

**NUTRIENT AVAILABILITY IN MINERAL SAND TAILINGS
AMENDED WITH YARD WASTE COMPOST AND WOOD ASH**

by

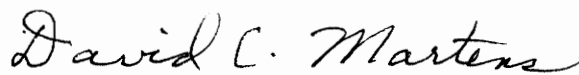
Regine N. Mankolo

Thesis submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Science
in
Crop and Soil Environmental Sciences

APPROVED:



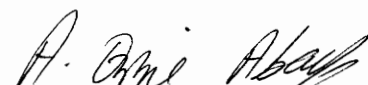
J. C. McKenna, co-chairman



D. C. Martens, co-chairman



J. C. Baker



A. O. Abaye



M. H. Stolt

May 1994

Blacksburg, Virginia

C.2

L1)
5655
V855
1994
M343
C.2

NUTRIENT AVAILABILITY IN MINERAL SAND TAILINGS AMENDED WITH YARD WASTE COMPOST AND WOOD ASH

by

Regine N. Mankolo

Co-chairman: J. R. McKenna

D. C. Martens

Crop and Soil Environmental Sciences

(ABSTRACT)

Mine tailings result from surface mining coastal plain soils and sediments and are redeposited in a slurry form to the mined area. Mine tailing contain a low amount of organic matter, a low pH, and a high P fixation capacity. This research was carried out in the Atlantic Coastal Plain region to determine if mine tailings reclamation could be accomplished by utilization of yard waste compost and wood ash. Yard waste compost was used to increase the organic matter content and wood to increase pH of the mine tailings. Field research was conducted to determine the effect of yard waste compost and wood ash incorporation into mine tailings on (Zea mays L.) and peanut (Arachis hypogaea) yields. Levels of yard waste compost applied to the mine tailings were 1, 2, 4, 6, 8, and 12% by weight, and wood ash was applied twice at a rate of 2.4 t ha⁻¹. Increases in corn and peanut yields on the mine tailings were attributed to

increased available water from application of yard waste compost and to increased pH from application of wood ash.

Successful use of the yard waste compost and wood ashes for reclamation of the mine tailing is shown by the higher peanut yields on the tailings soils than adjacent natural soils. Although the corn grain yields were relatively high (up to 7830 kg ha⁻¹) where yard waste compost and wood ash were applied to the tailings, the overall corn grain yields were higher on the adjacent natural soil. Probable reasons for lower corn grain on the tailings were inadequate available water at times of maximum need and N and/or P deficiencies. Zinc deficiency was induced in corn plants by the high level of P fertilization required to overcome the high P fixation capacity of the mine tailings. The Zn deficiency could be corrected by either foliar or broadcast-disk in application of ZnSO₄.

ACKNOWLEDGMENTS

The author wishes to express her sincerest appreciation to the members of her committee: Dr. James R. McKenna, Dr. David C. Martens, Dr. James C. Baker, Dr. A. Ozzie Abaye, and Dr. Mark H. Stolt. Their wisdom and attention to the author in discussing research was extremely helpful. Their encouragement and guidance throughout the course of her study program have been invaluable for the success of this present work.

The author wishes to express her gratitude and appreciation to Dr. David C. Martens for many hours of counsel, reading of this thesis, and for assistance on academic problems. Special thanks are expressed to my advisor, Dr. James R. McKenna for his guidance, his academic assistance, and support during my stay at Virginia Tech.

The author would like to thank Hubert Walker for his assistance in laboratory work. The list will be too long to mention, but the author would like to express special thank to Dan Lucero and Steward Reed, who is now Dr. Stewart Reed, for their help and encouragement.

Appreciation is expressed to the Director of IRA (Agronomic Research Institute), Dr. Jacob Ayuk Takem, for his helpful advice and encouragement before and during my program of study. Special thanks is directed to the chief of Party NCRE (National Cereals Research and Extension) for his encouragement and support during my work time with the NCRE project, and my study at

Virginia Tech. In addition, I will like to extend my gratitude to Dr. Stilwell for his dutiful coordination.

I would like to express my appreciation to my friend Dr. Laetitia K. Enyong whose unfailing love, support, and encouragement were instrumental for success of this work. Special thanks to my wonderful friends Martha Bayiee, Sarah Brown, Fatim, and John for their love and support.

Finally I would like to thank the USAID/IRA/NCRE for providing funds for my study and the Winrock officer who coordinated my program.

DEDICATION

This thesis is dedicated to my son Michael Banen who has been deprived of his mummy during the duration of my program.

To my parents Samuel and Alice Mankollo whose love and encouragement have brought me the happiness I now enjoy.

TABLE OF CONTENTS

INTRODUCTION	1
LITERATURE REVIEW	4
2.1 YARD WASTE COMPOST	4
2.1 SOIL PHOSPHORUS	6
2.2.1 Effect of Soil Acidity on Phosphorus uptake	8
2.3 CROP RESPONSE TO PHOSPHORUS	9
2.3.1 Corn Response to Phosphorus	9
2.3.2 Peanut Response to Phosphorus	9
2.4 WOOD ASH	10
MATERIALS AND METHODS	12
3.1 FIELD EXPERIMENT ON MINE TAILINGS SOILS	12
3.2 FIELD EXPERIMENT ON NATURAL SOILS	18
3.3 TISSUE SAMPLES ANALYSES	19
3.4 SOIL SAMPLES ANALYSES	20
RESULTS AND DISCUSSION	23
4.1 CROP RESPONSE TO YARD WASTE COMPOST AND WOOD	

