 61899544) was used to determination EC on the same soil water mixture.

Statistical Analysis

Statistical analysis was performed using the SAS 9.2 system software using a generalized linear model (GLM). The data was sorted by plant and by amendment and a 2-way GLM procedure (α=0.05), using the variables soil and rates.

Table 9: Soil test results for Cecil and Tifton A horizons used in the greenhouse experiments.

	Phosphorus (P) mg/kg	Potassium (K) mg/kg	Calcium (Ca) mg/kg	Magnesium (Mg) mg/kg	Zinc (Zn) mg/kg	Manganese (Mn) mg/kg	pH (Equivalent water)	pH $CaCl_2$	LBC (ppm $CaCO_3$/pH)	% Total Carbon
Cecil A	43.5	97	577.5	55	2	16	6	5.36	230	1.178
Tifton A	23	57.5	535	70	5	9.5	6.7	6.09	149	0.927

Table 10: Recommended fertilizer applications before planting.

	Plant	Nitrogen (N) mg/kg	Phosphate (P_2O_5) mg/kg	Potash (K_2O) mg/kg
Cecil	Wheat	30-60	0	10
	Sorghum	40	0	25
Tifton	Wheat	30-60	10	25
	Sorghum	40	20	35

Table 11: Particle size analysis determination by hydrometer, sand, silt, and clay percentages

	Cecil	Tifton
Sand %	78	90
Silt %	17	6
Clay %	5	4
Textural class	Loamy Sand	Sand

Table 12: Application rates of wallboard in the experiment in Metric and U.S. Ton.

Metric (Mg/Ha)	U.S. Ton (ton/acre)
11.2	5
22.4	10
44.8	20

Table 13: Full recommend fertilizer application quantities for greenhouse plants (AN (Ammonium Nitrate), K_2O (Potassium Oxide), and $NaH_2PO_4H_2O$ (Sodium Phosphate) in grams per pot).

	AN (g/pot)	K_20 (g/pot)	$NaH_2PO_4{\cdot}H_20$ (g/pot)
Cecil Wheat	15.66	2.95	N/A
Cecil Sorghum	20.88	7.39	N/A
Tifton Wheat	7.83	7.39	2.57
Tifton Sorghum	20.88	10.35	5.15

Table 14: Soil data prior to experimentation (Saturated media extract (SME) method, diethylene triamine pentaacetic acid (DTPA) for extraction)

Soil Series		Cecil A	Tifton A
Base Saturation	(%)	85.5	94.98
OM*	(%)	2.3	1.48
CEC	(meq/100g)	2.13	1.81
	(mg/kg)		
Ca		577	535
Cd		<.0084	<.007
Cr		0.28	0.094
Cu		1.12	0.02
Fe		20	9
K		97	58
Mg		55	70
Mn		16	9
Mo		0.01	0.05
Na		8.8	7.6
Ni		<.041	<.035
P		44	23
Pb		0.72	0.39
Zn		2	5

Figure 3: Sorghum before and after harvesting.

Figure 4: Wheat cut to approximately 2mm above soil surface.

Chapter 4

RESULTS AND DISSCUSSION

A. Amendment composition

The analysis of the amendments was completed and the results of the elemental concentrations are in Tables 15 and 16. Calcium was analyzed in all amendments and yielded no significant differences within the amendments ($\alpha=0.05$). This was an expected result as pure gypsum is approximately 24% calcium. The lower Ca content of the wallboard was due to the presence of the facing materials (paper, fiberglass). Potassium (K) yielded significant differences within the amendments ($\alpha=0.05$). The agricultural gypsum was found to have the highest concentrations of K. The fiberglass-faced wallboard had the lowest concentrations, while the mixed wallboard and paper-faced wallboard had mid-range values. The difference in the K concentrations in the wallboard products is likely due to processing or the natural occurrence in the mined gypsum. Magnesium (Mg) in the amendments yielded significantly higher Mg concentrations in the agricultural gypsum than in all other amendments. Fiberglass-faced wallboard had the lowest concentrations of Mg. The paper-faced wallboard and wallboard mixture had similar concentrations of Mg. Phosphorus (P) analysis showed that agricultural gypsum had the highest concentrations of P, with wallboard mixture the next highest concentration, and fiberglass-faced and Paper-faced wallboard with similar low concentrations of P.

Manganese (Mn) concentrations in amendments yielded significant differences between all amendments (Table 15). Agricultural gypsum was significantly higher in Mn while fiberglass-faced wallboard had the lowest concentrations. Paper-faced wallboard and mixture had concentrations between the fiberglass-faced and agricultural gypsum. Aluminum (Al) in the amendments also produced significant differences. Agricultural gypsum had the highest concentrations of Al and fiberglass-faced wallboard was the lowest. Paper-faced wallboard and the mixture yielded mid-range concentrations of Al, which were not different from each other but significantly different from agricultural gypsum and fiberglass-faced wallboard. Iron (Fe) concentration in amendments generated significant differences between all amendments. Agricultural gypsum was significantly higher in Fe while fiberglass-faced wallboard had the lowest concentrations. Paper-faced wallboard and wallboard mixture had mid-range concentrations Fe. Fiberglass-faced wallboard was significantly higher Na than all other amendments. Paper-faced wallboard and wallboard mixture had similar mid-range Na concentrations. Agricultural gypsum was the lowest in Na concentrations (Table 16). Zn concentrations in amendments were significantly different in agricultural gypsum and the wallboard mixture. The wallboard mixture had the highest Zn concentration while agricultural gypsum had the lowest. All other values were not significantly different ($\alpha=0.05$). The analysis of B concentrations in amendments yielded significantly higher concentrations in the agricultural gypsum. Fiberglass-faced wallboard was significantly lower in B than all other amendments and agricultural gypsum was the highest. Paper-faced wallboard and wallboard mixture had mid-range B concentrations. The highest concentration of cobalt (Co) was in agricultural gypsum and then wallboard mixture. The two lowest concentrations of Co were in paper-faced and fiberglass-faced wallboard. However, the concentrations of Co were near the detection limit of the analytical method used and were overall very low. The molybdenum (Mo) concentrations in the amendments generated significant difference in all amendments. Similar to the analysis for elements the fiberglass-faced wallboard yielded the highest Mo concentrations followed by wallboard mixture, paper-faced, and fiberglass-faced wallboard. The values of Cu found in the amendments were statistically similar.

Arsenic (As) concentrations in fiberglass-faced wallboard had significantly (α=0.05) higher concentrations than all other amendments, and wallboard mixture had the next highest concentration (Table 16). Fiberglass-faced and paper-faced wallboard had similar values of As. The chromium (Cr) concentrations in the amendments yielded significant differences between all amendments. Agricultural gypsum yielded the highest concentrations of Cr. Then wallboard mixture was the next highest Cr concentration, followed by paper-faced and fiberglass-faced wallboard. Agricultural gypsum had the highest concentrations of Pb and then wallboard mixture had the next highest concentrations. Paper-faced wallboard and fiberglass-faced wallboard had the lowest amounts. However, the concentrations were near to detections limits and are not considered consistent data. Both barium (Ba) and cadmium (Cd) were found to have similar values throughout wallboard amendments.

Overall the amendments used in this study were similar in composition to natural and byproduct gypsums reported in the literature (Shainberg et al., 1989; Miller et al., 2000). For the plant nutrients, the only anomaly was the relatively high Mg content (3.6%) of the agricultural gypsum. The trace elements, particularly the contaminant elements (As, Cd, Cr, Pb), were uniformly low in concentration. All were well below the EPA threshold concentrations for contaminants in land-applied sewage sludge (USEPA 503 rule; see Miller and Miller, 2000). Even when applied at high rates (e.g., 20 Mg/ha), amounts of contaminants added to the soil are relatively minor. For instance, mixing 20 Mg of an amendment containing 2 mg/kg As into a ha-20 cm volume of soil (weighing approximately 2,000 Mg) only increases the As concentration in the soil by about 0.02 mg/kg; this is insignificant compared to natural levels of As (and all other trace contaminants) in agricultural soils (Miller and Miller, 2000).

B. Soil extractions (Sorghum)

Agricultural gypsum

The average pH levels across all treatments of Cecil and Tifton soils were significantly different from each other, but within normal agronomic range (Table 17). The control was significantly more acidic than all rates of agricultural gypsum; however, the different rates yielded similar values. The soil electrical conductivity (EC) was significantly different in all rates of agricultural gypsum, as compared to control. As rates of agricultural gypsum increased so did the soil EC, though, the rate of 22.4 Mg/ha yielded no significant difference when compared to the other rates of application. The EC increased in the soils due to the fact that as rates increased the amount of ions increased. Soil extractions for Ca concentrations in soils amended with agricultural gypsum showed no significances ($\alpha=0.05$) between Cecil and Tifton soil series. However, control and rates were significantly different from each other. The Cecil soil series was higher in K than the Tifton soil series due to greater K content prior to experimentation (Table 14). The control was significantly ($\alpha=0.05$) lower in Mg than soils amended at 22.4 and 44.8 (Mg/ha). The high concentration of Mg in agricultural gypsum and the high application rate (44.8 Mg/ha) raised the Mg concentration in the soil. There was a significant soil and rate interaction ($\alpha=0.05$). The Cecil and Tifton soil series had similar increases in Mg. As the rates of application increased the concentrations of Mg increased due to the high concentrations of Mg within the agricultural gypsum. The analysis of soil extractions for P in soils planted with sorghum and amended with agriculture gypsum were not significant.

Manganese, Cu, and Al were higher in the Cecil soils compared to the Tifton (Table 17), due to initially high concentrations of these elements prior to experimentation (Table 14). The Cecil soil series had higher concentrations of Na (Table 18) due to concentrations prior to the experiment (Table 14). Zinc had higher concentrations in the Tifton soil series than the Cecil series, due to initially high concentrations prior to experimentation (Table 14). Cobalt had higher concentrations in the Cecil soil series when compared to the Tifton soil series, and concentrations increased at the 44.8 Mg/ha rate of amendment (Table 18). However, the concentrations were near the detection limit and considered not significant. Lastly, Boron (B), Iron (Fe) and Molybdenum (Mo) were found to not be significantly affected due to amendments.

Arsenic (As) concentrations were significantly higher in the Tifton when compared to the Cecil soil series (Table 18) this is likely due to past cropping history involving use of arsenical pesticides. Lead (Pb) concentrations increased when amended by a factor of 2 in all amended soils, from 0.4 mg/kg to approximately 0.8 mg/kg. This was unexpected due to low Pb levels in the amendment. Barium (Ba), cadmium (Cd), and chromium (Cr) were not significantly different between soils or rates in soil extractions.

Paper-faced wallboard

. The comparison of amendment rates yielded a lower control pH than all rates of paper-faced wallboard (Table 19), similar to the agriculture gypsum. The electrical conductivity (EC) yielded significances (α=0.05). The control had the lowest EC and increased as rates increased, although, not significantly between all rates. Calcium increased at all rates of application, and Mg increased in the 44 Mg/ha application. Also, interaction of soils by rates was observed. The Cecil apparently showed a significantly higher concentration of Mg in the 44 Mg/ha rate of paper-faced wallboard. The Cecil soil apparently showed a resistance to Mg leaching compared to the Tifton. This is due to the higher CEC and soil surface area of the Cecil soil. The Tifton bore a difference in the low concentration of Mg at 11.2 Mg/ha rate as opposed to the high concentration at 44.8 Mg/ha rate. As mentioned previously, Tifton was unable to resist the Mg leaching from the additions of $CaSO_4$ additions due to the low CEC (Table 14) and low surface area. The potassium (K) concentrations were significantly higher in Cecil than Tifton soil due to initial higher K prior to experimentation (Table 14). The P concentrations increased in all rates of application due to amendment concentrations. The iron (Fe) concentrations were higher in the Cecil when compared to the Tifton soil. Sodium (Na) was higher in the Tifton soil than the Cecil soil (Table 20). The Cecil was significantly higher in Cu than Tifton (Table 19) due to higher Cu concentrations prior to experiments (Table 14). Also, Cu was decreased at all rates of application of paper-faced wallboard. Aluminum was higher in the Cecil soil when compared to the Tifton (Table 19). Cobalt was higher in the Cecil soil when compared to the Tifton soil (Table 20), although Co concentrations are considered unreliable because they are at the detection limit of the ICP. Boron, manganese, zinc, and molybdenum were not significantly affected by amendments. Leads (Pb) was significantly increased by all application rates of paper-faced wallboard (Table 20) but were at relatively low levels in all treatments. Arsenic (As) increased at the higher amendment rates but only by a small amount. Barium (Ba) decreased in all rates of amendments because of the competition in the soil solution of the Ca cation. Chromium (Cr) increased at all rates of amendments but Cd was not significantly affected by the application of paper-faced wallboard.

Wallboard mixture

The pH reacted to amendment as discussed previously (Table 21). The electrical conductivity (EC) also increased as rates of wallboard mixture increased. Calcium increased at all rates of application, as did magnesium (Mg) in the 44.8 Mg/ha rate of amendment due to additions of Mg in the amendments (Table 15). The Cecil soil had higher K due to initially high concentrations prior to experimentation (Table 14). However, there was an increase of K at the highest rate of application (44.8 Mg/ha) of wallboard mixture. Phosphorus increased when soils were amended and boron was unaffected. The Cecil soil had a higher concentration of Mn due to initial concentrations prior to experimentation. There was a soil by rate interaction. The Cecil has a Mn increase in the 44.8 Mg/ha rate and the Tifton had a decrease in the 11.2 rate of application. Soil extractable Fe was unaffected by amendment application, Fe was higher in the Cecil when compared to the Tifton soil (Table 14). Also, Cecil was higher in Cu in the initial soil test which was also observed in soil extractions after experimentation. The Tifton soil had higher concentrations of Zn from the preliminary soil test (Table 14) than the Cecil soil, and these differences were also noted in soil extractions (Table 22). Soil extractable Mo showed no significance differences. Aluminum concentrations were higher in the Cecil soil series when compared to the Tifton, increased in all rates of amendments. A soil by rate interaction was noted in the Cecil due to the addition of Al in the amendments. The cobalt was at higher in the Cecil soil compared to the Tifton but was at very low levels. Tifton soil had higher soil extractable Na due to initial higher concentrations prior to experimentation. Lead (Pb) increased at all rates of application similar to the other amendments. Chromium concentrations increased as rates increased as did arsenic (As) but only in the 44.8 Mg/ha rate. Also, the Tifton soil series had a higher concentration of As and Cd when compared to the Cecil. Barium concentrations decreased as wallboard mixture increased (Table 22).

Fiberglass-faced wallboard

Soil pH and EC increased at all rates of amendment as did Ca; however, Ca significantly increased to each rate of application (Table 23). Magnesium concentrations decreased in the 11.2 and 22.4 Mg/ha rate. There was an increase in K concentrations in the 22.4 and 44.8 Mg/ha rates. Also, an interaction was noted in the soil by rates in Cecil soil, but not in Tifton. There was an evident K increase due to the additions of K in fiberglass-faced wallboard. Soil extractable B and Mn showed no treatment effect. Cecil soil was higher in Fe than Tifton and increased significantly at each rate of amendment. Copper (Cu) and molybdenum (Mo) were not significantly affected by applications of fiberglass-faced wallboard. Zinc had higher concentrations in Tifton than in the Cecil (Table 24) because of higher concentrations of Zn prior to experimentation (Table 14) but were unaffected by amendments. The Cecil soil series had the highest concentrations of Al when compared to Tifton, increased at all rates of application. The impact was particularly evident in the Cecil soil and where Al concentrations increased as rates increased (Table 23). There was an increase in Co at the rates of 22.4 and 44.8 Mg/ha, however, the concentrations were near the detection limits and are considered insignificant. Sodium (Na) increased in the 44.8 Mg/ha rate and was evident in the Cecil soil where Na significantly increased in the 44.Mg/ha rate. Phosphorus (P) concentrations significantly increased at all rates of application due to P additions in amendments (Table 15) as did lead (Table 24). Chromium (Cr) and arsenic (As) increased with all application rates, but these increases were relatively small. Cadmium was unaffected by applications of wallboard. Barium concentrations were significantly higher in the Cecil when compared to the Tifton soil series (Table 24) and tended to decrease Ba as amendment rate increased.

C. Sorghum biomass and tissue composition

Agricultural gypsum

Sorghum biomass grown on amended soils with agriculture gypsum was not affected by application rate (Table 25). The application of agricultural gypsum did not adversely affect the growth of sorghum. Calcium (Ca) and magnesium (Mg) in plant tissue did increase at all rates of amendment. The concentrations of Mg and phosphors (P) were significantly higher in Tifton soil, due to initial concentrations prior to experimentation (Table 14). The strong decrease in tissue P levels at the 11.2 and 22.4 Mg/ha rates compared to control and 44.8 Mg/ha rates was unexpected, and may be an artifact. Sorghum plant tissue potassium (K), aluminum (Al), sodium (Na), zinc (Zn), and iron (Fe), were unaffected by applications of agricultural gypsum (Table 25 and 26). Manganese (Mn) and copper (Cu) concentrations were significantly higher in the Cecil soil series due to initial concentrations prior to experimentation (Table 14). Also, Mn decreases as rates increase due to Ca competition for uptake within sorghum. Similarly, Cu decreases but only in the 44.8 Mg/ha rate of agricultural gypsum. Boron (B) and molybdenum (Mo) were similarly higher in the Tifton soil potentially due to the initial soil concentrations prior to experimentation (Table 26). Cobalt (Co) and cadmium (Cd) significantly decreased in the 11.2 and 22.4 Mg/ha rates; however, the concentrations were near the detection limits. Also, chromium decreased in the 11.2 and 22.4 Mg/ha rate and lead (Pb) was unaffected. Similarly, Arsenic (As) and Barium (Ba) decreased in the in the 11.2 and 22.4 Mg/ha rate and increased in the 44.8 Mg/ha rate. Likewise, the elements showed a soil rate interaction in the Tifton soil where concentrations decreased as applications of agricultural gypsum was added. The anomalies at the 11.2 and 22.4 Mg/ha rate may be due to analytical issues that were unresolved.

Paper-faced wallboard

Biomass was unaffected by applications of paper as were plant tissue Fe, Al, and P (Table 27). Calcium and Mg in plant tissue were significantly higher in the Tifton soil because of initially high concentrations prior to experimentations. However, Ca in the plants increased in all rates and Mg decreased in all rates of application of paper-faced wallboard. Manganese and Cu were higher in the Cecil soil and both decreased in concentration at the 44.8 Mg/ha rate. Potassium was significantly decreased in the Tifton soil at all rates of application. However, Boron (B), chromium (Cr), and zinc (Zn) were not significantly affected by applications of paper-faced wallboard (Table 28). The Tifton soil had high molybdenum (Mo) and arsenic (As) concentrations initially in the soil (Table 14). Cobalt (Co) and cadmium (Cd) were detection limits and not affected by treatments. Lead, despite being higher in amended soils, has not significantly increased in plant tissue by the wallboard additions. Barium (Ba) in plant tissue significantly decreased in the 22.4 Mg/ha application of paper-faced wallboard applications.

Wallboard Mixture

The sorghum biomass, Al, and Fe concentrations were unaffected by applications of the wallboard mixture (Table 29). Calcium was increased at all rates of applications of wallboard mixture. Magnesium and P were both higher in the Tifton soil series because of initial soil concentrations (Table 14) and they both decreased at all rates of amendments. However, P showed the anomalous behavior noted previously. Manganese (Mn) and Cu were significantly higher in the Tifton soil and the decrease of Mg was evident in the 22.4 and 44.8 Mg/ha rate of application. Potassium (K) was significantly decreased in the Tifton soil in all rates of application due to competitive uptake with Ca. Boron (B), zinc (Zn), molybdenum (Mo), and sodium (Na) showed no significance due to application of wallboard mixture (Table 30). Cobalt (Co), cadmium (Cd), and lead (Pb) concentrations were at low levels and unaffected by treatments. Arsenic (As) and chromium (Cr) in plant tissue decreased at the 11.2 and 22.4 Mg/ha rates, but increased to near control levels at the highest rate (44.8 Mg/ha). Barium (Ba) decreased at all rates of application.

Fiberglass-faced wallboard

The biomass of sorghum and tissue concentrations of calcium (Ca), aluminum (Al), copper (Cu), and iron (Fe) were not significantly affected by the application of fiberglass-faced wallboard (Table 31). Both magnesium (Mg) and phosphorus (P) decreased at all rates of application. Also, P was significantly decreased in both Tifton and Cecil soil series at all rates of application. Potassium (K) was similarly decreased in plants grown on the Tifton soil at all rates of application. Manganese (Mn) was significantly higher in the Cecil soil but it was due to the initially soil concentrations prior to experimentation (Table 14). Arsenic (As), chromium (Cr) and molybdenum (Mo) (Table 32) were all higher in the Tifton soil due to initially high concentrations (Table 14). Similarly, the concentrations of these elements decreased when amended at the 11.2 and 22.4 Mg/ha rate. Tissue arsenic and Cr were significantly decreased in the Tifton soil at the 11.2 and 22.4 Mg/ha rate of fiberglass-faced wallboard. Also, Cr was decreased in the Cecil soil at the same rates. Cobalt (Co), cadmium (Cd), and lead (Pb) concentrations were unaffected by treatments. Also, sodium (Na), zinc (Zn), and boron (B) were not significantly affected by the application of fiberglass-faced wallboard.

