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The Effects of Ground Gypsum Wallboard Application on Soil Physical and Chemical Properties and Crop Yield

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To the Graduate Council:

I am submitting herewith a thesis written by Christa LeAnne Davis entitled "The Effects of Ground Gypsum Wallboard Application on Soil Physical and Chemical Properties and Crop Yield." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental and Soil Sciences.

Joanne Logan, Major Professor

We have read this thesis and recommend its acceptance:

Richard G. Buggeln, Jaehoon Lee, Paul Denton

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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__Jaehoon Lee________________

__Paul Denton________________

Accepted for the Council:

_Anne Mayhew________
Vice Chancellor and
Dean of Graduate Studies

(Original signatures are on file with official student records.)

THE EFFECTS OF GROUND GYPSUM WALLBAORD APPLICATION ON SOIL PHYSICAL AND CHEMICAL PROPERTIES AND CROP YIELD

A Thesis

Presented for the

Master of Science

Degree

University of Tennessee Knoxville

Christa LeAnne Davis

May, 2006

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ABSTRACT

Crushed gypsum wallboard (CW) is a plentiful calcium and sulfur rich product that has been used as a soil amendment. CW is an excellent source of Ca and S that can help improve soil structure, increase infiltration rate, ameliorate subsoil acidity, and decrease surface crusting enabling the soil to supply more water to the crop through infiltration and better conditions for root growth. However it may cause magnesium deficiency in certain crops. In this study ground gypsum wallboard as a soil amendment at varying rates was investigated on typical Tennessee soils planted with fescue, tobacco, and sweet potato. Data collected included crop yields and soil physical and chemical properties such as bulk density, water content, pH, Ca, Mg, and K. Five experiments were conducted, pm fescue sod, tow on tobacco, and one on sweet potatoes. Tobacco and fescue experiments were conducted at the University of Tennessee Highland Rim Research and Education Center, experiments with fescue and sweet potatoes were conducted at the Tennessee State University Research and Demonstration Farm, and an experiment with tobacco was conducted at the University of Tennessee Research and Education center at Greeneville. In the fescue experiments CW was surface applied to fescue sod at three rates (0, 22, and 45 Mg/ha) in fall 2004. In the tobacco experiments, CW was surface applied and incorporated into the soil at three rates (0, 22 and 45 Mg/ha incorporated) and applied to the surface without incorporation at the 22 Mg/ha rate in spring 2005. in the sweet potato experiment, CW was applied a the same treatments as with tobacco, with an addition 22 Mg/ha treatment of a CW and wood mixture (CWW) incorporated into the soil, in spring 2005. In all cases, the CW treatments were compared to a no CW check. Results showed no detrimental effects of CW on crop yield. Soil pH was generally decreased by CW, but the decreases were small (0.1 to 0.3 pH units), and not detrimental to crop growth. Soil Ca was shown to increase at the soil surface with CW. In most cases, there was also an increase in subsurface Ca. A definite increase in exchangeable soil Ca was found from early season to after season soil samples at the surface and subsurface depths, indicating the much of the gypsum may have remained in the solid phase at the early sampling date. The Ca movement suggests the dissolution and leaching of gypsum had occurred in a short period of time, less than one year after application. The total increase in exchangeable Ca was less than the total Ca added, indicating that a large proportion of the gypsum added was still in the solid phase and available for continued dissolution over time. Soil Mg levels were found to be deficient in both fescue experiments at HR and TSU. K levels were shown to decrease when CW was applied, especially in the fescue and sweet potato experiments at TSU. Soil water content increased slightly and soil strength decreased, in some cases significantly, which could be beneficial to plant growth. Bulk density showed little decrease when CW was incorporated into the soil. From the results obtained by this study, using CW as a soil amendment not only helps waste management but can benefit the soil for a long period of time. Future studies should conduct plant analyses for possible deficiencies caused by the high rates of CW, collect more water data, and conduct the study for more than one year. It is probable that the short time frame in which the study was conducted may have prevented the effects of CW from being fully expressed.

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List of Abbreviations

CW	crushed wallboard
CWW	crushed wallboard and wood amendment
GR	University of Tennessee Greeneville Research and Education Center
TSU	Tennessee State University Demonstration Farm
HR	University of Tennessee Highland Rim Research and Education Center
Al	Aluminum
Ca	Calcium
Mg	Magnesium
K	Potassium
S	Sulfur
D_b	Bulk density
PG	Phosphogypsum
SO_4^{2-}	Sulfate

CHAPTER I: INTRODUCTION

It has been estimated that over 15 million Megagrams of new gypsum wallboard are used in construction in the United States annually (Wolkowski, 2000). Approximately 907 kg of waste wallboard material is generated per home in the United States (Wolkowski, 2000). The material is generated at building sites in a short period of time. Most of the waste wallboard is disposed of in landfills, which are quickly depleting in space; thus alternative uses of this material are being investigated. Recycling this material and applying it as a soil amendment would be both an economical and an environmentally feasible solution. Gypsum is an excellent source of calcium and sulfur for crops. Gypsum can improve soil structure, increase infiltration rate, ameliorate subsoil acidity, and decrease surface crusting to enable the soil to supply more water to the crop.

Objectives

With the current need to dispose of this material, an alternative is to apply crushed gypsum wallboard (CW) as a soil amendment. Limited attention has been directed toward examining and quantifying the effect of waste gypsum wallboard on plant growth and soil chemical/physical properties when applied at differing rates and depths. Current information about gypsum application is derived from a limited number of studies on soils and crops. More information is needed about the effects of waste wallboard gypsum when applied to typical Tennessee soils and crops. Therefore, the objectives of this study are to:

1) Examine the effects of CW on physical and chemical properties of key Tennessee soils when incorporated or surface applied at varying rates, and

2) Evaluate and compare the effects of CW on fescue, sweet potato, and tobacco yields.

CHAPTER II: LITERATURE REVIEW

The mineral gypsum

Gypsum (calcium sulfate dehydrate, ($CaSO_4$ *$2H_2O$)) is a naturally occurring and relatively common mineral that is widely available for agricultural use throughout the world. Mined gypsum has a yellowish to white color with crystals that range from silt size to several centimeters in length (Doner and Lynn, 1989). Most commonly, gypsum is found as tabular or needle crystals several centimeters in length (Doner and Lynn, 1989). Large gypsum deposits are commonly found in Arizona, New Mexico, New York, Texas, and Iowa (Doner and Lynn, 1989). The majority of this mined gypsum is used in the production of gypsum wallboard, as a cement additive for highways, or a soil amendment. Gypsum has also been found to occur in coastal wetlands as a result of the neutralization of acid sulfates formed by oxidation of sulfides during drainage, such as in mine spoils (Allen and Hajek, 1989).

Gypsum is approximately 100 times less soluble than other SO_4^{2+} minerals common to soils (Doner and Lynn, 1989). Gypsum is slightly soluble in aqueous solution and is able to contribute to the ionic strength of most soil solutions (Shainberg et al., 1989). It is able to allow the continued release of ions to the soil over a long period of time (Shainberg et al., 1989). The overall dissolution of gypsum in soils is promoted by the exchange of Ca for other exchangeable ions, which may have a limited effect on raising equilibrium Ca levels by releasing diverse ions into soil solution (Shainberg et al., 1989).

Saline and sodic soil reclamation

Alkaline soils such as sodic soils can be improved by amendment with gypsum. Sodic soils have more than 15 percent of their cation exchange sites occupied by Na^+ ions and are low in soluble salts (Thompson and Troech, 1993). Sodic soils contain dispersed colloids and have a pH above 8.5 due to the influence of Na^+ ions in solution (Thompson and Troech, 1993). These sodic soils are the most alkaline of all soils and the hardest to reclaim due to their dispersed colloids and very low permeability minimizing plant growth. Sodic soils are often referred to as *black alkali* due to the thin black deposit left from the organic matter accumulation on the soil surface (Thompson and Troech, 1993).

Reclamation of sodic soils occurs when the proportion of the cation exchange capacity occupied by the sodium ion Na^+ is reduced by exchanging with either the calcium ion Ca^{2+} or the hydrogen ion H^+ so that dispersion will not occur (Brady and Weil, 2000). The Na^+ is then displaced or leached from the soil (Brady and Weil, 2000). The most commonly used amendments for alkaline soil are gypsum and sulfur. When gypsum is applied to the soil in the form of $CaSO_4 * 2H_2O$ the following reactions occur:

$$2NaHCO_3 + CaSO_4 \rightarrow CaCO_3 + Na_2SO_{4\ (leachable)} + CO_2\uparrow + H_2O$$

$$Na_2CO_3 + CaSO_4 \leftrightarrow CaCO_3 + Na_2SO_{4\ (leachable)}$$

$$2Na^+ \text{ Micelle} + CaSO_4 \leftrightarrow Ca^{2+} \text{ Micelle} + Na_2SO_{4\ (leachable)}$$

A soluble salt is formed in all cases, thus allowing Na_2SO_4 to easily be leached from the sodic soil (Brady and Weil, 2000). With the addition of $CaSO_4$, the excess Ca^{2+} has the ability to replace nearly all of the Na^+ on the micelles and remove most of the carbonate ion from solution (Thompson and Troech, 1993). The removal of Na_2CO_3 is important because it can produce a very high pH, whereas Na_2SO_4 is a neutral salt. Calcium carbonate precipitates and Na^+ and SO_4^{2-} leach from the soil.

Gypsum ($CaSO_4 * 2H_2O$) is the most commonly used amendment for soil reclamation in arid regions due to its low cost and ease of handling. It was recognized by Hilgard (1906) and Kelley and Arany (1928) to be successful in preventing deflocculation and increasing leaching in these regions.

Gypsum use in semi-arid to humid, non-sodic soils

There are many soils in semi arid to humid regions that have similar problems of unstable structure, making them susceptible to erosion. They are difficult to manage due to their tendency to disperse and develop compacted structure at or near the soil surface. This breakdown of the surface soil structure can lead to problems such as soil crusting, reduced infiltration, increased runoff, erosion, and restricted plant establishment and growth (Shainberg et al., 1989). The breakdown of soil structural aggregates occurs from slaking and clay dispersion when wetted (Miller, 1987). Shainberg et al. (1989) proposed that these soils are unable to supply adequate electrolytes to the soil solution via mineral weathering to maintain flocculation and therefore lack the aggregate and soil pore stability to remain permeable to infiltrating water. Gypsum has been proposed as an additive to increase aggregate stability via the release of electrolytes to the soil solution. When an acidic, highly weathered soil is treated with gypsum the chemical and physical properties are affected. “When gypsum is applied to the soil surface, the electrical conductivity (EC) of the rainwater increases, preventing soil dispersion and crust formation, helping maintain larger aggregates at the soil surface” (Shainberg et al., 1989). Permeability is increased by means of EC effects with the addition of gypsum enhancing water movement into and through the soil profile (Loveday, 1976). Gypsum prevents swelling and dispersion, increases porosity, structural stability, hydraulic conductivity, soil tilth, drainage, and leaching, and reduces dry soil strength (Shainberg et al., 1989).

Amelioration of subsoil acidity in weathered soils

Gypsum is also an excellent source of calcium and sulfur for highly weathered soils, and has the potential to reduce subsoil acidity problems while increasing permeability. Therefore gypsum has potential as a soil amendment in humid regions where often toxic levels of aluminum are accompanied by deficient levels of calcium (Korcak, 1996). Although gypsum does not change the soil pH significantly, it can reduce aluminum toxicity in the subsoil, thus increasing crop yield (Shainberg et al., 1989). When gypsum is applied on the surface it slowly dissolves and leaches into the subsoil, where it can remain for long periods of time.

Subsoil acidity occurs below the depth at which lime can be incorporated into the soil by normal methods of cultivation. The amelioration of this acidity relies on the slow movement of lime or the use of more mobile amendments like gypsum. Gypsiferous materials may increase subsoil pH slightly due to the self-liming effect of gypsum, resulting from ligand exchange of sulfate anion for hydroxyl anions on hydrous Fe and Al surfaces (Shainberg et al., 1989). However, the effect is minimal, and in fact pH may also be decreased by the salt effect (Wolkowski, 2000). The addition of gypsum may provide benefits in overcoming Ca deficiency by increasing the Ca/Al ratio, and increasing the ionic strength of the soil solution. Hence these decrease the relative activity of Al (Shainberg et al., 1989).

Gypsum is able to ameliorate subsoil acidity by increasing the amount of exchangeable Ca down the profile while decreasing the exchangeable Al (Sumner, 1970). When gypsum or any other gypsum by-product is added to a soil, it replaces the exchangeable Al^{3+} with Ca^{2+}, promoting flocculation and reducing dispersion of clay particles (Miller, 1987). Clark et al., (2003); Noble et al., (1988); Pavan et al., (1982, 1986); and Tanaka et al., (1987) found that as the gypsum leaches downward in the profile, the sulfate ion pairs with the Al^{+} ion and reacts with OH^{-} to form $AlSO_4^{+}$, which is less toxic to plant roots than Al^{3+}. Essington (2004) concluded that the increase in soluble Ca^{2+} hastens the displacement of Al^{3+} and associated hydrolysis products from the soil exchange phase, resulting in the precipitation of jurbanite ($2AlOHSO_4$). Although the active acidity is increased with protons in this case, the overall total acidity is reduced when the basic Al sulfate (jurbanite) is formed (Essington, 2004). Liu and Hue (2001) conducted laboratory experiments and were able to show that 60% of the gypsum applied to an Ultisol moved beyond the applied layer. Liu and Hue (2001) also discovered that gypsum moved effectively down the soil profile and past the application zone with 6.4% leaching past the 45cm depth. Gypsum has the ability to transport calcium quickly from the topsoil and be retained for long periods of time in the subsoil. This has been shown to increase root density in deeper soil horizons (Farina, et al., 1999).

The effects of gypsum on soil pH are variable. When applied to four Wisconsin soils there was a reduction in pH, which was generally lowered 0.2-0.5 units at the highest gypsum application rate of 36 $Mgha^{-1}$. “This is likely the result of a salt effect in which the large Ca ion addition expels hydrogen ions from the soil exchange complex, increasing H^{+} in solution and reducing pH” (Wolkowski, 2000). This effect was noted throughout the experiment, which lasted 2 years (Wolkowski, 2000). In other experiments the soil pH was shown to increase a few tenths when gypsum was added to the soil as a result of the sulfate effect where SO_4 replaces the hydroxyl groups on particle surfaces and release OH^- in soil solution (Shainberg et al. 1989). For example, Farina (2000) showed significant pH increases. The difference in pH effects was apparently due to mineralogy. The soil studied by Farina had had an exchange complex dominated by Al and Fe oxides providing a large number of hydroxyl groups for ligand exchange reactions. However, in all cases exchangeable Al was significantly reduced, which is the more important effect (Toma et al., 1999). Farina (2000) showed evidence that acidity levels in the deepest horizon of both conventional and gypsum treated plots increased with time.

Effects on crop yield and seed emergence

The addition of gypsum for soil reclamation has sometimes resulted in dramatic improvement in yields on humid region soils with poor physical properties (Mays et al., 1986). The greatest potential use of gypsum lies in decreasing the crusting of these soils while reducing the acidity of subsoil horizons (Ultisols and Oxisols), improving water penetration, and ameliorating limitations to root growth. On soils that are dispersive, the use of gypsum increases crop yields through better water infiltration. Yield responses are generally higher on conventionally tilled soils than on no-till areas where surface sealing is already lessened because of the presence of crop residue (Shainberg et al., 1989 Howell, 1987; Hamblin and Howell, 1988). The addition of gypsum can be used to alleviate both physical and chemical factors that may hinder root growth. Radcliffe et al., (1986) reported that gypsum increased the subsoil root growth, which in turn improved water and nutrient uptake. The ability of gypsum to leach base cations into the subsoil is desirable when the depth of rooting of Al sensitive crops is limited by high Al levels in the subsoil (Clark et al., 2003). The calcium accumulation in deeper soil layers can reduce subsoil acidity and allow deeper root growth and water infiltration.

Toma et al., (1999) showed that total grain yield and biomass increased in both corn and alfalfa when gypsum was applied (Tables 2.1 and 2.2). These tables show the long term effects of gypsum on crop yield on a clayey, kaolintic, thermic Typic Kanhapludult located in South Africa in the 15th and 16th season, (indicated by experiments 1 & 2, respectively), after the gypsum was applied. Their results indicate that corn yields increased 29-50% and alfalfa yields increased almost 50% due to subsoil acidity amelioration.

Table 2.1. Long term effects of gypsum on corn yield.

Experiment	Soil type	Gypsum rate	Total biomass	Grain yield
		---------------(Mgha^{-1})---------------		
Experiment 1	Ultisol	0	28.2	6.7
Experiment 1	Ultisol	10	35.1	10.1
Experiment 2	Ultisol	0	27	6.1
Experiment 2	Ultisol	35	34.1	8.5

Source: Toma et al., (1999).

Table 2.2. Long term effects of gypsum on alfalfa yield.

Experiment	Soil	Gypsum rate	First yield	Second yield	Third yield	Total
		-------------------------(Mgha-1)-------------------------				
1	Ultisol	0	2.32	0.77	0.835	3.92
1	Ultisol	10	3.49	1.71	1.61	6.80
2	Ultisol	0	2.66	1.06	1.63	5.35
2	Ultisol	35	3.50	2.26	3.34	9.10

Source: Toma et al., (1999).

The addition of gypsum was shown to reduce crust strength, thus increasing seed emergence in dispersive soils (Shainberg et al., 1989). It was shown to increase cotton emergence on a Greenville soil from Georgia (Shainberg et al., 1989). Most of the reported emergence responses to applied gypsum have been in controlled laboratory studies. Observations in the southeastern United States have shown that rainfall conditions after planting are a crucial factor when trying to determine crust formation and the probability of a response to gypsum additions (Shainberg et al., 1989). Emergence responses are likely to be obtained when gypsum is applied before a heavy rainfall occurring immediately after planting, then followed by a dry period (Shainberg et al., 1989).

Other effects on soil properties

Recent studies have shown that gypsum changes chemical and physical properties of soil in ways beneficial to plant growth. Gypsum applied to the soil is able to increase infiltration rates and decrease sediment loss through reduced surface dispersion and maintenance of larger aggregates at the soil surface. These improvements in physical properties reduce surface crusting and enhance water penetration.

In addition to calcium, gypsum is also useful for applying S to the soil. Sulfur is an essential element for plant and animal nutrition (Brady and Weil, 2000). Healthy plant foliage usually contains 0.15 to 0.45% sulfur (Brady and Weil, 2000). A plant that is S deficient tends to exhibit chlorosis in the leaves. Some crops, such as legumes, cabbages, and the onion family require especially large amounts of sulfur (Brady and Weil, 2000). Excessive sulfur along with molybdenum has been shown to immobilize copper and make it unavailable to plants and animals, causing deficiencies in beef cattle (Mills, 2004). The lack of copper can lead to depigmentation and impaired keratiniztion of hair coats, poor growth, diarrhea, low reproduction, anemia, cardiac failure, and increases in pinkeye (Fisher et al., 2002).

Experiments conducted by Shainberg (1989) and Farina et al.(2000) showed that when gypsum was applied to the soil in both lab and field conditions, Mg was reduced in the upper part of the soil profile and accumulated for a time in the lower portion before its eventual removal from the profile. Farina et al. (2000) and Wolkowski (1998) found similar results showing the excess amount of applied Ca expelled Mg from the soil cation exchange sites, which subsequently leached from the sampled zone of the soil. Magnesium is an important element in plant growth. Farina et al., (2000) suggested that Mg be applied after gypsum application to maintain adequate Mg levels to avoid deficiencies, especially in sandy soils. Mg deficiency in forage crops can lead to grass tetany in grazing animals (Kayser, 2005).

The effect of gypsum on the soil P, K, B, Zn, and Mn were small and inconsistent (Farina et al., 2000). A reduction of K in the topsoil was detected when gypsum was applied, which was attributed to improved growth as a result of gypsum addition and therefore increased K removal (Farina et al., 2000). Fertilizer was suggested for these situations according to the initial recommendations of soil test.

Soil erosion and infiltration

CW and other gypsum by-products like phosphogypsum (PG) have been considered for their ability to reduce soil erosion and runoff. PG (calcium sulphate) is generated from the reaction of phosphate rock with phosphoric acid (P_2O_5) an essential component of many fertilizers (O'Brien and Sumner, 1988). The uses of these products show the potential for improving infiltration down the soil profile and subsequently help plant growth. Agassi et al., (1981) studied the effects of PG applied to the soil surface of a wheat field. He was able to show that PG was effective in reducing erosion by reducing runoff and stabilizing the soil structure at the surface. Agassi's results showed that when PG was applied at rates of 5 and 10 $Mgha^{-1}$ from 1980-1983 both runoff and erosion were reduced, compared to the control treatments. With these reductions, annual wheat yield increased by 0.59 $Mgha^{-1}$ (Agassi et al., 1981). Studies conducted showed that PG reduced surface sealing and erosion and improved water entry by releasing electrolytes that have the ability to keep clay particles flocculated and reduce crusting (USDA, 2005a). Crusting can decrease the infiltration rate of water into soils by breakdown of soil aggregates, compaction of the upper surface skin, and continuous sediment accumulation within the washed in zone (Oster and Singer, 1984). PG was found effective in reducing surface crusting and erosion even when surface applied and remaining in the upper one-sixteenth of an inch of the soil (USDA, 2005a).