ASH APPLICATION	23
4.1.1 Corn Grain Yield	24
4.1.1.1 Mine Tailings	24
4.1.1.2 Natural Soils	29
4.1.2 Peanut Yield	31
4.1.2.1 Mine Tailings	31
4.1.2.2 Natural Soils	34
4.2 NUTRIENTS IN PLANTS AS AFFECTED BY WOOD ASH AND YARD WASTE COMPOST	34
4.2.2 Nutrient Concentrations in Corn Ear Leaves	34
4.2.1.1 Mine Tailings	36
4.2.1.2 Natural Soils	41
4.2.2 Nutrient Concentrations in Peanut Leaves	44
4.2.2.1 Mine Tailings	44
4.2.2.2 Natural Soils	47
4.3 EXTRACTABLE PHOSPHORUS LEVELS AS RELATED TO YARD WASTE COMPOST APPLICATION	50
4.3.1 Extractable Phosphorus on Plots with Corn	51
4.3.1.1 On Tailings Soils	51
4.3.1.2 On Natural Soils	53
4.3.2 Extractable Phosphorus on Plots with Peanut	55

4.2.1.1 Mine Tailings	36
4.2.1.2 Natural Soils	41
4.2.2 Nutrient Concentrations in Peanut Leaves	44
4.2.2.1 Mine Tailings	44
4.2.2.2 Natural Soils	47
4.3 EXTRACTABLE PHOSPHORUS LEVELS AS RELATED TO YARD WASTE COMPOST APPLICATION	50
4.3.1 Extractable Phosphorus on Plots with Corn	51
4.3.1.1 On Tailings Soils	51
4.3.1.2 On Natural Soils	53
4.3.2 Extractable Phosphorus on Plots with Peanut	55
4.3.2.1 On Tailings Soils	55
4.3.2.2 On Natural Soils	55
 SUMMARY AND CONCLUSIONS	 59
LITERATURE CITED	62
APPENDIX	69
VITA	95

LIST OF FIGURES

Figure 1. Rainfall for 1992 at Tisand research site and
30-year mean at Emporia, Virginia 25

Figure 2. Rainfall for 1993 at Tisand research site and
30-year mean at Emporia, Virginia 26

LIST OF TABLES

	Page
Table 1 Elemental composition of yard waste compost	14
Table 2 Chemical composition of wood ash	15
Table 3 Fertilizer rate applied on corn and peanut	17
Table 4 Some chemical characteristics of the tailings and natural soils before planting	21
Table 5 Corn yield as a function of yard waste compost application on tailings soils	27
Table 6 Corn yield as a function of yard waste compost application on natural soils	30
Table 7 Peanut yield as a function of yard waste compost application on tailings soils	33
Table 8 Peanut yield as a function of yard waste compost application on natural soils	35
Table 9 Elemental composition of corn ear leaves sampled at early silk growth stage on tailings soils in 1992	37
Table 10 Elemental composition of corn ear leaves sampled at early silk growth stage on tailings soils in 1993	38
Table 11 Elemental composition of corn ear leaves sampled at early silk growth stage on natural soils in 1992	42
Table 12 Elemental composition of corn ear leaves sampled at early silk growth stage on natural soils in 1993	43
Table 13 Elemental composition of peanut leaves at the bloom stage on tailings soils in 1992	45
Table 14 Elemental composition of peanut leaves at the bloom stage on tailings soils in 1993	46

Table 15 Elemental composition of peanut leaves at the bloom stage on natural soils in 1992 48

Table 16 Elemental composition of peanut leaves at the bloom stage on natural soils in 1993 49

Table 17 Melhich 3 extractable P on tailings soils sampled with corn ... 52

Table 18 Melhich 3 extractable P on natural soils sampled with corn ... 54

Table 19 Melhich 3 extractable P on tailings soils sampled with peanut .. 56

Table 20 Melhich 3 extractable P on natural soils sampled with peanut . 57

Chapter 1

INTRODUCTION

Several deposits of heavy mineral sands (zircon, rutile and ilmenite) have been delineated in the Atlantic Coastal Plain region of North Carolina and southeastern Virginia (Carpenter and Carpenter 1991). In recent years, mining companies have been engaged in the extraction of heavy mineral from coastal plain soils. Soils to be mined in the Atlantic Coastal Plain are predominately sands and loams, but some clays are also found in this region. Tailings the by-product of mining are returned to the soil after the removal of minerals. Properties of mined tailings soils in Southern Illinois have been described by McSweeney (1987) and Seaker and Sopper (1988). These soils may contain a high percentage of clay, high level of acidity, and low amount of organic matter. Reclamation of the mined tailings is a challenge because of these unfavorable chemical and physical characteristics.

Public Law 95-97, a federal law of 1977, requires that surface-mined prime agricultural land be returned to its original level of productivity or better. Fehrenbacher (1982) pointed out that this federal law requires replacement of the A and B horizon. The surface soil is usually removed before mining, and subsequently replaced on the surface of the mined area to ensure adequate organic matter. Daniels and Haering (1990) indicated that the long-term success

of reclamation of mined land depends on maintenance of adequate soil organic matter.

A commonly used rule of thumb is that about half of the total amount of soil P is in an organic form which is mostly derived from plant residues. Hence, the low organic matter content in mined land results in less P available for absorption by crops (Dalton et al., 1952). Release of nutrients and organic acids occurs from soil organic matter with time during the mineralization process (Sanchez, 1980). Bumaya (1987) proposed a mechanism for the decreased sorption of P due to addition of organic matter. That is, the organic acid forms a stable complex with Al and Fe, and hence, prevents precipitation of soil P, and thereby, increases P availability to crops (Harter, 1969; Jackman, 1955; Sanchez, 1980).

The purpose of this study was to develop procedures for reclaiming mineral sand tailings for corn (Zea mays L.) and peanut (Arachis hypogaea L.) production. In this research, two waste materials, yard waste compost and wood ash, were evaluated as amendments to reclaim the mineral sand tailings. Yard waste compost was used to increase soil organic matter content and wood ash was applied to increase soil pH. Use of yard waste compost (YWC) to reclaim mined soils would help to solve the current crisis in municipal solid waste accumulation in the state of Virginia (May and Simpson, 1990). Specific objectives that form the basis of this study are as follows:

1) To determine the appropriate rate of yard waste compost needed to improve physical and chemical soil properties of mineral sand tailings in order to grow corn and peanuts;

2) To study the effect of YWC, lime, and wood ash on nutrient concentrations and yields of corn and peanuts; and

3) To evaluate P levels required for corn and peanut production on mine tailings soil.