D. Discussion and interpretation of sorghum data

Plant biomass (yield) can indicate problems in plant growth due to inhibiting compounds present in the amendments. The biomass of sorghum was unaffected by the application of waste wallboard and specifically the addition of fiberglass-faced wallboard (Figure 5). Similarly, previous research attests to increased yields or no effect (Burgar, 1993; Wolkolsiki, 1998; Townsend, 2001). For instance, corn grain production was increased by 26% and 25% on plots receiving low and high applications of wallboard, respectively, compared to control. The higher yields were hypothesized to result from higher Ca, Mg, and S in the soil solution (Burger, 1993). Also, Wolkolsiki (1998) found that alfalfa was unaffected by additions of paper-faced wallboard. Yields of bibb lettuce, chinese cabbage, collards, and green cabbage amended with paper-faced wallboard were unaffected by applications of up to 22.4 Mg/ha (Townsend et al., 2001).

While gypsum is not a liming material, it may affect soil pH via various secondary reactions. The pH was increased in all amended soils due to a secondary chemical reaction when $CaSO_4$ was applied, known as the "self-liming effect" (Figure 6). The interactions and subsequent chemical speciation has been described by Pavan et al. (1984). The chemical reactions are thought to be either sulfate polymerization of Al-oxide or the Ca-hydroxide and Al interactions. Another mechanism suggested is that OH^- is replaced by sulfate adsorption on Fe and Al oxides surfaces (Pavan et al., 1984).

$$[Fe, Al](OH)_2 + CaSO_4.2H_2O = [Fe, Al]OHSO_4^- \ 1/2Ca^{2+} + 1/2Ca(OH)_2$$

$$2Al_3 + 3Ca(OH)_2 = 2Al(OH)_3 + 3Ca^{2+}$$

(Reeve and Sumner, 1972)

These reactions resulted in a reduction of exchangeable Al from 1.6 to 0.6 $_c$mol /kg in the 0 to 10-cm horizon (in the gypsum treatment) (Pavan et al., 1984). Sub-soil acidity is an issue in highly weathered soils due to the high phytotoxic levels of exchangeable Al and Mn (Korcak, 1993). Additions of gypsum have reduced exchangeable Al and increased root penetration. In most cases the high Al and Mn is associated with low levels of Ca (Korcak, 1993). The GEOCHEM computer program has been used to describe the chemical interactions of $CaSO_4$. The addition of gypsum caused a decrease of Al by 40% in a surface horizon and approximately 60% in the subsoil. Gypsum additions contributed to only 3% of the exchangeable Al being leached, the remainder being polymerized into an insoluble forms (Pavan et al., 1984).

Calcium is an important part of this research due to the constant necessity to replenish the element. The application of amendments significantly (α=0.05) increased the Ca soil concentrations (Figure 7). The application of all amendments showed a significant increase in soil extractable Ca as well as a significant increase in sorghum tissue levels Ca as compared to control (Figure 8). The soil extractions show an expected increase in Ca concentrations in all amendments as the amendment rates increased. An increase in Ca concentrations within plant tissue has been noted in previous literature (Burger, 1993; Wolkowski, 2000; Townsend, 2001). For instance, Ca increased 3.2 and 8.4 times in soils receiving the low and high (24.6 Mg/ha and 49.3 Mg/ ha) applications of wallboard (Burger, 1993). Plant tissue digestions showed that Ca uptake into the plant increased in all rates, yet the concentrations were not significantly different from each other.

A reduction of plant available K was the expected response to high $CaSO_4$ additions and has been documented in the literature (Alva et al., 1991; Shainberg et al., 1989). However, no significant differences were shown in soil extractable K due to Ca interactions (Figure 9). The decrease in sorghum tissue K, however, was pronounced in all wallboard amendments and rates (Figure 10). This reduction of K in sorghum tissue was likely due to competition at the root surface between Ca and K ions. The high soluble levels of Ca in amended soils inhibited K uptake.

Extractable Mg increased in 3 of 4 wallboard amendments. The amendments applied had various amounts of Mg (Table 15). Agriculture gypsum had the highest concentration, decreasing in paper, mixture, and the lowest in fiberglass. No apparent leaching of Mg due to Ca amendment was observed (Figure 11). However, plant tissue levels were clearly depleted in Mg with amendment (Figure 12). Magnesium concentrations in the control were significantly higher in comparison to all rates of amendments. Previous research has shown significant gypsum effects on soil Mg. In one, study gypsum-amended soil contained approximately 0.10 $cmol_c$ Mg/kg and untreated soil contained approximately 0.55 cmol Mg/kg (Pavan, 1984). Furthermore, the application of waste wallboard decreased soil Mg, although 9 kg of Mg were applied for every Megagram of wallboard. In this case Ca displaced Mg from the topsoil due to competition. Soil Mg test in Spooner soil (Typic Dystrochrepts) decreased at high application rates (36 Mg/ha) in the last two years of the experiment. Mg had decreased so much that there was a possibility of deficiency of Mg in crops (Wolkowski, 2000). Similarly, forage Mg was reduced at higher applications rates and due to competitive uptake at the root surface. Forage Mg concentrations were below what is considered sufficient (< 3.0 g/kg) for alfalfa. Sandy textured soils that are low in Mg are susceptible to Mg deficiencies (Wolkowski, 2000). In terms of animal health, grass tetany can develop in ruminates that feed on forages low in Mg (Korcak, 1993). The application of gypsum to a Tifton soil planted with peanuts showed greater leaching of Mg compared to sandy clay loam soils. However, high Mg in the fruiting zone can cause an increase peanut pod rot, a decrease in sound mature kernels, and a decrease in yield (Alva et al., 1991). Applications of wallboard did increase corn grain production by 26% and 25% on plots receiving low and high application. Similarly, corn ear leaf Mg increased due to the addition of wallboard. Magnesium was found to be 2.7 times higher in plots receiving the high application (49.3 Mg/ha) of wallboard (Burger, 1993).

Barium ingestion is hazardous to human health at high levels. Moderate plant toxicity of Ba occurs at 220 ppm ash weight (Srivastava and Gupta, 1996) and has been shown to be greatly reduced by the addition of Ca, Mg, and S salts (Kabata-Pendias, 2001). Similarly, Ca competition reduced Ba in corn ear leaf tissue below detection limits (< 1.0 mg/kg) with the application of agricultural gypsum and waste wallboard (Burger, 1993). In this study soil extractions showed that increased rates of wallboard decreased soil extractable Ba, likely due to the displacement of Ba by Ca on the CEC sites (Figure 13). The control had the highest concentration of Ba, but amended treatments contained significantly less Ba. The amendments in this experiment had low Ba concentrations. Sorghum uptake of Ba was strongly reduced by all amendments. This was likely due to both reduced soil Ba and by Ca competition for uptake at the root surface (Figure 14).

Arsenic (As) is a known carcinogen (Fayiga et al., 2007) and the World Health Organization (WHO) has set a provisional tolerable weekly intake (PTWI) of inorganic As of 15 μg/kg body mass from food and water (Cao and Ma, 2004). Similarly, Japan has set an arsenic loading limit (15 ppm) on paddy soils, due to the high As accumulation in rice grains (Srivastava and Gupta, 1996). The amendments used in this experiment contained 0.7-2 mg As /kg, agriculture gypsum being the highest. However, paper, mixture, and fiberglass materials showed the largest increase in soil extractable As, most pronounced in the Tifton soil (Figure 15). The levels were not greatly elevated, however, increasing only from about 0.2 to 0.35 mg/kg. This increase may have been due to As added in the amendment, or to the effect of higher soil pH caused by amendment addition. However, arsenic was inhibited from being adsorbed into the sorghum plant tissue due to the antagonistic relationship with other elements particularly sulfate. Sulfate applications have shown to alleviate the effects of As toxicity in some soils (Srivastava and Gupta, 1996). Furthermore, in the acid soils the main species of As is $H_2AsO_4^-$ (Srivastava and Gupta, 1996). The As anion is bound by Fe at low pH (pH 4), as pH increases Al is the dominant complex, and pH 6-8 is bound by Ca-As (Fayiga et al., 2007). A hyperaccumlating plant (Pteris vittata) showed an increase in Ca-As complex after 8 weeks of growth in increasing pH (6.8-7.6). Furthermore, phosphorus (P) can decrease or increase bioavailability of As due to competition or displacement of adsorbed As. For instance, the use of MAP (monoammonium phosphate) in contaminated Pb-As soils increased As solubility and increased phytoavailability (Srivastava and Gupta, 1996). Also, P fertilizer applications showed an increase in As incorporated in carrots and lettuce in As contaminated soils (27 to 43 mg/kg) and decreased concentrations in biosolid compost additions (Cao and Ma, 2004). In this experiment, arsenic concentrations within the sorghum were at tolerable levels (0.4 ppm dry weight). Plant tissue As strongly decreased at the lowest two addition rates for 3 of the 4 amendments, but increased at the highest rate (Figure 16). This was an unexpected result, and was driven largely by the Tifton soil, which had initially higher As levels compared to Cecil. As uptake of the control Tifton soil was relatively high (0.45 mg/kg), and none of the tissue As levels in treated soils exceeded the control (untreated) levels.

Chromium (Cr) is commonly known for toxicity although it is required for human and animal nutrition (Kabata-Pendias, 2001). The amendments had varying concentrations of Cr, with agriculture gypsum having a significantly higher concentration than the mixture, paper, and fiberglass (Table 16). The highest Cr concentration in initial soil test was in the Cecil soil series

(Table 14), related to its high clay content. However, extractable Cr in the two soils increased with increasing rate of amendment, particularly for the three wallboard materials (Figures 17). It is unclear why the agriculture gypsum, with the highest Cr level of 16 mg/kg, did not result in increased Cr in the amended soils, while the lower Cr wallboards did so. The plant tissue Cr in the sorghum showed a response to amendment similar to As: the two lower rates caused decreases in tissue Cr compared to control, while the highest rate was similar to the untreated soil. This was true for all amendments except the paper wallboard, which had tissue levels unaffected by rates of amendments. Chromium has several different oxidation states, such as, Cr^{3+} which are very stable in soils (pH 5.5 mostly precipitated). However, Cr^{6+} (CrO_4^{2-}, $HCrO_4^{\ 2-}$) is relatively mobile in the soil (Kabata-Pendias, 2001). Other factors that can affect the mobility and speciation of Cr are clay content and organic matter. The absorption of Cr by clays is highly pH dependent: while Cr^{6+} adsorption decreases as pH increases, the adsorption of Cr^{3+} increases as soil pH increases. Lastly, organic matter stimulates the reduction of Cr^{6+} to Cr^{3+}, which is dependent on soil parameters and especially soil acidity (Kabata-Pendias, 2001).

The sorghum tissue concentrations (Figure 18) displayed some unusual results. The concentration of sorghum tissue Cr was not affected by paper applications. However, gypsum, mixture, and fiberglass amendments decreased Cr concentration in the 11.2 and 22.4 Mg/ha rate. Also, mixture and fiberglass amendments revealed interactions of soil series and rate. The mixture and fiberglass showed significant decreases in Cr in the 11.2 and 22.4 Mg/ha rate and an increased concentration in the 44.8 Mg/ha; the anomalous results did not exceed controls. The addition of Cr to soil affects the Cr contents of plants but uptake is inefficient (Kabata-Pendias, 2001). However, when the Cr is added to the soil Cr content of plants and the rate of Cr uptake by plants is dependent on several soil and plant factors (Kabata-Pendias, 2001). Other factors that can cause the decrease of Cr are, liming, P application, and organic matter are known to effective in reducing chromate toxicity in Cr polluted soils (Kabata-Pendias, 2001). Similarly, another mechanism of Cr loss in the soil solution is the leaching of SO_4^{-2} to obtain electrochemical neutrality (Burger, 1993). In conclusion the application of amendments significantly decreased Cr concentrations due to SO_4^{-2} interaction. But the application of Cr at the highest rate allowed Cr to become incorporated into the sorghum.

E. Wheat soil extractions

Agricultural Gypsum

Soil pH and EC measured at the end of the greenhouse experiment were significantly increased at all rates of application because of the addition of agricultural gypsum (Table 33). However, potassium (K), manganese (Mn), phosphorus (P), copper (Cu), and iron (Fe) were not significantly affected. Calcium increased at the 22.4 and 44.8 Mg/ha rate and Mg was decreased at the same rates. Aluminum was higher in the Cecil soil due to initially high concentrations prior to experimentation (Table 14). Cadmium (Cd), cobalt (Co), and Chromium (Cr) concentrations were near detection limits and were not strongly influenced by amendment (Table 34). Sodium (Na), barium (Ba), and molybdenum (Mo) were not significantly affected by the application of agricultural gypsum. Lead (Pb) was increased in soil extractions due to amendments, increasing from 0.4 to 0.86 in the highest rate. Boron (B) increased a similar amount. Zinc (Zn) and arsenic (As) were higher in the Tifton soil while chromium (Cr) was high in the Cecil soil, likely due to initial concentrations prior to experimentation (Table 14).

Paper-faced wallboard

The pH, Ca, and EC increased at all rates of application of the paper-faced wallboard (Table 35). Potassium (K), copper (Cu), and iron (Fe) were not significantly affected by applications of paper-faced wallboard. Magnesium (Mg) decreased in 11.2 Mg/ha while phosphorus increased at all rates of application. Aluminum (Al) was higher in the Cecil soil because of initial higher concentrations prior to experimentation (Table 14). Cadmium (Cd) and cobalt (Co) concentrations were again near detection limits and at low levels (Table 36). Boron and Pb again showed increases with higher amendment rates. Both molybdenum (Mo) and sodium (Na) were not affected by the application of paper-faced wallboard. Barium decreased with increasing amendment, presumably due to displacement by Ca added in the gypsum.

Wallboard Mixture

The soil pH, EC, and Ca were significantly increased in all rates of amendments due to wallboard mixture amendment (Table 37). Magnesium (Mg), phosphorus (P), and aluminum (Al) were increased in concentration at all rates of wallboard mixture, though Mg only increased at the 44.8 Mg/ha rate. Potassium content in soils was not affected by treatment. Boron (B) and Pb were significantly increased in the soils at the higher rates of application, as noted for the other amendments. Barium (Ba) decreased in the Cecil in all rates of application and decreased in the Tifton at the 22.4 and 44.8 Mg/ha rate (Table 38). Cadmium (Cd) and Cobalt (Co) were again very low. Molybdenum (Mo) was not significantly affected by applications of wallboard mixture. Chromium (Cr) and Arsenic (As) increased with application of the wallboard mixture, although both remained at concentrations less than 0.3 ppm in both soils.

Fiberglass-faced wallboard

The soil pH, EC, Ca, P, Al, and Fe were significantly increased at all rates of amendments due to the addition of fiberglass-faced wallboard (Table 39). Manganese (Mn) and copper (Cu) were not significantly affected by the application of fiberglass-faced wallboard. Magnesium (Mg) was decreased in the soil extractions while K was unaffected due to applications of fiberglass-faced wallboard. Cadmium (Cd), cobalt (Co), chromium (Cr) concentrations were again low and near detections limits (Table 40). Barium (Ba) decreased at only the 44.8 Mg/ha rate of fiberglass-faced wallboard.

F. Wheat tissue analysis

Agricultural gypsum

The wheat biomass was significantly higher on Cecil than Tifton soil (Table 41). The increased yield was likely due to higher CEC, nutrient retention, and waster holding capacity for the Cecil soil. However, yields were unaffected by gypsum additions. Plant tissue Ca increased dramatically with gypsum amendment at all rates, while K and Mg remained unaffected. However, P in tissue did decrease a the highest application rate. Cadmium (Cd), cobalt (Co), chromium (Cr) and lead (Pb) concentrations were at low levels and unaffected by treatments (Table 42). Molybdenum increased from 0.5 to 1.2 ppm at the highest rate, which was not observed in the sorghum tissue. Both As and Ba significantly decreased at all rates of amendments, and Ba was particularly decreased in the Tifton soil at the 22.4 and 44.8 Mg/ha rate of application.

Paper-faced wallboard

Wheat yields were not influenced by rates of paper-faced wallboard additions (Table 43). Potassium, P, Al, and Fe in plant tissue were unaffected by applications of paper-faced wallboard. Both Mg and Cu were higher in the Cecil because of initially concentrations prior to experimentation, as were Ca and Mn. Calcium (Ca) increased at all rates of amendments and Mn decreased in the 22.4 and 44.8 Mg/ha. Sodium, Zn, B, Cd, Co, Cr, and Pb were unaffected by applications of paper-faced wallboard (Table 44). Arsenic, Mo, and Ba were higher in wheat grown on Tifton soil due to higher soil concentrations prior to experimentation, while As and Ba decreased in all rates of amendment.

Wallboard mixture

Trends apparent in other wallboard amendments were also observed with the mixed wallboard waste: Cecil soil yielded better than Tifton, and amendment did not affect plant growth (Table 45), due to higher concentrations of plant nutrients in the initial soil test (Table 14). Calcium in tissue again increased in the 22.4 and 44.8 Mg/ha rates of amendment and Mn decreased at 44.8 Mg/ha. Potassium, P, Al, Mg, and Fe were not significantly affected by amendments. Molybdenum, As, and Ba were all higher in the Tifton soil because of the initial soil concentrations prior to experimentation (Table 46); As decreased at all rates of amendments and Ba decreased at the 11.2 and 22.4 rate of amendment. Molybdenum increased in plant tissue at the 22.4 and 44.8 Mg/ha. All other measured elements were unaffected by applications of wallboard mixture.

Fiberglass-faced wallboard

The fiberglass-faced wallboard waste again did not affect wheat yields at any application rate (Table 47). Calcium again increased in the plant tissue, but Mg and P both decreased at higher rates. Trace elements behaved similarly as well: As and Ba decreased with wallboard addition, and Mo increased, although erratically (Table 48).

G. Wheat biomass and tissue composition

Gypsum and waste wallboard effects on wheat biomass, pH and soil and plant tissue Ca were similar to sorghum as was expected (Figure 19, 20, 21, 22). Molybdenum showed quite different behavior in the wheat experiment initial soil concentrations of Mo prior to experimentation ranged from 0.01 ppm in the Cecil to 0.05 ppm in the Tifton (Table 14) and the soils test after experimentation show that 0.01 to 0.08 ppm (Figure 23). However, soil extractable Mo was not affected by amendments and soil Mo toxicity was not an issue in the soils used in this experiment. For instance, Mo concentrations of > 10 ppm dry weight is of great concern for most livestock and grazer toxicity has been noted at 1.5 to 5.0 ppm dry weight in grasses (Kabata-Pendias, 2001) . The analysis of Mo in the soil extractions yielded no significant differences throughout all amendments, although appreciable amounts of Mo were present in the amendments (Table 19). Mo was probably immobilized due to the acidic (< 5.5) pH of the control and strongly absorb onto Fe/Al oxides. Soils that are high in Fe/Al oxides typically have low Mo concentrations (Kabata-Pendiask, 2001). Molybdenum increased in wheat tissue (Table 24), which was related to chemical interaction of P fertilization, nitrate additions, and most importantly by the pH increase. The availability of soil Mo for plants is strongly increased by raising pH. Additions of P ($H_2PO_4^-$) can increase soil solution Mo by the exchange or displancment of absorbed $MoO_4{}^{2-}$ (Havlin, et al., 1999). Wheat grown on Tifton soil increased in Mo for all amendments, due initial high soil concentrations (Table 14), the additions in the amendments, and the lack of high concentrations of Fe/Al oxides that would absorb Mo. Similarly, Mo concentrations increased as rates increased. This was due to the increase in the pH and thus yielding more soil solution Mo. However, the 44.8 Mg/ha of fiberglass amendment decreased in Mo, perhaps due to lower inputs of Mo in amendments, competition for up-take with S, and a lesser pH increase. The speciation of Mo as MoO_4^{2-} leads to interactions with other major anions, and PO_4^{3-}, but especially SO_4^{2-} (Gupta, 1997). High levels of $SO_4{}^{2-}$ can cause Mo deficiencies (Havlin et al., 1999). Plant materials typically have < 1ppm Mo, deficient plants contain < 0.2 ppm and soils have ranges of 0.2 to 5 ppm Mo (Havlin et al. 1999). The soil and plant concentrations observed in this experiment fall within sufficient ranges it is unlikely the amendment had any deleterious effects due to Mo.

The soil extractions of Mn were not significantly affected by the application of amendments (Figure 25). Initial soil tests (Table 14) shows a higher concentration of Mn in the Cecil (16 ppm) than the Tifton (9 ppm) soil series and amendments had substantial concentrations of Mn. Wheat Mn uptake was affected by the application of amendments (Figure 26). The gypsum, paper, and mixture had significantly decreased concentrations of Mn at the higher rates. Fiberglass amendment significantly reduced Mn at all rates application. The reason for the Mn decrease is probably the increase in the pH due to applications of $CaSO_4$. A decrease in Mn in the soil solution has been recognized for each unit increase in pH (Kabata-Pendias, 2001; Havlin, 1999). The uptake is metabolically controlled as for other divalent cation species such as Mg^{2+} and Ca^{2+} (Havlin,1999). Mn in plant parts are considered to be deficient if they are below 15 to 20 ppm dry weight and wheat is particularly sensitive to low levels in the soil

(Havlin, 1999; Kabata-Pendias, 2001). Toxic levels of Mn in wheat (Triticum aestivum) have been recognized to be 1200 ppm and < 400 ppm was considered to not harmful to wheat growth (Sparrow and Uren, 1987). The application of wallboard amendments did decrease Mn concentrations but only as a secondary effect to due to pH increase. It seems likely that an application of fiberglass-faced wallboard within the parameters of the experiment (e.g. soil elemental concentrations, pH, etc.) would not hinder wheat growth due to decreases of Mn uptake.