Application strategies

The methods by which gypsum is applied or incorporated need to be taken into consideration. There is clear evidence that the rate of gypsum movement into the subsoil horizons is affected by tillage practices (Farina et al., 2000). Gypsum disked into previously deep-plowed soils moves far more rapidly than gypsum incorporated on conventionally plowed soil. On the other hand, spreading gypsum at the surface has been shown to decrease dispersion and the formation of surface crusts by promoting flocculation. The reduction or of surface crusting can reduce the effects of raindrop impact and decrease the amount of surface runoff. Agassi et al., (1982) found that surface application of PG was more beneficial than mixing to a depth of 5 mm. When the PG was mixed to a depth of 5 mm only one-fifth of the gypsum was available in the upper 1 mm of soil where the crust is formed (Agassi et al., 1982.) There is a trade off between the value of surface applied gypsum for infiltration enhancement versus the desirability of incorporating for more rapid movement into the subsoil.

The choice of the best approach for gypsum application is governed by economics and the type of soil is present. “Some soils, particularly those that are sandy or have been anthropogenically acidified, may not be responsive to gypsum; deep tillage is undesirable on soils with dense subsoils” (Farina et al., 2000).

Acid subsoil amelioration is an important agronomic objective in many areas of the world (Shainberg et al., 1989). “The most promising strategies for incorporation that are currently available for attaining this objective include surface incorporation of gypsum, plowsole incorporation of lime in quantities sufficient to ensure downward movement of the alkaline component, and subsoil incorporation of gypsum or lime using deep moldboard plows or specialized equipment designed to create tongues of ameliorated soil below normal tillage depth” (Farina et al., 2000).

Table 2.3 compares the effects of different methods of incorporation of gypsum at 10 Mg ha^{-1} on corn yield. Conventional incorporation was shown to be less effective in this study conducted by Farina et al., (1999). The Wye double digger was shown to have the most effect on corn yield as compared to the other methods.

Gypsum wallboard

As stated earlier it has been estimated that over 15 billion kg of new gypsum wallboard is used in construction in the United States annually, resulting in 0.5 kg of

Table 2.3. Different methods of gypsum incorporation on corn yield.

Method	Grain yield ($Mgha^{-1}$)
Conventional incorporation	5.39
Wye double digger	6.31
Deep moldboard incorporation	6.23

Source: Farina et al. (1999).

waste wallboard generated from every 0.09 m^2 of household floor space (Wolkowski, 2000). Currently most of the waste material is disposed of in landfills, contributing to landfill space depletion and potentially leading to the production of hydrogen sulfide gas and sulfide leachates (Wolkowski, 2000). As landfills fill up and close, siting of new landfills becomes more difficult and expensive. Through time the costs of waste disposal for construction and demolition debris will likely increase. This material is generated at building sites in a relatively short period of time; thus more economically and environmentally feasible options to recycle the material and apply it to land would be beneficial (Wolkowski, 2000). Across the country the alternative of land application has been investigated. Gypsum wallboard is composed of 92% gypsum (calcium sulfate dehydrate-$CaSO_4 * 2H_2O$), 7% paper, and 1% a combination of impurities in the gypsum rock additives (Marvin, 2000). The use of waste gypsum wallboard as a soil conditioner and fertilizer source of calcium and sulfur would reduce the amount of waste wallboard disposed of in landfills (Wolkowski, 2000).

Environmental impacts

Waste wallboard has the same basic constituents as other gypsum sources- calcium and sulfate- which are not considered to be environmentally damaging to ground or surface waters (Behel, 1997). There are some concerns with gypsum's ability to anaerobically decompose and produce the noxious, hydrogen sulfide gas. This gas can be dangerous at high concentrations and can occur in landfills or on very wet soils, but is not common or likely in agricultural situations (Shainberg et al., 1989).

A major beneficial environmental impact of gypsum on agricultural soils is the observed decrease in both total and clay-sized sediments generated from gypsum amended soils as a result of decreased surface crusting and erosion by raindrop impact (Shainberg et al., 1989) [as reported by Miller and Scifres, 1988]. Flocculation of eroded clay caused by the presence of dissolved gypsum decreases the transport of sediment into surface water. The ultimate effect is a reduction in the amount of sediment-associated agricultural nutrients leaving the field which can cause eutrophication in receiving streams, lakes and estuaries (Shainberg et al., 1989).

CHAPTER III: MATERIALS AND METHODS

General description

Five studies involving the application of crushed wallboard (CW) to the soil of fescue, burley tobacco and sweet potato plots were conducted. These five studies were distributed across three locations in Tennessee. Crushed wallboard was applied to fescue plots in the fall of 2004, and tobacco and sweet potato plots in the spring of 2005. Fescue (*Festuca spp.*), burley tobacco (*Nicotiana tabaccum spp.*), and sweet potato (*Ipomoea batatas spp.*) crop performance and soil property measurements were taken during and after the 2005 growing season.

Experimental site characterization at Highland Rim

Field experiments investigating crushed wallboard (CW) application to burley tobacco and fescue hay plots were conducted at the Highland Rim Research and Education Center, located near Springfield, Tennessee. Geographically, the experiment site is located in the Western Highland Rim, a subdivision of the largest physiographic region in the state. The Western Highland Rim is characterized by rolling terrain dissected by sharp valleys with streams (USDA, 1968). The elevations of this area range from 213 to 305 m above mean sea level (USDA, 1968). The underlying bedrock of this region is mainly Mississippian limestone and chert with some exposures of Mississippian shale and Devonian, Silurian, Ordovician, and Cambrian limestone, chert, and shale (USDA, 1968). On ridgetops, especially the wider inter-stream divides with undulating to gently rolling topography; the residuum material is covered by a layer of loess 0.5 to 1.0 m thick. This region has mild winters and hot summers that are periodically dry. The yearly average temperature is 15.6 °C with approximately 127 cm of precipitation. The precipitation is relatively evenly distributed throughout the year, but monthly averages are slightly higher in winter and early spring, and slightly lower than the fall (USDA, 1968).

Experimental site characterization at Tennessee State University

Experiments investigating CW application to fescue and sweet potato plots were conducted at Tennessee State University Research and Extension Demonstration Farm (TSU) is located near Ashland City, in north central Tennessee. This site is in the physiographic region of the Western Highland Rim (previously described for the Highland Rim Research and Education Center), but in this case it is located on a floodplain and terrace of the Cumberland River. Long and narrow floodplains with stream terraces adjacent to the Cumberland and Harpeth Rivers creates deep, loamy to moderately fine textured soils of variable drainage which characterize the experimental sites at TSU (USDA, 2002). The general topography of this site is level to undulating, with swales and low ridges running roughly parallel to the Cumberland River. The ridges are generally 1 to 2 m or so higher in elevation than the swales.

The climate of Cheatham County consist of is mild winters with an average temperature of 3.3°C and relatively hot summers with an average temperature of 22.4°C. The total annual precipitation is approximately 125 cm (USDA, 2002).

Experimental site characterization at Greeneville

Application of CW to burley tobacco plots was studied at the University of Tennessee Research and Education Center (GR) located in Greene County near Greeneville, Tennessee. Greene County is located in the northeastern part of Tennessee, in the Great Valley and Appalachian Upland physiographic regions. This site is in the

Great Valley region, which is characterized by its parallel valleys and ridges that were formed during a long period of geologic folding followed by erosion of underlying rocks. Exposed rocks from the folding mainly consist of shale and dolomitic limestone from the Cambrian age. The Center is located in a limestone valley, and the soils are formed in residuum from limestone overlain by alluvium from present or former streams.

Greene County has warm and moderately long summers with cool and moderately short winters with a yearly average temperature of 14.3°C and an average annual precipitation of about 127 cm (USDA, 1947).

Highland Rim (HR)-Fescue soil description

The fescue experiment at HR was conducted on a Mountview silt loam (fine-silty, siliceous, semi-active, thermic Oxyaquic Paleudult). The Mountview series consists of very deep, moderately-well to well drained soils located on undulating to rolling ridge tops. The soils have formed in 0.6 to 0.9 m of loess, and contain underlying residuum of limestone or old alluvium. The slope at the experiment site was approximately 1 to 3 percent (USDA, 2002).

Mountview soils are generally used for growing hay, pasture, small grains, soybean, corn, and tobacco. These soils have medium runoff, moderate permeability above the loess-residuum discontinuity, and moderately slow to slow permeability below the discontinuity. In general, the surface layer consists of 15 cm to 20 cm of brown silt loam. The subsoil, a silty clay loam, is yellowish brown in color and extends to an average depth of 0.9 m (USDAb, 2005). Below that depth there is a red cherty clay or

Table 3.1. Typical profile of Mountview silt loam

Horizon	Depth (m)	Texture	Color	Consistence
A	0-0.18	Silt loam	Brown	Friable
Bt1	0.18-0.89	Silt Loam or Silty Clay Loam	Yellowish Brown	Friable
Bt2	0.89-1.52+	Clay	Red / Yellow	Friable

Source: USDA, 1968.

clay that originated from weathered limestone bedrock which ranges from 3 to 12 m deep (USDA, 1968). A typical profile of a Mountview pedon is described in Table 3.1. This soil is representative of well drained soil in the state derived from loess, which are common upland agricultural soils found in western and middle Tennessee.

Highland Rim (HR)-Tobacco soil description

The HR tobacco experiment was conducted on a complex of Dickson and Mountview silt loam soils. Slope at the experiment site was 1-3 percent. Dickson soils are fine-silty, siliceous, semi-active, thermic Glossic Fragiudults. Dickson soils are located on nearly level to sloping uplands ranging from 0 to 12 percent slope. Dickson soils are silt loams that are moderately well drained, have medium to slow runoff, and contain a fragipan, a dense, non-cemented layer that perches water. The fragipan average depth is 0.6 m (USDA, 1968). This layer allows water to perch and inhibits plant root penetration. The soil is formed in a layer of loess 0.6 to 0.9 m thick, which overlies cherty yellowish-red clay or red clay that originated from limestone residuum or old alluvium (USDA, 1968). The typical horizons of the Dickson series are shown in Table 3.2. Dickson soils are generally adjacent to Mountview soils. Mountview soils, as stated above, are well

Table 3.2. Typical profile of a Dickson silt loam.

Horizon	Depth (m)	Texture	Color	Consistence
A	0-0.18	Silt Loam	Brown	Friable
Bt1	0.18-0.63	Silt Loam	Yellow/Brown	Friable
Btx	0.64-0.91	Silt Loam	Yellow/Brown/Gray	Firm/Cemented
2Bt	0.91-1.07+	Silty Clay Loam	Yellow/Brown	Firm

Source: USDA, 1968

drained soils that developed in a layer of loess 0.6 to 0.9 m thick that overlies reddish clay or cherty clay. The Dickson soil is representative of the fragipan soils formed from loess, which are commonly used for crop production in western Tennessee, and are the second most common soil used for crop production on the Highland Rim, after the well drained loess derived soils represented by Mountview.

Tennessee State University (TSU)-Fescue soil description

The fescue experiment at TSU was conducted on a Beason silty clay loam, which is classified as a fine, mixed, semi-active, thermic Aquic Hapludult. This soil is very deep, nearly level, and somewhat poorly drained. It is located on a stream terrace along the Cumberland River. Slope ranges from 0 to 3 percent (USDAb, 2005). This soil is well suited for pasture and hay crops that lack a deep rooting zone. The surface layer, upper (0.15 m), is composed of a brown silty clay loam. The subsoil, (0.15 to 1.52 m) is composed of either a yellowish-brown silty clay loam or brownish silty clay (USDA, 2002). Table 3.3 shows the typical sequence, depth, and composition of the horizons of a Beason silty clay loam. Beason soils are representative of imperfectly drained soils

Table 3.3. Typical profile of a Beason silty clay loam.

Horizon	Depth (m)	Texture	Color	Consistence
A	0-0.15	Silty Clay Loam	Brown	Friable
Bt1	0.15-0.33	Silty Clay Loam	Yellowish/Brown Gray Mottles	Friable
Bt2	0.33-0.58	Silty Clay	Yellowish/Brown Gray Mottles	Firm
Bt3	0.58-1.07	Silty Clay	Yellowish/Brown	Firm
Bt4	1.07-1.35	Silty Clay	Yellowish/Brown Gray Mottles	Firm
BC	1.35-1.52+	Silty Clay Loam	Yellowish/Brown Gray	Friable

Source: USDA, 2002.

located on floodplains and low terraces, which are widely used for agricultural production all across the state.

TSU-Sweet potato soil description

The experiment at TSU with sweet potatoes was conducted on a Nolin silt loam, which is classified as a fine-silty, mixed, active, mesic Dystric Fluventic Eutrudept. This soil is very deep, nearly level, well drained, and formed from alluvium derived from limestones, sandstones, siltstones, shales, and loess. The experiment was located on a floodplain of the Cumberland River with slopes ranging from 0 to 2 percent. This soil is generally well suited for row crops. In a typical profile, the surface layer is a brown silt loam that extends to 0.15 m in depth. The subsoil, 0.15 to 1.52 m in depth, is composed of two brown silt loam horizons. A typical Nolin silt loam profile is shown in Table 3.4.

Table 3.4. Typical profile of a Nolin silt loam.

Horizon	Depth (m)	Texture	Color	Consistence
A	0-0.15	Silt Loam	Brown	Friable
Bw1	0.15-0.66	Silt Loam	Yellowish/Brown	Friable
Bw2	0.66-1.52	Silt Loam	Brown	Firm

Source: USDA, 2002.

Greeneville (GR)-Tobacco soil description

The GR experiment with burley tobacco was conducted on an Etowah silt loam, which can be classified as a fine-loamy, siliceous, semi-active, thermic, Typic Paleudult. This site was mapped on an old survey of the Greeneville center as Hermitage silt loam, but this series is inactive and has been recorrelated into Etowah. The slope of the site was 1-2 percent. This soil series consists of very deep, well drained, moderately permeable soils on stream terraces, alluvial fans and foot slopes with slopes ranging from 2 to 5 percent (USDA, 1947). The parent material is alluvium or colluvium material underlain by limestone residuum below 1.0 m (USDA, 1947). This brown soil is high in plant nutrients and organic matter. The surface is a dark brown silt loam, 0 to 0.2 m thick. The subsoil typically consists of two horizons, a clay loam or silty clay loam in the upper subsoil extending to approximately 1 m in depth, and a silty clay loam subsoil below 1 m in depth. A typical profile of a Hermitage (Etowah) silt loam, as surveyed in Greene County, is shown in Table 3.5. Etowah soils are representative of the loamy upland and high terrace soils found in limestone valleys in eastern Tennessee and of the deep loamy upland soils formed in loess or alluvium in the Central Basin and Highland Rim of Central Tennessee. These soils are the most productive soils used for crop production in upland areas of eastern and middle Tennessee.

Table 3.5. Typical profile of a Hermitage silt loam.

Horizon	Depth (m)	Texture	Color	Consistence
A	0-0.25	Silt Loam	Brown	Friable
Bt1	0.25-1.0	Silty Clay Loam	Brown/Yellow/Red	Firm
Bt2	1.0+	Silty Clay	Yellow/Red	Very Firm

Source: USDA, 1947.

Crushed wallboard

Waste wallboard from manufactured homes was placed into a Packer grinder and crushed for use in all experiments in this study. Samples of the CW were obtained from each experimental site after application. The samples of CW and crushed wallboard and wood mixture (CWW) were stored in plastic bags for transport to the laboratory, where sub-samples were taken, weighed wet, and placed into a Fisher Scientific oven to be dried at 60°C for 24 hours. Dry weights of the samples were obtained and water content was determined. In all CW used in this study, water content was 25%. Water contents of CW and CWW were obtained by the same equation used for fescue moisture content (page 25). The amount of calcium applied to each plot was calculated based on moisture content and an average gypsum content of 92% of dry weight (page 14). Approximately 3500 and 7000 kg/ha of Ca was applied at the 22 and 45 Mg/ha rates, respectively.

Fescue-Experimental procedures

The HR and TSU fescue experiments were conducted on established fescue sod. The experimental design was a randomized complete block consisting of four replications of three CW rates of 0, 22, and 45 Mg/ha. CW was spread evenly on the soil surface by hand to the fescue plots in December 2004. The plot dimensions for HR and TSU were 3.1 m X 4.6 m, with a 1.5 m alley, and 3.1 m X 6.1 m, with a 3.1 m alley, respectively. Fescue production practices were standard for fescue (see Appendix I. Table A-1), except at HR fertilization was omitted in the spring of 2005. As noted above, both studies were conducted on previously established sod.

HR fescue was harvested on May 5 and September 10, 2005 using a self propelled forage harvester that harvested in a 0.9 m X 4.6 m swath from the center of each plot. The harvester at HR contained an automatic scale, which weighed the harvested fescue from each plot in the field. TSU fescue was harvested on May 5 and September 19, 2005 with a two wheel walk behind sickle bar mower with a width of 1.0 m. As at HR, a single swath was harvested from the center of each plot, giving a harvested area of 1.0 X 6.1 m. The forage was harvested and weighed on an Ohaus Corporation portable electronic scale with an indicator screen, models CD-11 and B100P, respectively.

Sub-samples were then taken and placed into labeled paper bags and transported to the laboratory. The wet samples were then placed in open metal containers, weighed wet, oven dried at 60º C, and weighed dry. The wet and dry weights were used to calculate the moisture content and yield of the fescue.

$$W_1 - W_2 = W_3$$

$$\{(W_3) \div (W_1 - W_c)\} \times 100 = \text{Water \%}$$

where:

W_1= Wet weight of fescue

W_2= Dry weight of fescue

W_3= Total weight of water

W_c= Weight of container

Yields for both fescue experiments were calculated on a dry weigh basis by using the actual harvested area and the dry matter content of the harvested fescue. For HR, the harvested plot size was 0.9 m X 4.6 m. The following equation was used to calculate the yield for each plot. Yields were actually calculated in English units of pounds, feet, and acres, and then converted from pounds/acre to kg/ha by using a factor of 1.12.

[[(harvested weight) * (Fescue dry weight/ fescue wet weight)] / (.00103 acre)] * 1.12 = kg/ha

For TSU fescue, the harvesting machine cut at a width of 1.0 m X 6.1 m. The following equation was used to calculate the yield for each plot.

[[(harvested weight)*(Fescue dry weight/ fescue wet weight)] / (.001515 acre)] * 1.12 = kg/ha

Tobacco-Experimental procedures

The HR and GR burley tobacco experiments were arranged in randomized complete block designs consisting of four replications of four CW treatments. CW was hand spread evenly on the soil surface to GR tobacco plots on March 15, 2005 at rates of 0, 22 Mg/ha and 45 Mg/ha incorporated, and 22 Mg/ha non-incorporated on May 31, 2005. For incorporated plots, CW was applied to the soil surface prior to transplanting then incorporated to a depth of approximately 10 cm by disking. For unincorporated plots, the CW was applied to the soil surface after seed bed preparation, and remained there through transplanting. During the early season the CW was partially incorporated to a depth of 2 to 4 cm by cultivation. Both tobacco experiments had plot dimensions of 4.3 m X 9.1 m, with a 0.9 m alley, between replications. Standard burley tobacco production practices were followed. A detailed description of standard burley tobacco practices is located in Appendix I. Table A-2. HR and GR tobacco were transplanted on June 3 and harvested on August 29, 2005.

HR and GR tobacco experiments were harvested on August 29, 2005. Plants were cut from the two middle rows of each plot near soil level and spiked onto wooden sticks. Then the tobacco was staked and hung to dry and cure in a standard tobacco barn for approximately eight weeks until ready to grade. The tobacco leaves were stripped into four standard grades (by stalk position), in accordance with standard tobacco production practices. Yield was then calculated based on mass of cured leaf from harvested acreage. As is customary for burley tobacco, the yield was reported as air dry leaf with no determination of moisture content. Yield for this study was total leaf yield, with all grades combined.

Sweet potatoes - Experimental procedures

The TSU experiment with sweet potatoes was in a randomized complete block design consisting of four replications of four CW treatments, plus a treatment consisting of a CW +wood mix (CWW). The CWW mix is a by product of mobile home manufacturing and consists of CW plus a varying content of framing wood. It differs from the CW product in having more high C fiber and less gypsum. This treatment was added as a matter of interest to two committee members who are involved in an on-farm application project with this material. No attempt was made to determine the proportion of wood. The intent was to obtain some information about this material relative to CW without wood. CW and CWW waste were hand spread evenly on the soil surface on May 25, 2005 with CW rates of 0, 22, 45 Mg/ha incorporated into the soil, 22 Mg/ha non-incorporated, and then 22 Mg/ha of CWW incorporated into the soil. There were five treatments and four replications, which made up twenty plots for sweet potatoes. The sweet potato plot dimensions were 6.1 m X 4.1 m with a 1.5 m alley.

Sub-samples of the CWW mix were taken from stockpiles, which had been stored uncovered, placed into plastic bags, and transported to the laboratory to determine water content. The sub-samples CWW were weighed and then dried at 60°C for 24 hours to determine water content. The water content of the CWW mix was 22%.

Sweet potatoes were harvested on October 25, 2005 by hand from each plot. The top of each sweet potato mound was removed, and then the potatoes were dug by hand and graded as marketable or non-marketable grades. The marketable potatoes were then graded into number ones (most desirable) and canners plus jumbos (less desirable). The marketable yield, number one yield, and proportion of number ones were calculated for each plot based on fresh weight per harvested acre. Production practices were standard for sweet potatoes (Appendix I. Table A-3).