Chapter 2

LITERATURE REVIEW

2.1 Yard waste compost

Incorporation of YWC mine tailings is a novel approach to improve soil structure by adding organic matter which is too low in the mined soils (Hortensville and Rothwell, 1968; Seaker and Sopper, 1988). Conversion of mineral sand tailings into highly productive soils would prevent loss of these mined lands from agricultural production. Tisdale and Oades (1982) indicated that organic materials are commonly used to improve soil structure and fertility which are lost during intensive agriculture. Soil organic matter, improves structure and releases plant nutrients during mineralization and, therefore, is an important component of soil fertility. The overall effect of yard waste application is to improve the soil physical, chemical, and microbial properties that are related to crops growth (Clap et al., 1986). Hortensville and Rothwell (1968), Macdoff (1992), and Mays et al. (1973) reported that organic amendment addition increased crop yields and water holding capacities of sandy soils. Compaction during the mining process contributed to the poor physical properties of mine tailings soils (Fehrenbacher, 1982). Incorporation of YWC into mine tailings soils would improve the soil for plant growth by increasing porosity and therefore by decreasing compaction and increasing water holding capacity (Clap et al., 1986;

McConnell et al., 1993).

Yard waste compost affects soil pH which, in turn, affects the plant availability of nutrients (McConnell et al., 1993). When applied to the acid soil, YWC application increases the pH slightly and reduces Al toxicity which occurs at soil pH levels below 5.5 (Clap et al., 1986). Yard waste compost application also increased cation exchange capacity (CEC) and soil microorganism activity (Clap et al., 1986). Hortensville and Rothwell (1968) reported that a large application rate of garbage increased CEC, while a low application rate did not affect CEC. Yard waste compost supplied considerable amounts of N, P, and K for crop growth on an agricultural soils (Terman et al., 1973).

Researchers have reported that YWC increases soil C:N ratio because of high C and low N contents (Barkdoll, 1991; Mays et al., 1973). The range of N in soil organic matter is about 5 to 5.5% and C is 50 to 58% (Tisdale and Oades, 1983). The C:N ratio is much wider for YWC than for soil. Immobilization of N in YWC amended soils decreased soluble N and caused N stress in plants (Finestein et al., 1986).

Enwezor (1987) reported that energy materials in organic matter are required by certain microorganism populations that participate in the P mineralization process. Generally plant and microorganisms utilize mainly inorganic P for growth and development (Herbien, 1990). Birch (1961) observed that the mineralization of P from organic P to inorganic P occurred during the

decomposition of plant residues.

High temperature and moisture affect the decomposition rate of plant materials (Dalal, 1977) and, therefore, mediate P sorption and desorption processes (Barrow, 1961). Ayodele and Bennoah (1989) found that there was a low correlation between either clay or organic matter content and P sorption in the soil. Yuan (1980) reported that the organic matter has a minimal role in P sorption. In contrast, some researchers suggested that organic molecules may form bonds with Al and Fe and, thereby, decrease P absorption and precipitation (Dalton, 1952; Gaur, 1969; Strutchers, 1950; Vyas, 1964). This relationship may explain the competition between the fixation of P in soil and its P absorption by plants.

2.2 Soil phosphorus

There are several processes that tend to decrease P availability in mine tailings. One of the more important is the low pH (Diggle and Bell, 1984). Sanyal and De Datta (1989), Torbert (1982), and Tukaki and Malher (1990) pointed out that P deficiency occurs even in soils well supplied with P because of its decreased availability in acid or alkaline soil. Inorganic soil P occurs almost exclusively as the orthophosphate anions, H_2PO_4^- and HPO_4^{2-} . The fraction of each species in solution varies with soil pH. Most plant available P occurs as H_2PO_4^- in acid soil, and the HPO_4^{2-} availability increases as pH increases (Olsen

and Khasawneh, 1980). Chen and Barber (1990) found that the amount of H_2PO_4^- in soil solution usually governed P uptake by plant roots in slightly acid and acid soils. Since mine tailings soils have numerous exposed Al and Fe oxide surfaces with low P saturation (Diggle and Bell, 1984), P fixation by adsorption and precipitation reactions would occur at low pH levels.

Mine tailings, like virgin soils, have a high potential to fix P in a plant unavailable form. Alley and Bertsch (1983) reported that, with application rates of 200 and 300 kg P ha⁻¹ on new cleared sandy loam soils, P level in corn were still below the critical level established by Jones et al. (1990). In their study, they found that amounts of P in the tissue was not related to levels of extractable soil P in the newly cleared soil.

Triplett et al. (1969) indicated that P accumulated in the soil surface where the no till planting method was used for corn production. In similar studies, Lutz and Hillard (1973), Hargrove (1985), Cruse et al. (1983), and Fink (1974) showed that, with no tillage in humid climates, P retention was mainly within 5.0 to 7.0 cm of the soil surface where applied. Mengel and Kirkby (1987) determined that the mobility of P in the soil is very low and varies with the type of soil. For this reason, there is low risk of P fertilizer loss by leaching for a short time after application. Evans et al. (1985) showed that downward movement of P is greater in sandy soils than in heavier textured soils. Fox and Kamprath (1970) found that a large amount of P is retained by clay and specifically by kaolinite. Hence, the

risk of P entrance into ground water is greater in sandy soils than in clayey soils (Olsen and Watanabe, 1970). Often P fertilization improves crop production but losses of P by erosion can result in eutrophication which causes deterioration of water quality (Sharpley, 1985).

Black and Goring (1953) suggested that organic matter in mineral soils contains C, N, and P in the ratio of roughly 110:9:1. This ratio is wider in organic soils. Humus may increase the solubility of P and, thus the plant availability of P. Mengel and Kirkby (1987) attributed this increase to the formation of phospho-humic acid complexes which are absorbed by plant.