In this experiment, amended soils showed an increase in As in soil extractions (Figure 27). There was 1-2 ppm As concentrations in the amendments (Table 16), which was not sufficient to increase soil extractable As by 0.05 to 0.1 ppm. The likely reason for this was the noted pH increase, which makes AsO_4^{-3} anion more soluble due to weaker adsorption to Fe and Al oxides. Interestingly, however, As uptake by wheat decreased significantly with all amendments and rates (Figure 28). The opposite behavior of Mo discussed previously, is likely due to the greater effect of SO_4^{2-} anion in inhibiting As uptake, as noted in the literature (Srivastava and Gupta, 1996). Phosphate may also inhibit As uptake, and the amounts of P added in the amendments may have had an effect as well. Soil extractable P increased with most treatments, although tissue P tended to decrease, similar to the situation with As. In conclusion, the decrease of As in the plant material was due to high additions of $CaSO_4$ by the increase in pH and competition for uptake by S or P.

Barium toxicity has been shown to be greatly reduced by the addition of Ca, Mg, and S salts (Kabata-Pendias, 2001). Consequently, the reduction of Ba in corn ear leaf nutrients was lowered below detection limits (< 1.0 mg/kg detection limit) in agricultural gypsum, low and high wallboard treatments due to Ca competition for uptake (Burger, 1993). In this study, Ca competition for uptake was the reason for Ba reduction in wheat plant tissue. Barium was present in moderate amounts in the amendments (20-50 ppm), but except for the agricultural gypsum extractable Ba decreased with increasing amendment rates (Figure 29). This was likely due to the high Ca levels which displaced added Ba from CEC sites and leached it away. Plant uptake of Ba was uniformly reduced by Ca-containing amendments (Figure 30).

CHAPTER 5

SUMMARY AND CONCLUSIONS

This study was undertaken in order to assess the effect of ground waste wallboard, particularly fiberglass-faced wallboard that had not be studied previously, on agronomic plant growth and composition. Rates from 11 to 44 Mg/ha were applied in a greenhouse experiment with sorghum and wheat grown over a 108 day period on two common Georgia topsoils, and the impact of the amendments determined on soil properties, plant yield, and plant tissue composition, including both plant nutrients and environmental contaminants. In addition to untreated controls, commercial agricultural gypsum was used as a further control to evaluate impacts of the wallboard amendments.

The three ground wallboard amendments used contained low amounts of both plant nutrients (other than Ca and S, which made up the majority of the mass) and contaminants; contaminant levels (e.g., As, Pb, and Cr) were typically lower in the wallboards than in the agricultural gypsum. Even at the highest rate of amendment (44 Mg/ha), amounts of contaminants added to the soils were lower, in most cases much lower, than the levels present in the soils initially. However, the large Ca and SO_4 additions made with the amendments certainly had the potential to cause significant changes in soil chemistry and plant uptake of elements in the amended soils.

At the end of the plant growth phase of the greenhouse experiment, considerable undissolved gypsum remained in the treated soils, and the pH and electrical conductivity of the soil had been increased significantly. Soil extractable K and Mg were unaffected by amendments. Of the trace elements, some consistently increased in treated soils (Pb, As), but the levels never were high enough for environmental concern, and for the wallboard wastes, levels were consistently equal to or less than the agricultural gypsum treatment. This suggests that the ground wallboard wastes do not have a deleterious effect on soil properties or quality.

Plant growth as measured by biomass at the end of the experiment was not statistically affected by kind or rate of amendment. Plant tissue composition did vary systematically on amended soils for certain elements. Wheat tissue K and Mg were unaffected but sorghum tissue was decreased but not to deficient levels. Of the trace elements several increased (Mo) and several decreased (Ba) but within very limited ranges. Despite these changes, the overall quality of the plant material was still within normal ranges for nutrients and not excessive with respect to contaminants.

The overall conclusion of this study is that these wallboard amendments may be safely used on residential or agricultural lands as amendments to supply Ca without deleterious soil or environmental effects. The limitations of the study are that only a limited number of wallboard wastes were evaluated on just two crops and two soils, and only in a short-term greenhouse trial. Nutrient imbalances observed in this study may become more pronounced as crops mature and form seed; uptake of contaminants likewise might change over time of maturation. Further studies are warranted in a field setting, potentially using other waste wallboards. The relative uniformity of the three materials tested here, however, suggest that the longer-term effects in a field setting would be the most profitable for further research.

Table 15: Amendment elemental composition (Part 1).

Amendment	Ca	K	Mg	Mn	P	Al	Cu	Fe
				mg/kg				
Gypsum	207278	1445_{a}	36266_{a}	151_{a}	186_{a}	2110_{a}	4.19	4918_{a}
Paper	176168	590_{b}	3098_{bc}	68_{b}	64_{b}	1140_{b}	7.27	1894_{b}
Mixed	182096	810_{c}	3690_{c}	83_{c}	78_{c}	1529_{b}	6.39	2354_{c}
Fiberglass	166788	389_{d}	596_{b}	23_{d}	63_{db}	437_{c}	6.39	891_{d}
	NS						NS	

Table 16: Amendment elemental composition (Part 2).

Amendment	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Gypsum	332_{a}	38_{a}	141_{a}	1.96_{a}	21	0.01	2.31_{a}	16_{a}	1.1_{a}	4.71_{a}
Paper	1041_{b}	83_{ab}	48_{b}	0.68_{bd}	52	0.03	0.82_{b}	4_{b}	0.53_{b}	2.06_{ab}
Mixed	1076_{b}	102_{b}	52_{b}	0.94_{c}	53	0.04	1.02_{c}	5_{c}	0.62_{c}	2.61_{b}
Fiberglass	1522_{c}	62_{ab}	30_{c}	0.67_{d}	18	0.04	0.59_{d}	3_{d}	0.17_{d}	2.01_{c}
					NS	NS				

Table 17: Elemental concentrations in soil extractions from two soils planted with sorghum and amended by various rates of agricultural gypsum (Part 1)

Soil	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS				mg/kg				
Cecil	5.99_{a}	1.28	2340	29_{a}	108	20_{a}	34	108_{a}	4.34_{a}	27
Tifton	6.39_{b}	1.23	2324	19_{b}	104	17_{b}	34	71_{b}	1.26_{b}	21
		NS	NS		NS		NS			NS

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.64_{a}	0.1_{a}	521_{a}	22	36_{a}	18	27	87	4.11	20
11.2	6.72_{b}	1.27_{b}	1912_{b}	24	76_{ab}	18	35	94	2.55	24
22.4	6.69_{b}	1.71_{bc}	2842_{c}	24	122_{b}	18	37	87	2.45	24
44.8	6.72_{b}	1.94_{c}	4053_{d}	25	190_{c}	21	37	90	2.08	27
				NS		NS	NS	NS	NS	NS

Soil	Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.43	0.10	492	25	26_{a}	17	26	98	5.49	21
Cecil	11.2	6.47	1.49	2149	31	89_{ab}	21	37	120	4.36	30
Cecil	22.4	6.52	1.73	3227	29	143_{b}	20	33	103	4.08	27
Cecil	44.8	6.55	1.82	3493	30	174_{b}	22	39	111	3.42	30
Tifton	0	4.85	0.10	550	18	45_{a}	18	28	77	2.73	19
Tifton	11.2	6.96	1.05	1675	17	63_{a}	14	33	69	0.74	18
Tifton	22.4	6.86	1.68	2458	19	101_{a}	17	40	71	0.81	22
Tifton	44.8	6.89	2.07	4612	20	206_{b}	20	35	68	0.74	25
		NS	NS	NS	NS		NS	NS	NS	NS	NS

Table 18: Elemental concentrations in soil extractions from two soils planted with sorghum and amended by various rates of agricultural gypsum (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	65_{a}	2.11_{a}	0.72	0.10_{a}	0.59	0.03	0.14_{a}	0.10	0.02	0.68
Tifton	77_{b}	6.85_{b}	0.96	0.24_{b}	0.55	0.04	0.05_{b}	0.08	0.01	0.65
			NS		NS	NS		NS	NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	68	4.37	1.03	0.15	0.62	0.04	0.07_{a}	0.07	0.01	0.39_{a}
11.2	72	5.80	0.67	0.17	0.59	0.03	0.09_{ab}	0.10	0.02	0.75_{b}
22.4	67	3.95	0.77	0.17	0.56	0.03	0.09_{ab}	0.09	0.02	0.76_{b}
44.8	77	3.81	0.88	0.17	0.51	0.03	0.11_{b}	0.10	0.01	0.76_{b}
	NS	NS	NS	NS	NS	NS		NS	NS	

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	61	1.78	0.42	0.07	0.67	0.03	0.10	0.06	0.01	0.38
Cecil	11.2	69	2.39	0.76	0.11	0.64	0.03	0.14	0.13	0.01	0.84
Cecil	22.4	59	2.12	0.83	0.10	0.53	0.03	0.14	0.10	0.03	0.74
Cecil	44.8	71	2.16	0.86	0.11	0.55	0.03	0.16	0.12	0.02	0.74
Tifton	0	75	6.95	1.64	0.23	0.57	0.05	0.04	0.07	0.01	0.39
Tifton	11.2	75	9.22	0.58	0.23	0.54	0.04	0.04	0.07	0.02	0.66
Tifton	22.4	74	5.79	0.72	0.25	0.59	0.04	0.05	0.09	0.01	0.77
Tifton	44.8	82	5.45	0.91	0.23	0.47	0.04	0.06	0.09	0.01	0.78
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 19: Elemental concentrations in soil extractions from two soils planted with sorghum and amended by various rates of paper-faced wallboard (Part 1)

Series	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS	mg/kg							
Cecil	5.86_{a}	1.62	2752	30_{a}	44	18	35	118_{a}	3.50_{a}	24_{a}
Tifton	6.15_{b}	1.67	2587	18_{b}	37	16	38	80_{b}	1.19_{b}	20_{b}
		NS	NS		NS	NS	NS			

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.64_{a}	0.09_{a}	521_{a}	22	36_{a}	18	27_{a}	87_{a}	4.11_{a}	20
11.2	6.14_{b}	2.09_{b}	2003_{b}	24	27_{a}	16	38_{b}	96_{ab}	1.68_{b}	18
22.4	6.54_{c}	2.17_{bc}	3533_{c}	25	41_{a}	17	38_{b}	105_{b}	1.70_{b}	22
44.8	6.69_{c}	2.21_{c}	4621_{d}	26	59_{b}	18	42_{b}	108_{b}	1.88_{b}	26
				NS		NS				NS

Series	Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.43	0.10	492	25	26_{a}	17	26	98	5.49	21
Cecil	11.2	5.95	2.08	1849	30	31_{a}	17	34	113	2.75	19
Cecil	22.4	6.41	2.10	3673	31	47_{ab}	18	40	127	2.64	24
Cecil	44.8	6.64	2.20	4993	33	71_{b}	20	39	135	3.11	30
Tifton	0	4.85	0.10	550	18	45_{ab}	18	28	77	2.73	19
Tifton	11.2	6.33	2.09	2157	17	23_{a}	15	42	78	0.62	16
Tifton	22.4	6.67	2.24	3393	18	34_{ab}	17	36	83	0.75	21
Tifton	44.8	6.74	2.23	4249	19	48_{b}	15	44	82	0.65	22
		NS	NS	NS	NS		NS	NS	NS	NS	NS

Table 20: Elemental concentrations in soil extractions from two soils planted with sorghum and amended by various rates of paper-faced wallboard (Part 2)

Series	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	57_{a}	1.70	0.59	0.10_{a}	0.47	0.03	0.11_{a}	0.11	0.02	0.56
Tifton	65_{b}	8.03	0.89	0.25_{b}	0.42	0.04	0.04_{b}	0.11	0.01	0.55
		NS	NS		NS	NS		NS	NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	68	4.37	1.03	0.15_{a}	0.62_{a}	0.04	0.07	0.07_{a}	0.01	0.39_{a}
11.2	57	8.01	0.47	0.17_{ab}	0.46_{b}	0.03	0.07	0.12_{b}	0.01	0.54_{b}
22.4	58	3.58	0.66	0.20_{b}	0.37_{bc}	0.03	0.08	0.13_{b}	0.02	0.63_{bc}
44.8	63	3.50	0.81	0.18_{ab}	0.32_{c}	0.03	0.09	0.14_{b}	0.01	0.67_{c}
	NS	NS	NS			NS	NS		NS	

Series	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	61	1.78	0.42	0.07	0.67	0.03	0.10	0.06	0.01	0.38
Cecil	11.2	52	1.56	0.42	0.10	0.51	0.03	0.11	0.12	0.01	0.53
Cecil	22.4	54	1.63	0.63	0.11	0.39	0.03	0.11	0.13	0.04	0.64
Cecil	44.8	62	1.82	0.88	0.12	0.33	0.03	0.13	0.14	0.01	0.69
Tifton	0	75	6.95	1.64	0.23	0.57	0.05	0.04	0.07	0.01	0.39
Tifton	11.2	63	14.45	0.52	0.25	0.42	0.04	0.04	0.12	0.01	0.56
Tifton	22.4	61	5.53	0.69	0.28	0.35	0.04	0.04	0.13	0.00	0.62
Tifton	44.8	63	5.19	0.73	0.24	0.32	0.03	0.04	0.13	0.00	0.65
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 21: Elemental concentrations in soil extractions from two soils planted with sorghum and amended by various rates of wallboard mixture (Part 1)

Soil	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS				mg/kg				
Cecil	5.91_{a}	1.57	2435	31_{a}	40	18_{a}	38	123_{a}	4.12_{a}	27
Tifton	6.23_{b}	1.58	2280	19_{b}	43	16_{b}	41	82_{b}	1.24_{b}	25
		NS	NS		NS		NS			NS

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.64_{a}	0.10_{a}	521_{a}	22_{a}	36_{a}	17_{ab}	27_{a}	87_{a}	4.11	20
11.2	6.32_{b}	1.86_{b}	1508_{b}	24_{ab}	26_{a}	15_{a}	42_{b}	103_{b}	1.60	20
22.4	6.55_{c}	2.14_{c}	2702_{c}	26_{ab}	38_{a}	17_{ab}	43_{b}	109_{b}	2.56	27
44.8	6.77_{d}	2.21_{c}	4698_{d}	28_{b}	66_{b}	18_{b}	45_{b}	111_{b}	2.44	37
									NS	NS

Soil	Rate (Mg/kg)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.43	0.10	492	25	26	16_{a}	26	98_{a}	5.49	21
Cecil	11.2	6.15	1.92	1724	31	30	17_{ab}	41	128_{b}	2.55	21
Cecil	22.4	6.40	2.09	2748	34	39	18_{ab}	41	129_{b}	4.41	29
Cecil	44.8	6.66	2.19	4776	35	67	20_{b}	45	138_{b}	4.02	36
Tifton	0	4.85	0.10	550	18	45	18_{a}	28	77	2.73	19
Tifton	11.2	6.49	1.80	1292	17	22	13_{b}	44	78	0.65	19
Tifton	22.4	6.70	2.19	2656	19	37	15_{ab}	46	89	0.72	26
Tifton	44.8	6.88	2.24	4620	22	66	15_{ab}	46	84	0.86	37
		NS	NS	NS	NS	NS		NS		NS	NS

Table 22: Elemental concentrations in soil extractions from two soils planted with sorghum and amended by various rates of wallboard mixture (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	59 $_{a}$	1.97 $_{a}$	0.56	0.11 $_{a}$	0.54	0.03 $_{a}$	0.11 $_{a}$	0.18	0.02	0.63
Tifton	66 $_{b}$	6.31 $_{b}$	1.05	0.28 $_{b}$	0.53	0.04 $_{b}$	0.04 $_{b}$	0.16	0.02	0.68
			NS		NS			NS	NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	68	4.37	1.03	0.15 $_{a}$	0.62 $_{a}$	0.04	0.07 $_{a}$	0.07 $_{a}$	0.01	0.39 $_{a}$
11.2	59	3.86	0.66	0.19 $_{ab}$	0.63 $_{a}$	0.03	0.07 $_{a}$	0.18 $_{b}$	0.01	0.68 $_{b}$
22.4	63	4.07	0.67	0.21 $_{ab}$	0.50 $_{ab}$	0.03	0.08 $_{ab}$	0.22 $_{b}$	0.03	0.76 $_{b}$
44.8	62	4.26	0.85	0.22 $_{b}$	0.38 $_{b}$	0.03	0.09 $_{b}$	0.22 $_{b}$	0.02	0.81 $_{b}$
	NS	NS	NS			NS			NS	

Soil	Rate (Mg/kg)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	61	1.78	0.42	0.07	0.67	0.03	0.10	0.06	0.01	0.38
Cecil	11.2	58	1.68	0.47	0.11	0.62	0.03	0.11	0.19	0.01	0.64
Cecil	22.4	59	1.95	0.53	0.13	0.49	0.03	0.11	0.24	0.02	0.72
Cecil	44.8	59	2.47	0.80	0.14	0.37	0.03	0.13	0.24	0.03	0.79
Tifton	0	75	6.95	1.64	0.23	0.57	0.05	0.04	0.07	0.01	0.39
Tifton	11.2	60	6.05	0.85	0.27	0.65	0.04	0.04	0.18	0.02	0.73
Tifton	22.4	66	6.19	0.81	0.30	0.52	0.04	0.05	0.20	0.05	0.79
Tifton	44.8	64	6.06	0.90	0.30	0.39	0.04	0.05	0.20	0.01	0.82
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 23: Elemental concentrations in soil extractions from two soils planted with sorghum and amended by various rates of fiberglass-faced wallboard (Part 1)

Soil	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS	mg/kg							
Cecil	5.55	1.54	2941	33$_{a}$	28	18	42	137$_{a}$	6	42$_{a}$
Tifton	5.96	1.54	2823	20$_{b}$	23	16	42	89$_{b}$	4	35$_{b}$
	NS	NS	NS		NS	NS	NS		NS	

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.63$_{a}$	0.1$_{a}$	521$_{a}$	22$_{a}$	36$_{a}$	18	27$_{a}$	87$_{a}$	4	20$_{a}$
11.2	5.88$_{b}$	1.87$_{b}$	1544$_{b}$	26$_{ab}$	17$_{b}$	16	43$_{b}$	113$_{b}$	5	31$_{b}$
22.4	6.17$_{b}$	2.05$_{bc}$	3540$_{c}$	29$_{b}$	21$_{b}$	17	47$_{b}$	121$_{bc}$	6	45$_{d}$
44.8	6.33$_{b}$	2.14$_{c}$	5922$_{d}$	30$_{b}$	27$_{ab}$	17	51$_{b}$	130$_{c}$	5	58$_{c}$
						NS			NS	

Soil	Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.43	0.10	492	25$_{a}$	26	17	26	98$_{a}$	5	21
Cecil	11.2	5.68	1.88	1656	32$_{ab}$	24	17	43	137$_{b}$	8	36
Cecil	22.4	5.95	2.05	3824	36$_{b}$	27	18	47	149$_{b}$	7	50
Cecil	44.8	6.15	2.13	5792	40$_{b}$	34	19	53	164$_{b}$	6	60
Tifton	0	4.85	0.10	550	18	45	18	28	77	3	19
Tifton	11.2	6.10	1.87	1432	21	10	15	43	89	3	26
Tifton	22.4	6.39	2.04	3256	22	16	16	47	94	5	40
Tifton	44.8	6.52	2.15	6052	21	21	16	49	96	4	56
		NS	NS	NS		NS	NS	NS		NS	NS

Table 24: Elemental concentrations in extracts of two soils planted with sorghum amended by rates of fiberglass-faced wallboard (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	69	1.99_{a}	0.46	0.13	0.69_{a}	0.03	0.12_{a}	0.20	0.04	0.80
Tifton	73	6.38_{b}	0.73	0.30	0.59_{b}	0.04	0.05_{b}	0.20	0.02	0.80
	NS		NS	NS		NS		NS	NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	68_{a}	4.37	1.03	0.15_{a}	0.62_{a}	0.04	0.07_{a}	0.07_{a}	0.01	0.39_{a}
11.2	70_{ab}	4.13	0.30	0.21_{b}	0.95_{b}	0.04	0.08_{ab}	0.24_{b}	0.03	0.91_{b}
22.4	69_{ab}	4.09	0.40	0.24_{b}	0.58_{ac}	0.04	0.09_{b}	0.23_{b}	0.03	0.93_{b}
44.8	77_{b}	4.17	0.64	0.26_{b}	0.42_{c}	0.04	0.10_{b}	0.26_{b}	0.06	0.96_{b}
		NS	NS			NS			NS	

Soil	Rate (Mg./ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	61_{a}	1.78	0.42	0.07	0.67	0.03	0.10	0.06	0.01	0.38
Cecil	11.2	65_{a}	1.93	0.29	0.13	1.07	0.03	0.12	0.22	0.04	0.94
Cecil	22.4	68_{a}	2.08	0.39	0.16	0.59	0.03	0.14	0.25	0.04	0.93
Cecil	44.8	84_{b}	2.20	0.73	0.17	0.45	0.04	0.14	0.27	0.05	0.94
Tifton	0	75	6.95	1.64	0.23	0.57	0.05	0.04	0.07	0.01	0.39
Tifton	11.2	74	6.32	0.31	0.30	0.83	0.04	0.04	0.26	0.01	0.89
Tifton	22.4	70	6.10	0.41	0.33	0.56	0.04	0.05	0.22	0.01	0.93
Tifton	44.8	71	6.15	0.56	0.35	0.40	0.04	0.06	0.24	0.07	0.98
			NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 25: Elemental concentrations of sorghum planted in two soils amended with rates of agriculture gypsum (Part 1)

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g				mg/kg				
Cecil	26	6415	12441	2379$_{a}$	50$_{a}$	919$_{a}$	6	4.53$_{a}$	45
Tifton	30	6459	11575	3023$_{b}$	35$_{b}$	1400$_{b}$	8	1.93$_{b}$	55
	NS	NS	NS				NS		NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	27	5452$_{a}$	12520	3731$_{a}$	56$_{a}$	2364$_{a}$	13	3.54$_{a}$	53
11.2	24	7059$_{b}$	12029	2479$_{b}$	43$_{ab}$	202$_{b}$	1	3.59$_{a}$	45
22.4	30	6563$_{b}$	12053	2439$_{b}$	37$_{b}$	184$_{b}$	1	3.10$_{ab}$	49
44.8	31	6674$_{b}$	11429	2154$_{b}$	32$_{b}$	1889$_{ac}$	11	2.70$_{b}$	53
	NS		NS				NS		NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	27	5126	11529	2863	57	1478$_{a}$	8	4.75	41
Cecil	11.2	22	7310	14397	2619	58	202$_{ab}$	1	5.27	48
Cecil	22.4	28	6416	12082	2194	46	183$_{b}$	1	4.43	46
Cecil	44.8	28	6809	11756	1840	37	1812$_{c}$	12	3.66	45
Tifton	0	27	5779	13511	4599$_{a}$	55	3249$_{a}$	19	2.34	64
Tifton	11.2	27	6808	9662	2340$_{b}$	28	202$_{b}$	1	1.90	42
Tifton	22.4	32	6710	12024	2683$_{b}$	29	186$_{b}$	2	1.77	53
Tifton	44.8	35	6538	11102	2469$_{b}$	27	1965$_{c}$	9	1.73	60
		NS	NS	NS		NS		NS	NS	NS

Table 26: Elemental concentrations of sorghum planted in two soils amended with rates of agriculture gypsum (Part 2).