Soil analysis

For all soil samples taken the undecomposed excess paper particles and any visible undissolved gypsum were brushed from the surface before obtaining the samples. Soil samples were taken using a standard 1.9 cm diameter soil probe. HR and TSU samples in fescue were taken March 15 and November 1, 2005 at depths from 0-0.15 m and 0.15-0.30 m. Soil samples were taken in tobacco on HR July 1 and November 3, 2005 at a depth of 0-0.15 m. GR tobacco soil samples were taken in June at 0-0.15 m depth and in October 12, 2005 at 0-0.15 to 0.15-0.30 m depths. TSU sweet potato soil samples were collected July 6, 2005 from 0-0.15 m depth and September 19, 2005 from 0-0.15 to 0.15-.30 m. Early season samples at HR and GR in tobacco along with TSU sweet potatoes were only sampled from the surface depth because the CW had only been applied a short time before and it was considered unlikely that there would be significant dissolution and movement below the 0.15 m depth at that time. For HR November samples, the soil was too dry to insert the soil probe to the 0.15-.30 m depth. Rainfall data for the summer 2005 at GR and HR experiment stations is shown in Appendix I. Tables A-4 and 5.

Six to eight soil cores were taken randomly from the two center rows of tobacco or sweet potatoes and from the center of fescue plots, in a zigzag pattern, within the plot to obtain representative soil samples. At HR fescue in November, the soil was very dry and difficult to penetrate; therefore only six cores per plot were taken.

All soil samples were air dried, ground by hand with a mortar and pestle, passed through a 2 mm sieve, and stored at room temperature. Soil samples were sent to the University of Tennessee Soil Testing Laboratory in Nashville, Tennessee where they were analyzed for plant available Ca, Mg, and K, and pH. Soil pH was determined by taking a sub-sample, approximately 10 cm^3, of the air dried sample, mixing with 10 ml of pure water, and reading the pH with an H^+ sensing electrode (Hanlon, 2001). Potassium, Ca, and Mg were determined by Mehlich I (0.05N HCL and 0.025N H_2SO_4) extraction using a sulfuric-molybdate solution as the reagent (Hanlon, 2001). An air dried sub-sample of soil approximately 5 cm^3 was placed into a 50 ml extraction bottle with extraction solution and shaken 5 minutes, and absorbance was read with a 718nm spectrometer (Hanlon, 2001).

Mg results were not determined for every experiment at the early date due to a miscommunication with the soil test lab, therefore Mg levels were not determined for HR tobacco (July, 2005), GR tobacco (June 2005) and TSU sweet potatoes (June, 2005). Due to time limitations and the fact we had later samples of all the sites with Mg determinations we did not have the lab rerun these samples.

Soil water analysis

Soil water content was obtained for GR and HR tobacco sites during the summer 2005 by using both gravimetric and Echo probes methods. The gravimetric method is much more laborious; therefore we wanted to examine a possible alternate method with the Echo probe. Echo[1] probes use capacitance to measure the dielectric permittivity of the surrounding medium. Dielectric permittivity is influenced by the volume of water in the total volume of soil, due to water having a much greater dielectric contact than the other constituents in the soil. When the amount of water changes in the soil the probes will measure a change in capacitance (dielectric permittivity). This change can be directly correlated with a change in water content (Decagon, 2004). Echo probes were placed 0.07 m deep in plots containing the 0, 22 incorporated and 22 Mg/ha unincorporated CW treatments. The shallow depth chosen was to specifically determine near surface soil water after a rainfall event. Measuring soon after a rainfall event allows us to measure soil water before the crop is able to remove much water, so the effect of infiltration on water content should be most strongly expressed. Due to the number of probes available, eighteen probes were placed in each tobacco experiment. Two probes were placed each plot in replications 1, 2, and 3. The probes were placed in the two middle rows between tobacco plants. Probe readings were taken for HR on June 6, July 6, and August 8, 2005. Probe readings for GR were taken on June 21, August 1, and

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[1] Echo is a trademark of the Decagon Corporation. The use of trademark names by the University of Tennessee does not imply endorsements.

August 22, 2005. Probe readings were taken by connecting the probe outlet to a portable datalogger that was able to read soil water as a proportion by weight, which was converted to percent by multiplying by 100. The two probes in each plot were distinguished by designating them as “left” and “right” probes. The left probe was located in the second row of tobacco between the fifth and sixth tobacco plants from the back of the plot. The right probe was located in the third row between the fifth and sixth tobacco plants from the front of the plot.

Gravimetric samples were taken in tobacco and sweet potato experiments to determine soil water in the treatments in which the Echo probes were used. HR and GR tobacco gravimetric samples were taken on the same dates probe readings were collected. Gravimetric samples for TSU sweet potatoes were obtained three times on July 7, August 3, and September 19, 2005 from the 0, 22 Mgha incorporated and 22 Mgha surface applied CW treatments. All replications were sampled for gravimetric water determination. A standard soil probe was used to take six soil samples at 0-0.07 m depth randomly from the two middle rows of the plot. The soil was placed in a bucket, mixed and transferred to a labeled metal canister for transportation to the lab. In the lab, the canisters were opened and weighed with the soil, before placing the canisters in the Fisher Scientific (Stabil-therm) oven to be dried at 105°C for 24 hours. After drying, the soil and canister was weighed. The soil was discarded after weighing and the canister for each plot was weighed. Water content of the soil was calculated by the equation below (Hillel, 1998).

$$W_1 - W_2 = W_3$$

$$\{(W_3) \div (W_2 - W_c)\} \times 100 = \text{Water \%}$$

where:

W_1= Wet weight of soil + canister

W_2= Dry weight of soil + canister

W_3= total weight of water

W_c= Weight of canister

Bulk density

Bulk density samples for HR and GR tobacco were taken October 5 and September 14, 2005, respectively. Bulk density samples for TSU sweet potatoes were taken on September 19, 2005. All samples were taken by using the short core method (Grossman and Reinsch, 2002). The cylindrical core was 75 mm in diameter, the height was same as the diameter, and the wall thickness of the cylinder was 0.5 mm. The cylinder was placed in a heavy sleeve with a beveled lower edge at the bottom of the siding hammer apparatus. The device sits on the soil surface. The sliding hammer was then moved up and down the shaft to supply force to insert the sleeve containing the cylinder into the soil. Grossman and Reinsch (2002) describe the methods used to obtain bulk density samples in detail. Two bulk density samples were taken within each plot at a depth of 75 mm. Once the cylinder was filled with soil, it was dug out of the ground with a shovel. The ends of the cylinder were trimmed flush with a knife. The soil was then pushed from the cylinder, placed into bags, and taken to the lab for drying. The samples were dried at 105°C for 24 hours and weighed. Bulk density was calculated by the following equation:

$$Db = \text{Mass of oven dried soil (grams)} \div \text{Total volume of soil (cm}^3\text{)}$$

Penetrometer readings

Penetrometer readings were taken at both HR and GR on October 5 and September 8, 2005 respectively. Penetrometer readings were taken at TSU sweet potato plots on September 19, 2005. Measurements were taken with a cone type penetrometer, model CN-970 that consists of a T-handle, one 45.72 cm penetration rod, one proving ring of 113 kg capacity with dial indicator, and a removable cone point with a base area of 6.34 cm^2 and a conical area of 12.5 cm^2. Measurements were taken by inserting the tip of the cone vertically into the soil at two randomly chosen spots from the two middle rows of the tobacco plots at a depth of 0-0.07 m at HR and from 0-0.15 m at GR and TSU. A depth of 0-0.07 m was used at HR because the soil was too dry below this depth to obtain meaningful measurements within the calibration range of the instrument. Soil penetration resistance measurements were recorded and the following conversion equation was used in Excel spreadsheets to determine the kilograms of pressure for penetration resistance:

$$X \text{ (kg)} = 0.146730302 * Y \text{ (indicator gage reading)} + 0.9881864888$$

Statistical analysis

Statistical analysis of the data for all experiments was conducted using standard analysis of variance procedures with NCSS (2004) software package. When a main effect of CW rate was significant at $P \leq 0.10$ means were compared using least significant difference and linear regression. Linear contrasts were chosen for each experiment to compare treatments at the probability of 0.10. A probability level of $p \leq 0.10$ was chosen because this work is of an applied nature and a probability of 90% for a real difference between treatment means was considered to be the most realistic. Contrasts for fescue were: (1) 22 and 45 Mg/ha incorporated versus the control and (2) 22 Mg/ha incorporated versus 45 Mg/ha incorporated. The set of contrasts used for tobacco was: (1) all CW treatments (22 Mg/ha incorporated and non-incorporated plus 45 Mg/ha) versus the control, (2) 22 and 45 Mg/ha incorporated versus 22 Mg/ha non-incorporated and (3) 22 Mg/ha incorporated versus 45 Mg/ha incorporated. Sweet potato contrasts were: (1) all CW and CWW treatments versus the control, (2) 22 Mg/ha non-incorporated versus 22 and 45 Mg/ha incorporated, (3) the CWW versus 22 Mg/ha non-incorporated plus 22 Mg/ha and 45 Mg/ha incorporated and (4) 22 Mg/ha versus 45 Mg/ha. These sets of contrasts are orthogonal, meaning they are independent of each other. All were pre-chosen, to avoid selection bias based on “data snooping” for likely significant differences and therefore maintain the actual 0.10 probability level for each contrast. The use of linear contrasts is generally considered to be the most appropriate method of mean comparison when there is a logical structure involved in treatments, such as rate or depth of placement, and logical hypotheses about the likely response to treatments.

CHAPTER IV: RESULTS AND DISCUSSION

Soil Chemical Properties

HR fescue- early season (March 2005)

Soil pH

Early season soil pH in HR fescue was significantly lower in the 22 and 45 Mg/ha treatments compared to the control compared at the 0-0.15m depth with means between 5.4 and 6.0 (Table 4.1). The decrease in soil pH in CW amended plots supports previous studies by Wolkowski (2000) stating that this is caused by the salt effect. The salt effect occurs when Ca from the CW replaces H^+ and Al^{3+} from the exchange complex resulting in a higher H^+ concentration in soil solution (Pavan et al., 1984). This is generally accompanied by a decrease in exchangeable Al^{3+}; it is not generally a serious problem for crop growth (Shainberg et al., 1989). Subsurface soil pH was similar to that of the surface, showing significantly higher pH in the control compared to the 22 and 45 Mg/ha treatments with means between 5.5 and 5.8.

Soil Ca, Mg, and K

Table 4.1 also shows results for early season soil Ca, Mg, and K. Soil Ca at the 0-0.15 m increased significantly when CW was added. Levels ranged from 451 and 636 kg/ha for the control and 45 Mg/ha treatments respectively. These numbers are what we expected after loading the soil with a high rate of gypsum. However, the increase in exchangeable Ca only accounts for a very small fraction of the total applied. It is likely that most of the gypsum had not fully dissolved at this time and still remained in solid phase on the soil surface, and was slowly dissolving over time. Soil Mg was significantly

Table 4.1. Soil pH, Ca, Mg, and K- HR Fescue March, 2005.

Depth	Treatment & linear comparisons	pH	Ca	Mg	K
(m)	(Mgha^{-1})		-----(kg/ha)-----		
0-0.15	Control	6.0	451	61	121
	22	5.4	515	46	145
	45	5.5	636	39	137
	C* vs. 22 & 45	S**	S	S	NS
	22 vs. 45	NS	S	NS	NS
0.15-0.3	Control	5.8	448	44	60
	22	5.6	498	48	68
	45	5.5	501	46	72
	C* vs. 22 & 45	S	S	NS	NS
	22 vs. 45	NS	NS	NS	NS

*C= Control, 22=22 Mg, 45=45 Mg
**S= Significant at 90% probability

higher in the control compared to 22 and 45 Mg/ha treatments, with values between 39 and 62 kg/ha at 0-0.15m depth. The values decreased as the amount of gypsum applied increased, but there was not a statistical difference between the 22 and 45 Mg/ha treatments. This supports previous results of Shainberg (1989) and Farina (2000), stating that Mg^{2+} is expelled from the exchange sites by flooding the system with Ca^{2+}. In this case, the Mg level of CW treatments fell below the state recommended critical level of 48 kg/ha for the upper 15 cm of the soil. Therefore, addition of Mg was recommended for sensitive crops, as noted by Savoy, 2003. Fescue is not a sensitive crop, but tobacco is. The upland soils of the Highland Rim and Cumberland Plateau in Tennessee are known to sometimes be marginal in Mg (Savoy, 2003). These results support Savoy's statement and indicate a need to monitor Mg in these areas when high amounts of Ca are added from gypsum. Soil K was not affected by treatments, indicating no displacement by Ca at this time.

HR fescue-after season (November 2005)

Soil pH

On November 1, 2005, about one year after CW application, pH was still significantly lower in the 22 and 45 Mg/ha treatments compared to the control, with values of 5.6, and 5.5, and 6.0 respectively (Table 4.2). There was no significant difference between the 22 and 45 Mg/ha treatments for the surface depth (0-0.15 m). Subsurface pH also did not differ significantly between treatments at (0.15-0.30 m) depth, unlike on March 15.

Soil Ca, Mg, and K

November Ca showed no significant differences between treatments at the 0-0.15m depth with values ranging from 487 to 599 kg/ha (Table 4.2). The overall Ca levels had not increased at the surface depth which may be attributed a dry season at HR in 2005, causing much of the gypsum to remain in the undissolved solid phase at the surface. The numerical differences were similar to March, but greater variability in the data resulted in a lack of statistical significance. The trend in Ca concentration increased as the amount of gypsum applied increased. The subsurface showed significant differences in all comparisons, increasing at the subsurface depth as the amount of gypsum applied increased. By November, the Ca had dissolved and moved deeper into the profile and showed higher levels than in March (Table 4.1). Although the season was very dry, there were two significant rainfall events that were associated with hurricanes which had evidently provided enough drainage through the profile to move the Ca below

Table 4.2. Soil pH, Ca, Mg, and K-HR fescue November 2005.

Depth	Treatment & linear comparisons	pH	Ca	Mg	K
(m)	($Mgha^{-1}$)		------(kg/ha)------		
0-0.15	Control	6.0	487	64	103
	22	5.6	563	56	154
	45	5.5	599	50	119
	C* vs. 22 & 45	S**	NS	S	NS
	22 vs. 45	NS	NS	NS	NS
0.15-0.30	Control	5.6	479	53	63
	22	5.5	577	56	68
	45	5.5	613	53	63
	C* vs. 22 & 45	NS	S	NS	NS
	22 vs. 45	NS	S	NS	NS

*C= Control, 22=22 Mg, 45=45 Mg

**S= Significant at 90% probability

0.15 m depth in the profile. The total increase in Ca one year after application is much less than the total originally applied. This indicates that most of the gypsum still remained undissolved and near or on the soil surface.

Magnesium was significantly lower in the 22 and 45 Mg/ha treatments compared to the control with values of 56, and 50, and 64 respectively, thus showing a slight decrease possibly due to ability of Ca^{2+} to expel Mg^{2+} from the exchange sites. The 22 and 45 Mg/ha treatments were not significantly different at the 0-0.15 m depth. Mg values increased slightly from March, which could be due to variability in laboratory techniques, but could also be from the release of Mg during the season by organic matter decomposition or recycling of Mg from deeper in the soil by plants during the growing season. Potassium showed no significant differences for both depths measured, thus indicating that gypsum had no effect on K levels.

TSU fescue-early season (March 2005)

Soil pH

Early season soil pH for TSU fescue plots showed no significant differences among treatments at depths from 0.0-0.15m and 0.15-0.30 m. Soil pH was between 5.5 and 5.6 at the surface and from 5.8 to 6.0 for the subsurface horizon (Table 4.3). There was a numerical decrease in the subsoil of approximately 0.2 units with the addition of CW, which was also observed in HR fescue soil pH.

Soil Ca and K

Table 4.3 also shows early results for soil Ca, and K at 0-0.15m and 0.15-0.30m depths. Means for Ca showed no significant differences between the 22 and 45 Mg/ha treatments versus the control at both depths. There was a significant difference between the 22 and 45 Mg/ha treatments at the 0-0.15m depth for Ca values. Ca values were 977 kg/ha and 879 kg/ha for 22 and 45 Mg/ha treatments, which is contrary to our expectations and unexplainable. These data lead us to believe that the gypsum had not dissolved to any great extent. The Ca levels in the control were surprisingly high, for unknown reasons. It is possible that the experiment site had been previously limed, causing the control to have a higher value than we expected. However, the pH did not indicate heavy liming. There were no significant differences in soil K with the addition of CW.

Table 4.3. Soil pH, Ca, Mg, and K-TSU fescue March, 2005.

Depth	Treatment & linear comparisons	pH	Ca	K
(m)	($Mgha^{-1}$)		--(kg/ha)--	
0-0.15	Control	5.6	941	80
	22	5.6	977	77
	45	5.5	879	79
	C* vs. 22 & 45	NS	NS	NS
	22 vs. 45	NS	S**	NS
0.15-0.30	Control	6.0	960	47
	22	5.8	888	53
	45	5.9	958	51
	C* vs. 22 & 45	NS	NS	NS
	22 vs. 45	NS	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg
**S= Significant at 90% probability

TSU fescue-after season (November 1, 2005)

Soil pH

After season pH was significantly different between treatments at for 0-0.15 m and 0.15-0.30m depths, which can be attributed to the salt effect, which was previously discussed in HR fescue soil results. Soil pH values were between 5.4 and 5.8 at 0-0.15m and between 5.7 and 6.1 at 0.15-0.30 m (Table 4.4). The control was significantly higher by 0.4 units in pH for both depths. This corresponds with HR results for the first sample date.

Soil Ca, Mg, and K

Table 4.4 shows soil Ca, Mg, and K values after the season. No significant differences were detected between treatments for Ca, Mg, or K for 0-0.15 m and 0.15-

Table 4.4. Soil pH, Ca, Mg, and K- TSU fescue November, 2005.

Depth	Treatment & linear comparisons	pH	Ca	Mg	K
(m)	(Mgha^{-1})		--------(kg/ha)-------		
0-0.15	Control	5.8	1016	154	80
	22	5.5	1016	136	76
	45	5.4	1481	141	82
	C* vs. 22 & 45	S**	NS	NS	NS
	22 vs. 45	S	NS	NS	NS
0.15-0.30	Control	6.1	1296	129	55
	22	5.8	1663	129	51
	45	5.7	1288	143	53
	C* vs. 22 & 45	S	NS	NS	NS
	22 vs. 45	S	NS	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg
**S= Significant at 90% probability

0.30 m depths. Due to higher variability, Ca values did not show a significant difference between the 22 and 45 Mg/ha treatments at 0-0.15 m depth with means of 1016 kg/ha and 1481 kg/ha, respectively. The results here contrast strongly with all other experiments, and reason is unclear. It is notable that Ca levels were higher overall in November than in March, which may in part be due to more dissolution of solid gypsum on the soil surface. However, the control was also noticeably higher at the 0.15-0.30 m depth. The higher pH in the control, and the trend toward higher Ca in the CW treatments were similar to other experiments, but the differences were less consistent. One possible explanation is that the gypsum, for whatever reason, had not dissolved and moved downward as much. Also, there were higher background levels of Ca here than at any other site, based on the Ca levels in the control, and it may be that the higher background levels and preexisting variability obscured any treatment affects. This may have been enhanced by the relatively short time frame since the CW application and a generally dry year in 2005, which may have limited gypsum dissolution and leaching. The gypsum at TSU was applied later than at HR and the year was relatively dry.

HR tobacco- early season (July, 2005)

Soil pH

Early season soil pH in HR tobacco plots on (July 1, 2005) showed no significant differences in pH between treatments, with values between 5.7 and 5.9, suggesting that the Ca from the CW had not dissolved enough to affect the pH at the time of sampling (Table 4.5).

Soil Ca and K

Soil Ca showed significantly higher values in the 22 and 45 Mg/ha incorporated and 22 Mg/ha non-incorporated treatments compared to the control with means of 879, 714, and 865 kg/ha, and 624, respectively (Table 4.5). The 22 Mg/ha incorporated treatment exhibited the highest values in replications one, two and three with means of 930, 974, and 930 kg/ha respectively (Appendix I. Table A-6). Significant differences were found when the 22 and 45 Mg/ha incorporated were compared with means of 879 and 714 kg/ha. The Ca levels were overall lower for the first set of samples than what we had expected, but follow the same decreasing trend found in other studies. Possible lower values were caused by the lack of dissolution of the gypsum at this time, with much of the gypsum still remaining in the solid phase. The weather between the time of application of CW and July was very dry at HR. The values for 45 Mg/ha are lower than

Table 4.5. Soil pH, Ca, Mg, and K – HR tobacco July, 2005.

Depth	Treatment & linear comparisons	pH	Ca	K
(m)	(Mgha^{-1})		--(kg/ha)--	
0-0.15	Control	5.9	624	280
	22	5.9	879	277
	45	6.0	714	269
	22 top	5.7	865	277
	C* vs. 22, 45, & 22 top	NS	S**	NS
	22 & 45 vs. 22 top	NS	NS	NS
	22 vs. 45	NS	S	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg
**S: Significant at 90% probability

for 22 Mg/ha treatment, for unknown reasons (Appendix Table A-6). Potassium means showed no significant differences between all compared treatments, with means ranging from 269 to 277 kg/ha.

HR tobacco-after season (November, 2005)

Soil pH

On November 3, 2005, after season samples were taken for HR tobacco plots from 0-0.15 m depth only, due to very dry soil conditions. Like previous studies, the control treatment had a significantly higher pH than the CW treatments, but only 0.1 to 0.3 units higher (Table 4.6). The control treatment had a higher overall value primarily due to a pH value of 6.6 in replication one (Appendix I. Table A-7). Also, the 22 Mg/ha non-incorporated treatment in replication one had a pH of 5.7, which lowered the overall value of this treatment (Appendix I. Table A-7). The overall decrease supports previous studies by Pavan et al. (1984) stating gypsum application can cause a slight decrease in

Table 4.6. Soil pH, Ca, Mg, and K- HR tobacco November, 2005.