2.2.1 Effect of soil acidity on phosphorus uptake

Phosphorus availability is correlated with soil acidification and other factors such as temperature and soil moisture. Barrow (1980), Naidu et al. (1990), and Chen and Barber (1990) reported that pH has an influence on nutrient adsorption and plant growth. The reasons for abnormal plant growth on acidic soils are complex and may be due to deficiencies of P, Mg, Ca, and Mo or to toxicities of Al, Mn, and H (Fox et al., 1978; Kamprath and Fox 1985). In most cases, insoluble P compounds of Fe and Al are formed when P is added to soil with a low pH (Dalton, 1952; Swenson, 1949).

The use of lime or ash to lessen the problem of low soil pH has proven to be efficient and practical in agriculture (Chen and Barber, 1990). Lime

application rates are calculated to raise the pH 5.2 to 7.0 depending on the crop and the type of soil. Adams (1980) concluded the beneficial effects of liming are to reduce Al and Mn toxicities and to increase Ca, P, Mg, and Mo availabilities.

2.3 Crop response to phosphorus

2.3.1 Corn response to phosphorus

The capacity for P uptake differs from plant to plant. There is an interaction between the root growth and P uptake (Barber and Kovar 1989). Phosphorus uptake by corn depends on characteristics of roots and on the amount of soluble P in soil. Barber and Kovar (1989) found that root elongation rate was the most important parameter for uptake of soil P. Because P is slowly diffusible in soil solution, roots must closely approach the area with high readily available P in order to be easily taken by the plant. Increased root growth increases the surface area for P absorption. Corn root development in constructed surface mined land was studied by Fehrenbacher et al. (1982). They found that mined lands were frequently unsuitable for corn root development as a result of high bulk density, unfavorable structure, and low pH.

2.3.2 Peanut response to phosphorus

Grandt (1988) related that N deficiencies in plants are common on disturbed soils with low N and organic matter contents. He recommended use of a legume plant on mined areas to return the land to high productivity and to

improve soil texture for root penetration. High peanut yields are highly dependent on adequate growth rate and nutrients uptake. Relatively small amount of P is absorbed by peanut plant compared with other crops (Cope et al., 1984). Hence, P deficiency is not usually severe for peanut production as for other crops, since there is a small amount of P required by the peanut crop. Calcium is critical element in peanut production because of its thionic fruiting habit. Liming mine tailings to improve P availability would also increase the Ca sorption by the peanut plant.

2.4 Wood ash

Wood ash is a residual material from wood burned for energy production. Wood ashes have been applied to agricultural soils to increase pH and to supply plant nutrients (Ohno and Erich, 1990; Naylor and Schmidt, 1986; Donohue, 1982). Lerner and Utzinger (1986) found that soil pH increased with an increase in rate of application of wood ash. Ohno and Erich (1990) found that the amount of nutrients and acid neutralizing power of wood ash varied from source to source. Wood ash can be considered as a substitute of lime even though the neutralizing value of wood ash is about half of that for limestone (Naylor and Schmidt, 1986; Donohue, 1982).

In general, the major macronutrients in wood ash are Ca averaging 26%, followed by about 7.2% K, 1.5% Mg, 0.8% P, and then small amount of other

nutrients. (Lerner and Utzinger, 1986). This composition shows that slight increases of P, K, and Mg would occur in soil from wood ash application. The form of Ca in the wood ash is in CaO. The CaO reacts with atmospheric H_2O and CO_2 to form $Ca(OH)_2$ and then $CaCO_3$ which are commonly used liming materials in agriculture (Lerner and Utzinger, 1986).

Application of wood ash may have detrimental effects on plant growth. Excess levels of wood ash can lead to build up of heavy metals such as Cd, Cu, Ni, Pb, and Zn (Page et al., 1979; Lerner and Utzinger, 1986; Donohue, 1982). High concentration of salt from the high level of K in the ash may also be detrimental for crop roots (Donohue, 1982). According to Lerner and Utzinger (1986), wood ash is known to contain a high amount of K_2O (4 to 6% by weight), which is highly soluble in soil solution.

Hartikainen (1984) and Erich and Ohno (1992a) demonstrated that P added to soils with wood ash was readily available for plant uptake. Wood ash increases P in solution by two mechanisms. Firstly, the amount of P in the solution increases as wood ash dissolves during the neutralization reaction. Secondly, the concentration of P in solution increases as a result of desorption of P from soil as the pH increases. Ohno (1992) stated that farmers who follow sustainable practices are receptive to use of wood ash to replace or supplement chemical fertilizer.

Chapter 3

MATERIALS AND METHODS

The research reported herein is a portion of a study on reclamation of mineral sand tailings which was initiated in 1990 at Brink East site in Greenville County, Virginia. Natural soils on this study area were classified as fine-loamy, siliceous, thermic Typic Hapludults. In the first phase of the study, exploratory research was started in 1991 to determine rates of amendment for treatments, and this exploratory research was completed in early of 1992. During phase 1, corn growth was evaluated in the field on mine tailings covered with topsoil and, simultaneously, greenhouse experiments were conducted to establish the amount of wood ash, lime, fertilizer, and YWC to test in the field plots during phase 2. For phase 2 of this study, field and laboratory research were initiated in early 1992 and completed in late 1993. During this period, corn and peanut production was evaluated on mine tailings and natural soils.