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	22	16.96	7.18_{a}	0.09_{a}	2.60	0.05	0.02	0.80_{a}	0.17_{a}	0.15
Tifton	153	20.87	8.40_{b}	0.22_{b}	4.48	0.08	0.03	1.34_{b}	0.55_{b}	0.26
	NS	NS			NS	NS	NS			NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	41	21.15	8.38	0.26_{a}	10.61_{a}	0.13_{a}	0.03_{ab}	1.93_{a}	0.49	0.38
11.2	4	19.19	7.12	0.02_{b}	0.79_{b}	0.00_{b}	0.00_{a}	0.11_{b}	0.22	0.01
22.4	5	18.81	7.48	0.02_{b}	0.35_{b}	0.00_{b}	0.01_{a}	0.39_{b}	0.27	0.01
44.8	301	16.52	8.18	0.32_{c}	2.40_{b}	0.13_{ac}	0.05_{b}	1.84_{ac}	0.45	0.41
	NS	NS	NS						NS	NS

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	36	17.18	7.44	0.07_{ab}	6.38	0.09	0.02	1.11	0.36	0.48
Cecil	11.2	4	20.00	5.67	0.01_{a}	0.84	0.00	0.00	0.12	0.00	0.01
Cecil	22.4	3	17.05	7.70	0.02_{a}	0.31	0.00	0.00	0.13	0.14	0.00
Cecil	44.8	46	13.62	7.91	0.26_{b}	2.85	0.11	0.04	1.86	0.24	0.11
Tifton	0	47	25.11	9.33	0.45_{a}	14.84_{a}	0.18	0.03	2.75	0.62	0.29
Tifton	11.2	4	18.38	8.56	0.03_{b}	0.74_{b}	0.00	0.00	0.11	0.50	0.00
Tifton	22.4	8	20.57	7.25	0.03_{b}	0.39_{b}	0.00	0.01	0.66	0.41	0.02
Tifton	44.8	555	19.42	8.44	0.38_{c}	1.94_{b}	0.14	0.06	1.83	0.66	0.71
		NS	NS	NS			NS	NS	NS	NS	NS

Table 27: Elemental concentrations of sorghum planted in two soils amended with rates of paper-faced wallboard waste (Part 1)

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g	mg/kg							
Cecil	27	6243 $_a$	12387	2364 $_a$	53 $_a$	1713	16	4.54 $_a$	47
Tifton	27	7380 $_b$	12846	2841 $_b$	38 $_b$	2356	8	1.79 $_b$	66
	NS		NS			NS	NS		NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	27	5452 $_a$	12520	3731 $_a$	56 $_a$	2364	13	3.54 $_a$	53
11.2	26	7092 $_b$	12271	2247 $_b$	46 $_{ab}$	1813	8	3.10 $_{ab}$	56
22.4	25	7460 $_b$	13049	2287 $_b$	41 $_{ab}$	1870	0	3.33 $_{ab}$	61
44.8	30	7242 $_b$	12626	2147 $_b$	38 $_b$	2092	27	2.69 $_b$	56
	NS		NS			NS	NS		NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	27	5126	11529	2863	57	1478	8	4.75	41
Cecil	11.2	27	6078	12061	2274	53	1368	8	4.53	43
Cecil	22.4	26	6937	13404	2332	53	2099	1	4.86	49
Cecil	44.8	29	6832	12553	1987	48	1907	47	4.03	53
Tifton	0	27	5779	13511 $_a$	4599	55	3249	19	2.34	64
Tifton	11.2	26	8107	12481 $_b$	2220	40	2257	8	1.67	70
Tifton	22.4	25	7983	12695 $_b$	2241	29	1642	0	1.82	72
Tifton	44.8	30	7653	12698 $_b$	2306	27	2276	7	1.36	59
		NS	NS		NS	NS	NS	NS	NS	NS

Table 28: Elemental concentrations of sorghum planted in two soils amended with rates of paper-faced wallboard waste (Part 2).

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	186	17.72	8.27	0.10 a	4.50	0.09	0.03	1.92	0.32 a	0.28
Tifton	29	22.45	8.88	0.35 b	5.25	0.23	0.04	2.96	0.60 b	1.48
	NS	NS	NS		NS	NS	NS	NS		NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	41	21.15	8.38	0.26	10.61 a	0.13	0.03	1.93	0.49	0.38
11.2	34	19.72	6.57	0.24	3.36 ab	0.19	0.05	3.27	0.38	2.65
22.4	21	19.05	8.94	0.15	0.63 b	0.11	0.02	1.81	0.53	0.15
44.8	332	20.43	10.40	0.26	4.89 ab	0.20	0.05	2.76	0.43	0.34
	NS	NS	NS	NS		NS	NS	NS	NS	NS

Soil	Rate	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	36	17.18	7.44	0.07	6.38	0.09	0.02	1.11	0.36	0.48
Cecil	11.2	34	16.19	6.46	0.09	3.21	0.05	0.02	1.06	0.25	0.08
Cecil	22.4	17	18.24	7.90	0.10	0.00	0.10	0.03	2.53	0.38	0.11
Cecil	44.8	655	19.27	11.28	0.15	8.39	0.11	0.06	2.99	0.30	0.44
Tifton	0	47	25.11	9.33	0.45	14.84	0.18	0.03	2.75	0.62	0.29
Tifton	11.2	34	23.25	6.67	0.40	3.51	0.32	0.09	5.48	0.52	5.23
Tifton	22.4	25	19.86	9.99	0.20	1.26	0.12	0.02	1.10	0.68	0.18
Tifton	44.8	9	21.59	9.52	0.36	1.39	0.28	0.04	2.53	0.56	0.23
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 29: Elemental concentrations of sorghum planted in two soils amended with rates of wallboard mixture waste (Part 1)

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g				mg/kg				
Cecil	27	6274	12163	2319 $_{a}$	51 $_{a}$	932 $_{a}$	3	4.52 $_{a}$	42
Tifton	29	6653	11626	2952 $_{b}$	36 $_{b}$	1403 $_{b}$	15	1.61 $_{b}$	47
	NS	NS	NS				NS		NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	27	5452 $_{a}$	12520	3731 $_{a}$	56 $_{a}$	2364 $_{a}$	13	3.54	53
11.2	26	6987 $_{b}$	11627	2265 $_{b}$	43 $_{ab}$	193 $_{b}$	1	3.27	44
22.4	29	6833 $_{b}$	11289	2243 $_{b}$	39 $_{b}$	171 $_{b}$	1	2.66	41
44.8	30	6581 $_{b}$	12143	2304 $_{b}$	36 $_{b}$	1943 $_{c}$	22	2.79	40
	NS		NS				NS	NS	NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	27	5126	11529	2863	57	1478 $_{a}$	8	4.75	41
Cecil	11.2	23	7244	12734	2476	56	195 $_{ab}$	1	4.99	43
Cecil	22.4	28	6618	12286	1972	47	159 $_{b}$	1	4.14	48
Cecil	44.8	29	6107	12104	1966	43	1897 $_{c}$	2	4.19	36
Tifton	0	27	5779	13511 $_{a}$	4599	55	3249 $_{a}$	19	2.34	64
Tifton	11.2	29	6730	10519 $_{b}$	2054	31	190 $_{b}$	1	1.55	45
Tifton	22.4	30	7049	10292 $_{b}$	2514	30	183 $_{b}$	1	1.18	35
Tifton	44.8	30	7055	12182 $_{b}$	2642	28	1988 $_{c}$	41	1.38	45
		NS	NS		NS	NS		NS	NS	NS

Table 30: Elemental concentrations of sorghum planted in two soils amended with rates of wallboard mixture waste (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
	mg/kg									
Cecil	14	17.13	7.57	0.05_{a}	1.70	0.04_{a}	0.01	0.87	0.27	0.20
Tifton	63	21.97	8.02	0.22_{b}	6.05	0.08_{b}	0.02	1.26	0.48	0.16
	NS	NS	NS		NS		NS	NS	NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	41	21.15	8.38	0.26_{a}	10.61_{a}	0.13_{a}	0.02_{ac}	1.93_{a}	0.49	0.38
11.2	26	21.84	6.83	0.02_{b}	0.37_{b}	0.00_{b}	0.00_{b}	0.17_{b}	0.32	0.05
22.4	6	17.60	7.59	0.02_{b}	0.25_{b}	0.00_{b}	0.00_{b}	0.14_{b}	0.27	0.07
44.8	80	17.61	8.38	0.23_{c}	4.25_{ab}	0.12_{ac}	0.03_{ac}	2.03_{ac}	0.42	0.21
	NS	NS	NS						NS	NS

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	36	17.18	7.44	0.07	6.38	0.09	0.02	1.11_{ab}	0.36	0.48
Cecil	11.2	3	18.56	7.36	0.01	0.25	0.00	0.00	0.14_{a}	0.20	0.01
Cecil	22.4	9	16.78	7.83	0.01	0.17	0.00	0.00	0.14_{a}	0.24	0.02
Cecil	44.8	9	16.00	7.67	0.09	0.00	0.09	0.03	2.10_{b}	0.28	0.28
Tifton	0	47	25.11	9.33	0.45_{a}	14.84	0.18	0.03	2.75_{ac}	0.62	0.29
Tifton	11.2	49	25.12	6.30	0.03_{b}	0.50	0.00	0.00	0.20_{b}	0.44	0.08
Tifton	22.4	3	18.43	7.34	0.03_{b}	0.34	0.00	0.00	0.13_{b}	0.31	0.13
Tifton	44.8	151	19.22	9.10	0.36_{c}	8.51	0.15	0.03	1.95_{c}	0.56	0.15
		NS	NS	NS		NS	NS	NS		NS	NS

Table 31: Elemental concentrations of sorghum planted in two soils amended with rates of fiberglass-faced wallboard (Part 1).

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g				mg/kg				
Cecil	28	6573	12472	2470	55_{a}	908_{a}	10	4.72	49
Tifton	28	7090	11882	2794	40_{b}	1455_{b}	8	2.72	52
		NS	NS	NS			NS	NS	NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	27	5452	12520	3731_{a}	56	2364_{ac}	13	3.54	53
11.2	27	7758	12352	2439_{b}	51	197_{b}	1	5.88	56
22.4	29	7038	12015	2167_{b}	43	183_{b}	1	2.77	47
44.8	31	7079	11821	2192_{b}	40	1981_{ac}	20	2.68	45
	NS	NS	NS		NS		NS	NS	NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	27	5126	11529	2863	57	1478_{a}	8	4.75	41
Cecil	11.2	26	7824	14083	2831	63	192_{a}	1	5.76	67
Cecil	22.4	29	6724	12925	2151	51	181_{ab}	1	4.24	50
Cecil	44.8	32	6621	11351	2037	50	1779_{ac}	32	4.11	38
Tifton	0	27	5779	13511_{a}	4599	55	3249_{a}	19	2.34	64
Tifton	11.2	29	7693	10621_{b}	2047	40	202_{b}	1	5.99	46
Tifton	22.4	30	7352	11104_{b}	2183	36	184_{b}	1	1.30	44
Tifton	44.8	30	7537	12291_{b}	2346	30	2183_{c}	9	1.26	52
		NS	NS		NS	NS		NS	NS	NS

Table 32: Elemental concentrations of sorghum planted in two soils amended with rates of fiberglass-faced wallboard (Part 2).

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
	mg/kg									
Cecil	40	18.39	6.93	0.05_{a}	3.50	0.04_{a}	0.01	0.80_{a}	0.28_{a}	0.15
Tifton	24	21.71	8.04	0.25_{b}	4.46	0.09_{b}	0.02	1.34_{b}	0.42_{b}	0.17
	NS	NS	NS		NS		NS			NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	41	21.15	8.38	0.26_{a}	10.61_{a}	0.13_{a}	0.03_{a}	1.93_{a}	0.49_{a}	0.38
11.2	5	23.10	7.62	0.02_{b}	0.74_{b}	0.00_{b}	0.01_{ab}	0.14_{b}	0.24_{b}	0.06
22.4	4	18.98	6.69	0.02_{b}	0.30_{b}	0.00_{b}	0.00_{b}	0.19_{b}	0.29_{ab}	0.02
44.8	78	16.97	7.26	0.29_{c}	4.28_{a}	0.12_{ac}	0.04_{ac}	2.03_{ac}	0.37_{ab}	0.17
	NS	NS	NS							NS

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	36	17.18	7.44	0.07	6.38	0.09	0.02	1.11_{ab}	0.36	0.48
Cecil	11.2	6	22.64	7.37	0.01	0.99	0.00	0.00	0.13_{a}	0.28	0.01
Cecil	22.4	3	17.52	6.37	0.01	0.29	0.00	0.00	0.16_{a}	0.22	0.01
Cecil	44.8	116	16.21	6.55	0.10	6.34	0.08	0.03	1.81_{b}	0.24	0.11
Tifton	0	47	25.11	9.33	0.45_{ac}	14.84	0.18	0.03	2.75_{a}	0.62	0.29
Tifton	11.2	4	23.56	7.87	0.04_{b}	0.49	0.00	0.01	0.15_{b}	0.19	0.11
Tifton	22.4	5	20.44	7.01	0.03_{b}	0.30	0.00	0.00	0.22_{b}	0.36	0.03
Tifton	44.8	39	17.74	7.96	0.47_{ac}	2.21	0.17	0.05	2.25_{ac}	0.51	0.24
		NS	NS	NS		NS	NS	NS		NS	NS

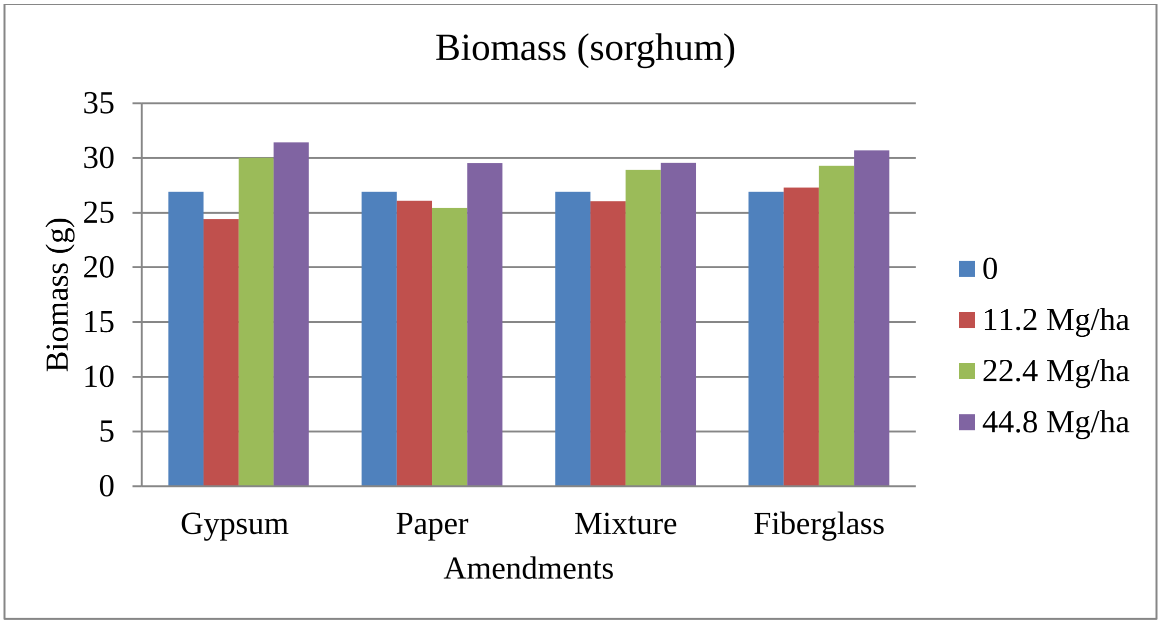

Figure 5: Biomass (g) planted in two soils (Cecil and Tifton) and amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

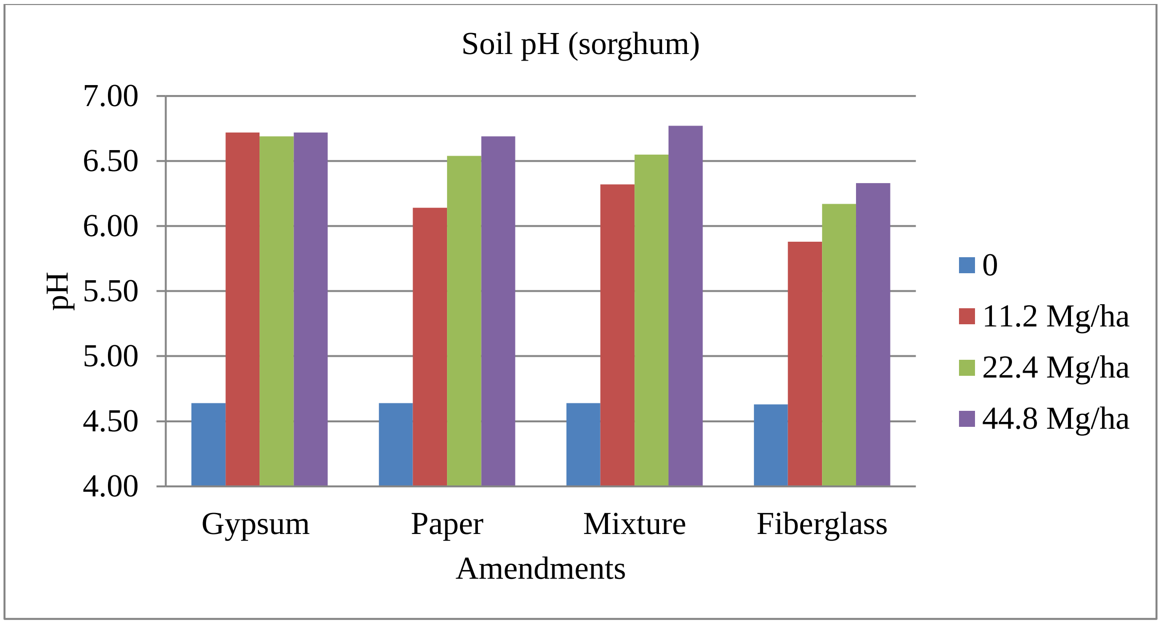

Figure 6: Soil pH (Cecil and Tifton) in sorghum and amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

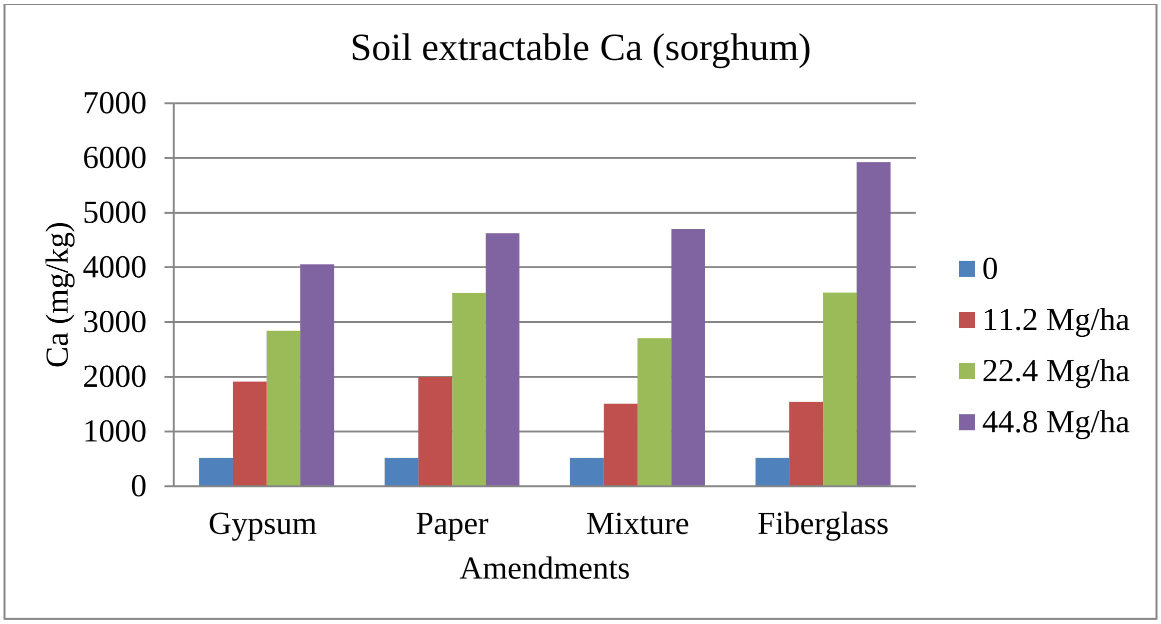

Figure 7: Soil extractable Ca (mg/kg) from two soils (Cecil and Tifton) planted with sorghum amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