Depth	Treatment & linear comparisons	pH	Ca	Mg	K
(m)	(Mgha^{-1})		------------(kg/ha)------------		
0-0.15	Control	6.3	736	302	210
	22	6.1	3262	231	192
	45	6.2	2892	271	207
	22 top	6.0	2674	228	216
	C* vs. 22, 45, & 22 top	S**	S	S	NS
	22 & 45 vs. 22 top	NS	NS	NS	NS
	22 vs. 45	NS	NS	NS	NS

*C = Control, 22 = 22, 45 = 45
**S: Significant at 90% probability

the soil pH by replacing H$^+$ and Al with Ca on the exchange complex, increasing the amount of H$^+$ in solution and making the pH more acidic. This reaction was also seen in previous experiments in HR and TSU fescue plots and is likely to occur in soils with high in exchangeable Al and H$^+$.

Soil Ca, Mg, and K

After season Ca results showed significant differences between the control and CW treatments (Table 4.6). Calcium highest in the 22 Mg/ha incorporated treatment at 3262 kg/ha. No significant differences in Ca levels were found between CW treatments when sampled at the surface depth. There was a numerical difference between the 22 Mg/ha incorporated and 22 Mg/ha non-incorporated treatments with means of 3262 and 2674 kg/ha. It would be expected that the incorporated treatments would dissolve at a quicker rate and move Ca deeper into the soil profile. The incorporated CW is subjected to continuous moist conditions, which would allow it to dissolve more rapidly. The incorporated treatments were also disked into the soil; therefore they would be smaller pieces than the non-incorporated CW. The combination of smaller CW particles and the soil's moist environment would increase the ability of the CW to dissolve when incorporated. However, this effect was not large enough to be statistically significant at the 10% probability level. The 45 Mg/ha incorporated treatment was numerically lower than that of the 22 Mg/ha incorporated treatments, which also was apparent when first sampled in July, but the difference was not statistically significant.. After season Ca levels were much higher, which suggest that Ca had not fully dissolved into the soil at the earlier date. Magnesium was significantly higher in the control compared to the other treatments, suggesting that the Ca had expelled Mg. Mg was not statistically different between the CW treatments. The Mg levels in all treatments were above critical levels for plant growth, so the reduction in this case in not an issue of concern. It is notable that the Mg is so much higher here than in the HR fescue. The soils are very similar, but the tobacco soil has been in a long term tobacco and soybean rotation and has received regular application of dolomitic lime, while the fescue soil has a history of much less fertilizer application and lime inputs. The Mg level for the 45 Mg/ha treatment was numerically higher, but this was caused by a higher value of 308 kg/ha in replication two (Appendix A-7). Potassium was not significantly different for any treatments with values ranging between 192 and 216 kg/ha. The potassium values did not show any negative effect from the added gypsum rates.

GR tobacco-early season (June, 2005)

Soil pH

Early season soil pH showed no significant differences between all treatments with values that ranged from 5.7 to 6.1 (Table 4.7). Results taken from the surface, 0-

Table 4.7. Soil pH, Ca, Mg, and K - GR tobacco June, 2005.

Depth	Treatment & linear comparisons	pH	Ca	K
(m)	(Mgha^{-1})		--(kg/ha)--	
0-0.15	Control	5.8	353	283
	22	5.9	958	286
	45	6.1	924	272
	22 top	5.7	708	297
	C* vs. 22, 45, & 22 top	NS	S**	NS
	22 & 45 vs. 22 top	NS	S	NS
	22 vs. 45	NS	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg,
**S: Significant at 90% probability

0.15 m, actually showed there was a small numerical increase of 0.1 to 0.3 units in pH when CW was incorporated into the soil. These results contradict our previous studies but are similar to results found by Farina and Channon, 1988. Farina and Channon (1988) found that pH increases by the sulfate effect, when sulfate replaces the OH^- by ligand exchange. This may reflect the differences in soil. Of the five sites investigated the GR site is the most highly weathered, with a higher proportion of kaolinite and iron and aluminum oxides in the clay fraction. In this sense it is the most like the soil studied by Farina and Channon (1988). It is possible that the OH^- released by ligand exchange is balancing the salt effect, leading to no significant changes in pH.

Soil Ca and K

Soil Ca showed significant differences between the control and other treatments (Table 4.7). The 22 and 45 Mg/ha incorporated and the 22 Mg/ha non-incorporated treatments were substantially higher than the control with values of 958, 924, and 708, and 353, kg/ha respectively. These results resemble previous experiments exhibiting a significant increase in Ca when CW was incorporated into the soil due to the large amounts of CW originally added to the soil. Significant differences were also shown when the 22 and 45 Mg/ha incorporated treatments were compared to 22 Mg/ha non-incorporated treatments. The values for the 22 Mg/ha incorporated and non-incorporated treatments were different suggesting the incorporated CW was able to dissolve more rapidly. The 22 and 45 Mg/ha incorporated treatments had similar values of 958 and 924 kg/ha respectively. The lack of differences between the treatments may reflect the incomplete dissolution of gypsum in the time period since application of CW, which mimics the results found in HR tobacco.

Potassium values showed no significant differences between all treatments with values that range from 272 to 297 kg/ha. All values for K were in the high range requiring no additional nutrients according to the University of Tennessee Soil Test Laboratory.

GR tobacco-after season (October 2005)

Soil pH

After the growing season, soil pH showed significant differences in the 0-0.15 m depth when 22 and 45 Mg/ha incorporated treatments were compared to the 22 Mg/ha non-incorporated treatment with values of 5.9, 6.1, and 5.7 respectively (Table 4.8). This could be due to the ligand exchange of SO_4^{2-} for OH^- being more extensive when the CW was incorporated more deeply, and had more soil contact. However, since the control pH was higher in October than July and numerically as high the CW incorporated treatments we can assume that high variability is a more likely explanation for this result. No significant differences were found between any other comparisons at 0-0.15 m depth.

Table 4.8. Soil pH, Ca, Mg, and K - GR tobacco October, 2005.

Depth	Treatment & linear comparisons	pH	Ca	Mg	K
(m)	(Mgha^{-1})		----------(kg/ha)----------		
0-0.15	Control	6.1	384	299	165
	22	5.9	1092	283	154
	45	6.1	3354	262	171
	22 top	5.7	720	274	168
	C* vs. 22, 45, & 22 top	NS	S**	NS	NS
	22 & 45 vs. 22 top	S	S	NS	NS
	22 vs. 45	NS	S	NS	NS
0.15-0.30	Control	6.6	420	363	111
	22	6.4	750	413	130
	45	6.2	1546	333	129
	22 top	6.5	468	410	108
	C* vs. 22, 45, & 22 top	S	NS	NS	NS
	22 & 45 vs. 22 top	S	NS	NS	NS
	22 vs. 45	NS	NS	S	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg
**S: Significant at 90% probability

Significant differences were found in after season samples at 0.15-0.30 m depth when control treatments were compared to the other treatments. The 22 and 45 Mg/ha incorporated versus the 22 Mg/ha non-incorporated treatments also showed significant differences with values of 6.4, 6.2, and 6.5 respectively. These values support our previous results and studies by Pavan et al., (1984) demonstrating the ability of gypsum to move more rapidly down the profile when incorporated. This is clearly shown by the decrease in pH when the CW was incorporated. These results are consistent with the salt effect mentioned previously. The pH for the non-incorporated treatments was 6.5. No significant differences were found between the 22 and 45 Mg/ha incorporated treatments. The 22 Mg/ha non-incorporated treatments had a higher value in replication one causing an overall higher value than expected (Appendix I. Table A-8). Values for surface depths were lower in pH than at the subsurface depths. This is not common in Tennessee soils. In this case, it probably represents a history of liming and relatively deep moldboard plowing as part of a long term tobacco rotation. Inversion of the soil by plowing deeper than 15 cm has moved some lime into the subsurface depth. Also, heavy nitrogen fertilization is often associated with tobacco production and may have contributed to the acidity in the surface.

Soil Ca, Mg, and K

Soil Ca at 0-0.15 m depth showed significant differences between all treatments with values ranging from 384 to 3354 kg/ha (Table 4.8). The control treatment gave expected results with a much lower value than any of the other treatments at 384 kg/ha. Exchangeable Ca levels were highest in the 45 Mg/ha incorporated treatment with a value of 3354, which contrast to June. Significant differences were found when the 22 and 45 Mg/ha incorporated treatments were compared to the 22 Mg/ha non-incorporated treatment with values of 1092, 3354, and 720 kg/ha respectively. The values for the 22 Mg/ha incorporated and non-incorporated treatments were significantly different, which reflects the more complete dissolution of gypsum when the CW was incorporated. The 22 Mg/ha non-incorporated CW was shown to have lower Ca means than that of the 22 Mg/ha incorporated. These numbers are lower than would be expected, which could be attributed to the gypsum remaining in the solid phase. These results support the theory presented by Shainberg et al. (1989) and the importance of application method and its ability to influence gypsum movement through the soil profile. When gypsum is disked into deep plowed soils rather than conventionally plowed or surface applied, it is able to move far more rapidly down the profile and supply Ca to plant roots (Shainberg et al., 1989).

The Ca for 0.15-0.30 m depth showed no significant differences between all treatments (Table 4.8). The higher values for the 45 Mg/ha treatments can be attributed to extremely high Ca values of 3696 and 1074 kg/ha in replications three and four, respectively (Appendix I. Table A-8). The results of Ca at this depth follow the trend seen in previous experiments. We did not believe the CW had been applied long enough for the Ca to move down the profile below 0.15 m, especially with a relatively dry season, but the trend indicated there may have been some movement. Surprisingly, there were no significant differences when the 22 Mg/ha was compared to the 45 Mg/ha incorporated and 22 Mg/ha non-incorporated treatments. The contrasts were actually significant at the 0.11 probability, and likely reflect movement of Ca into the subsurface depth.

Soil Mg showed no significant differences at the surface 0-0.15m depth (Table 4.8). Although there was a slight decrease in values, 299 to 262 kg/ha, from the control to 45 Mg/ha incorporated treatments, Mg levels still remained more than sufficient. Syed (1987) also found that Mg decreased in three soils as the amount of PG was applied to the topsoil at a rate of 10 Mg/ha over a two year study. Values for Mg at a depth of 0.15-0.30 m showed significant differences when the 22 and 45 Mg/ha incorporated treatments were compared with values of 413 and 333 kg/ha respectively, which could reflect expulsion of Mg^{2+} by Ca^{2+} from the exchange complex. The values were higher at the lower depth measured. This could be attributed to the CW application in the surface layer and Mg accumulating in the lower depths of the profile, thus the increase in Mg at

0.15-0.30 m. However, the control was also somewhat higher. The overall high Mg levels reflect the heavy use of dolomitic limestone over time.

Values for K (Table 4.8) showed no significant differences between treatments at either depth measured. Means at both depths only showed slight numerical differences in values. These results suggest no K displacement or leaching occurred at this time. The ability of K to be depleted to deficient levels is more likely to occur on sandier soils with lower cation exchange capacities (Syed et. al., 1987). The overall decrease in K from early season is a bit surprising, but tobacco is a heavy user of K and this may reflect crop removal.

TSU sweet potatoes-early season (June 6, 2005)

Soil pH

Early season results for soil pH for samples at 0-0.15 m depth showed no significant differences between any compared treatments with values ranging from 4.9 to 5.1 (Table 4.9). There was a numerical decrease in pH when CW or CWW was added to the soil, which follows the same trends seen in the other sites, but it was small.

Soil Ca and K

Soil Ca showed significant differences for all statistical comparisons (Table 4.9). Calcium values increased as the amount of CW applied increased, which is what we expected due to previous experiment results. The control treatment had substantially lower Ca values compared to the other treatments with a lower value of 434 kg/ha. There were significant differences between the 22 and 45 Mg/ha incorporated versus 22 Mg/ha non-incorporated treatments with values of 759, 991, and 714 kg/ha, respectively. Incorporation of CW allowed the ca to dissolve and move more rapidly into the soil. The

Table 4.9. Soil pH, Ca, and K – TSU sweet potatoes June 6, 2005.

Depth	Treatment & linear comparisons	pH	Ca	K
(m)	(Mgha^{-1})		--(kg/ha)--	
0-0.15	Control	5.1	434	139
	22	5.0	759	133
	45	4.9	991	130
	22 top	5.0	714	140
	W+G	5.0	711	131
	C* vs. 22, 45, 22 top & W+G	NS	S**	NS
	22 & 45 vs. 22 top	NS	S	NS
	W+G vs. 22, 45, 22 top	NS	S	NS
	22 vs. 45	NS	S	NS

*C = Control, 22 = 22 Mg, 45 =45 Mg, W+G = 22 Mg W+G

**S: Significant at 90% probability

values for both 22 Mg/ha incorporated and non-incorporated treatments were similar, with values of 759 and 714 kg/ha, respectively. We expected the values of the 22 incorporated treatments to be numerically higher than the 22 Mg/ha non-incorporated in the surface layer. Much of the surface applied gypsum would have been brushed off the surface when we sampled. These results show that the surface applied gypsum was able to dissolve as quickly as the 22 Mg/ha incorporated treatments. Soil K values showed no significant differences between all treatments for 0-0.15 m depth (Table 4.9). Values for K in this case are similar to previous results indicating no negative effects have occurred from the application of CW.

TSU sweet potatoes-after season (September, 2005)

Soil pH

Soil pH showed significant differences between the control and other treatments when compared and measured after season for 0-0.15 m depth (Table 4.10). There was a statistical decrease in pH values when the CW was added to the soil. The higher pH for the control can be attributed to a higher pH value in replication four of 5.5 (Appendix I. A-9). This value was the highest pH value at the 0-0.15 m depth, and increased the overall value of the control of 0.1 units contributing to the significance between treatments. These data follow the trend seen at other sites, decreases in pH with the addition of CW, which can be attributed to the salt effect.

Soil pH values for 0.15-0.30 m depth also showed a significant difference between the control and other treatments compared (Table 4.10). Once again, the control treatment had a slightly higher pH than the other treatments and can be attributed in part to the higher pH of 5.6 in replication four (Appendix A-9).

Soil Ca, Mg, and K

Soil Ca at 0-0.15 m showed significant differences between the control and other treatments with values ranging from 490 to 1095 kg/ha (Table 4.10). The Ca values showed a definite increase when the CW was applied at 22 and 45 Mg/ha incorporated and 22 Mg/ha non-incorporated with values of 1008, 1095, and 955 kg/ha, respectively. No statistical differences were established between the CW treatments. Values for Ca at 0.15-0.30 m depth mimicked the results found in the surface showing an increase in Ca with CW application. Significant differences were found between the control and other

Table 4.10. Soil pH, Ca, Mg, and K - TSU sweet potatoes September, 2005.

Depth	Treatment & linear comparisons	pH	Ca	Mg	K
(m)	(Mgha^{-1})		----------(kg/ha)----------		
0-0.15	Control	5.3	490	77	98
	22	5.0	1008	48	74
	45	5.1	1095	47	69
	22 top	5.1	955	50	71
	C* vs. 22, 45, & 22 top	S**	S	S	S
	22 & 45 vs. 22 top	NS	NS	NS	NS
	22 vs. 45	NS	NS	NS	NS
0.15-0.30	Control	5.3	507	62	62
	22	5.1	605	61	57
	45	5.0	652	79	54
	22 top	5.1	580	67	60
	C* vs. 22, 45, & 22 top	S**	S	NS	NS
	22 & 45 vs. 22 top	NS	NS	NS	NS
	22 vs. 45	NS	NS	NS	NS

*C = Control, 22 = 22 Mg, 45 =45 Mg, 22 top = 22 Mg surface applied
**S: Significant at 90% probability

CW treatments with values ranging from 507 to 652 kg/ha. The Ca for the 45 Mg/ha treatments had the highest value of 652 kg/ha. In this experiment there was significant movement of Ca below the application zone in less than one year. There was an evident increase in exchangeable Ca after season from the early season results. This supports the previously stated theory of gypsum dissolution over time. By the time the samples were taken after season we were able to see the amount of Ca had increased in the surface depth and moved down to the subsurface depth. Results from the June samples indicate that most of the gypsum may have still remained in the solid phase and could not be detected by the soil test extract.

Magnesium showed significant differences for the 0-0.15 m depth between CW treatments the control and with values ranging from 47 to 77 kg/ha (Table 4.10). Magnesium was shown to numerically decrease when CW was applied. This reduction in Mg suggests it has been reduced or removed from the upper portion of the profile by Ca, which was also seen by Syed et al., 1987 on a Georgia Ultisol. The CW treatments of 22 and 45 Mg/ha incorporated and 22 Mg/ha non-incorporated definitely showed a decrease in the amount of Mg present in the soil with values of 48, 47, and 50 kg/ha, respectively versus the control value of 77 kg/ha. Values for Mg measured at 0.15-0.30 m depth showed no significant differences between treatments. Mg levels in the CW treatments measured at the surface depth were close to the critical values, again, indicating a need to monitor Mg levels when gypsum is applied.

K showed significant differences between the control and CW treatments measured at 0-0.15 m depth (Table 4.10). The control treatment had a much higher K value than the other treatments, thus suggesting replacement or leaching by Ca. Syed et al., 1987 found that K, although less vulnerable than Mg to leaching, was seen to decrease in small increments with the addition of PG at the surface. The K values act similar to the Mg in this case. Values for 0.15-0.30 m depth showed no significant differences between all treatments with values ranging from 54 to 62 kg/ha. K continued to reduce as the depth increased in the profile. Potassium levels for both the surface and subsurface depths were in the low to seriously deficient range according to the University of Tennessee Soil Test Laboratory. Potassium application is needed for optimal plant production.

Overall, CW was shown to slightly decrease pH by 0.2 to 0.5 units with the addition of CW to the soil. The salt effect was commonly seen when CW was incorporated or surface applied. Ca levels were obviously higher in CW treatments at the surface depths. Gypsum dissolution was more evident in the incorporated plots for both surface and subsurface soil samples, and was often easier to see in the "after season" soil samples, taken less than one year after CW application. Ca levels in the CW treatments increased in almost all cases form early season to late season. Mg was shown to be displaced by Ca^{2+} with CW treatments. According to soil tests Mg deficiencies were found early season in HR fescue and late season in TSU sweet potatoes. K values slightly decreased with the CW additions, showing a deficiency at one site according to the soil tests. Soils low or at deficient levels should be monitored and fertilized according to soil tests recommendations.

Soil water analysis

Gravimetric soil water

HR-Tobacco

Gravimetric samples were collected on three dates throughout summer 2005 (Table 4.11 and Figure 4-1). Samples collected on June 21, 2005 showed a significant difference between the control and CW treatments of 22 Mg/ha incorporated and non-incorporated with values. Samples collected July 6, 2005 showed significant differences between 22 Mg/ha incorporated and non-incorporated treatments, with values of 10.9 and 14.0 %, respectively. These values are what we expected; indicating moisture at the surface had increased due to the CW. The control should have had a slightly lower value than the 22 incorporated treatments. The higher overall value in the control can be attributed to a high value in replication four of 16.1 % (Appendix I. Table A-10). The high control value along with a high value in the 22 Mg/ha non-incorporated treatments in replication three of 18.9 % was able to affect the analysis of variance results. On August 3, 2005 results showed no significant difference between all treatments versus the control. Soil moisture tended to numerically increase when the CW was surface applied. However these values were not enough to show statistical differences between treatments. Overall, there were small increases in soil water near the surface of 1-2%. Most increases were quite small and probably not very important for plant growth.

GR-Tobacco

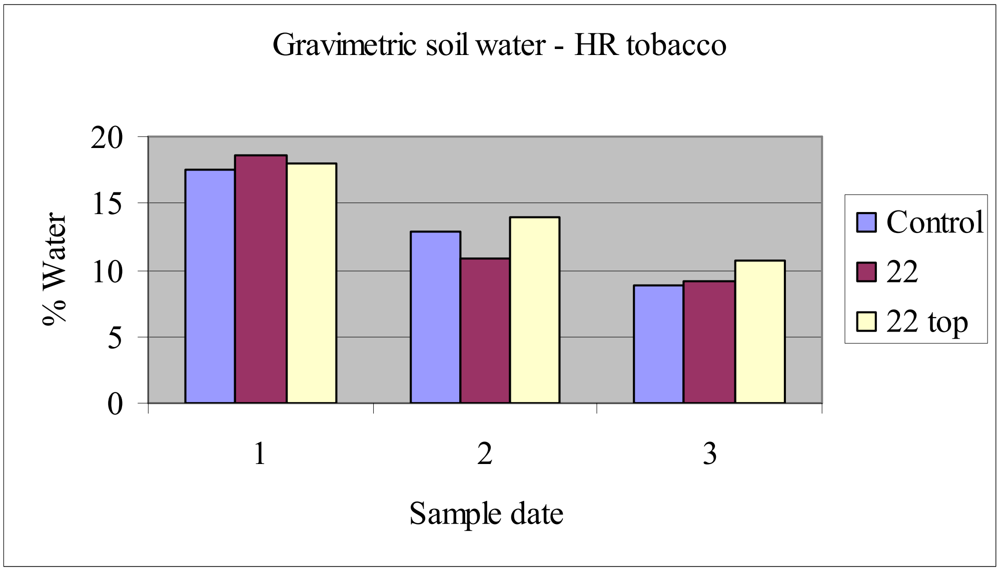
Gravimetric soil water samples were collected on three dates in the summer 2005 (Table 4.12). Values for June 22 showed no significant differences between treatments versus

Table 4.11. Gravimetric soil water - HR tobacco.