3.1 Field experiment on mine tailings

Field experiments were established on natural soils and mine tailings to compare corn and peanut yields on the two different areas. The mine tailings area was divided into two experiment with identical treatments (Appendix A). Treatments applied for the two experiments were as follows:

1. Control (tailings)
2. Control + 2.2 metric tons (t) ha⁻¹ of lime
3. Control + 2.4 t ha⁻¹ of wood ash
4. Topsoil over tailings
5. Tailings + 1% compost + 2.4 t ha⁻¹ of wood ash
6. Tailings + 2% compost + 2.4 t ha⁻¹ of wood ash
7. Tailings + 4% compost + 2.4 t ha⁻¹ of wood ash
8. Tailings + 6% compost + 2.4 t ha⁻¹ of wood ash
9. Tailings + 12% compost + 2.4 t ha⁻¹ of wood ash

These treatments were applied to 3.0- by 7.0-m plots arranged in a randomized complete block design with four replications. The compost used in this experiment was derived from the organic fraction of yard waste and was obtained from Chesterfield County, Virginia. The dry weight of compost for the treatments were 22.4, 44.8, 89.6, 134.4, and 268.8 t ha⁻¹ at the 1%, 2%, 4%, 6%, and 12% compost levels, respectively. Amounts of pertinent elements in the yard waste compost are shown on Table 1. Either 2.2 t ha⁻¹ of dolomitic limestone or 2.4 t ha⁻¹ of wood ash was added to increase the pH of the soil surface. Pertinent chemical parameters of wood ash are shown on Table 2.

Dolomitic limestone, wood ash, and compost were incorporated to a depth of 25 cm by rototilling. Corn (var. Pioneer 3140) was planted in the spring of 1992 in the 4 row plots at 76 cm widths and 0.75 m row lengths and at a population

Table 1. Elemental composition of yard waste compost[†].

Al	Ca	Fe	K	Mg	N	P	S	Zn
-----g kg ⁻¹ -----								
9.5	10.7	8.3	1.5	0.6	6.1	1.3	1.3	0.07

† Dry weight basis.

Table 2. Chemical composition of wood ash.

pH	CCE [†]	macronutrients					micronutrients		
		N	P	K	Ca	Mg	Zn	Mn	Fe
		-----g kg ⁻¹ -----					-----mg kg ⁻¹ -----		
12.4	20.7	0.4	2.4	24	19.3	1.2	183	5090	6530

† CCE = Calcium carbonate equivalent.

of 47,839 plants ha⁻¹. Dual 8E (metolachlor) and AAtrex (atrazine) were applied at a rate of 4.5 kg ha⁻¹ at planting to control weeds.

Peanut (var. VNC 851) was planted in the spring of 1992 and (var. NC 7) in the spring of 1993 in the 4 row plots at 76 cm row widths and 0.75 m row lengths and at a population of 267,236 plants ha⁻¹. Treatments were arranged in a randomized complete block design with 4 replications. Pursuit 21 and Dual 8E were applied at recommended rates as herbicides and Temik as an insecticide.

A corn-peanut rotation was followed, i.e., corn was grown on area in 1992 and peanuts on this area in 1993, and vice versa. Fertilizer application rates were as follows in the spring of 1992 (Table 3): for corn, P application rates were 289 kg P ha⁻¹ as triple superphosphate (TSP) and 12.5, 25, 50, 75, and 150 kg P ha⁻¹ for the 1%, 2%, 4%, 6%, and 12% YWC treatments, respectively; and N application rates were 168 kg N ha⁻¹ as NH₄NO₃ applied at 168 kg N ha⁻¹ and 134, 269, 538, 806, and 1613 kg N ha⁻¹ as the respective YWC treatments. One half of N from fertilizer was broadcast and disked into the soil prior to planting, and the second half was sidedressed when corn was approximately 45 cm in height, i.e., on June 1, 1992. For peanuts, N was applied in the spring of 1992 at rates of a 67 kg N ha⁻¹ as NH₄NO₃ and variable rates of 134, 269, 538, 806, and 1613 kg N ha⁻¹ were added from the respective compost treatments. All plots received the 126 kg K ha⁻¹ as KCl and 28, 56,

Table 3. Fertilizer rate on corn and peanuts.

Amendment	<u>Natural soils</u>		<u>Tailings soils</u>	
	Corn	Peanuts	Corn	Peanuts
-----kg ha ⁻¹ -----				
<u>Year 1992</u>				
N	168	34	168	67
P	29	29	289	289
K	126	126	126	126
<u>Year 1993</u>				
N	196	37	196	34
P	29	29	14	14
K	112	112	112	112

112, 168, and 336 kg K ha⁻¹ from respective compost treatments. Foliar Zn (ZnSO₄) was applied to plants on tailings plots during the growing season 1992 at the rate of 1.12 kg ha⁻¹. Broadcast ZnSO₄ was applied on mine tailings soils prior to planting in 1993 at the rate of 16.8 kg ha⁻¹. In 1993, all P and K were broadcast applied on mine tailings at the rate of 14 kg P ha⁻¹ as TSP, and 112 kg K ha⁻¹ as KCl for both crops (Table 3). All corn plots received a broadcast application of 112 kg N ha⁻¹ from NH₄NO₃ prior to planting and a sidedress application of 84 kg N ha⁻¹ as NH₄NO₃ when corn height was 45 cm. For peanuts, N as NH₄NO₃ was applied at a rate of 34 kg N ha⁻¹ and CaSO₄ was applied as recommended for peanut fertility (3360 kg ha⁻¹).

3.2 Field experiment on natural soils

Two field experiments were established on natural soil to compare the corn and peanut yields on mine tailings with those on natural soils. The following five treatments were applied to 3.0- by 7.5-m plots arranged in randomized complete block design with four replications for each field experiment:

1. natural soil
2. natural soil + 2.4 t ha⁻¹ of wood ash
3. natural soil + 2% compost + 2.4 t ha⁻¹ of wood ash
4. natural soil + 4% compost + 2.4 t ha⁻¹ of wood ash
5. natural soil + 6% compost + 2.4 t ha⁻¹ of wood ash

A rotation between corn and peanut was followed, i.e., corn was grown on area in 1992 and peanuts on this area in 1993, and vice versa. The rates of fertilization on the experiment area in 1992 were of 168 kg N ha⁻¹ on corn and 34 kg N ha⁻¹ on peanut as NH₄NO₃ and the same quantity of P (29 kg ha⁻¹) as TSP and K (126 kg ha⁻¹) as KCl on both crops. In 1993, the rate of fertilizer application was 37 kg N ha⁻¹ as NH₄NO₃ for peanuts, and 112 kg K ha⁻¹ as KCl and 29 kg P ha⁻¹ as TSP for both crops. Split application of N was used for corn, i.e., 112 kg ha⁻¹ as NH₄NO₃ was broadcast and disk in prior to planting and 84 kg N ha⁻¹ as NH₄NO₃ was sidedressed when corn plants heights were 45 cm (Table 3). Broadcast ZnSO₄ was applied on natural soils in 1993 prior to planting at the rate of 3.4 kg ha⁻¹.