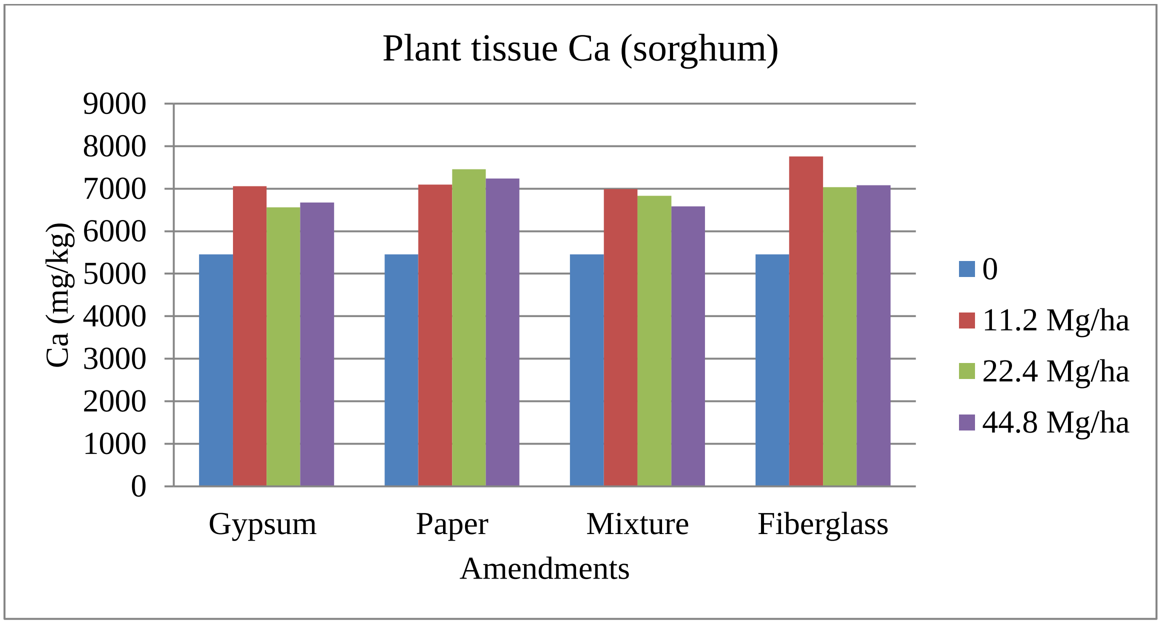

Figure 8: Plant tissue Ca (mg/kg) in sorghum in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) amended at three rates (11.2, 22.4, and 44.8 Mg/ha)

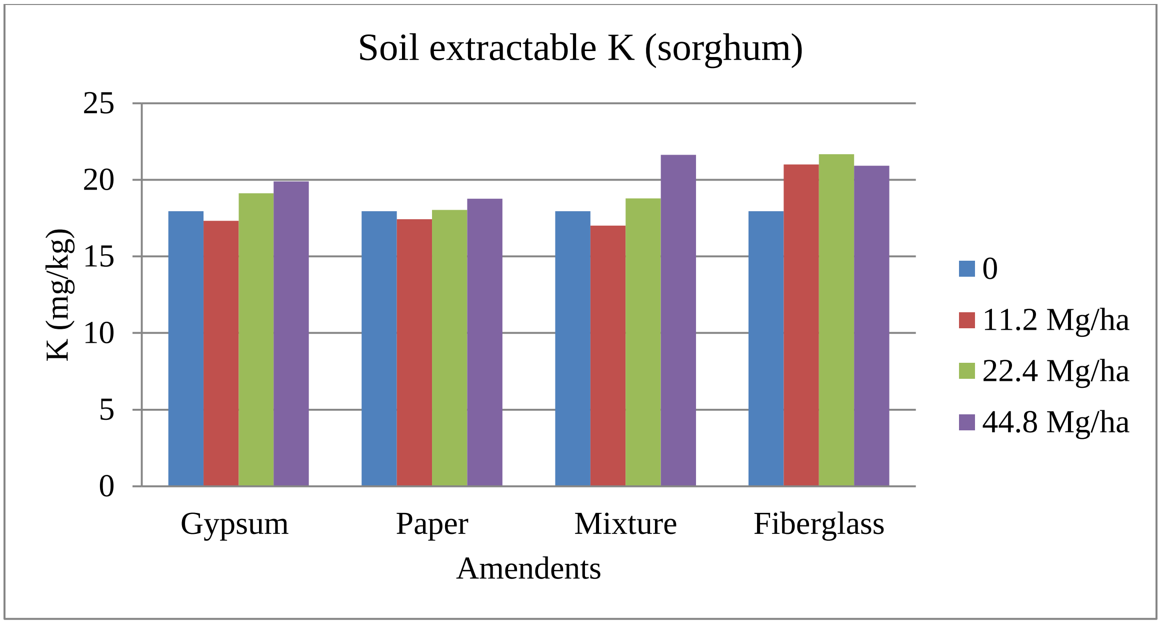

Figure 9: Soil extractable K (mg/kg) from two soils (Cecil and Tifton) planted with sorghum amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

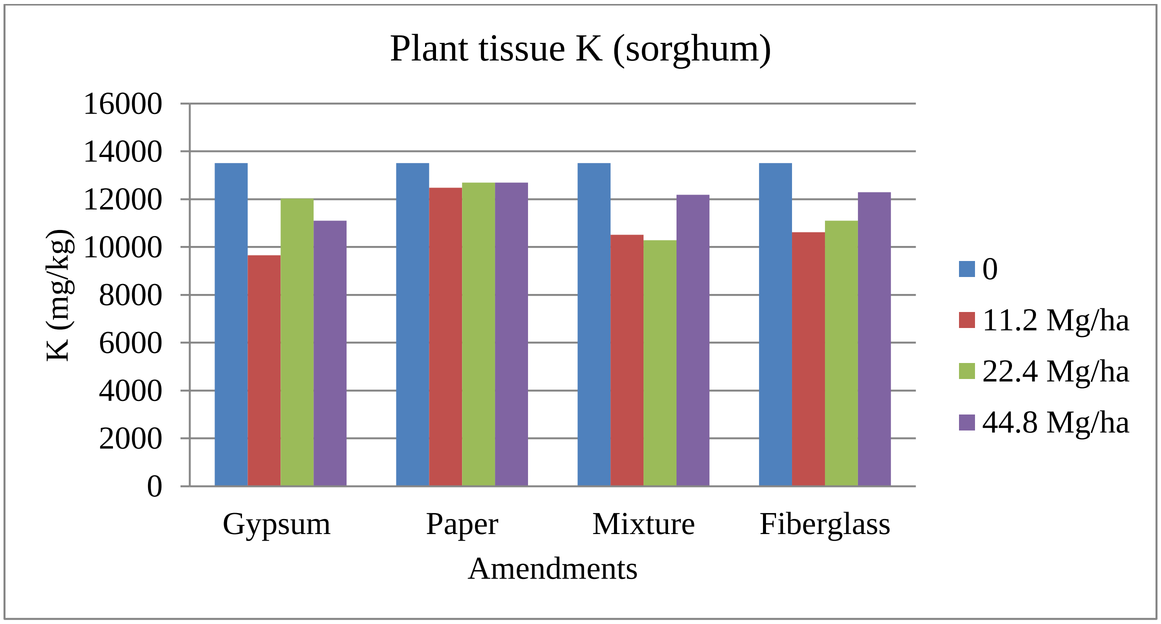

Figure 10: Plant tissue K (mg/kg) in sorghum in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

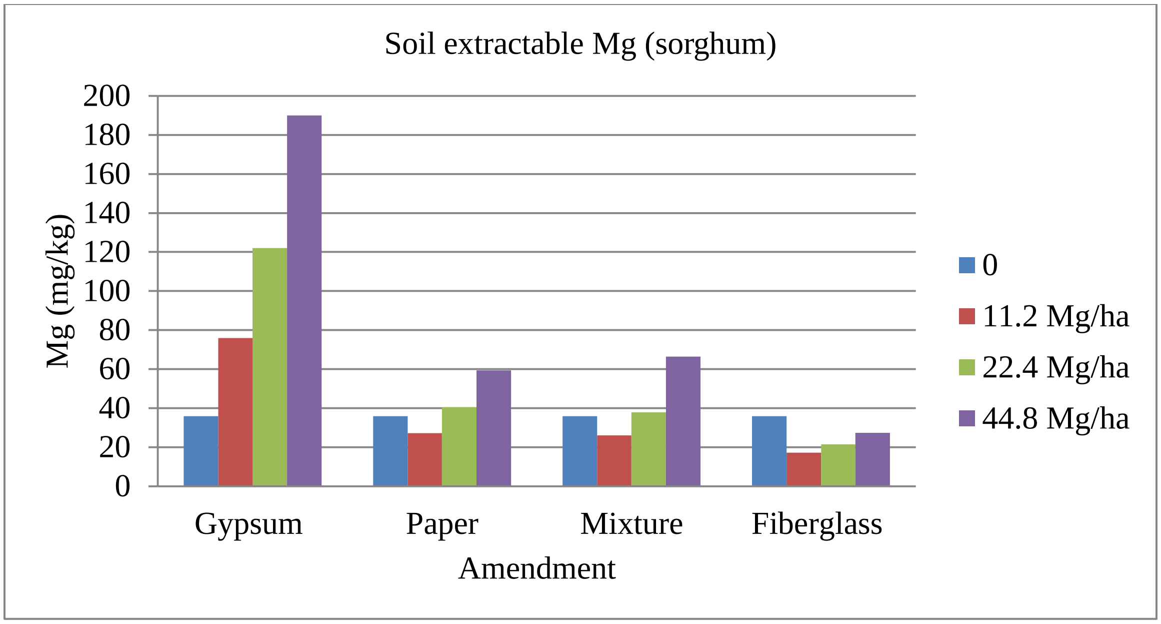

Figure 11: Soil extractable Mg (mg/kg) from two soils (Cecil and Tifton) planted with sorghum amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

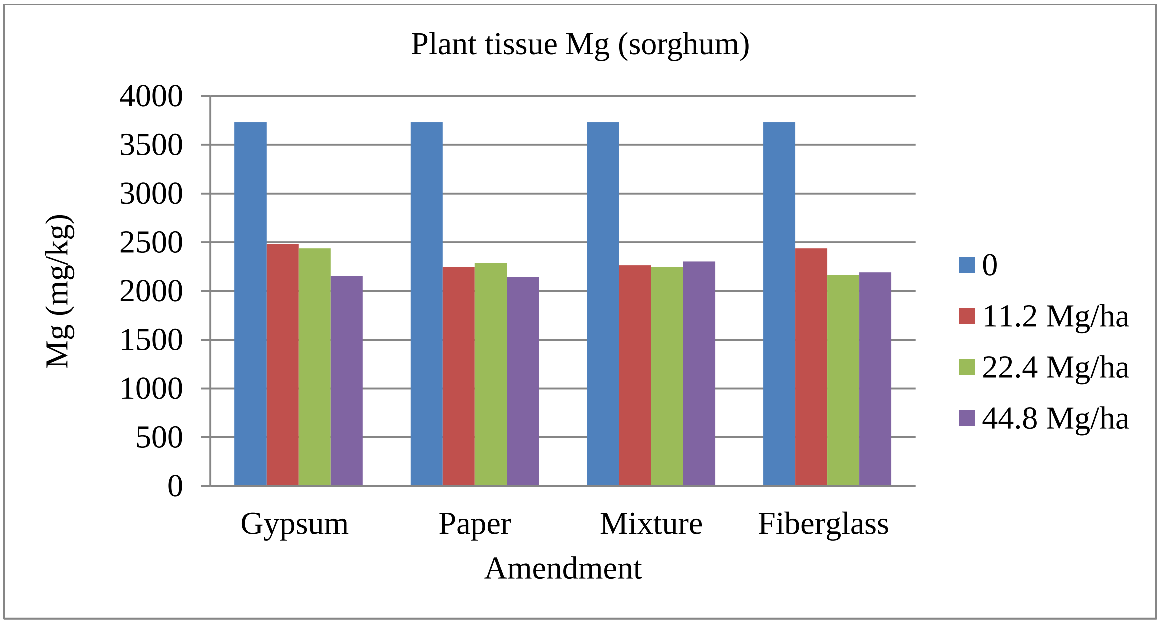

Figure 12: Plant tissue Mg (mg/kg) in sorghum in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

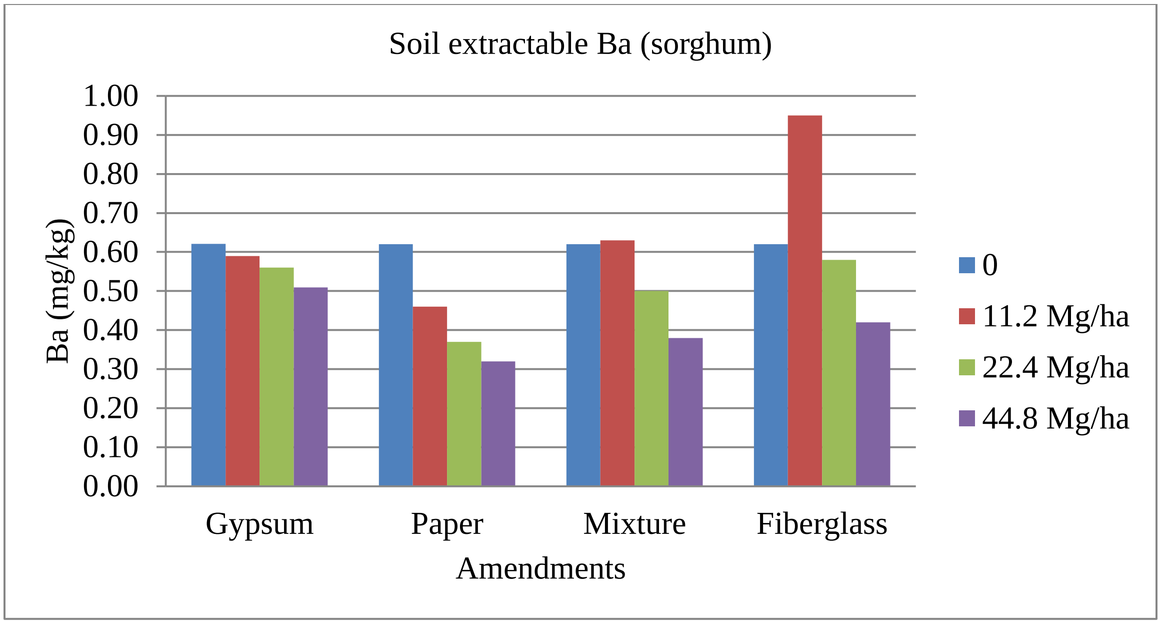

Figure 13: Soil extractable Ba (mg/kg) from two soils (Cecil and Tifton) planted with sorghum amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

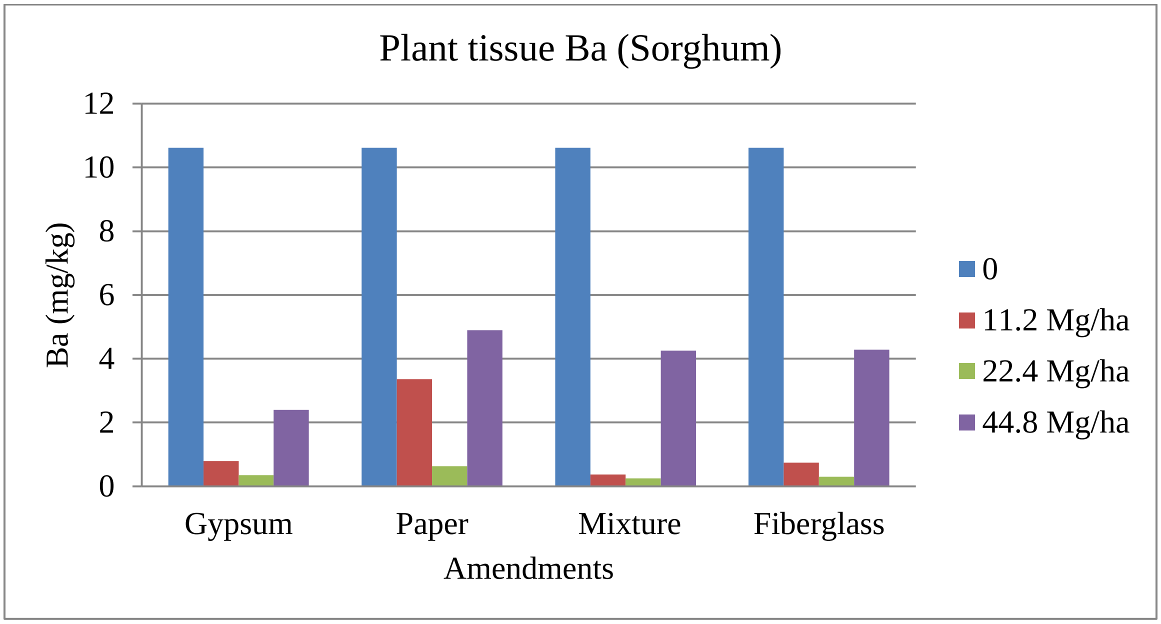

Figure 14: Plant tissue Ba (mg/kg) in sorghum in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

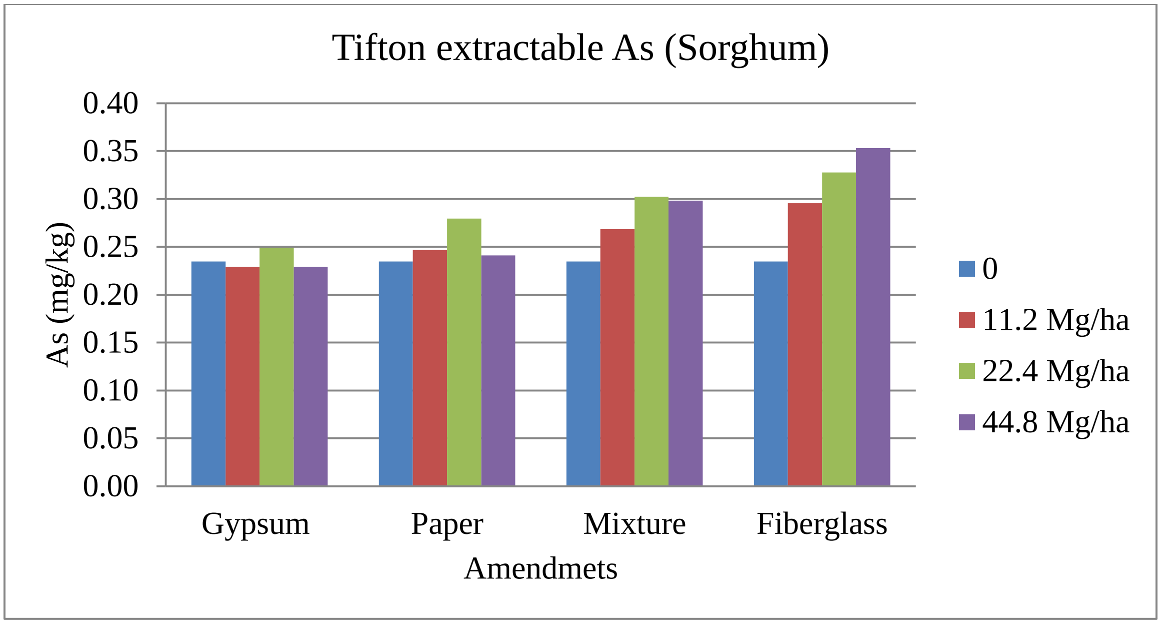

Figure 15: Soil extractable As (mg/kg) from Tifton soil planted with sorghum amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

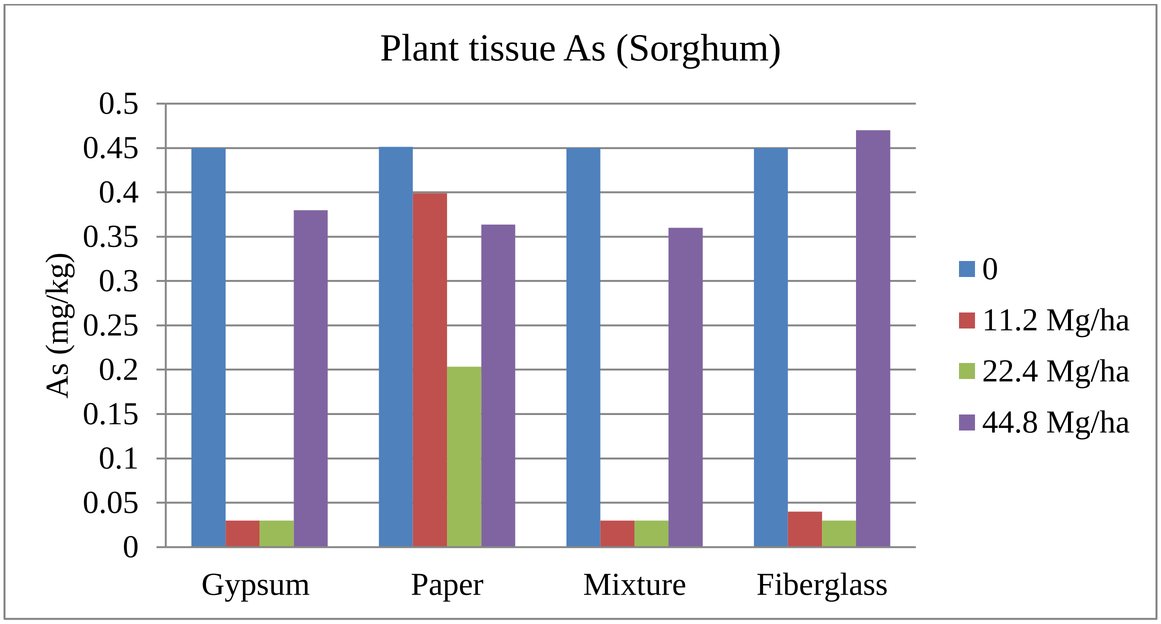

Figure 16: Plant tissue As (mg/kg) in sorghum in Tifton soil amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