Treatment & linear comparisons	6/21/05	7/6/05	8/3/05
($Mgha^{-1}$)	------------	(Water %)	------------
Control	17.5	12.9	8.9
22	18.7	10.9	9.1
22 top	17.9	14.0	10.7
C* vs. 22 & 22 top	S**	NS	NS
22 vs. 22 top	NS	S	NS

*C = Control, 22 = 22 Mg

**S = Significant at 90 % probability



1: sampled June 21, 2005
2: sampled July 21, 2005
3: sampled August 3, 2005

Figure 4-1. Soil water for three dates in summer 2005 - HR tobacco.

Table 4.12. Gravimetric soil water - GR tobacco.

Treatment & linear comparisons	6/22/05	8/8/05	8/22/05
(Mg/ha)		------ (Water %) ------	
Control	12.6	9.0	19.8
22	11.6	9.3	20.5
22 top	15.5	9.6	19.8
C* vs. 22 & 22 top	NS	S**	NS
22 vs. 22 top	NS	NS	NS

*C = Control, 22 = 22 Mg
**S = Significant at 90 % probability

the control. The soil water for June 22nd ranged from 11.6 to 15.5 %. Although the 22 Mg/ha non-incorporated treatments were numerically higher, there were no statistical differences among treatments on this date. Soil water for August 8th showed significant differences between the control and CW treatments with values ranging from 9.0 to 9.6 %. When the CW was incorporated or applied to the surface the water content was shown to increase. Lastly, soil water for August 22nd showed no significant differences among treatments with values ranging from 19.8 and 20.5 %. Similar to HR tobacco, it is hard to assume that the CW actually was able to increase soil water content for this site. The August data was obtained shortly after a substantial rainfall, and might have been expected to show infiltration advantages for the CW treatments, but the data did not show this.

TSU-Sweet potatoes

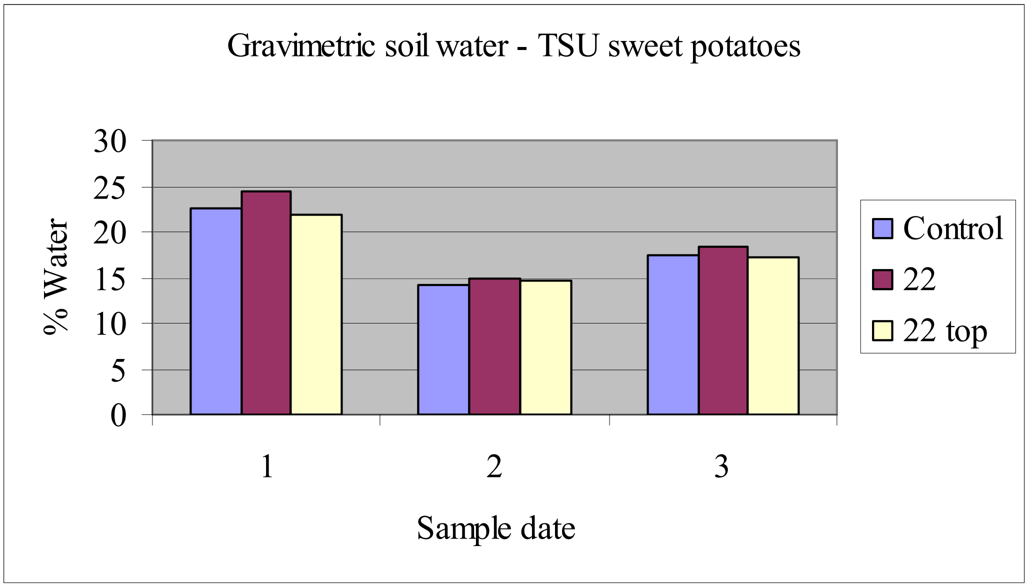
Gravimetric soil water samples were collected three times throughout the summer 2005 (Table 4.13 and Figure 4-2). Samples collected on July 6th showed no significant differences between treatments. Soil water was shown to increase numerically from the control when 22 Mg/ha of CW were incorporated into the soil with values of 24.5 and 22.5 %, respectively. Soil water values on August 3rd showed significant differences between the control and other treatments when compared. There was only a 0.30-0.70% increase in soil water from the control when the CW was added. Soil water means for September 19th showed no significant differences between treatments when compared. These values, like the values in July show only a slight numerical increase when 22 Mg/ha CW was incorporated into the soil with a value of 18.5 %. As at the tobacco sites, there were indications of higher soil water with CW treatments, but the differences were small and not always statistically significant.

Overall, gravimetric soil water was shown to increase numerically by 1-2%, above the control with CW. Although soil water increased with CW, the values were quite small and not always statically significant due to variability between treatments. The summer of 2005 was a very dry season, with the majority of the rainfall at TSU and HR from remnants of two large hurricanes. On most of the dates sampled there had been little or no rainfall for many days. Ideally we would have liked to collect soil water samples directly after a rainfall event, allowing us to obtain samples when infiltration rate was highest, before much crop removal had occurred. The effects of gypsum would be expected to be more visible in a season when most rainfall was from typical summer thunderstorms of 1.0 to 3.0 cm. In these cases, infiltration capacity differences would be

Table 4.13. Gravimetric soil water - TSU sweet potato.

Treatment & linear comparisons	7/6/05	8/3/05	9/19/05
(Mg/ha)	-------- (Water %) --------		
Control	22.5	14.3	17.4
22	24.5	15	18.5
22 top	21.9	14.7	17.1
C* vs. 22 & 22 top	NS	S**	NS
22 vs. 22 top	NS	NS	NS

*C = Control, 22 = 22 Mg
**S = Significant at 90 % probability



1: sampled June 6, 2005
2: sampled August 3, 2005
3: sampled September 19, 2005

Figure 4-2. Soil water for three dates - TSU sweet potatoes.

expected to make more difference. Therefore, we cannot assume the small increase is important to plant growth or that CW was able to increase soil water at this time.

Use of Capacitance (Echo) probes for soil water

HR-Tobacco

Echo moisture probe readings were taken on two dates in the summer 2005 (Table 4.14 and Appendix II. Figure A-1). Probe readings on July 6, 2005 showed no significant differences between all treatments with values ranging from 12.1 to 13.5 %. August 3, 2005 also showed no statistical differences between all treatments with values ranging from 12.1 to 13.9 %. Soil moisture was slightly higher in the 22 Mg/ha non-incorporated treatments on this date. These were similar to the gravimetric data for the same dates in showing no differences, but the numerical values were different for August 3.

Two linear regressions were preformed to determine the relationship of gravimetric and probes samples collected on July 7 and August 3, 2005 (Appendix II. Figures A-2 and 3). Figure A-2 shows the correlation of gravimetric samples versus probe readings for both dates by treatment. The control, 22 Mg/ha incorporated and 22

Table 4.14. Echo probe readings for HR tobacco.

Treatment & linear comparisons	7/6/05	8/3/05
(Mgha^{-1})	---------- (Water %)	---------
Control	12.1	12.1
22	13.5	12.9
22 top	13.0	13.9
C* vs. 22 & 22 top	NS	NS
22 vs. 22 top	NS	NS

*C = Control, 22 = 22 Mg

**S = Significant at 90 % probability

mg/ha non-incorporated treatments are represented by the equations: ($y = 0.5086x + 6.9178$), ($y = 0.693x + 6.5464$), and ($y = -0.0112x + 13.617$), respectively (Appendix II. Figure A-2). The R-squared values for each of the treatments show little correlation between the gravimetric samples and probe readings.

A second linear regression (Appendix II. Figure A-3) with the same dates considered and no differentiation between treatments has an equation of ($y = 0.1263x + 11.596$) and an R-squared value of 0.0163. These results also suggest little correlation between the gravimetric samples and probes readings.

Echo probe data were collected as a possible alternative to the gravimetric method, which we accept as the standard method. The use of Echo probes would be less laborious than the gravimetric method. The results suggest that the two probes were not sufficient for obtaining soil water content in this experiment, giving us unequivalent soil water results. This could be due to the incorrect installation of the probes and/or high spatial variability. We were able to collect gravimetric samples over the entire plot. The probes were only able to measure soil water for two specific locations in each plot. The use of more probes per plot is probably needed for a reliable estimate of soil water for the plot area as a whole.

GR-Tobacco

Echo moisture probe readings were taken the same dates that gravimetric samples were collected throughout the summer 2005 (Table 4.15 and Appendix II. Figure A-4). On all dates significant differences were shown between the control treatment and the 22 Mg/ha incorporated and non-incorporated treatments, unlike the gravimetric results. On all dates the soil water content in the control was much lower than gravimetric values,

Table 4.15. Echo probe readings - GR tobacco.

Treatment & linear comparisons	6/22/05	8/8/05	8/22/05
(Mgha^{-1})	------------	(Water %)	------------
Control	7.1	3.6	8.2
22	10.8	7.7	20.1
22 top	13	7.9	18.4
C* vs. 22 & 22 top	S**	S	S
22 vs. 22 top	NS	NS	NS

*C = Control, 22 = 22 Mg

**S = Significant at 90 % probability

while CW treatments gave similar results for both methods. Since gravimetric sampling is considered the standard, it has to be assumed that the echo probe readings did not accurately reflect the upper surface soil water content for the entire plot for the control treatment. The discrepancy was primarily in the control treatments.

Linear regressions for probe water versus gravimetric water were calculated (Appendix II. Figure A-5) and show the R- squared values for each treatment, 0, 22 Mg/ha incorporated and non-incorporated, with values of 0.54, 0.77, and 0.63 respectively. It is evident that the R- squared value increases when the CW was added to the soil. Also, for the CW treatments the slope is close to 1.0, which is what it should ideally be. The control treatments had the lowest R squared value and a slope of considerably less than 1.0. These values indicate that the gravimetric samples and probes were better correlated when the CW was added. It is not clear why results differ for the control. The difference could be due to spatial variability or differences in soil structure affecting the probe contact. As stated previously, CW is able to provide a more stable soil structure by increasing aggregation and porosity. In this soil, there is a tendency toward cloddiness with large void spaces and compacted aggregates. It is possible that the probes in the CW treatments were able to maintain better contact with the soil probe than in the control treatments. Another likely explanation is spatial variability. The probes measured two particular points in the plot, while eight gravimetric samples were taken from the entire plot.

A second linear regression was calculated with all dates and no differentiation between treatments (Appendix II. Figure A-6). Results showed an R-squared value of 0.54 derived from the equation ($y = 0.9247x - 2.2033$). These results are much better than the HR correlation coefficients, thus suggesting that the probes were not installed properly or the equipment was not calibrated correctly for that particular soil or that the spatial variability was greater. Results also allow us to speculate that the CW was able to improve aggregation and clay flocculation, which increased the probe contact with the soil following a rainfall event. The control treatments could have undergone separation from the probe due to more shrinkage and larger aggregates, decreasing its ability to accurately measure soil water.

Soil density and strength

Bulk density and penetrometer readings

HR-Tobacco

Soil bulk density at the 1-8.5 cm depth was significantly different between treatments (Table 4.16). Bulk density was shown to decrease as the amount of CW increased. Bulk density was highest in the control treatment and lowest in the 45 Mg/ha treatments with values of 1.49 and 1.28 g/cm^3 respectively. This indicates that the addition of CW has the ability to decrease bulk density. CW treatments were able to

Table 4.16. Bulk density and penetrometer values - HR tobacco.

Treatment & linear comparison	Bulk density	Penetrometer
(Mgha^{-1})	(g/cm^3)	(kg/pressure)
Control	1.44	75
22	1.36	75
45	1.28	70
22 top	1.36	70
C* vs. 22, 45, & 22 top	S**	NS
22 & 45 vs. 22 top	NS	NS
22 vs. 45	S	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg
**S: Significant at 90% probability

increase aggregation and pore space, therefore bulk density decreased. The bulk density values also indicate that there is no difference in the 22 Mg/ha incorporated and non-incorporated treatments with values of 1.36 and 1.36 g/cm^3 respectively.

Penetrometer readings were taken from the 0-0.07 m depth at the end of the season at two locations in each plot row ranging from 70 to 75 kg of pressure (Table 4.16). Penetrometer values showed no significant differences between any treatments, which were surprising due to the bulk density results. Although no significant differences were found there was a small numerical decrease as the amount of CW increased and when it was surface applied. Studies conducted by Radcliffe et al. (1986) showed when gypsum was surface applied there was a reduction in the cone index (resistance to penetration) down the entire profile of a Georgia Ultisol. Radcliffe et al. (1986) also concluded that the Ca and ionic strength increase clay flocculation, causing a change in shear modulus, which could influence the penetrometer resistance.

GR-Tobacco

Bulk density showed no significant differences between all treatments (Table 4.17). Bulk density was numerically highest in the 22 Mg/ha non-incorporated treatments due to a value in replication three of 1.6 g/cm^3 (Appendix I. Table A-11). This value is much higher than what is expected for this particular soil, therefore the 22 Mg/ha non-incorporated treatments had a slightly higher mean. The bulk density values for this experiment do not coincide with the results from HR tobacco. We would have expected a decrease in bulk density values from prior results from HR tobacco. Application of CW may have been more effective at HR due to prior management practices rotating tobacco and soybeans for the past years. This rotation should result in more tillage, less organic matter, and less stable structure than at GR tobacco, which had been rotated with fescue for three years. Hence gypsum might be more effective.

Table 4.17. Bulk density and penetrometer values - GR tobacco.

Treatment & linear comparisons	Bulk density	Penetrometer
(Mgha^{-1})	(g/cm^3)	(kg of pressure)
Control	1.34	91
22	1.33	84
45	1.37	89
22 top	1.44	100
C* vs. 22, 45, & 22 top	NS	NS
22 & 45 vs. 22 top	NS	S**
22 vs. 45	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg

**S: Significant at 90% probability

Penetrometer readings showed significant differences when the 22 and 45 Mg/ha incorporated treatments were compared to the 22 Mg/ha non-incorporated treatments (Table 4.17). Penetrometer values numerically decreased when CW was incorporated at 22 and 45 Mg/ha with values of 84 and 89 kg of pressure, respectively. It is possible that the incorporation of CW slightly decreased the penetrometer values, increasing aggregation and porosity when incorporated into the soil. These results follow HR tobacco results, showing soil strength or resistance decreased slightly with CW. However, it should be noted that the control was not much different from the 22 and 45 Mg/ha incorporated treatments. Penetrometer results match the bulk density, and reflect the higher D_b in the 22 Mg/ha non-incorporated treatments.

TSU-Sweet potatoes

Bulk density means were taken after season and showed no significant differences between treatments with values ranging from 1.10 to 1.16 g/cm^3 (Table 4.18). Although no statistical differences were found there was a numerical decrease in means when CW was incorporated into the soil at 22 and 45 mg/ha with values of 1.13 and 1.10 g/cm^3, which is what we expected due to previous results for HR tobacco. With these results we are able to assume CW incorporated into the soil is able to reduce bulk density by increasing soil porosity.

Penetrometer values showed significant differences between the control and other compared treatments of CW and CWW with values ranging from 58 to 126 kg/pressure (Table 4.18). There was a substantial decrease in values with the CW or CWW versus

Table 4.18. Bulk density and penetrometer-TSU sweet potatoes.

Treatment & linear comparisons	Bulk density (g/cm^3)	Penetrometer (kg of pressure)
Control	1.14	126
22	1.13	70
45	1.10	68
22 top	1.16	78
22 W+G	1.13	58
C* vs. 22, 45, 22 top & W+G	NS	S**
22 top vs. 22 & 45	NS	NS
22 W+G vs. 22, 45, & 22 top	NS	NS
22 vs. 45	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg, W+G = wood + CW

**S = Significant at 90 % probability

the control, suggesting less resistance was needed to penetrate the soil, presumably due to an increase in aggregation and porosity. There were no significant differences between the three CW and CWW treatments. The decrease in kg of pressure may be due to the silty soil at this particular site. Some of the control plots in this study were noticeably more resistant when readings were taken in the field. This was particularly at a depth of about 0.10 to 0.15 m, which may be why the difference was not well reflected by bulk density measurements.

Yields

HR-fescue

Fescue yields were determined for two dates in 2005 (Table 4.19 and Figure 4-3). Yields for May 5, 2005 showed no significant differences between the control and other treatments. Yields for the first harvest were 2822, 2014, and 2983 kg/ha for the control, 22 and 45 Mg/ha treatments respectively. Significant differences were found the first

Table 4.19. Fescue yields – HR 2005.

Treatment & linear comparisons	Yields 5/5/05	Yields 10/10/05
($Mgha^{-1}$)	--------------(kg/ha)---------------	
Control	2822	2152
22	2014	1620
45	2983	1674
C* vs. 22 & 45	NS	S**
22 vs. 45	S	NS

*C= Control, 22=22 Mg, 45= 45 Mg
**S=: Significant at 90% probability

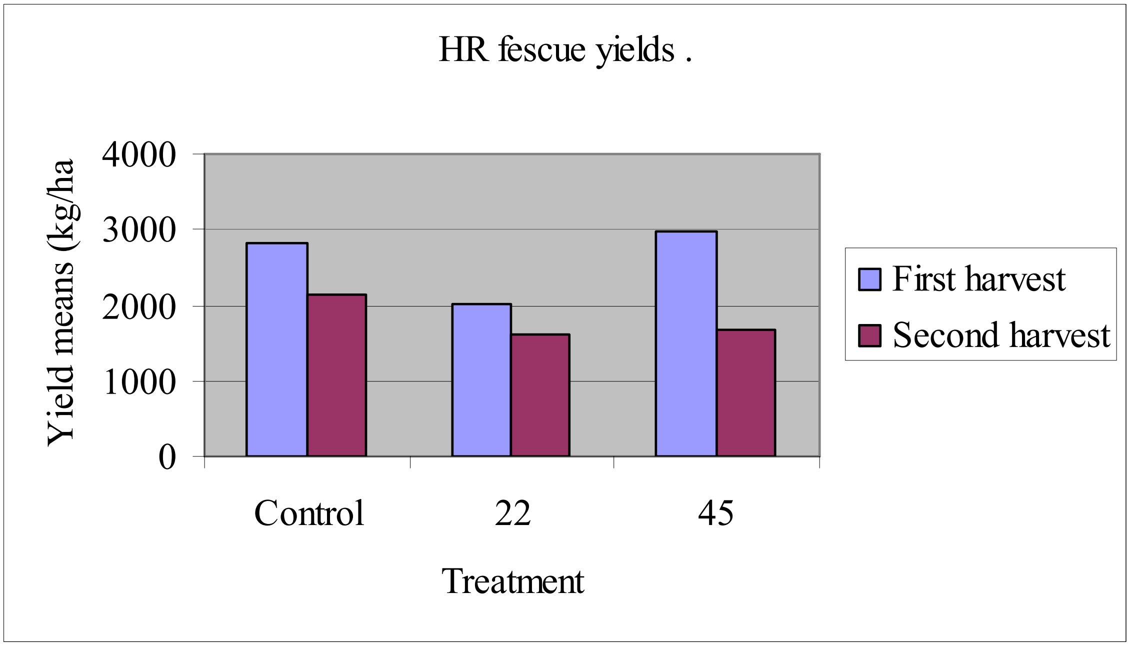


Figure 4-3. HR fescue yields 2005.

harvest between the 22 and 45 Mg/ha treatments with values of 2014 and 2983 Mg/ha respectively. The 22 value was unaccountably low. It is likely that a lack of fertilization and low rainfall resulted in high variability in this experiment. The addition of 45 Mg/ha was shown to have the highest yield for the first harvest. Sumner et al. (1986) also found similar results in alfalfa hay yield when mined gypsum and PG were added at 10 Mg/ha. Alfalfa yields were shown to have beneficial effects from gypsum application even up into the sixth and final year of the study. Yields for the second harvest on October 10, 2005 were much lower than the prior harvest and showed significant difference between the treatments. The control treatments were substantially higher than any other treatment, especially in replication one, which had the highest yield of the entire experiment with 3040 kg/ha (Appendix I. Table A-12). This plot along with the control yields in replications two and four were also higher than any other plots (Appendix I. Table A-12). The low overall yields in this experiment can be attributed to a failure to fertilize in the spring and early summer and a very dry season causing the yields to fall well below the average yield of the state of approximately 5000 kg/ha for the entire season. The lack of fertilizer was unintentional, and resulted from an oversight at the research center.

TSU fescue

Fescue yields for May 25, 2005 and September 19, 2005, showed no significant statistical differences between treatments. Yields for May 25, 2005 were between 7631 and 8123 kg/ha, quite high for fescue. As the amount of gypsum applied increased, yields did show a slight trend toward a decrease in yield for this date (Table 4.20 and Figure 4-4). The values for the 22 Mg/ha treatment were numerically higher than that of the 45 Mg/ha treatment due the high variability within replications, specifically due the

Table 4.20. Fescue yields - TSU.