3.3 Tissue samples analyses

Tissue samples were collected at the early silk growth stage of corn and at the early bloom growth stage of peanut to determine the nutrient status of the crops. Samples collected from corn were the entire leaf at the ear node at the early silk growth stage because calibration data is available only at this stage of growth (Jones et al., 1990). Hallock et al., (1971) has shown that nutrient concentrations in the upper mature leaf blades sampled during the bloom provide a good indication of the nutrient status for stage peanut plants. Peanuts leaf blades were collected at the early blossom growth stage. Eight leaves of corn and

seventy five leaf blades of peanut were collected from each plot for the nutrient analyses.

Leaf samples of peanut were washed to remove dirt and spray residues of ZnSO_4 . All tissue samples of corn and peanut were then are dried in an oven (69°C) for at least 48 hours and weighed before analysis (Appendix B). The dried plant tissue was ground and passed through a 20 mesh stainless steel sieve. Total N in tissue samples was determined by stream distillation following Kjeldahl digestion (Bremner et al., 1982). Plant tissue was digested in a $\text{HNO}_3\text{-HClO}_4$ mixture in preparation for Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, and Zn analyses. Absorption spectrophotometry was used to determine these nutrients in the digests.

3.4 Soil samples analyses

The field soil was sampled to a depth of 15 cm surface layer before planting prior to application of YWC and fertilizer in 1991 (Table 4). In 1992, soil samples were taken during the growing season after application of all amendments. The second year of our experiment soil samples were taken before amendment application. A composite sample, five cores plot⁻¹ was collected of all field experiments. The amount of extractable P in the soil sample was determined by the Mehlich-3 procedure (Mehlich, 1984). The

Table 4. Some chemical characteristics of the natural and tailings soils before planting.

Natural		Tailings	
partial	%	partial	%
sand	81.7	sand	74.6
silt	1.6	silt	5.6
clay	16.7	clay	19.8
Exchangeable cations			
-----cmol kg ⁻¹ -----			
Ca	0.97	Ca	0.40
Mg	0.15	Mg	0.20
K	0.18	K	0.06
H	3.60	H	4.60
Al	0.18	Al	0.75
pH	5.3	pH	4.7

Mehlich-3 extractant solution consists of 0.2 N CH_3COOH - 0.25N NH_4NO_3 + 0.015 N HNO_3 + 0.002 N EDTA 0.001 M. For this procedure, 3.13 g of soil was shaken with 25 ml of Mehlich-3 extraction solution for 5 minutes. Amounts of P extracted from the soil was determined by a colorimetric procedure.

Statistics analyses

All data were subjected to analyses of variance by use of the SAS System for Elementary Statistical Analysis (Schlotzhauer, 1987). Means were separated by least significant difference procedure where the analysis of variance indicated significant differences at the 0.05 probability level. Linear regression and simple correlation analysis were ran to evaluate relationships between rate of YWC application (Treatments 3, 5, 6, 7, 8 and, 9) and both corn and peanut yields.

Chapter 4

RESULTS AND DISCUSSION

This research was conducted to determine if mine tailings reclamation could be accomplished by utilization of waste materials. Wastes evaluated for mine tailings reclamation in the research were YWC and wood ash. Yard waste compost was used to increase the organic matter content, and the wood ash was used to increase the pH of mine tailings. It was necessary to address these chemical properties because the tailings contained a negligible amount of organic matter and had a very low pH of 4.7.

The goal of this research is to develop reclamation procedures to the extent that crop yields would be similar on the mine tailings and natural soils in the region. The test crops selected were a rotation of corn and peanuts, which is a common crop pattern in the region where the mining would occur. During the course of the research, attention was directed toward treatment effects of the amendment application for the reclamation on corn and peanut yields and nutrient concentrations and on soil test P levels.

4.1 Crop response to yard waste compost and wood ash application

Corn and peanuts were grown during the 1992 and 1993 growing seasons to evaluate crop response to YWC and wood ash application.

The amount of rainfall differed widely during the two growing seasons (Figure 1, Figure 2). There was an ample amount of rainfall with a relatively good distribution during the 1992 growing season. In 1993, a period of drought occurred in June even though the total accumulation was above the 30-year average. Precipitation in July and August of 1993 was below the 30-year average and, as a result, there was inadequate rainfall for normal pollination and kernel development of corn. Overall, the amount and distribution in 1993 was not favorable to obtain high yields of corn and peanuts on well-drained soils.

4.1.1 Corn grain yield

4.1.1.1 Mine tailings

Corn grain yields were higher on the topsoil replacement treatment than on the control in the wet year, i.e., in 1992 (Table 5). Low yield on the control may reflect low available water and unfavorable chemical properties in the mine tailings due to a lack of organic matter. A lack of organic matter was also reported for areas where coal was removed by strip mining procedures (Daniels et al., 1991). Compaction in the topsoil replacement treatment probably negatively affected corn grain yield in 1993 (Table 5). Lack of root growth due to the compaction would decrease plant uptake of water and nutrients. Low yields on the topsoil replacement treatment in 1993 show that simple addition of surface soil above the mine tailing with subsoiling is not a satisfactory