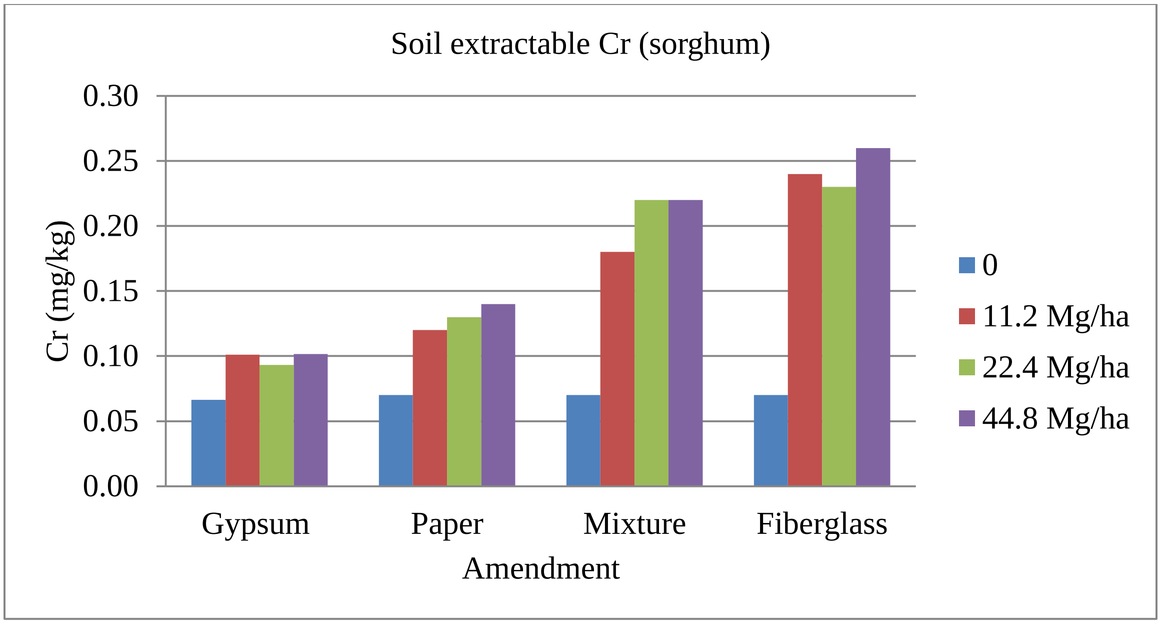

Figure 17: Soil extractable Cr (mg/kg) from two soils (Cecil and Tifton) planted with sorghum amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

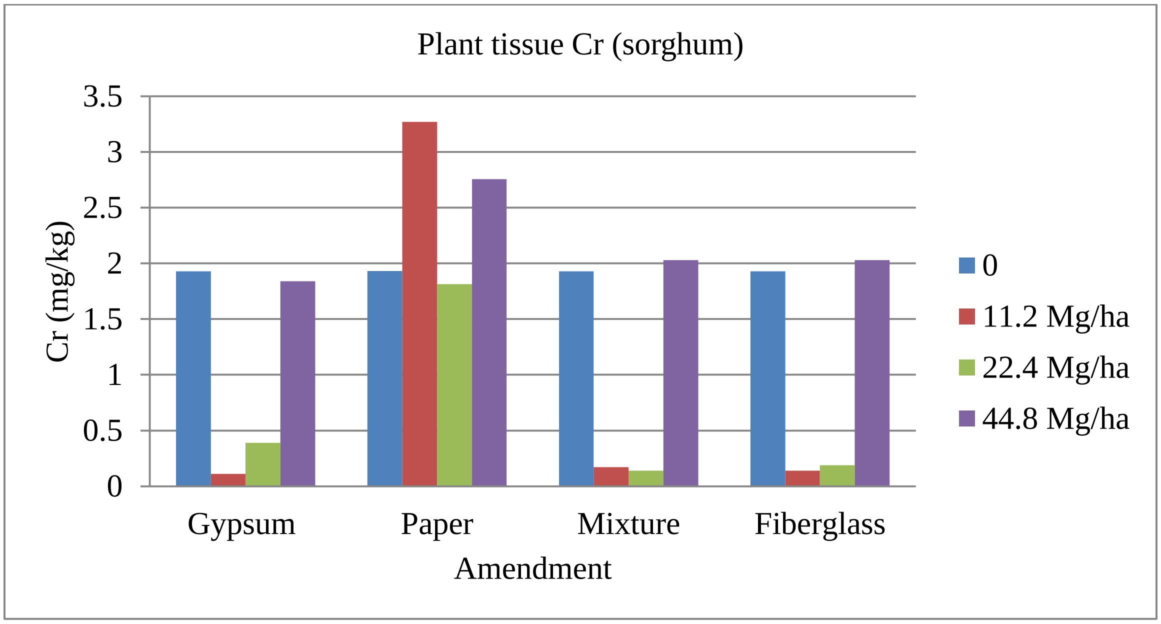

Figure 18: Plant tissue Cr (mg/kg) in sorghum in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

Table 33: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of agriculture gypsum (Part 1)

Soil Series	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS	mg/kg							
Cecil	6.03	1.18	2305	37	102	22	100	112$_{a}$	5	32
Tifton	6.34	1.17	2154	26	106	18	42	64$_{b}$	4	22
	NS	NS	NS	NS	NS	NS	NS		NS	NS

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.81$_{a}$	0.12$_{a}$	543$_{a}$	34	47$_{a}$	17	27	85	10	27
11.2	6.50$_{b}$	1.07$_{b}$	1878$_{ab}$	28	84$_{ab}$	20	33	92	3	28
22.4	6.68$_{b}$	1.59$_{bc}$	2659$_{bc}$	34	108$_{bc}$	21	161	86	3	26
44.8	6.76$_{b}$	1.90$_{c}$	3839$_{c}$	30	178$_{c}$	22	61	88	2	28
				NS		NS	NS	NS	NS	NS

Series	Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.68	0.13	562	34	38	19	30	107	7	31
Cecil	11.2	6.31	1.20	1841	33	81	22	38	118	4	33
Cecil	22.4	6.55	1.57	2582	47	102	23	295	110	4	33
Cecil	44.8	6.58	1.81	4236	34	188	24	35	112	3	32
Tifton	0	4.95	0.11	525	34	55	16	24	63	12	23
Tifton	11.2	6.69	0.95	1915	23	87	17	29	66	1	23
Tifton	22.4	6.80	1.61	2735	22	113	19	27	61	1	19
Tifton	44.8	6.94	1.99	3441	26	169	20	87	64	1	24
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 34: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of agriculture gypsum (Part 2)

Soil Series	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	133	2.05$_{a}$	0.72	0.11$_{a}$	0.77	0.03	0.15$_{a}$	0.13$_{a}$	0.02	0.67
Tifton	80	5.76$_{b}$	0.73	0.24$_{b}$	0.77	0.04	0.05$_{b}$	0.07$_{b}$	0.01	0.59
	NS		NS		NS	NS			NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	63	3.92	0.50$_{a}$	0.16	0.65	0.03	0.08$_{a}$	0.05	0.01	0.40$_{a}$
11.2	69	3.43	0.73$_{bc}$	0.20	0.79	0.03	0.10$_{ab}$	0.08	0.01	0.67$_{bc}$
22.4	189	4.59	0.79$_{c}$	0.16	0.57	0.04	0.11$_{ab}$	0.13	0.02	0.60$_{a}$
44.8	104	3.68	0.88$_{c}$	0.18	1.08	0.03	0.12$_{b}$	0.13	0.01	0.86$_{bc}$
	NS	NS		NS	NS	NS		NS	NS	

Series	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	66	1.89	0.42	0.10	0.77	0.03	0.12	0.06	0.01	0.40
Cecil	11.2	74	1.76	0.69	0.12	1.10	0.03	0.16	0.11	0.01	0.78
Cecil	22.4	309	2.20	0.93	0.12	0.67	0.03	0.16	0.20	0.03	0.71
Cecil	44.8	82	2.34	0.83	0.12	0.55	0.03	0.18	0.14	0.01	0.81
Tifton	0	60	5.95	0.58	0.23	0.52	0.04	0.04	0.04	0.01	0.39
Tifton	11.2	64	5.10	0.77	0.27	0.47	0.03	0.05	0.05	0.01	0.57
Tifton	22.4	69	6.97	0.65	0.20	0.47	0.04	0.05	0.05	0.01	0.49
Tifton	44.8	125	5.01	0.93	0.24	1.61	0.03	0.07	0.11	0.01	0.91
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 35: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of paper-faced wallboard (Part 1)

Series	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS	mg/kg							
Cecil	5.99_{a}	1.62	2583_{a}	32	45	20	37_{a}	121_{a}	3	30
Tifton	6.30_{b}	1.59	2130_{b}	28	40	17	32_{b}	75_{b}	4	20
		NS		NS	NS	NS			NS	NS

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.82_{a}	0.12_{a}	543_{a}	34	47_{a}	17	27_{a}	85	10	27
11.2	6.41_{b}	1.93_{b}	1594_{b}	28	27_{b}	19	38_{b}	102	2	20
22.4	6.52_{c}	2.13_{bc}	2772_{c}	28	35_{ab}	19	37_{b}	100	1	24
44.8	6.86_{d}	2.23_{c}	4517_{d}	30	59_{ac}	19	37_{b}	104	1	28
				NS		NS		NS	NS	NS

Series	Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.68	0.13	562	34	38	19	30	107	7	31
Cecil	11.2	6.23	2.04	1935	30	32	21	39	123	3	27
Cecil	22.4	6.35	2.12	2992	30	39	22	38	125	2	30
Cecil	44.8	6.73	2.17	4845	35	69	20	40	129	2	31
Tifton	0	4.95	0.11	525	34	55	16	24	63	12	23
Tifton	11.2	6.59	1.81	1254	25	23	17	36	81	1	14
Tifton	22.4	6.68	2.13	2553	26	31	17	35	76	1	19
Tifton	44.8	6.99	2.29	4189	25	49	17	35	79	1	24
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 36: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of paper-faced wallboard (Part 2)

Series	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	64	1.75_{a}	0.53	0.12_{a}	0.51	0.03	0.13_{a}	0.12_{a}	0.01	0.56
Tifton	53	5.36_{b}	0.60	0.26_{b}	0.44	0.04	0.05_{b}	0.09_{b}	0.01	0.55
	NS		NS		NS	NS			NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	63	3.92	0.50_{a}	0.16	0.65_{a}	0.03	0.08	0.05_{a}	0.01	0.40_{a}
11.2	56	3.58	0.44_{a}	0.19	0.55_{ab}	0.03	0.09	0.12_{b}	0.00	0.57_{ab}
22.4	55	3.33	0.55_{a}	0.19	0.39_{bc}	0.03	0.10	0.11_{b}	0.01	0.62_{b}
44.8	61	3.42	0.77_{b}	0.20	0.33_{c}	0.03	0.09	0.13_{b}	0.01	0.62_{b}
	NS	NS		NS		NS	NS		NS	

Series	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	66	1.89	0.42	0.10	0.77	0.03	0.12	0.06	0.01	0.40
Cecil	11.2	60	1.71	0.39	0.12	0.61	0.03	0.14	0.14	0.00	0.62
Cecil	22.4	60	1.78	0.52	0.12	0.35	0.03	0.14	0.12	0.01	0.61
Cecil	44.8	71	1.64	0.77	0.13	0.33	0.03	0.14	0.15	0.01	0.62
Tifton	0	60	5.95	0.58	0.23	0.52	0.04	0.04	0.04	0.01	0.39
Tifton	11.2	51	5.45	0.50	0.26	0.49	0.03	0.05	0.11	0.01	0.53
Tifton	22.4	49	4.88	0.57	0.26	0.43	0.03	0.05	0.10	0.01	0.63
Tifton	44.8	52	5.20	0.77	0.27	0.33	0.04	0.05	0.11	0.01	0.65
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 37: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of wallboard mixture (Part 1)

Series	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS	mg/kg							
Cecil	6.03_a	1.59	2577	32_a	52_a	20_a	38_a	125_a	3	32
Tifton	6.37_b	1.58	2238	28_b	44_b	16_b	35_b	80_b	4	27
		NS	NS						NS	NS

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.82_a	0.12_a	543_a	34	47_a	17	27_a	85_a	10	27
11.2	6.49_b	1.89_b	1540_b	29	31_a	16	37_b	103_b	2	20
22.4	6.69_c	2.14_c	3060_c	28	45_a	18	39_{bc}	109_b	1	34
44.8	6.80_c	2.20_c	4486_d	30	70_b	21	42_c	114_b	1	38
				NS		NS			NS	NS

Series	Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.68	0.13	562	34	38	19	30	107	7	31
Cecil	11.2	6.27	1.87	1574	30	35	18	38	127	2	21
Cecil	22.4	6.54	2.15	3524	30	52	21	41	130	2	37
Cecil	44.8	6.64	2.21	4648	35	85	24	43	137	2	40
Tifton	0	4.95	0.11	525	34	55	16	24	63	12	23
Tifton	11.2	6.72	1.91	1506	28	28	15	36	78	1	20
Tifton	22.4	6.85	2.13	2596	26	38	16	38	88	1	30
Tifton	44.8	6.97	2.18	4324	26	55	17	41	91	1	36
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 38: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of wallboard mixture (Part 2)

Series	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
	mg/kg									
Cecil	62_{a}	1.77_{a}	0.61	0.13_{a}	0.51	0.03_{a}	0.13_{a}	0.16	0.02	0.61
Tifton	57_{b}	6.23_{b}	0.57	0.30_{b}	0.50	0.04_{b}	0.05_{b}	0.16	0.05	0.70
			NS		NS			NS	NS	NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	63	3.92	0.50_{a}	0.16_{a}	0.65_{a}	0.03	0.08_{ab}	0.05_{a}	0.01	0.40_{a}
11.2	58	4.26	0.46_{ab}	0.20_{ab}	0.55_{ab}	0.04	0.07_{a}	0.19_{b}	0.07	0.66_{b}
22.4	55	3.84	0.63_{ac}	0.25_{b}	0.44_{bc}	0.03	0.09_{ab}	0.20_{b}	0.03	0.77_{b}
44.8	61	3.98	0.76_{c}	0.24_{b}	0.37_{c}	0.04	0.10_{b}	0.21_{b}	0.01	0.80_{b}
	NS	NS				NS			NS	

Series	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	66	1.89	0.42_{a}	0.10	0.77_{a}	0.03	0.12	0.06	0.01	0.40
Cecil	11.2	60	1.53	0.48_{a}	0.12	0.53_{b}	0.03	0.11	0.19	0.01	0.64
Cecil	22.4	57	1.69	0.70_{a}	0.14	0.37_{b}	0.03	0.14	0.19	0.04	0.68
Cecil	44.8	65	1.97	0.83_{b}	0.14	0.35_{b}	0.03	0.16	0.20	0.01	0.74
Tifton	0	60	5.95	0.58_{a}	0.23	0.52_{a}	0.04	0.04	0.04	0.01	0.39
Tifton	11.2	57	6.99	0.44_{b}	0.29	0.56_{ab}	0.04	0.04	0.18	0.13	0.69
Tifton	22.4	54	6.00	0.57_{ab}	0.35	0.50_{b}	0.04	0.05	0.21	0.03	0.87
Tifton	44.8	57	5.99	0.68_{a}	0.33	0.40_{b}	0.04	0.05	0.21	0.01	0.85
		NS	NS		NS		NS	NS	NS	NS	NS

Tables 39: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of fiberglass-faced wallboard (Part 1)

Soil	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
		mS	mg/kg							
Cecil	5.84 $_{a}$	1.62	3216 $_{a}$	35 $_{a}$	38 $_{a}$	20	43 $_{a}$	139 $_{a}$	8	50 $_{a}$
Tifton	6.09 $_{b}$	1.50	2491 $_{b}$	29 $_{b}$	28 $_{b}$	17	37 $_{b}$	87 $_{b}$	5	37 $_{b}$
		NS				NS			NS	

Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	4.82 $_{a}$	0.12 $_{a}$	543 $_{a}$	34	47 $_{a}$	17	27 $_{a}$	85 $_{a}$	10	27 $_{a}$
11.2	6.26 $_{b}$	1.88 $_{b}$	2212 $_{b}$	29	23 $_{b}$	18	41 $_{b}$	116 $_{b}$	4	41 $_{b}$
22.4	6.29 $_{b}$	2.07 $_{bc}$	3206 $_{b}$	32	29 $_{b}$	19	44 $_{b}$	124 $_{b}$	6	46 $_{bc}$
44.8	6.51 $_{c}$	2.17 $_{c}$	5452 $_{c}$	32	33 $_{b}$	19	46 $_{b}$	128 $_{b}$	7	60 $_{c}$
				NS		NS			NS	

Soil	Rate (Mg/ha)	pH	EC	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	4.68	0.13	562	34	38	19	30	107	7	31
Cecil	11.2	6.23	2.10	2960	32	33	19	42	139	6	47
Cecil	22.4	6.09	2.09	3264	38	38	20	47	145	9	51
Cecil	44.8	6.38	2.14	6076	36	44	23	52	166	11	71
Tifton	0	4.95	0.11	525	34	55	16	24	63	12	23
Tifton	11.2	6.28	1.66	1464	27	13	18	40	92	2	35
Tifton	22.4	6.49	2.05	3148	26	20	17	42	102	3	40
Tifton	44.8	6.65	2.19	4828	28	23	16	40	91	3	50
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 40: Elemental concentrations in soil extractions from two soils planted with wheat and amended by various rates of fiberglass-faced wallboard (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	75 $_{a}$	2.13 $_{a}$	0.47	0.15 $_{a}$	0.59	0.03 $_{a}$	0.15 $_{a}$	0.20	0.05	0.76 $_{a}$
Tifton	61 $_{b}$	5.85 $_{b}$	0.49	0.33 $_{b}$	0.63	0.04 $_{b}$	0.06 $_{b}$	0.18	0.01	0.86 $_{b}$
			NS		NS			NS	NS	

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	63	4	0.50	0.16 $_{a}$	0.65 $_{a}$	0.03	0.08 $_{a}$	0.05	0.01	0.4 $_{a}$
11.2	65	4	0.39	0.26 $_{b}$	0.76 $_{ab}$	0.04	0.10 $_{ab}$	0.21	0.01	0.92 $_{bc}$
22.4	70	4	0.46	0.26 $_{b}$	0.57 $_{ac}$	0.04	0.11 $_{ab}$	0.24	0.08	0.89 $_{b}$
44.8	72	4	0.57	0.27 $_{b}$	0.46 $_{c}$	0.04	0.13 $_{b}$	0.25	0.02	1.02 $_{c}$
	NS	NS	NS			NS		NS	NS	

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	66	2	0.42	0.10	0.77 $_{a}$	0.03	0.12	0.06	0.01	0.40
Cecil	11.2	72	2	0.39	0.15	0.60 $_{ab}$	0.03	0.14	0.23	0.01	0.82
Cecil	22.4	77	2	0.47	0.16	0.57 $_{ab}$	0.03	0.15	0.25	0.15	0.81
Cecil	44.8	83	3	0.59	0.19	0.43 $_{b}$	0.03	0.19	0.27	0.03	1.00
Tifton	0	60	6	0.58	0.23	0.52 $_{a}$	0.04	0.04	0.04	0.01	0.39
Tifton	11.2	58	6	0.39	0.37	0.93 $_{b}$	0.04	0.06	0.20	0.02	1.03
Tifton	22.4	64	6	0.45	0.36	0.57 $_{ac}$	0.04	0.06	0.24	0.02	0.96
Tifton	44.8	61	6	0.55	0.35	0.48 $_{ac}$	0.04	0.06	0.24	0.01	1.04
		NS	NS	NS	NS		NS	NS	NS	NS	NS

Table 41: Elemental concentrations of wheat planted in two soils amended with rates of agriculture gypsum (Part 1)