Treatment & linear comparisons	Yield 5/25/05	Yield 9/19/05
($Mgha^{-1}$)	----------(kg/ha)----------	
Control	8123	3936
22	8018	4014
45	7631	4039
C* vs. 22 & 45	NS	NS
22 vs. 45	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg
**S: significant at 90% probability

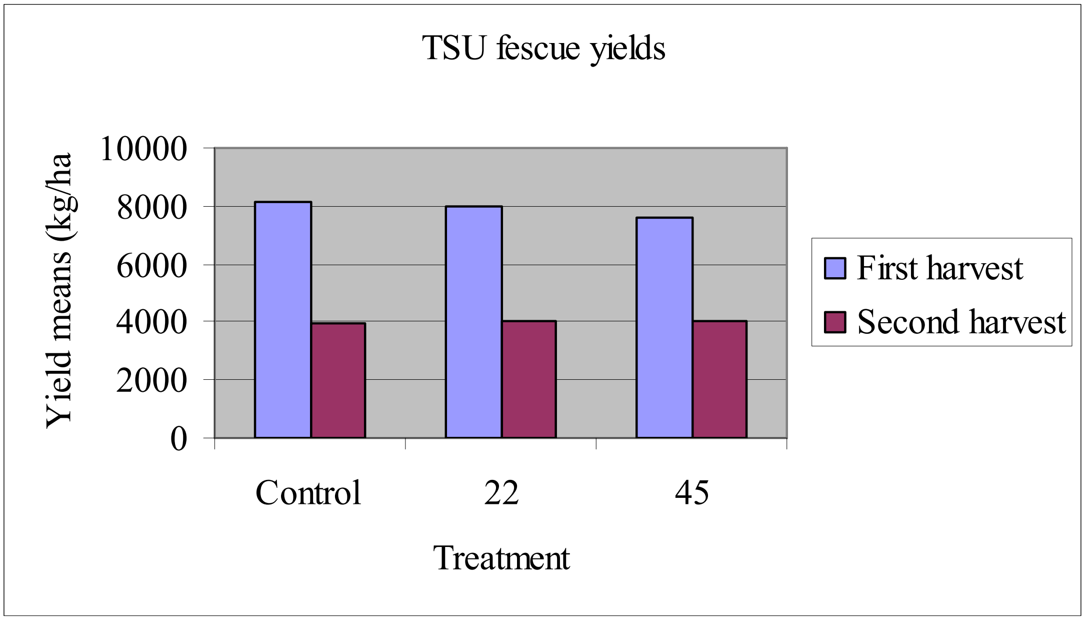


Figure 4-4. Fescue yields for TSU.

higher mean in replication four with a yield of 10071 kg/ha (Appendix I. Table A-13). This value in replication four was much higher than the other means in the entire experiment. Yields for September 19, 2005 showed no significant difference in yields as the amount gypsum applied increased with means between 3936 and 4039 kg/ha. There was less variability in values for this harvest date. Gypsum applied at 22 and 45 Mg/ha rates did not negatively affect the fescue yields nine months after application. For both harvests combined, the yields were exceptionally well above the average state yield of 5000 kg/ha.

HR-Tobacco

HR tobacco was harvested on October 10, 2005 and showed no significant differences in yield between treatments with values ranging from 2533 to 2631 kg/ha for the control and 22 Mg/ha incorporated treatments respectively (Table 4.21). Values for the grade index did show significant differences when the control was compared to the other treatments and when the 22 and 45 Mg/ha treatments were compared. The 45 Mg/ha incorporated treatments had a higher quality of grade index value at 59.0, which may be attributed to the higher rate Ca applied from the CW. Although statistically significant, this difference is not very important in market value.

GR-Tobacco

Tobacco was harvested on August 29, 2005. Yield results showed no significant differences between all treatments (Table 4.22 and Figure 4-5). Yields did show a slight numerical decrease in yields when CW was added to the soil, but not enough to show

Table 4.21. Tobacco yields and grade index - HR.

Treatment & linear comparisons	Yields	Grade Index
(Mgha^{-1})	(kg/ha)	
Control	2533	56
22	2631	56
45	2618	59
22 top	2550	57
C* vs. 22, 45, & 22 top	NS	S**
22 & 45 vs. 22 top	NS	NS
22 vs. 45	NS	S

*C = Control, 22 = 22 Mg, 45 = 45 Mg

**S: Significant at 90% probability

Table 4.22. Tobacco yields and grade index - GR

Treatment & linear comparisons	Yield	Grade index
(Mgha^{-1})	(kg/ha)	
Control	2991	65.7
22	2957	63.3
45	2804	65.4
22 top	2881	57.1
C* vs. 22, 45, & 22 top	NS	NS
22 & 45 vs. 22 top	NS	NS
22 vs. 45	NS	NS

*C = Control, 22 = 22 Mg, 45= 45 Mg

**S: Significant at 90% probability

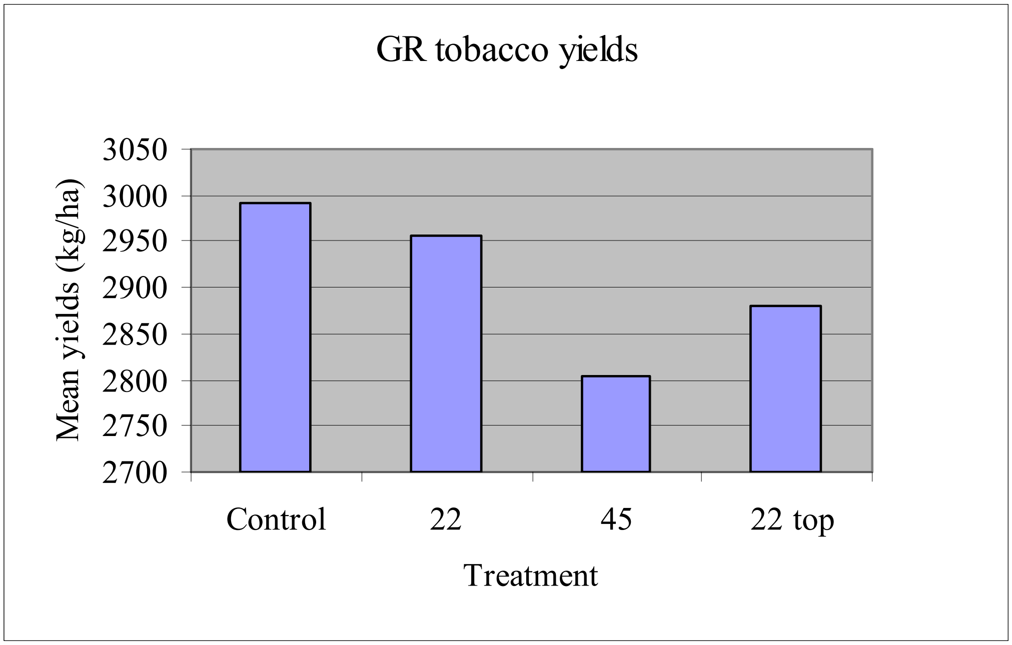


Figure 4-5. Tobacco yields - GR tobacco.

statistical differences. The control and 22 incorporated treatments had the highest yields with 2991 and 2957 kg/ha respectively. Grade index results showed no significant differences between all treatments despite values ranging from 57.1 to 65.7. Due to higher values in replication three for the control and 45 Mg/ha treatments, with values of 69.5 and 72.1 respectively, the overall grade index values were slightly higher (Appendix I. Table A-14). Also the 22 Mg/ha non-incorporated treatments had a very low value in replication one that decreased the overall grade index (Appendix I. Table A-14).

TSU-Sweet Potatoes

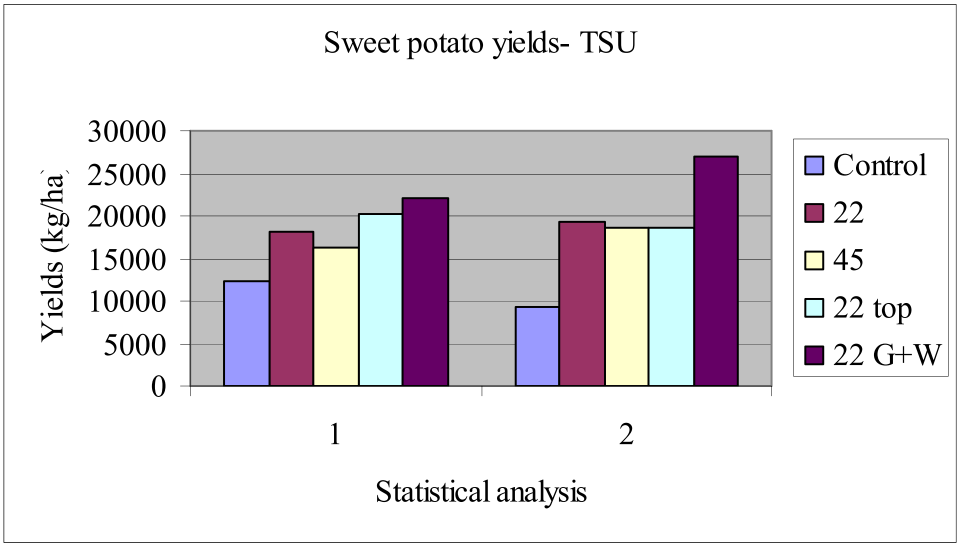
Sweet potato yields showed no significant differences between all treatments at $p \leq 0.1$, despite values ranging from 12241 to 22080 kg/ha (Table 4.23 and Figure 4-6). This was due high variability between replications. All treatments of CW and CWW

Table 4.23. Yields - TSU sweet potatoes.

Treatment & linear comparisons	Means with rep 2	Means without rep 2
(Mgha^{-1})	-------(kg/ha)------	
Control	12241	9238
22	18200	19216
45	16303	18535
22 top	20140	18661
W+G	22080	26976
C* vs. 22, 45, 22 top & W+G	NS	S**
22 top vs. 22 & 45	NS	NS
22 W+G vs. 22, 45, & 22 top	NS	S
22 vs. 45	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg, W+G = 22 Mg W+G

**S = Significant at 90 % probability



1: Replication two included in statistical analysis

2: Replication two not included in statistical analysis

Figure 4-6. Sweet potato yields-TSU

were shown to numerically increase yield, but values for the control and CWW treatments in replication two were contrasting to other replications with values of 21248 and 7391 kg/ha respectively (Appendix I. Table A-15). The low yield for the CWW plot in rep 2 was due to a serious infestation of Bermudagrass. The reason for the very high yield for the control in replication two is unknown. Due to the highly contrasting results in the single rep, analysis of variance was run with and without replication two to evaluate if there were any significant differences. Without replication number two, yields showed significant differences between the control and other treatments with values ranging from 9238 and 26976 kg/ha. There was a definite increase in sweet potato yield in the presence of CW or CWW. Statistics also showed a significant difference between CWW and the other CW treatments. The CWW treatment overall yield was higher than the other treatments at 26976 kg/ha. The CWW treatment was 7760 kg/ha higher than the highest CW value of the 22 Mg/ha incorporated treatment. These higher results for the CWW may have resulted from the added wood component; which could have contributed to a possible increase of soil K, which was quite low at this site. The extra Ca from the CW and Ca and K from the CWW could have positively increased sweet potato yields. Yields may have also increased due to the decrease of compaction with CW and CWW treatments. The increased electrolyte from the gypsum is able to increase aggregation and allows the sweet potato itself to grow more uniformly without constraint of a more compacted soil not containing CW or CWW treatments.

The total yield of grade one sweet potatoes was also statistically analyzed with replication number two included and excluded (Table 4.24 and Figure 4-7). When replication two was not included, significant differences were found between the control

Table 4.24. Yield of grade 1 – TSU sweet potatoes.

Treatment & linear comparisons	Yield with rep 2	Yield without rep 2
(Mgha^{-1})	-------(kg/ha)-------	
Control	4296	3819
22	7021	7452
45	6328	7083
22 top	7298	6960
22 W+G	8545	10593
C* vs. 22, 45, 22 top & W+G	S	S
22 top vs. 22 & 45	NS	NS
22 W+G vs. 22, 45, & 22 top	NS	S
22 vs. 45	NS	NS

*C = Control, 22 = 22 Mg, 45 = 45 Mg, W+G = 22 Mg W+G
**S = Significant at 90 % probability

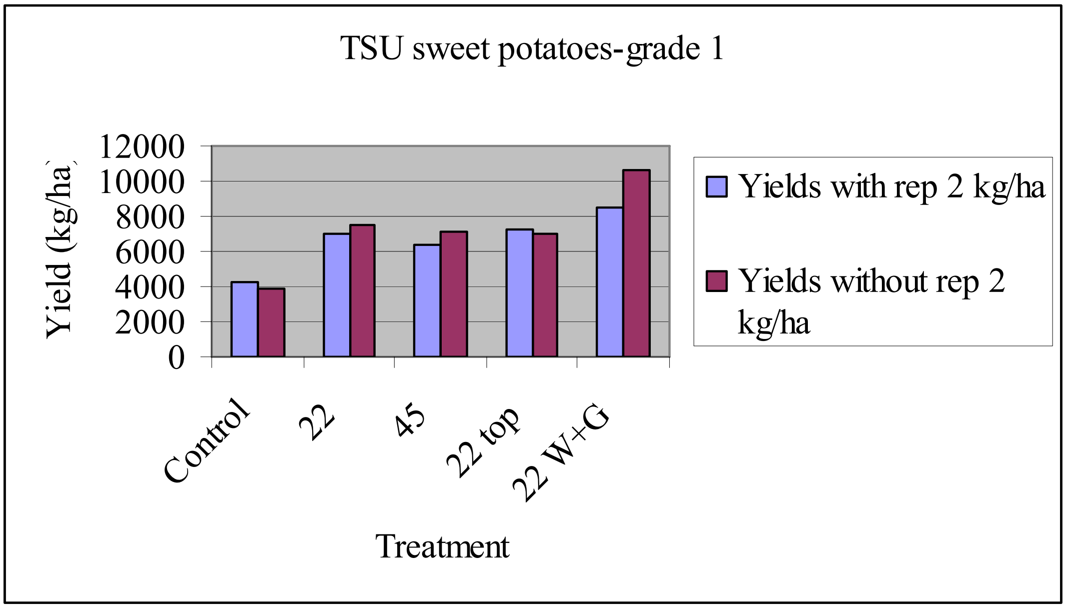


Figure 4-7. Sweet potato yields for grade 1 with and without rep – TSU.

and all other treatments with values ranging from 4296 to 8545 kg/ha. The control was substantially lower than any of the other treatments of CW, which can be attributed to the low value in replication one of 2587 kg/ha (Appendix I. Table A-15). The gypsum plus wood treatment had a much higher value than the other treatments with a value of 8545 kg/ha. There were no other significant differences between other treatments. The proportion of number one grade varied from 37 to 41% with rep 2 excluded, and was not significantly different (data not shown).

Due to the high variability in replication two we also ran analysis of variance without replication two on grade one sweet potatoes (Table 4.24 and Figure 4-7). Significant differences were found between the control and other treatments with values ranging from 3819 to 10593 kg/ha. Once again the control was much lower than the CW and CWW treatments. The 45 and both 22 Mg/ha incorporated and non-incorporatedCW treatments had similar results with values of 7083, 7452, and 6960 kg/ha, respectively. The highest yield of 10593 kg/ha was when the CWW mixture was added to the soil and was statistically different from the other CW treatments. This particular treatment had much higher yields in replication one and four of 11271 and 11640 kg/ha (Appendix I. Table A-15). No other statistical differences were found between the treatments when replication two was excluded. These data indicate a strong possibility of improved sweet potato yields with CW. It had been speculated that the CW might enhanced the soil's physical conditions for potato development. By adding CW or CWW the soil is better aggregated and clings less to the sweet potato. The potato is able to grow more uniformly, increasing the grade and yield. However, at this site with very low pH, the response was more likely due to reduced aluminum toxicity and improved Ca supply. The reduction in soil strength, exhibited in the penetrometer results, could have attributed to decreasing the soil’s compaction in the control plots.

CHAPTER V: SUMMARY AND CONCLUSIONS

The issue of using ground gypsum wallboard (CW) as a soil amendment has become a matter of interest as a means for disposal of waste wallboard. The gypsum in waste wallboard has the potential to provide calcium and sulfur to soils as well as influence soil physical and chemical properties. It has the ability to increase infiltration rates, decrease erosion, ameliorate subsoil acidity, reclaim alkaline soils, increase crop yields, and increase soil water. The influence of CW on pH is variable with possible negative effects when applied at higher rates in some soils. The goal of this study was to determine the effects of CW application on soil physical and chemical properties of Tennessee soils and the typical crops grown on them such as tobacco, fescue, and sweet potato.

Overall yields for all crops were little affected by the application of CW up to 45 Mg/ha. Forage yields showed no significant differences between treatments in the first harvests at both HR and TSU. For the second harvest at HR yields were shown to significantly decrease when CW was added, but the numerical decrease was small due to low overall yields. No significant differences in the second harvest yield were observed at TSU. Tobacco yields at HR and GR were not affected by CW application. Sweet potato yields showed numerical differences with highest yields occurring at the 22 Mg/ha non-incorporated and CWW treatments. The difference in yield was substantial, with high variability resulting from conflicting results in one replication causing it to be non-significant statistically. When the conflicting replication was excluded, a large significant increase was found in the CW and CWW treatments. The potential yield effects of gypsum consist of a short term effect from increased infiltration, and the long term effect from reduced Al toxicity that would enhance rooting in the subsoil. There was not much soil water advantage in 2005, and a one year study is not long enough to evaluate long term subsoil effects.

Grade index for tobacco at HR showed small but significant differences in plant leaf quality when CW was applied. Grade index of GR tobacco showed no significant changes in grade when the addition of CW.

In general, soil pH showed slight decreases of 0.2 to 0.3 units. These slight changes in pH were statistically significant for at least one sampling date and depth at every location. Overall, significant reductions were more common after season, which supports the theory of continuous dissolution of gypsum. GR tobacco showed the least response for pH, which may be due to more kaolinite, and more iron and aluminum oxides in the soil exchange complex, resulting in more ligand exchange of SO_4^{2-} for the OH^- causing an increase in pH and counteracting the salt effect. Although there were changes in pH the decreases were not enough to be very important especially if they were counteracted by Al^{3+} reduction, as would be expected based on other studies.

Overall, exchangeable Ca was shown to increase in the soil surface. The greatest increase was when the CW was incorporated. There were some instances when the increase was less than expected, probably reflecting that the gypsum had not fully dissolved and still remained in the solid state. The undissolved gypsum was not dissolved by the test extractant at the laboratory. It is also possible some gypsum actually leached below the sampling depth, but the magnitude would be small. There was a definite increase in Ca levels from early season to after season at the 0.15-0.30 m depth in

CW amended plots on HR and TSU fescue. In HR fescue and TSU sweet potato experiments the CW was shown to have higher values than the control when sampled at the 0.15-0.30 m depth after season. GR tobacco and TSU fescue experiments showed a substantial numerical increase in Ca after season at the subsurface depth in CW amended plots, but it was not statistically significant. This suggests the dissolution and movement of gypsum had occurred in a fairly short period of time. TSU sweet potato, HR and GR tobacco Ca levels were also shown to increase in the surface horizon from early to late season, indicating the gypsum may not have fully dissolved at the time first sampled. For the fescue soils, there was less differences. The total additional Ca in CW plots to a depth of 0.30 m in fescue only was a small portion that was actually added, indicating that most of the gypsum remained on the soil surface in the solid form. In the incorporated treatments in the tobacco and sweet potato experiments, the proportion of the Ca accounted for was much higher, thus indicating greater dissolution of gypsum,. However, it was still not all accounted for, indicating the release of Ca from gypsum was likely to continue form some time.

Soil Mg was shown to significantly decrease mainly in the surface horizon with the addition of CW. This suggests Mg was displaced by over loading the soil with Ca from the CW. In some cases where the soil originally was low in Mg, the decrease in Mg caused some concern about deficiencies in crops. When CW is applied to the soil, Mg levels should be monitored. Instances where Mg levels become deficient should be supplemented with fertilizers.

The ability of Ca to move to the 0.15-.30 m depth is critical for ameliorating aluminum toxicity that often occurs below the depth of incorporation of highly weathered soils in the Southeastern United States. Toxic levels of Al are often accompanied by deficient levels of Ca, which can prevent or restrict root growth making them susceptible to drought. The results we found are able to verify that crushed wallboard has the ability to dissolve and supply Ca to the subsurface in less than one year after application. The combination of the continuous release of Ca and increased infiltration to deeper depths may potentially improve yields in future years.

In general, soil K was not affected by CW addition, suggesting little K displacement and leaching occurred in the majority of the experiments. However, significant differences were found in the TSU sweet potato plots sampled in the fall, six months after CW addition. The lowest level of soil K was found when 45 Mg/ha was added to the sweet potato plots. This low level may be due to some leaching, but the control level was also had a low value. Potassium levels should be monitored by soil test and supplemented with fertilizer when necessary.

Soil water readings monitored by gravimetric samples showed an occasional small increase with the addition of CW at TSU, GR, and HR. Although the changes in soil water were not large and not always significant, both methods detected a definite increase in soil water when CW was applied. Even this small increase in soil water could possibly be beneficial to a plant’s productivity. Summer 2005 was a drier than average season. Most of the rainfall received at TSU and HR came from large events from the remnants of two hurricanes. This may have affected our data. Better soil water results may have been obtained with typical thunderstorms with 1.0 to 3.0 cm of rainfall. In these cases, infiltration differences are more likely to be reflected in differential soil water recharge than in longer, relatively gentle rain.

The correlations of gravimetric and Echo probe water for the sites were very different. Correlation at HR was much lower than at GR. We can assume the gravimetric results are an accurate estimate of soil water at HR, GR, and TSU. The gravimetric samples were collected randomly from the entire plot, giving a more representative soil water estimate. The probes may be a reliable estimate of soil water, if they are correctly calibrated for a particular soil, installed correctly and randomly placed throughout the entire plot. It is likely that two probes per plot were not adequate given spatial variability in soil water. Our results also raise the question of whether accurate readings can be obtained under dry conditions at shallow depths in soil that tends to be cloddy. Soil probe contact may not be adequate in this particular case.

Soil physical properties such as bulk density and strength were measured after season. Bulk density showed no significant changes in GR tobacco and TSU sweet potato plots. HR tobacco plots showed a significant decrease in bulk density with the addition of CW. A penetrometer was used to measure soil strength in the same experiments, where bulk density was measured. The only significant changes in kg/pressure were seen at GR and TSU. The data overall suggests that the incorporation of CW has the potential to increase soil aggregation and reduce soil strength, but the effects were not seen everywhere. This can provide a better environment for roots and possibly increase infiltration to the plant. Initial soil properties are an important issue to address before CW application. Weak structured soils are more apt to benefit from CW enhancement of stable aggregates, which may explain whey the smallest effects were seen at GR.