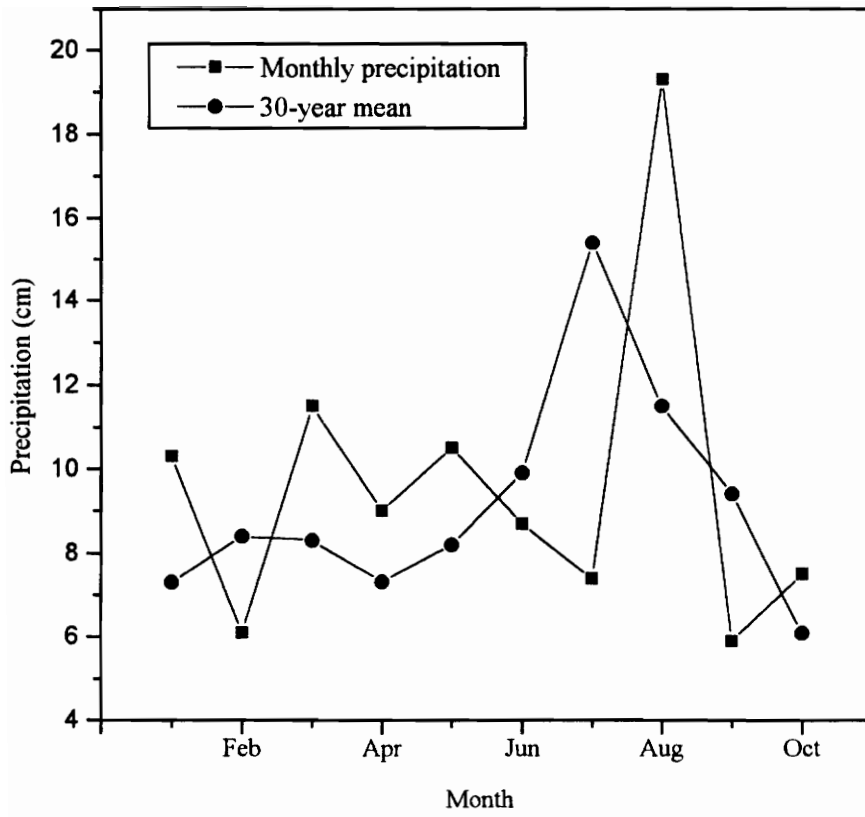


Figure 1. Rainfall for 1992 at Tisand research site and 30-year mean at Emporia, Virginia.

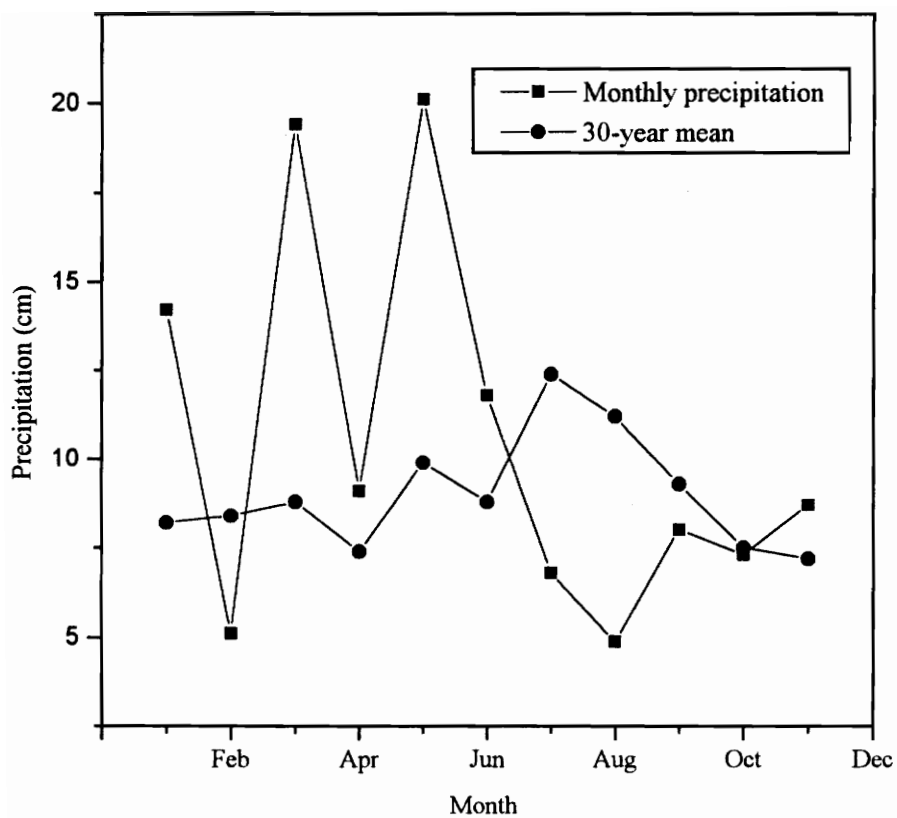


Figure 2. Rainfall for 1993 at Tisand research site and 30-year mean at Emporia, Virginia.

Table 5. Corn grain yield as a function of wood ash, yard waste compost, and limestone application

Treatment		Yield		
Number	Description	1992	1993	Average
		----- kg ha ⁻¹ -----		
1.	Control	3960bc*	5354ab	4657ab
2.	Control + lime ††	2982c	6016ab	4499ab
3.	Control + ash	3789c	4680b	4235ab
4.	Topsoil	6594a	1371c	3933c
5.	1% YWC † + ash	5509a	5593ab	5551abc
6.	2% YWC + ash	6322a	4607b	5465abc
7.	4% YWC + ash	5473ab	5762ab	5618b
8.	6% YWC + ash	5509a	6255ab	5882b
9.	12% YWC + ash	6426a	7830a	7128a

* Means followed by different letters within columns are significantly different at 0.05 level of significance

† YWC = Yard waste compost

†† Lime = Limestone

reclamation procedure.

Yields in 1992 were generally higher on the YWC + wood ash treatments than on the control, control + lime, and control + wood ash treatments. There was a general increase in yield with an increase YWC from 0 to 12%. An increase in pH from wood ash alleviates Al and Mn toxicities in plants and increases P uptake by plants (Kamprath, 1970). Incorporation of YWC with mine tailings supplies nutrients and improves soil structure which increases plant available water.