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g	mg/kg							
Cecil	13$_{a}$	7868$_{a}$	17354	2872$_{a}$	74$_{a}$	2875	28	4.96$_{a}$	58
Tifton	10$_{b}$	5256$_{b}$	21581	1970$_{b}$	33$_{b}$	3136	37	2.55$_{b}$	42
			NS			NS	NS		NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	11	4713$_{a}$	21000	2468	70$_{a}$	3230$_{a}$	81	4.08	49
11.2	12	6767$_{ab}$	17166	2275	48$_{ab}$	3093$_{a}$	8	3.43	51
22.2	12	7980$_{b}$	21311	2734	57$_{ab}$	3283$_{a}$	23	4.23	68
44.8	12	6789$_{ab}$	18392	2207	40$_{b}$	2416$_{b}$	18	3.29	32
	NS		NS	NS			NS	NS	NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	12	5802	19922	2799	95	2760	63	5.27	54
Cecil	11.2	13	7861	12111	2719	64	2967	7	4.65	63
Cecil	22.2	12	10156	21767	3274	80	3444	25	5.71	86
Cecil	44.8	14	7654	15618	2696	57	2329	15	4.23	31
Tifton	0	9	3624	22079	2137	44	3699	99	2.89	44
Tifton	11.2	10	5672	22222	1830	32	3220	8	2.21	39
Tifton	22.2	11	5805	20855	2193	34	3122	20	2.75	50
Tifton	44.8	10	5923	21166	1718	23	2502	21	2.35	34
		NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 42: Elemental concentrations of wheat planted in two soils amended with rates of agricultural gypsum (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
	mg/kg									
Cecil	331	14.66	13.79	0.26_{a}	19.81_{a}	0.03	0.08	4.56	0.76_{a}	0.16
Tifton	855	10.67	13.45	0.43_{b}	30.88_{b}	0.04	0.04	2.66	1.08_{b}	0.31
	NS	NS	NS			NS	NS	NS		NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	667	17.48	15.08	0.68_{a}	37.06_{a}	0.04	0.11	5.91	0.52_{a}	0.17
11.2	420	10.44	9.27	0.21_{b}	24.63_{b}	0.03	0.02	1.84	0.77_{a}	0.06
22.2	581	13.41	15.62	0.22_{b}	19.36_{b}	0.04	0.09	5.45	1.15_{b}	0.51
44.8	704	9.33	14.51	0.26_{b}	20.33_{b}	0.03	0.01	1.23	1.23_{b}	0.20
	NS	NS	NS			NS	NS	NS		NS

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	302	25.04	14.56	0.56	25.73	0.03	0.17	7.83	0.41	0.16
Cecil	11.2	163	11.10	9.77	0.14	16.16	0.03	0.03	1.92	0.69	0.02
Cecil	22.2	239	13.34	17.23	0.12	20.20	0.05	0.10	7.30	0.97	0.32
Cecil	44.8	620	9.16	13.61	0.21	17.17	0.02	0.01	1.19	0.96	0.17
Tifton	0	1032	9.92	15.59	0.81	48.39_{a}	0.04	0.06	4.00	0.63	0.18
Tifton	11.2	677	9.77	8.76	0.29	33.11_{ab}	0.04	0.01	1.77	0.85	0.11
Tifton	22.2	922	13.49	14.01	0.32	18.53_{b}	0.04	0.07	3.61	1.32	0.70
Tifton	44.8	787	9.51	15.42	0.31	23.50_{b}	0.04	0.01	1.26	1.51	0.24
		NS	NS	NS	NS		NS	NS	NS	NS	NS

Table 44: Elemental concentrations of wheat planted in two soils amended with rates of paper-faced wallboard waste (Part 1)

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g				mg/kg				
Cecil	11.69 $_{a}$	7107 $_{a}$	19766	2585 $_{a}$	72 $_{a}$	2814	33	4.92 $_{a}$	54
Tifton	8.72 $_{b}$	5117 $_{b}$	22935	1712 $_{b}$	31 $_{b}$	3290	53	2.82 $_{b}$	54
			NS			NS	NS		NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	11	4713 $_{a}$	21000	2468	70 $_{a}$	3230	81	4.08	49
11.2	10	7031 $_{b}$	21971	2382	54 $_{ab}$	3508	40	4.39	64
22.4	10	6291 $_{ab}$	21816	1909	43 $_{b}$	3054	33	3.53	57
44.8	10	6411 $_{b}$	20616	1834	41 $_{b}$	2417	17	3.48	45
	NS		NS	NS			NS	NS	NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	12	5802	19922	2799	95	2760	63	5.27	54
Cecil	11.2	11	8269	21134	3064	74	3631	51	5.28	61
Cecil	22.4	11	7017	20507	2123	59	2592	6	4.39	53
Cecil	44.8	12	7338	17502	2353	60	2273	11	4.74	47
Tifton	0	9	3624	22079	2137	44	3699	99	2.89	44
Tifton	11.2	9	5793	22808	1699	33	3385	29	3.50	68
Tifton	22.4	9	5566	23125	1696	26	3516	61	2.67	61
Tifton	44.8	8	5483	23730	1314	22	2561	23	2.21	43
		NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 44: Elemental concentrations of wheat planted in two soil amended with rates of paper-faced wallboard waste (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	578	15.12	15.74	0.28 a	18.71 a	0.05	0.07	3.26	0.70 a	0.23
Tifton	1003	12.21	12.31	0.40 b	29.00 b	0.06	0.12	5.65	1.15 b	0.47
	NS	NS	NS			NS	NS	NS		NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	667	17.48	15.08	0.68 a	37.06 a	0.04	0.11	5.91	0.52 a	0.17
11.2	1117	15.73	12.09	0.22 b	22.82 ab	0.04	0.19	8.71	0.93 b	0.65
22.4	476	12.12	11.78	0.20 b	19.91 ab	0.06	0.05	2.15	1.10 b	0.21
44.8	901	9.33	17.15	0.27 b	15.64 b	0.08	0.02	1.05	1.16 b	0.37
	NS	NS	NS			NS	NS	NS		NS

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	302	25.04	14.56	0.56	25.73	0.03	0.17	7.83	0.41	0.16
Cecil	11.2	1142	15.88	13.30	0.17	23.46	0.04	0.06	2.68	0.57	0.36
Cecil	22.4	148	11.32	13.40	0.18	15.09	0.05	0.02	1.68	0.91	0.02
Cecil	44.8	721	8.24	21.71	0.23	10.55	0.08	0.02	0.86	0.93	0.40
Tifton	0	1032	9.92	15.59	0.81	48.39	0.04	0.06	4.00	0.63	0.18
Tifton	11.2	1092	15.58	10.88	0.27	22.17	0.05	0.32	14.75	1.29	0.94
Tifton	22.4	805	12.91	10.15	0.21	24.72	0.06	0.07	2.62	1.28	0.40
Tifton	44.8	1081	10.42	12.60	0.30	20.74	0.07	0.02	1.24	1.38	0.35
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 45: Elemental concentrations of wheat planted in two soils amended with rates of wallboard mixture (Paper-faced and Fiberglass-faced wallboard mixture) wallboard waste (Part 1)

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g				mg/kg				
Cecil	11_a	7147_a	17586	2782_a	73_a	2832	32	4.91_a	56
Tifton	8_b	5316_b	22089	1732_b	36_b	3099	42	2.44_b	47
			NS			NS	NS		NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	11	4713_a	21000	2468	70_a	3230	81	4.08	49
11.2	11	7213_b	18487	2513	58_{ab}	3257	17	4.32	58
22.4	10	6965_b	21454	2145	51_{ab}	3096	13	3.43	51
44.8	10	6035_{ab}	18409	1901	38_b	2278	36	2.86	49
	NS		NS	NS		NS	NS	NS	NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	12	5802	19922	2799	95	2760	63	5.27	54
Cecil	11.2	12	7594	13077	3062	67	3163	4	5.42	63
Cecil	22.4	11	8138	20211	2650	72	3215	22	4.78	56
Cecil	44.8	12	7052	17134	2616	58	2189	39	4.18	51
Tifton	0	9	3624	22079	2137	44	3699	99	2.89	44
Tifton	11.2	9	6831	23897	1964	49	3350	31	3.23	52
Tifton	22.4	9	5792	22696	1641	30	2978	5	2.09	46
Tifton	44.8	9	5017	19685	1185	19	2368	32	1.54	47
		NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 46: Elemental concentrations of wheat planted in two soils amended with rates of wallboard mixture (Paper-faced and Fiberglass-faced wallboard mixture) wallboard waste (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
	mg/kg									
Cecil	631	15.18	15.97	0.24 a	17.30 a	0.04	0.07	3.82	0.64 a	0.29
Tifton	797	10.61	13.55	0.40 b	31.92 b	0.05	0.44	11.76	1.03 b	0.42
	NS	NS	NS			NS	NS	NS		NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	667	17.48	15.08	0.68 a	37.06 a	0.04	0.11	5.91	0.52 a	0.17
11.2	478	12.36	11.00	0.17 b	21.19 b	0.04	0.02	2.04	0.75 ab	0.19
22.4	606	10.62	14.92	0.17 b	15.84 b	0.03	0.05	3.11	1.01 b	0.15
44.8	1105	11.13	18.06	0.25 b	24.35 ab	0.07	0.86	20.11	1.05 b	0.90
	NS	NS	NS			NS	NS	NS		NS

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	302	25.04	14.56	0.56	25.73	0.03	0.17	7.83	0.41	0.16
Cecil	11.2	172	11.19	11.04	0.10	11.82	0.04	0.00	1.46	0.49	0.05
Cecil	22.4	609	12.77	17.47	0.13	13.28	0.03	0.07	4.31	0.82	0.18
Cecil	44.8	1442	11.72	20.80	0.18	18.37	0.07	0.05	1.70	0.83	0.77
Tifton	0	1032	9.92	15.59	0.81	48.39	0.04	0.06	4.00	0.63	0.18
Tifton	11.2	784	13.52	10.95	0.24	30.57	0.05	0.03	2.62	1.01	0.34
Tifton	22.4	602	8.46	12.36	0.22	18.41	0.02	0.03	1.91	1.19	0.12
Tifton	44.8	768	10.53	15.31	0.31	30.33	0.07	1.66	38.52	1.28	1.03
		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 47: Elemental concentrations of wheat planted in two soils amended with rates of fiberglass-faced wallboard waste (Part 1).

Soil	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
	g	mg/kg							
Cecil	12.30_{a}	6605_{a}	12977	2673_{a}	70_{a}	2657_{a}	37	5.04_{a}	56
Tifton	9.03_{b}	5196_{b}	15758	1724_{b}	34_{b}	3419_{b}	42	2.84_{b}	41
			NS				NS		NS

Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
0	11	4713_{a}	21000	2468_{a}	70_{a}	3230_{a}	81	4.08	49
11.2	10	5974_{ab}	8077	2099_{ab}	45_{b}	3164_{a}	34	4.00	50
22.4	11	6934_{b}	9472	2292_{ab}	49_{b}	3339_{a}	14	4.37	55
44.8	11	5980_{ab}	18921	1935_{b}	45_{b}	2420_{b}	29	3.30	41
	NS		NS				NS	NS	NS

Soil	Rate (Mg/ha)	Biomass	Ca	K	Mg	Mn	P	Al	Cu	Fe
Cecil	0	12	5802	19922	2799	95_{a}	2760	63	5.27	54
Cecil	11.2	12	6127	6611	2650	54_{b}	2735	31	5.43	55
Cecil	22.4	12	7452	7435	2811	68_{b}	2709	4	4.93	67
Cecil	44.8	13	7037	17940	2432	64_{b}	2424	52	4.53	49
Tifton	0	9	3624	22079	2137	44	3699_{a}	99	2.89	44
Tifton	11.2	9	5821	9542	1549	36	3592_{a}	38	2.57	45
Tifton	22.4	9	6416	11510	1773	29	3969_{a}	23	3.82	43
Tifton	44.8	9	4923	19902	1438	25	2415_{b}	7	2.07	34
		NS	NS	NS	NS			NS	NS	NS

Table 48: Elemental concentrations of wheat planted in two soils amended with rates of fiberglass-faced wallboard waste (Part 2)

Soil	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
					mg/kg					
Cecil	536	16.35	12.88	0.23 $_{a}$	16.70 $_{a}$	0.05	0.09	2.87	0.52 $_{a}$	0.45
Tifton	478	10.55	13.31	0.41 $_{b}$	27.71 $_{b}$	0.05	0.21	1.95	0.80 $_{b}$	0.19
	NS	NS	NS			NS	NS	NS		NS

Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
0	667	17.48	15.08	0.68 $_{a}$	37.06 $_{a}$	0.04	0.11	5.91	0.52 $_{a}$	0.17
11.2	552	10.82	13.11	0.22 $_{b}$	19.71 $_{b}$	0.04	0.02	1.14	0.70 $_{ab}$	0.19
22.4	232	14.30	11.76	0.21 $_{b}$	18.75 $_{b}$	0.08	0.02	1.47	0.99 $_{b}$	0.41
44.8	576	11.20	12.41	0.17 $_{b}$	13.29 $_{b}$	0.04	0.44	1.12	0.43 $_{a}$	0.51
	NS	NS	NS			NS	NS	NS		NS

Soil	Rate (Mg/ha)	Na	Zn	B	As	Ba	Cd	Co	Cr	Mo	Pb
Cecil	0	302	25.04	14.56	0.56	25.73	0.03	0.17	7.83	0.41	0.16
Cecil	11.2	790	11.02	13.17	0.12	11.11	0.03	0.03	0.81	0.42	0.35
Cecil	22.4	166	15.44	12.90	0.13	15.15	0.11	0.04	1.33	0.80	0.68
Cecil	44.8	886	13.92	10.87	0.12	14.80	0.04	0.12	1.52	0.43	0.60
Tifton	0	1032	9.92	15.59	0.81	48.39 $_{a}$	0.04	0.06	4.00	0.63	0.18
Tifton	11.2	314	10.62	13.05	0.32	28.31 $_{b}$	0.05	0.01	1.47	0.98	0.03
Tifton	22.4	297	13.16	10.62	0.28	22.34 $_{b}$	0.05	0.01	1.61	1.17	0.13
Tifton	44.8	267	8.49	13.96	0.22	11.78 $_{b}$	0.05	0.77	0.73	0.42	0.41
		NS	NS	NS	NS		NS	NS	NS	NS	NS

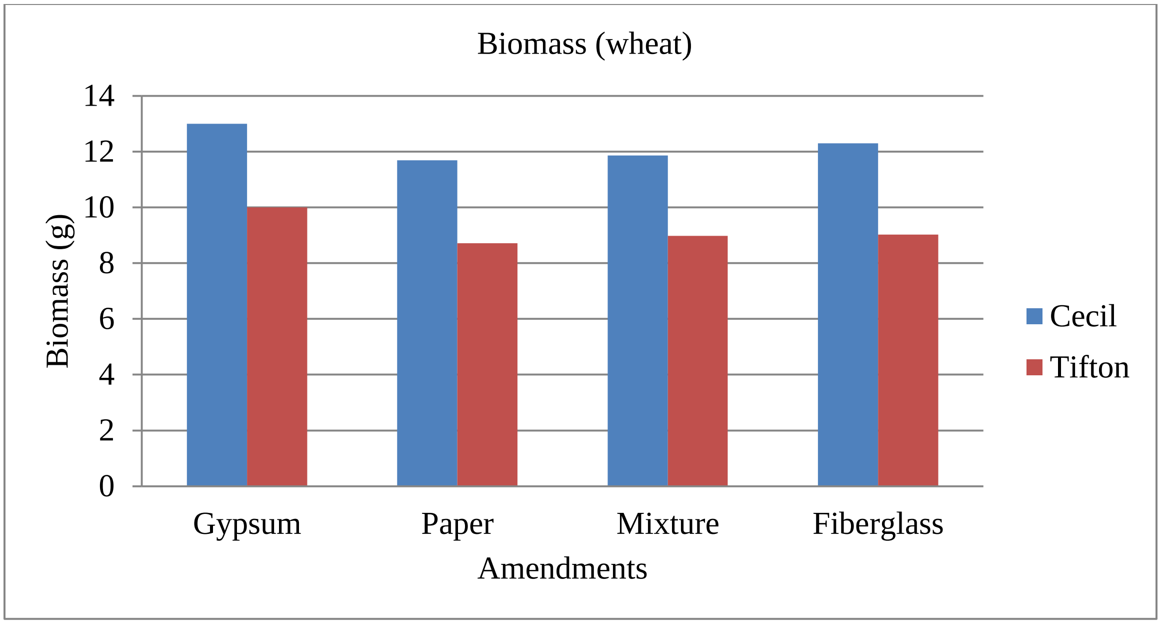

Figure 19: Wheat Biomass (g) in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

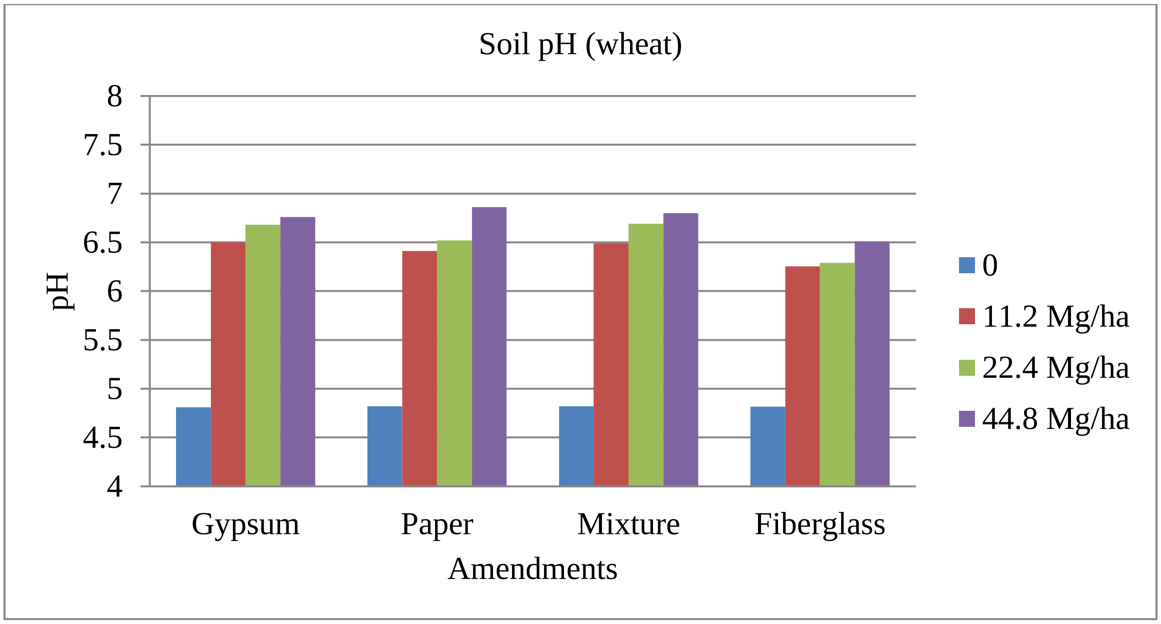

Figure 20: Soil pH (Cecil and Tifton) planted with wheat and amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

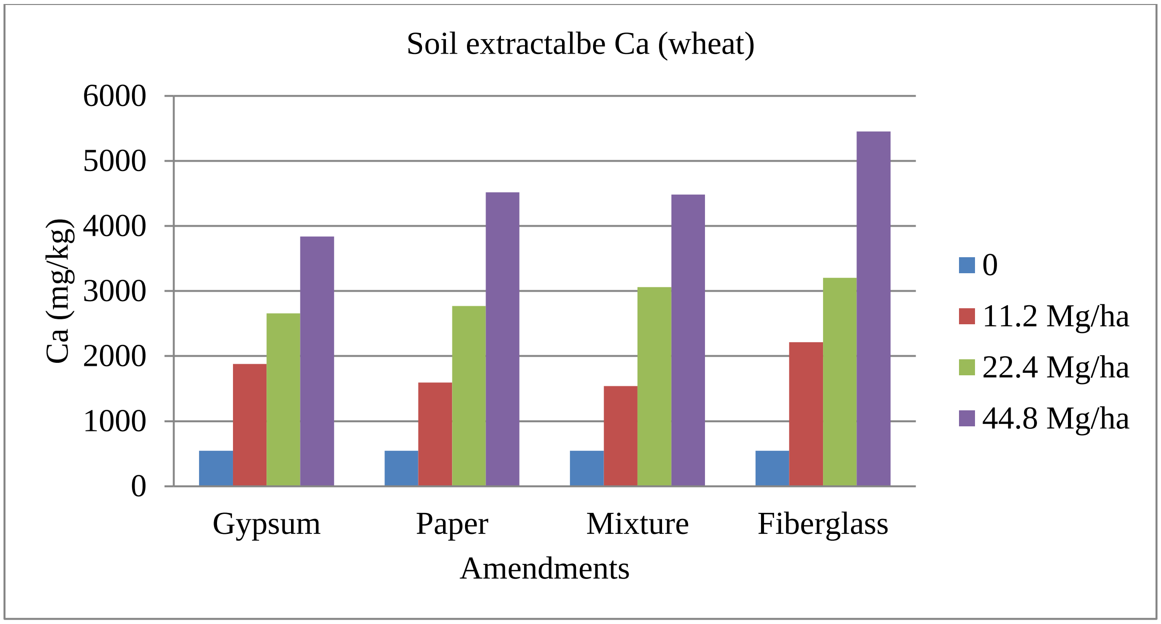

Figure 21: Soil extractable Ca (mg/kg) from two soils (Cecil and Tifton) planted with wheat amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