This study revealed no major detrimental effected on yields or soil chemical and physical properties when CW was added at varying rates, up to 45 Mg/ha. There were small increases in soil moisture, usually not statistically significant, but always occurring in CW plots. We can assume that soil aggregation was increased from the decrease in soil strength when CW was incorporated into the soil. From the results obtained by this study, using CW as a soil amendment not only helps waste management but can benefit the soil for a long period of time. However, there was not short term enhancement of yield in most cases. The exception was TSU sweet potatoes, which may have been due to enhanced Ca supply and reduced Al availability in this very acidic soil. Therefore, in general there would be little incentive for farmers to pay to have CW applied to their fields. However, there should be no objections to using it if provided for free, or if the farmer was paid to accept it. The only concerns would be possible Mg deficiency, and possible excess sulfur in forage, which was not addressed in this study. Factors that should be taken into consideration for future studies include: (1) conducting plant analyses for any deficiencies caused by the high rates of CW applied, (2) more soil water data collected to fully understand CW effects on soil moisture (3) and conducting a study over a longer period of time than one year will help develop more comprehensive conclusions.

REFERENCES

Agassi, M., I. Shainberg, and J. Morin. 1981. Infiltration and runoff in wheat fields in the semi-arid region of Israel. *Geoderma* 36:263:276.

Agassi, M., J. Morin, and I. Shainberg. 1982. Infiltration and runoff control in the semi-arid region of Israel. *Geoderma* 38:345-355.

Allen, B.I., and B.F. Hajek. 1989. Minerals occurrence in soil environments. P. Soil Sci. Am. J. 1:199-278.

Behel, D. 1997. Arsenic, metal, and nutrients in soil. Vegetation and groundwater following high rate application of FGD to soil. Tennessee Valley Authority Muscle Shoals Alabama.

Brady, N.C., and R.R. Weil. 2000. Elements of the nature and properties of soils.

Clark, R.B., S.K. Zeto, K.D. Richey, and V.C. Baligar. 2001. Minerals acquisition by maize grown in acidic soil amended with coal combustion products. Commun. Soil Sci.Plant Anal. 32(11&12), pp. 1861-1884.

Clark, R.B., and V.C. Baligar. 2003. Mineral concentrations of forage legume grasses grown in acidic soil amended with flue gas desulfuraiztion products. Commun. Soil Sci.Plant Anal. 34:1681-1707.

Decagon Devices Inc. Frequently asked question about the ECH2O soil moisture probes and accessories. Available at: www.decagon.com. Accessed: February 16, 2006.

Doner, H.E. and W.C. Lynn. 1989. Carbonate, halide, sulfate, and sulfide minerals. In: J.B. Dixon and S.B. Weed (eds.), Minerals in soil environments. Soil Sci. Am. J. 1: 279-330.

Essington, M.E. 2002. Water and soil chemistry: An integrative approach. CRC Press, Boca Raton. Fl.

Farina, M.P.W., Channon, P., & Thibaud, G.R. 1999. A comparison of strategies for ameliorating subsoil acidity: I. Long term growth effects. Soil Sci. Am. J. 64: 646-651.

Farina, M.P.W., P. Channon, and G.R.Thibaud. 2000. A comparison of strategies for ameliorating subsoil acidity: II. Long term soil effects. Soil Sci. Am. J. 64: 652-658.

Fisher, A.E., W.W. Gill, C.D. Lane, D.K. Joines, J.B.Neel, and C.J. Richards. 2002. Focus on mineral for beef cattle: Part 2-Deficiencies and imbalances revealed in Tennessee tall fescue forage systems. University of Tennessee Dept. of Animal Science and Dept. of Biosystems Engineering and Environmental Science.

Grossman, R.B., and T.G. Reinsch. 2002. The soil phase-bulk density and linear extensibility. P. 207-209. In J.H. Dane and G.C. Topp (ed). Methods of soil analysis-physical methods. Part 4. Agron. Monogr. 5. SSSA, Madison, WI.

Hamblin, A., and M. Howell. 1988. Maintenance and improvement of soil structure. Tech. Bull., Western Australia Dept of Agriculture

Hanlon, E.A. 2001. Procedures used by state soil testing laboratories in the southern region of the United States: South. Coop. Ser. Bull. 190-C. August pp.1-29.

Hilgard, E.W. 1906. Soils-Their formation, properties, composition and relation to climate and plant growth in the humid and arid regions. Macmillian, London.

Hillel, D. 1998. Environmental Soil Physics. Academic Press. New York.

Howell, M. 1987. Gypsum use in the wheat belt. J Agric. W. Aus. 28:40-43.

Kayser, M. 2005. Potassium cycling and losses in grassland systems: a review. Grass & For. Sci.. Vol.60, 3:213-224.

Kelly, W.P., and A. Arany. 1928. The chemical effect of gypsum, sulfur, iron sulphate and alum on alkali soil. Hilgardia 3:458-463

Korcak, R. 1996. Scrap Construction Gypsum Utilization. Plant Sciences Institute, USDA-Agricultural Research Service, Final Report to the Gypsum Association, pp. 1-54, July 1996.

Liu, J., and N.V. Hue. 2001. Amending Subsoil Acidity by Surface Applications of Gypsum, Lime, and Composts. Commun. Soil Sci.Plant Anal. Vol. 32 (13&14), pp. 2117-2132.

Loveday, J. 1976. Relative significance of electrolyte and cation exchange effects when gypsum is applied to a sodic clay soil. Aust. J Soil Res. 14:362-371.

Marvin, E. 2000. Gypsum wallboard recycling and reuse opportunities in the state of Vermont. Vermont Agency of Natural Resources with the Waste Management Division, pp. 1-42.

Mays, D.A., and Mortvedt. 1986. Crop response to soil applications of phosphogypsum. J. Env. Qual. 15: 78-81.

Mills, Becky. 2004. Copper is the culprit: Beef industry sleuths partner to investigate mystery of poor performance. Angus Journal. July 2004.

Miller, W.P. 1987. Infiltration and soil loss of three gypsum-amended Ultisols under simulated rainfall. Soil Sci. Am. J.51:1314-1319.

NCSS and PASS. 2004. Statistical and power analysis software trial version.

Noble, A.D., M.E. Sumner and A.K. Alva. 1988. Effect of pH on calcium sulfate alleviation of aluminum phytotoxicity. Soil Sci. Am. J. *Proc* 35: 8881-883.

O'Brien, L.O. and M.E. Sumner. 1988. Effects of phosphogypsum on leachate and soil chemical composition. Commun. Soil Sci.Plant Anal. Vol. 19 (7-12), pp. 1319-1329.

Oster, J.D., and M.J. Singer. 1984. Water penetration problems in California soils. University of California, Davis, California.

Pavan, M.A., F.T. Bingham, and P.F. Pratt. 1982. Toxicity of Al to coffee in Ultisols and Oxisols amended with $CaCO_3$, $MgCO_3$, and $CaSO_4 * 2H_2O$. Soil Sci. Soc. Am J. 46:1201-1207.

Pavan M.A., and F.T. Bingham. 1986. Effects of phosphogypsum and line on yield, root density and fruit and foliar composition of apple in Brazilian oxisols. *Proc.* 2nd *Int. Symp. Phosphoypsum*. Universtiy of Miami, Miami, Florida.

Radcliffe, D.E., R.L.Clark, and M.E. Sumner. 1986. Effect of gypsum and deep rooting perennials on subsoil mechanical impedance. Soil Sci. Am. J. 50:1566-1570.

Savoy, H. 2003. Secondary and micronutrient guidelines for Tennessee. The University of Tennessee Agricultural and Extension Service. Biosystems Engineering and Environmental Science Department. pp.1-4.

Shainberg, I., M.E. Sumner, W.P. Miller, M.P.W. Farina, M.A. Pavan, M.A., and M.V. Fey. 1989. Use of Gypsum on Soils: A Review. Adv. Soil Sci. 9: 2-101.

Sumner, M.E. 1970. Aluminum toxicity-A growth limiting factor in some Natal sands. Proc. S. Afr. Sugar. Technol. Assoc. 44: 391-291.

Syed, O.S.R. 1987. Deleterious effects of gypsum amendments on potassium and magnesium status of field soils. M.S. Thesis, University of Georgia, Athens, Georgia.

Tanaka, A., T. Tadano, K. Yamamoto, and N. Kanamura. 1987. Comparison of toxicity to plants among Al3+, AlSO4+, and Al-F complex ions. J. Plant Nutri. and Soil Sci. 33:43-56.

Thompson, L.M., and F.R. Troech. 1993. Soils and soil fertility. New York: Oxford University Press.

Toma, M., M.E. Sumner, G. Weeks, and M. Saigusa. 1999. Long term effect of gypsum on crop yield and subsoil chemical properties. Soil Sci. Am._J. 39: 891-895.

USDA, 1947. Soil Survey of Greene County, Tennessee. Series Number 7. Issued: August 1947. US Government Printing Office. Washington 25, DC.

USDA, 1968. Soil Survey of Robertson County, Tennessee. Issued: March 1968. US Government Printing Office. Washington, DC.

USDA, 2002. Soil Survey of Cheatham County, Tennessee. US Government Printing Office. Washington, DC.

USDA-ARS. 2005a. News and events. Stopping erosion with gypsum and PAM. [Online] Available at: www.ars.usda.gov/is/AR/archive/sep97/gypsum0997.html. Accessed February 9, 2006.

USDA-NRCS. 2005b. Official soil series description. [Online] Available at www.soils.usda.gov/technical/classification/osd/index.html. Accessed October 10, 2005.

Wolkowski, R.P. 1998. Demonstration of land application of crushed gypsum wallboard Waste for alfalfa: A final report prepared for the Wisconsin Dept. of Natural Resources Waste Reduction and Recycling Grant Program and Dane Co. Dept. of Public Works. pp. 1-12.

Wolkowski, R.P. 2000. Land application of crushed gypsum wallboard waste for alfalfa. Commun. Soil Sci.Plant Anal. 31 (1&2), pp.182-199.

APPENDIXES

APPENDIX I: ADDITIONAL TABLES

Table A-1. Fescue production practices-TSU.

Date	Activity
11/05	CW was hand applied to established fescue plots
3/21/05	Applied fertilizer 38 kg/ha oh N
5/25/05	First harvest
9/19/05	Second harvest

Table A-2. Timeline for burley tobacco plots at Greeneville.

Date	Activity
1/13/05	Plots plowed
4/6/05	Plots disked
3/15/05	CW spread on 22 and 45 Mg incorporated plots
5/3/05	Plots disked
5/25/05	Fertilizer applied 70.6 kg/ha N, 61.6 kg/ha P and 175.7 kg/ha K, 190 kg/ha of N applied
5/31/05	Sprayed herbicide and fungicides, Sulfentrazone N-[2,4-dichloro 5-[4-(difluoromehthyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide 0.385 kg/ha, Clomazone 2-(2-Chlorophenyl)methyl-4, 4-dimethyl-3-isoxaidinone 0.84 kg/ha, Mefenoxan 1.12 kg/ha, Spread CW on 22 Mgha non incorporated plots
6/3/05	Tobacco transplanted, Acephate (0,5-Dimethyl acetylposhophoramidothioate) 0.84 kg/ha, and Imidacloprid, 1-[(6-chloro-3-pyridinyl methyl]—N-nitro-2-imidazolidinimine .12425 kg/ha applied in transplant water
6/23/05	Sprayed Sethoxydim 2-[1-(ethoxyimino)butyl]-5-[2-(ethythio)propyl]-3-hydroxy-2-cyclohexen-1-one .32 kg/ha, Surfactant 2.3 L/ha
6/24/05	Nitrogen sidedress applied, Cultivated entire field
6/27/05	Sprayed Dimethomorph 1.68 kg/ha, Mancozeb .88 L/ha, , Acephate (0,5-Dimethyl acetylposhophoramidothioate) 0.84 kg/ha
7/6/05	Sprayed Sethoxydim 2-[1-(ethoxyimno)butyl]-5-[2-(ethythio)propyl]-3-hydroxy-2-cyclohexen-1-one .315 kg/ha, Surfactant 4.675 L/ha
7/12/05	Sprayed Spinosad .105 kg/ha, Dimethomorph 1.68 kg/ha, Mancozeb .88 L/ha
7/19/05	Sprayed Dimethomorph 1.68 kg/ha, Mancozeb .88 L/ha, 1,2,3-benzothiadiazole-7-thiocarbonxylic acid-S-methyl-ester .50oz/acre, Acephate (0,S-Dimethyl acetylphosphosphoramidothioate) .84 kg/ha
7/26/05	Sprayed 1,2,3-benzothiadiazole-7-thio-carboxylic acid-S-mehtyl-ester.50 oz/acre, Lambda-cyhalothrin [1α(S*), 3α(Z)-(±)-cyano-(3-phenoxyphenyl)methyl-3-(2-chloro-3,3,3-trifluro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate .02625 kg/ha
8/4/05	Topped tobacco Sprayed Maleic hydrazide, potassium salt (1,2-dihydro-3, 6-pyridazinedione, potassium salt) 2.52 kg/ha, Flumetralin (2-chloro-N-[2,6-dinitro-4(trifluoromethyl)phenyl]-N-ethyl-6 flurorobenzenemethanamine .672 kg/ha, Fatty alcohols (0.4% C_6; 46.1%C_8; 53.2%C_{10}; 0.3% C_{12}) 3.3824 kg/ha
8/29/05	Harvest tobacco

Table A-3. Timeline for sweet potato plots at TSU.

Date	Activity
5/30/05	Applied 67 kg/ha N, 30 kg/ha P, and 55.78 kg/ha K
5/24/05	Applied CW and CWW to plots
6/16/05	Planted sweet potato plants
Applied after transplant	Clomazone: 2-(2 chlorophenyl)methyl-4, 4-dimethyl-3-isoxazolidinone 1.68 kg/ha, napropamide .43 L/ha,
Applied as needed	Clethodin: (E)-(+)-2-[1-[[(3-Chloro-2- Propenyl)oxy]imino] propyl-5-[2-(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one .28 kg/ha for grass control
Applied as needed	Imitator plus: Glyphosate (isopropylamine salt) 70 WP .10 kg/ha
10/13/05	Harvested sweet potato every third row in each 6.1 m

Table A-4. Rainfall data for summer 2005 – HR.

Date	Max Air Temp	Min Air Temps	Rain (inches)	Wind	Evaporation	Max Soil Temp
1-May-05	55	32	0	9404	2.12	57
2-May-05	64	42	0	9446	1.93	62
3-May-05	59	33	0	9495	1.73	62
4-May-05	62	35	0	9524	1.66	61
5-May-05	66	41	0	9548	1.48	63
6-May-05	72	44	0	9568	2.72	67
7-May-05	74	45	0	9587	2.51	69
8-May-05	80	56	0	9619	2.38	71
9-May-05	83	56	0	9647	2.03	75
10-May-05	79	57	0	9699	1.96	71
11-May-05	84	59	0	9733	1.42	76
12-May-05	88	61	0	9756	1.57	79
13-May-05	89	64	0.03	9778	1.3	79
14-May-05	86	67	0	9873	2.77	78
15-May-05	78	49	0.02	9948	2.64	71
16-May-05	67	40	0	10001	2.38	74
17-May-05	69	40	0	10018	2.12	71
18-May-05	78	45	0	10033	1.92	75
19-May-05	83	50	0	10055	1.78	78
20-May-05	86	63	0.31	10136	1.87	77
21-May-05	79	54	0	10197	1.59	75
22-May-05	74	53	0	10214	1.47	72
23-May-05	80	59	0	10264	1.23	74
24-May-05	80	52	0	10306	3	76
25-May-05	72	44	0	10359	2.86	76
26-May-05	71	43	0	10389	2.66	74
27-May-05	78	46	0	10406	2.34	76
28-May-05	81	56	0	10446	2.02	80
29-May-05	81	57	0	10479	1.84	81
30-May-05	79	50	0	10492	1.61	75
31-May-05	84	57	0	10506	1.49	81
1-Jun-05	83	60	0	10519	2.91	80
2-Jun-05	75	60	0.45	10536	3.31	72
3-Jun-05	74	61	0.16	10578	3.42	71
4-Jun-05	80	58	0	10616	3.38	75
5-Jun-05	90	64	0	10658	3.02	79
6-Jun-05	91	72	0	10727	2.71	85
7-Jun-05	91	61	0	10770	2.59	85
8-Jun-05	87	66	0	10795	2.36	86
9-Jun-05	89	66	0	10831	2.02	85
10-Jun-05	89	69	0	10864	1.82	86

Table A-4. continued.

Date	Max Air Temp	Min Air Temps	Rain (inches)	Wind	Evaporation	Max Soil Temp
11-Jun-05	83	67	2.03	10911	3.53	80
12-Jun-05	77	66	0.71	10953	2.8	76
13-Jun-05	74	68	1.06	11032	0	73
14-Jun-05	89	68	0	11084	2.81	82
15-Jun-05	89	60	0.21	11150	2.72	81
16-Jun-05	85	62	0	11205	2.41	79
17-Jun-05	78	52	0	11246	2.26	78
18-Jun-05	80	54	0	11259	2.07	77
19-Jun-05	76	56	0	11300	1.72	77
20-Jun-05	83	58	0	11329	1.5	82
21-Jun-05	83	60	0	11348	1.39	81
22-Jun-05	85	58	0	11367	2.96	83
23-Jun-05	89	61	0	11382	2.75	85
24-Jun-05	91	63	0	11394	2.34	88
25-Jun-05	94	64	0	11406	2.15	90
26-Jun-05	93	67	0	11422	1.89	89
27-Jun-05	88	66	0	11441	1.6	87
28-Jun-05	92	66	0	11465	1.49	89
29-Jun-05	90	70	0	11488	2.8	88
30-Jun-05	93	71	0	11504	2.65	89
1-Jul-05	95	71	0	11536	2.24	92
2-Jul-05	90	66	0	11583	1.94	90
3-Jul-05	88	65	0	11617	1.76	90
4-Jul-05	93	69	0	11643	1.56	90
5-Jul-05	93	69	0.07	11702	1.14	89
6-Jul-05	88	66	0	11740	2.87	86
7-Jul-05	85	64	0	11756	2.66	85
8-Jul-05	90	64	0	11774	2.3	87
9-Jul-05	92	66	0	11783	2.16	90
10-Jul-05	94	69	0	11795	1.87	90
11-Jul-05	94	69	0.46	11813	2.02	89
12-Jul-05	77	66	0.37	11901	2.33	79
13-Jul-05	80	66	0.74	12027	2.98	76
14-Jul-05	75	67	0.51	12073	2.54	73
15-Jul-05	84	69	1.29	12111	1.93	78
16-Jul-05	85	71	0	12159	1.8	80
17-Jul-05	84	71	0	12224	1.76	79
18-Jul-05	89	72	0	12272	1.57	82
19-Jul-05	90	72	0	12322	1.36	84
20-Jul-05	85	70	0.57	12346	3.7	79
21-Jul-05	92	72	0	12375	0	91

Table A-4. continued.

Date	Max Air Temp	Min Air Temps	Rain (inches)	Wind	Evaporation	Max Soil Temp
22-Jul-05	93	66	0.23	12413	2.58	87
23-Jul-05	92	66	0	12448	2.36	86
24-Jul-05	93	71	0	12455	2.09	89
25-Jul-05	93	74	0	12473	1.73	90
26-Jul-05	95	75	0	12496	1.46	92
27-Jul-05	94	75	0	12544	1.21	91
28-Jul-05	88	65	0	12610	2.89	86
29-Jul-05	81	60	0	12638	2.63	82
30-Jul-05	85	61	0	12673	2.48	85
31-Jul-05	89	63	0	12697	2.13	87
1-Aug-05	90	66	0	12717	1.99	88
2-Aug-05	92	68	0	12728	1.71	88
3-Aug-05	94	64	0	12742	1.58	88
4-Aug-05	95	65	0	12753	3.26	90
5-Aug-05	96	67	0	12769	2.92	89
6-Aug-05	95	65	0	12786	2.78	88
7-Aug-05	93	65	0	12801	2.41	89
8-Aug-05	92	65	0	12825	2.26	90
9-Aug-05	91	65	0	12840	2.06	89
10-Aug-05	93	66	0	12858	1.7	90
11-Aug-05	96	66	0	12874	1.41	90
12-Aug-05	99	70	0	12892	3.18	90
13-Aug-05	98	72	0	12942	2.73	90
14-Aug-05	98	68	0	13000	2.57	89
15-Aug-05	98	70	0	13040	2.22	89
16-Aug-05	95	69	0.09	13070	2.13	89
17-Aug-05	92	69	0.06	13091	2.17	84
18-Aug-05	93	69	1.56	13131	3.38	88
19-Aug-05	92	71	0.05	13186	3.1	84
20-Aug-05	98	74	0	13234	2.81	85
21-Aug-05	98	72	0	13281	2.5	89
22-Aug-05	92	70	0	13305	2.23	91
23-Aug-05	89	67	0	13314	2.19	84
24-Aug-05	90	64	0	13339	1.84	88
25-Aug-05	94	64	0	13351	1.62	90
26-Aug-05	92	71	0	13399	1.42	87
27-Aug-05	78	67	0.77	13444	2.11	79
28-Aug-05	85	70	0.03	13462	2.01	82
29-Aug-05	86	68	0.4	13485	2.38	81
30-Aug-05	74	68	3.94	13522		76
31-Aug-05	75	60	1.1	13640		74

Table A-5. Rainfall data for summer 2005 – GR.