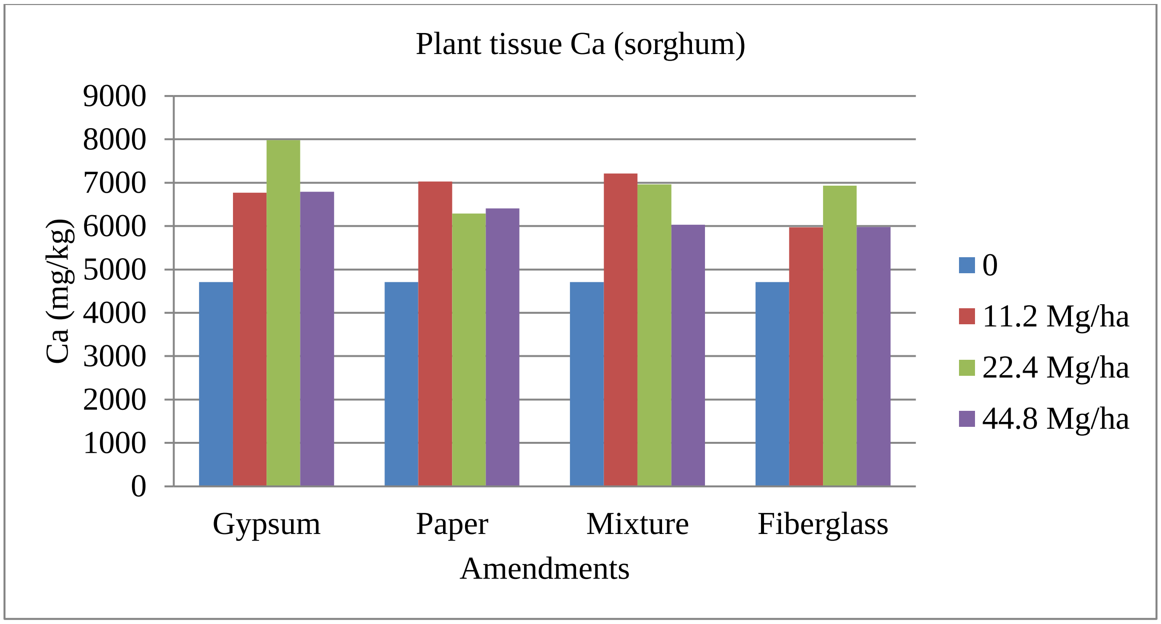

Figure 22: Plant tissue Ca (mg/kg) in wheat in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

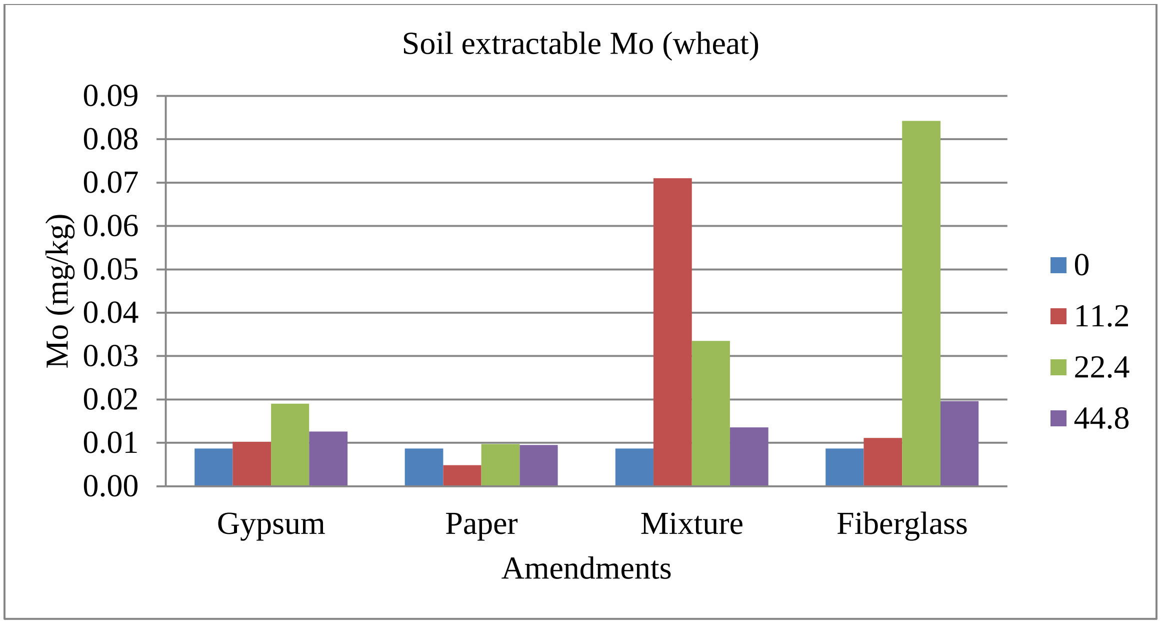

Figure 23: Soil extractable Mo (mg/kg) from two soils (Cecil and Tifton) planted with sorghum amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

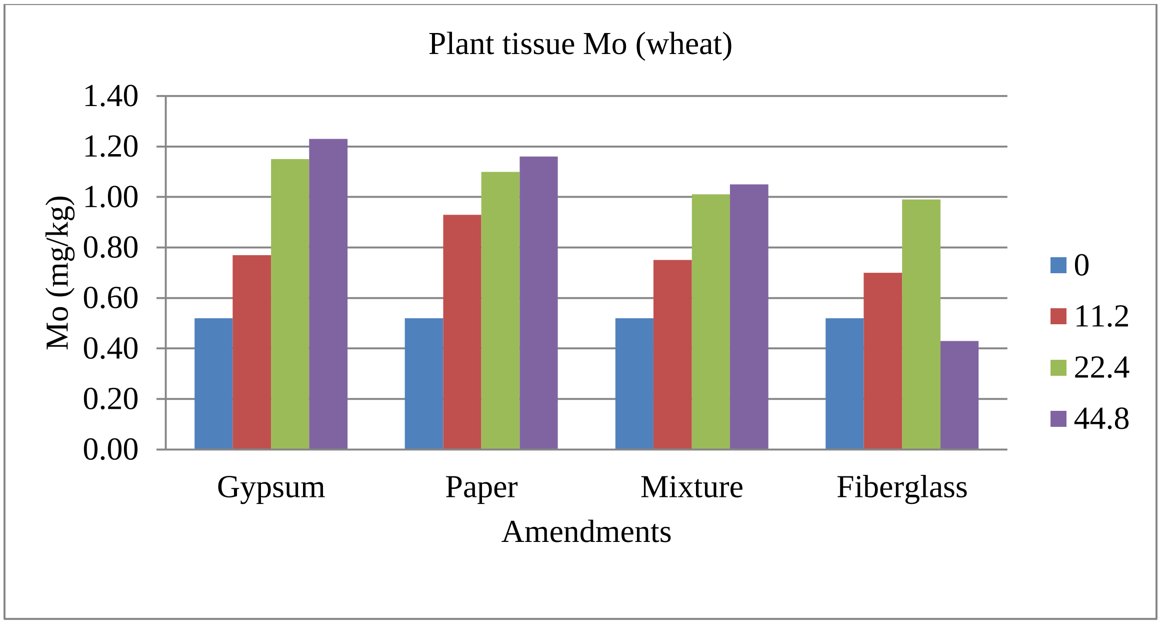

Figure 24: Plant tissue Mo (mg/kg) in wheat in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

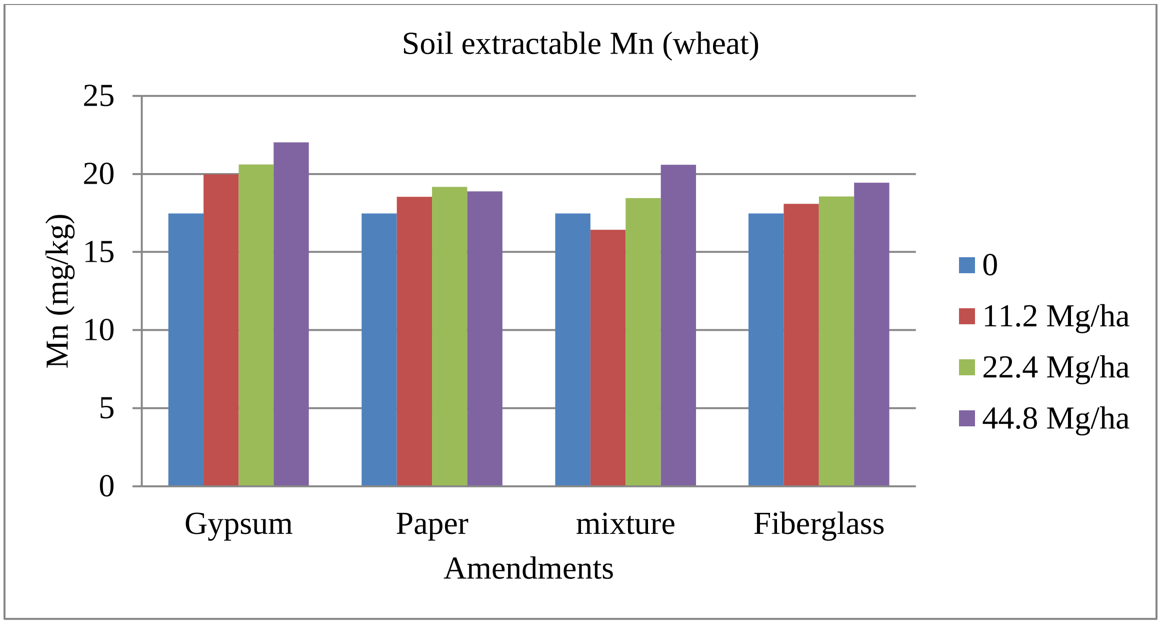

Figure 25: Soil extractable Mn (mg/kg) from two soils (Cecil and Tifton) planted with wheat amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

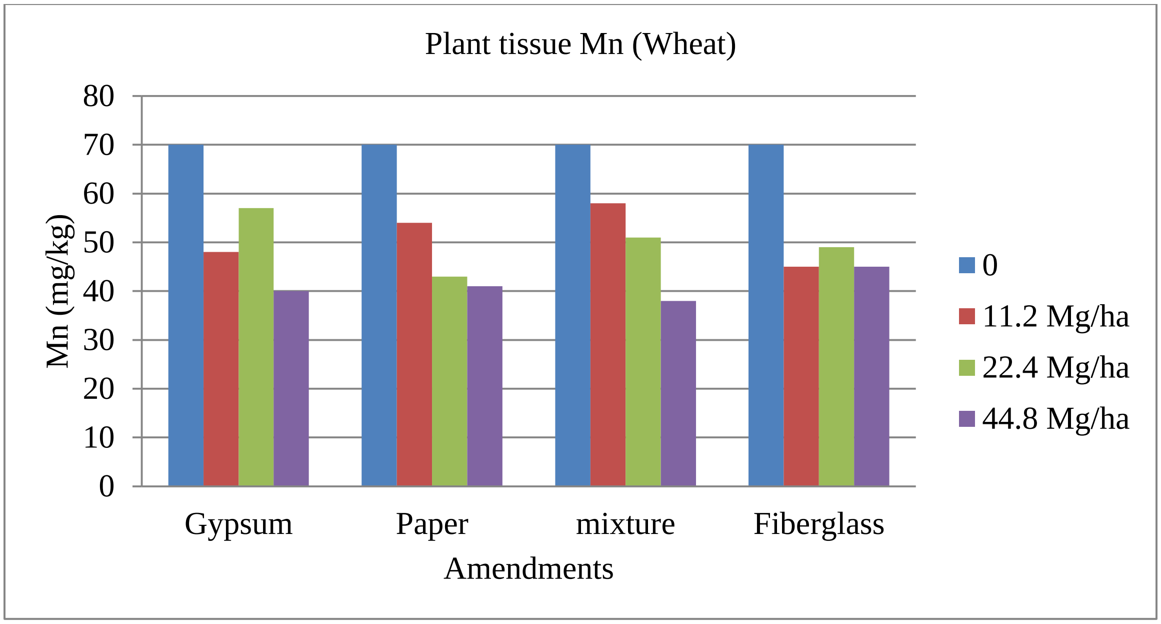

Figure 26: Plant tissue Mn (mg/kg) in wheat in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/h)

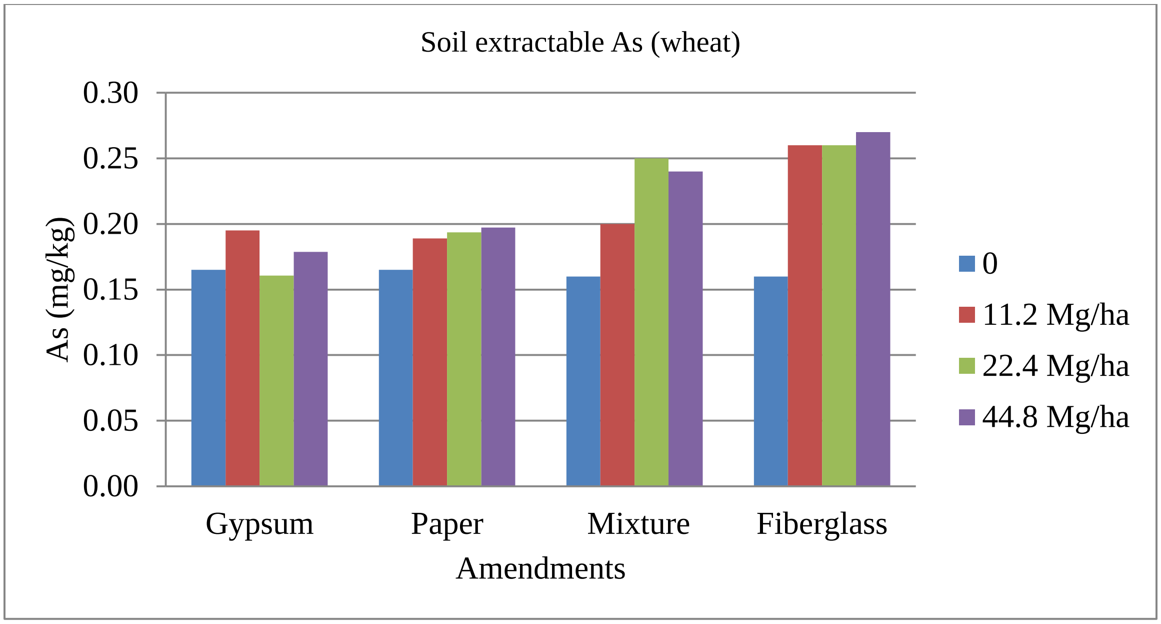

Figure 27: Soil extractable As (mg/kg) from two soils (Cecil and Tifton) planted with wheat amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

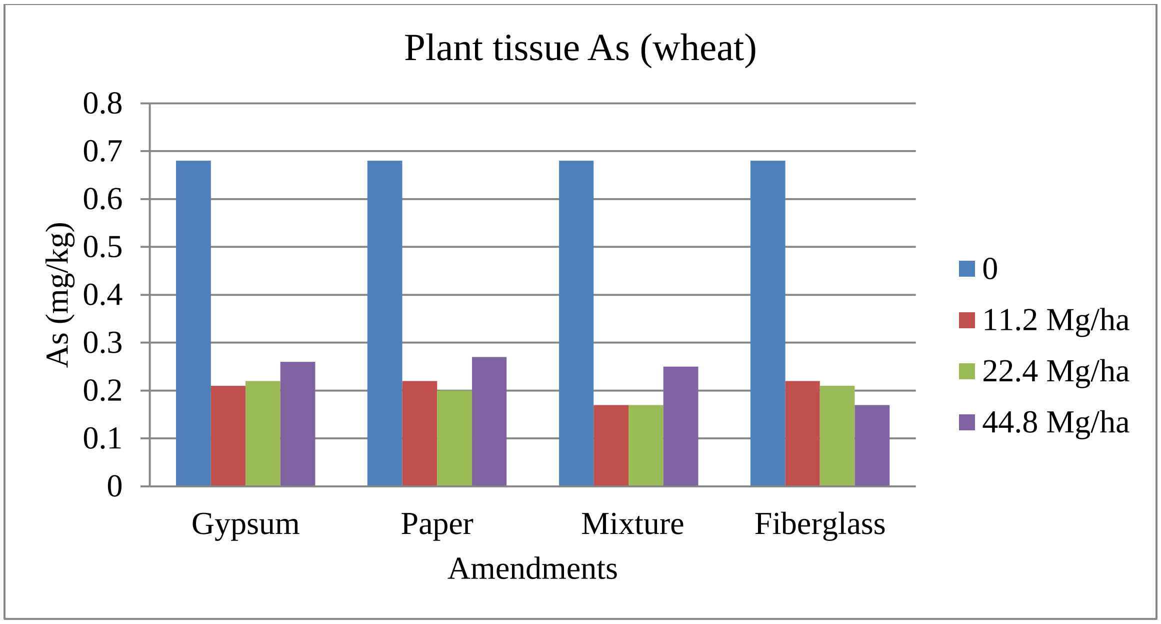

Figure 28: Plant tissue As (mg/kg) in wheat in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

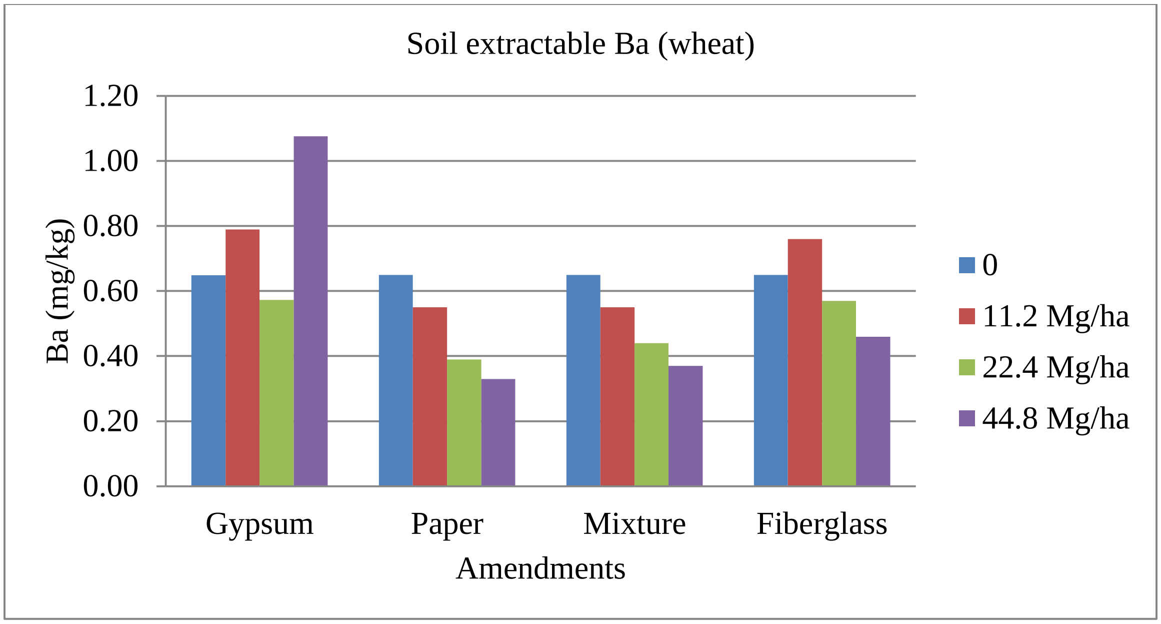

Figure 29: Soil extractable Ba (mg/kg) from two soils (Cecil and Tifton) planted with wheat amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) at three rates (11.2, 22.4, and 44.8 Mg/ha)

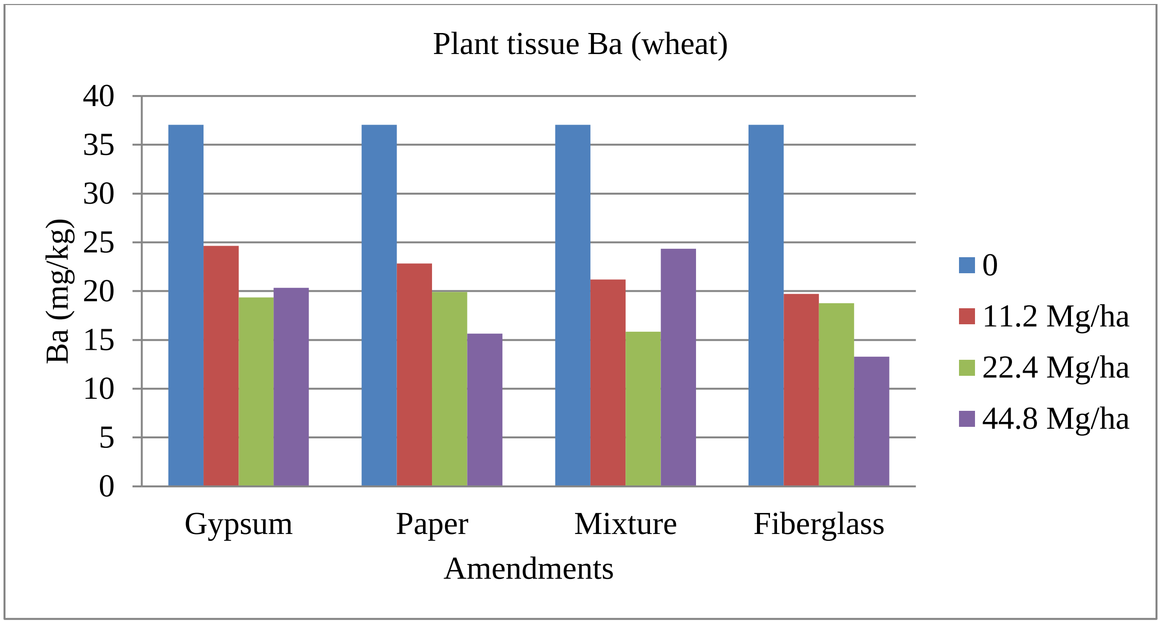

Figure 30: Plant tissue Ba (mg/kg) in wheat in two soils (Cecil and Tifton) amended with agriculture gypsum (gypsum), paper-faced wallboard (paper), paper-faced and fiberglass-faced wallboard (mixture) and fiberglass-faced wallboard (fiberglass) three rates (11.2, 22.4, and 44.8 Mg/ha)

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