Month Day	Inches Rain	Month Day	Inches Rain	Month Day	Inches Rain	Month Day	Inches Rain	Month Day	Inches Rain	Month Day	Inches Rain
April		May		June		July		Aug		Sept.	
2	0.88	1	0.13	1	0.01	2	0.01	8	0.28	3	0.02
3	0.35	6	0.07	2	0.57	3	0.02	9	0.02	17	0.18
8	0.01	11	0.38	4	0.06	5	0.67	14	3.07	18	0.01
9	0.1	14	0.76	7	0.01	7	0.8	17	0.02	26	0.13
13	0.74	15	0.42	8	0.08	8	0.84	18	0.89	27	0.17
14	0.98	16	0.27	9	0.05	11	0.41	19	0.7	30	0.25
22	0.05	20	1.28	10	0.27	12	0.03	20	0.24		
23	0.59	21	0.07	11	0.23	13	0.18	21	0.01		
24	0.1	23	0.03	12	0.02	14	0.35	24	0.02		
25	0.03	28	0.07	13	0.23	15	0.05	27	0.18		
27	0.14	29	0.11	20	0.07	16	0.28	28	0.02		
28	0.23	30	0.01	27	0.28	17	0.05	29	0.74		
29	1.79			29	0.09	20	2.41	30	0.37		
30	0.43			29	0.03	22	0.03	31	0.01		
						23	0.01				
						29	0.06				
						30	0.02				
Total	5.82		3.60		2.00		6.22		6.57		.76
Normal	3.59		3.72		3.72		4.62		3.30		2.98

Table A-6. Soil pH, Ca, and K – HR tobacco (July, 2005).

plot #	Rep	Ton/acre	pH	Ca	K
				--(kg/ha)--	
A8AA	1	0	6.3	728	291.2
B8AA	1	10	5.9	929.6	280
A7AA	1	20	5.9	694.4	224
B7AA	1	10 top	5.5	840	280
B6AA	2	0	5.7	582.4	257.6
B5AA	2	10	5.8	974.4	246.4
A6AA	2	20	5.9	683.2	235.2
A5AA	2	10 top	5.8	907.2	212.8
B4AA	3	0	5.9	627.2	324.8
A3AA	3	10	6	929.6	235.2
B3AA	3	20	6	784	302.4
A4AA	3	10 top	6	772.8	257.6
B2AA	4	0	5.6	560	246.4
A2AA	4	10	5.9	672	347.2
A1AA	4	20	6.1	694.4	313.6
B1AA	4	10 top	5.6	940.8	358.4

Table A-7. After season soil pH, Ca, Mg, and K- HR tobacco.

Plot	Rep	Gypsum applied	pH	Ca	Mg	K
		(kg/ha)		----------(kg/ha)----------		
A8A	1	0	6.6	929.6	246.4	145.6
B8A	1	22400	6.1	1344	197.12	62.72
A7A	1	44800	6.2	4558.4	283.36	76.16
B7A	1	22400 top	5.7	1344	197.12	235.2
B6A	2	0	6.2	672	332.64	224
B5A	2	22400	6	3819.2	234.08	201.6
A6A	2	44800	6.1	1344	308	235.2
A5A	2	22400 top	6	3572.8	209.44	179.2
B4A	3	0	6.3	694.4	332.64	235.2
A3A	3	22400	6.1	3696	246.4	246.4
B3A	3	44800	6.1	1232	234.08	235.2
A4A	3	22400 top	6.1	4435.2	295.68	224
B2A	4	0	6.1	649.6	295.68	235.2
A2A	4	22400	6.1	4188.8	246.4	257.6
A1A	4	44800	6.2	4435.2	258.72	280
B1A	4	22400 top	6.1	1344	209.44	224

Table A-8. After season soil pH, Ca, Mg, and K- GR tobacco.

Samples	Plot	Rep	Tons/acre applied	Gypsum (kg/ha)	pH	Ca	Mg	K
(m)						---------(kg/ha)---------		
0-0.15	101A	1	0	0	6	470	308	179
	102A	1	10 top	22400 top	6.2	493	370	179
	103A	1	10	22400	6.1	1120	308	112
	104A	1	20	44800	6.2	1344	246	157
	201A	2	10	22400	5.9	1232	320	157
	202A	2	0	0	5.9	426	308	179
	203A	2	20	44800	5.9	3573	259	146
	204A	2	10 top	22400 top	5.3	806	222	123
	301A	3	20	44800	6.1	4189	271	179
	302A	3	10 top	22400 top	5.6	896	246	235
	303A	3	0	0	6.3	336	320	146
	304A	3	10	22400	5.5	963	185	134
	401A	4	10	22400	6.1	1053	320	213
	402A	4	20	44800	6	4312	271	202
	403A	4	10 top	22400 top	5.5	683	259	134
	404A	4	0	0	6	302	259	157
0.15-.30	101B	1	0	0	6.7	493	370	123
	102B	1	10 top	22400 top	6.8	538	517	112
	103B	1	10	22400	6.6	560	480	112
	104B	1	20	44800	6.5	627	431	123
	201B	2	10	22400	6.2	818	394	179
	202B	2	0	0	6.4	470	382	95
	203B	2	20	44800	6.2	784	259	68
	204B	2	10 top	22400 top	6.3	426	283	82
	301B	3	20	44800	6.1	3696	283	157
	302B	3	10 top	22400 top	6.4	459	419	146
	303B	3	0	0	6.7	314	333	123
	304B	3	10	22400	6.3	504	370	96
	401B	4	10	22400	6.3	1120	407	134
	402B	4	20	44800	6.1	1075	357	168
	403B	4	10 top	22400 top	6.6	448	419	91
	404B	4	0	0	6.7	403	370	101

Table A-9. After season soil pH, Ca, Mg, and K- TSU sweet potato.

Plot #	Rep	Treatment	Treatment	pH	Ca	Mg	K
		(t/acre)	(kg/ha)		----------(kg/ha)----------		
101	1	10top	22400	5.2	818	45	81
102	1	0	0	5.3	392	114	103
103	1	10	22400	4.9	997	57	97
105	1	20	44800	4.9	1109	45	97
201	2	0	0	5.1	459	69	99
202	2	10	22400	5	762	46	66
203	2	20	44800	5	1232	43	62
204	2	10top	22400	5.2	952	53	60
301	3	10top	22400	5.1	1019	50	72
302	3	10	22400	5.1	930	41	66
303	3	20	44800	5.3	986	44	56
305	3	0	0	5.1	493	55	97
402	4	0	0	5.5	616	68	92
403	4	10	22400	5	1344	49	67
404	4	20	44800	5.2	1053	58	60
405	4	10top	22400	4.9	1030	50	69
101	1	10top	22400	5.1	392	53	54
102	1	0	0	5.2	392	66	63
103	1	10	22400	4.9	459	64	78
105	1	20	44800	4.9	549	112	88
201	2	0	0	5.3	526	68	62
202	2	10	22400	5	526	59	50
203	2	20	44800	4.9	571	59	43
204	2	10top	22400	5.2	560	59	41
301	3	10top	22400	5.2	728	91	83
302	3	10	22400	5.1	638	55	48
303	3	20	44800	5.2	750	59	35
305	3	0	0	5.1	459	51	58
402	4	0	0	5.6	650	64	64
403	4	10	22400	5.2	795	66	53
404	4	20	44800	5.1	739	62	49
405	4	10top	22400	4.9	638	65	64

Table A-10. Gravimetric data for July 6, 2005- HR tobacco.

Plot	Treatment	Rep	Wet weight	Dry weight	Empty can weight	Moisture content
			------------(g)------------			%
A2	22400	4	157	143	32	12.6
A3	22400	3	192	178	37	9.9
A4	22400 top	3	178	155	33	18.9
A5	22400 top	2	210	189	33	13.5
A8	0	1	225	207	36	10.5
B1	22400 top	4	176	159	32	13.4
B2	0	4	192	170	33	16.1
B4	0	3	180	162	33	14.0
B5	22400	2	205	188	35	11.1
B6	0	2	182	167	32	11.1
B7	22400 top	1	194	179	34	10.3
B8	22400	1	193	179	36	9.8

Table A-11. Bulk density – GR tobacco.

Plot Number	Treatment	Rep	Bulk density	Average Db
			----------(g/cm^3)----------	
101	0	1	1.31	1.34
101	0	1	1.35	
102	10top	1	1.45	1.36
102	10top	1	1.26	
103	10	1	1.33	1.34
103	10	1	1.35	
104	20	1	1.2	1.23
104	20	1	1.25	
201	10	2	1.29	1.31
201	10	2	1.32	
202	0	2	1.36	1.35
202	0	2	1.33	
203	20	2	1.39	1.33
203	20	2	1.28	
204	10top	2	1.37	1.30
204	10top	2	1.22	
301	20	3	1.47	1.48
301	20	3	1.48	
302	10top	3	1.62	1.63
302	10top	3	1.63	
303	0	3	1.21	1.33
303	0	3	1.45	
304	10	3	1.35	1.35
304	10	3	1.36	
401	10	4	1.39	1.33
401	10	4	1.27	
402	20	4	1.44	1.42
402	20	4	1.41	
403	10top	4	1.32	1.33
403	10top	4	1.35	
404	0	4	1.41	1.37
404	0	4	1.32	

Table A-12. Fescue yields-HR.

Treatment	Rep	Gypsum applied	5/5/05	10/10/05
		----------(kg/ha)---------		
101	1	22400	2479	2065
102	1	44800	2324	1723
103	1	0	2759	3040
201	2	0	2168	2127
202	2	22400	1472	1404
203	2	44800	2399	1382
301	3	44800	2617	1588
302	3	0	1577	1317
303	3	22400	1487	1534
401	4	0	4783	2124
402	4	44800	4591	2002
403	4	22400	2621	1480

Table A-13. Fescue yields-TSU.

Gypsum applied	5/25/05	9/19/05
-----------(kg/ha)------------		
22400	7375	4231
0	8507	3613
44800	7720	3999
22400	6935	3359
44800	7704	3758
0	7992	4085
0	7957	4606
22400	7690	3724
44800	6503	4057
0	8036	3441
44800	8596	4243
22400	10071	4840

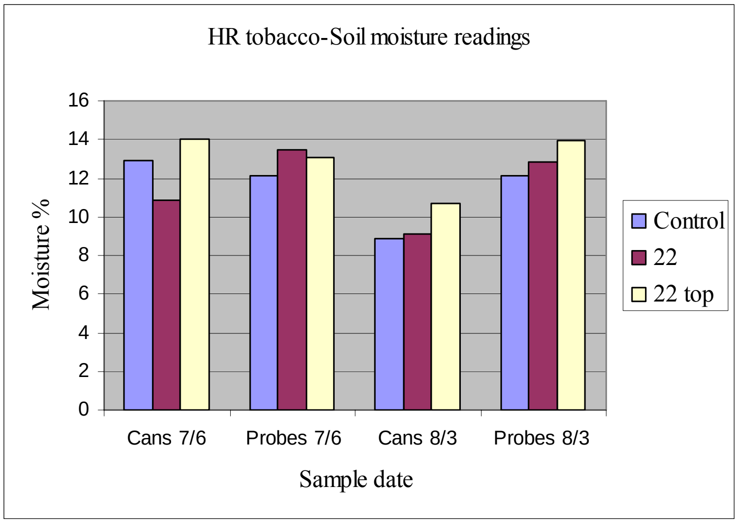
Table A-14. Tobacco yields-GR

Treatment (kg/ha)	Rep	GR Index	Yield (kg/ha)
0	1	64.3	3380
0	2	65	2865
0	3	69.5	2894
0	4	64.1	2826
22 top	1	38.6	2853
22 top	2	64.4	3177
22 top	3	58.6	2508
22 top	4	66.8	2985
22	1	67.2	3255
22	2	66.5	2948
22	3	55.1	2849
22	4	64.4	2774
45	1	65.4	3257
45	2	54.2	2974
45	3	72.1	2531
45	4	70	2454

Table A-15. Sweet potato yields-TSU.

Plot #	Rep	Treatment t/acre	Treatment kg/ha	Total marketable kg/ha	Total 1's kg/ha	1's %
101	1	10top	22400	9977	4065	41
102	1	0	0	5913	2587	44
103	1	10	22400	11086	4065	37
104	1	W+G	22400	27530	11271	41
105	1	20	44800	14042	5913	42
201	2	0	0	21248	5728	27
202	2	10	22400	15151	5728	38
203	2	20	44800	9608	4065	42
204	2	10top	22400	24574	8315	34
205	2	W+G	22400	7391	2402	33
301	3	10top	22400	27346	9977	36
302	3	10	22400	29933	10716	36
303	3	20	44800	19574	6467	33
304	3	W+G	22400	24204	8869	37
305	3	0	0	7205.913	2587	36
401	4	W+G	22400	29194	11640	40
402	4	0	0	14597	6282	43
403	4	10	22400	16629	7575	46
404	4	20	44800	21987	8869	40
405	4	10top	22400	18661	6836	37

APPENDIX II: ADDITIONAL FIGURES



Cans = Gravimetric samples
Probes = echo probe readings

Figure A-1. Echo probe and gravimetric values - HR tobacco.

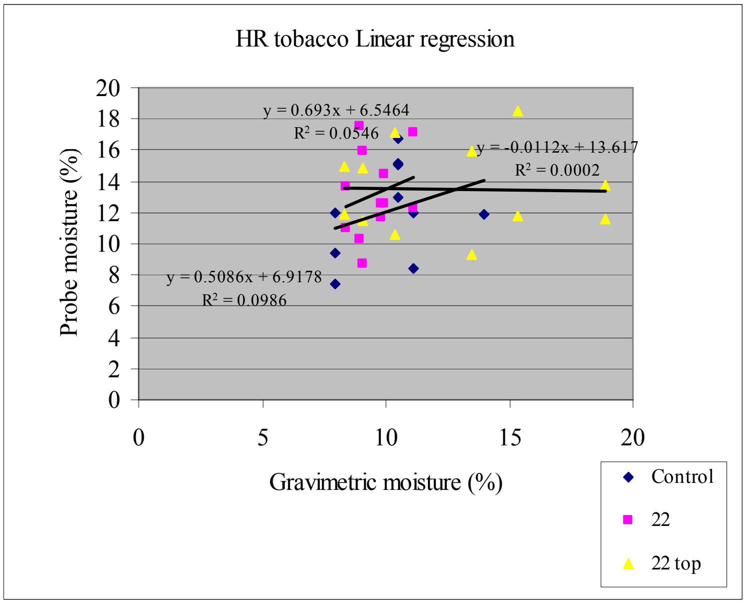


Figure. A-2. Linear regression by treatment for three dates – HR tobacco.

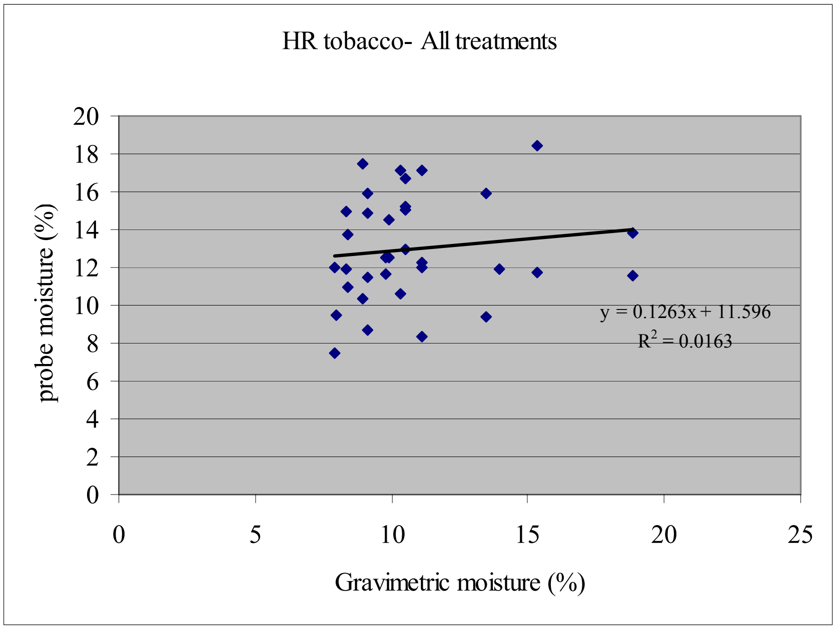
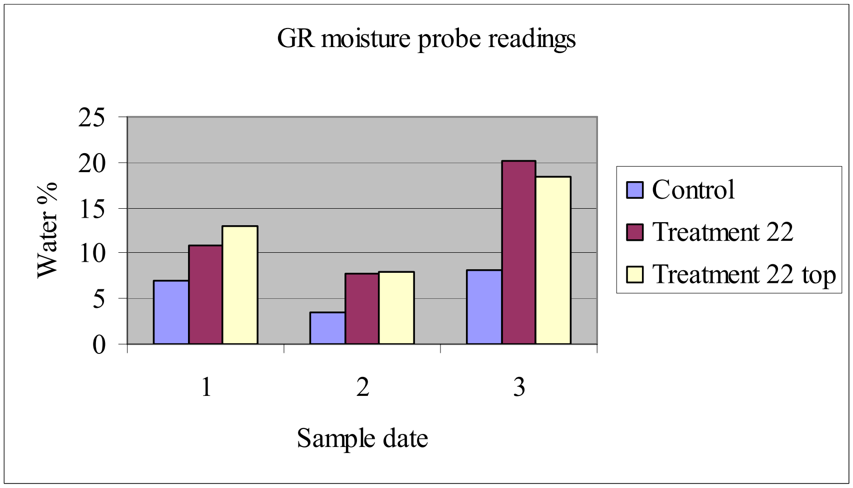


Figure A-3. Linear regression for all treatments and dates – HR tobacco.



1: sampled June 22, 2005
2: sampled August 8, 2005
3: sampled August 22, 2005

Figure A-4. Echo probes readings for three dates - GR tobacco

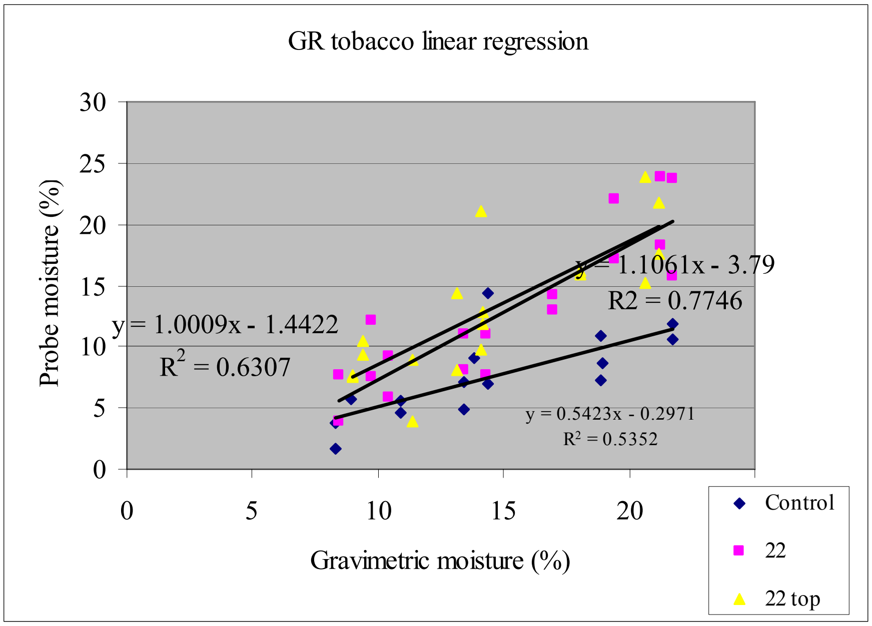


Figure A-5. Linear regression of Echo probes vs. gravimetric - GR tobacco.

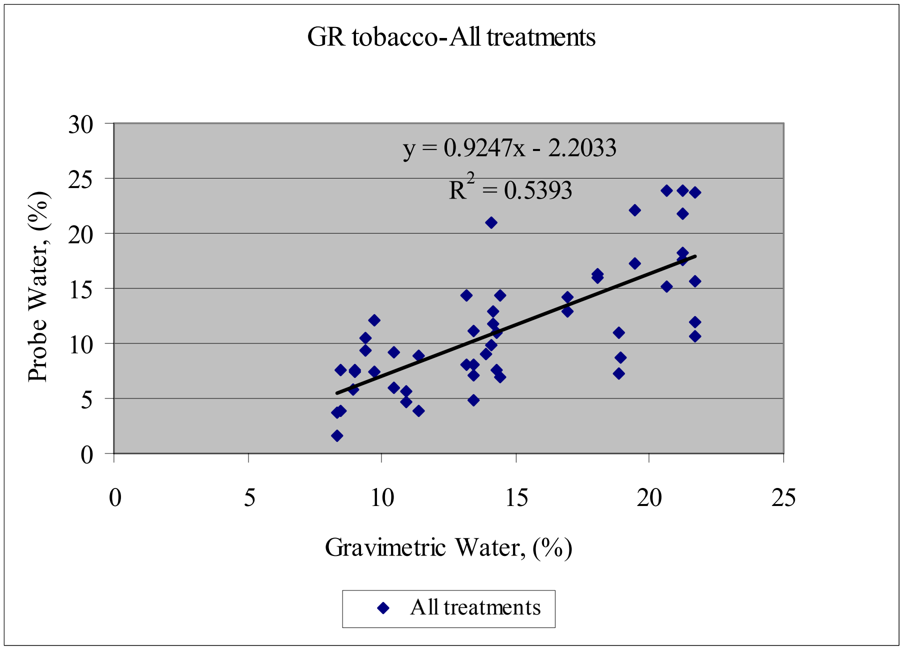


Figure A-6. Linear regression of all moisture probes vs. gravimetric - GR tobacco.

VITA

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