Zinc deficiency occurred in corn plants on all treatments during the 1992 growing season but was most severe on the control + lime treatment. Lower Zn uptake would be expected when lime was applied because Zn uptake decreases with an increase in soil pH (Mengel and Kirkby, 1985). This abnormally, was attributed to P induction of Zn deficiency and was controlled by foliar application of Zn. Zinc deficiency symptoms were not observed on control + lime or other treatments in 1993 due to soil application of Zn.

Corn grain yields were highest on topsoil replacement and 12% YWC + ash treatments in 1992 and on the 12% YWC + wood ash treatment in 1993 (Table 5). The 12% YWC + ash treatment also had the higher average yield over the two years. These data show the high potential for use of YWC and wood ash as amendments for corn production on mine tailings.

Correlation analysis were run to assess the relationship between corn grain

yield and YWC rate of application (Treatments 3, 5, 6, 7, 8, and 9). The coefficients of simple correlation for the relationship were 0.50 ($P=0.01$) in 1992 and 0.42 ($P=0.04$) in 1993 (Appendix A2). The corn grain yield increases from YWC rate of application are similar to those reported by Tisdale and Oades (1982). They attributed the yield increases to improvement in soil fertility from application of the organic materials. In our study, YWC probably increased yield by increasing plant available water, by improving P availability, and by alleviating Al and/or Mn toxicity.

4.1.1.2 Natural soils

Corn grain yields grown on the natural soils are shown on Table 6. During the first year of study (1992), overall yields averaged $10,588 \text{ kg ha}^{-1}$ on the natural soils which was much higher than the average yield of 5173 kg ha^{-1} on the mine tailings. Yields were not different between the control and compost treatments at 0.05 level of significance. High productivity on the natural soils in 1992 may be related to adequate nutrient supply and timely rainfall. An increase in the rate of YWC application from 2% to 6% did not increase grain yield. Corn grain yields were substantially lower in 1993 compared with the 1992 growing season. The lower yields in 1993 likely reflect water stress due to insufficient rainfall in July and August.

Table 6. Corn grain yield as a function of yard waste compost application on natural soils.

Treatment		Corn-Grain Yield		
Number	Description	1992	1993	Average
		-----kg ha ⁻¹ -----		
1.	Control	10602a*	7994ab	9298ab
2.	Control + ash ††	10671a	7207c	8939b
3.	2% YWC † + ash	10417a	7714bc	9065b
4.	4% YWC + ash	10337a	7872bc	9104b
5.	6% YWC + ash	10912a	8904a	9908a

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC = Yard waste compost.

†† Ash = Wood ash.

Coefficients of simple correlation were calculated to evaluate the relationship between corn grain yield and YWC application. In 1992 corn yields and rates of compost application (treatments 2, 3, 4, and 5) on the natural soil were poorly correlated ($r=0.08$, not significant). In 1993 corn yields were weakly correlated ($r=0.51$, $P=0.04$) (Appendix A3) with rates of compost application (treatments 2, 3, 4, and 5). The significant correlation in 1993 between yields and levels of YWC application show that increased available water from the organic matter addition increased corn yield. This finding demonstrates the value of YWC addition to natural soils as well as to mine tailings.

4.1.2 Peanut yield

4.1.2.1 Mine tailings

The effect of YWC application on peanut yield was similar to that on corn yield. Peanut yields in 1992 were higher on the YWC + ash treatment than on the control, control + lime, control + ash, and topsoil replacement treatments. The average yields of peanuts on tailings treatments with YWC were 2012 kg ha^{-1} in 1992 and 3198 kg ha^{-1} in 1993. The lower average yield in 1992 was probably caused by a combination of poor emergence, poor growth, and incidence of *centracladium* black root rot disease. As previously discussed with corn, the difference in yield can be attributed to either soil fertility (i.e., Al toxicity or Zn deficiency) or soil physical properties (i.e., plant available water).

The average yields on tailings treatments without YWC was 1285 kg ha⁻¹ in 1992 and 2076 kg ha⁻¹ in 1993 (Table 7). In 1992 peanut yields did not vary with the rate of YWC application (Table 7). On the other hand, in 1993, the two highest rates of YWC + ash were higher than the control, control + ash, and control + lime treatments. The total rainfall was 96.2 cm in 1992 and only 115.5 cm in 1993. Higher peanut yields in the drier year reflects, in part, the lower susceptibility of moisture stress than many other crops.

Peanut yields on some of the treatments (1, 2, 9) were more than double in 1993 as compared with 1992 (Table 7). In 1993 the average peanut yield increased in all treatments with or without YWC application. Several of the following factors may account for the higher yields in 1993: a more favorable pH was established in the tailings by a second application of wood ash; the NC7 variety of peanuts grown in 1993 has less canopy, is a more compact plant, and appears to have a higher yield potential than the variety grown in 1992; and the NC7 variety has more resistance to *celenteraladium* black root rot disease than the VNC 851 variety.

Coefficients of simple correlation were determined for the relationship between peanut yields and YWC application rate. The correlation coefficient, r , for the relationship was 0.51 ($P=0.009$) in 1992, and 0.71 ($P=0.0001$) in 1993. This relationship is consistent with the conclusion that YWC + wood ash application is a promising treatment for reclamation of mine tailings.

Table 7. Peanut seed yield as a function of yard waste compost application on tailings soils.

Treatment		Peanut Seed Yields		
Number	Description	1992	1993	Average
		-----kg ha ⁻¹ -----		
1.	Control	1395b*	2228cd	1812b
2.	Control + lime ††	1100b	2454cd	1777b
3.	Control + ash §	1317a	2268cd	1793b
4.	Topsoil	1330b	3433bc	2385b
5.	1% YWC † + ash	2630a	3211bcd	2922bcd
6.	2% YWC + ash	2505a	3073bcd	2789bcd
7.	4% YWC + ash	2602a	3255bcd	2928bcd
8.	6% YWC + ash	2883a	3883ab	3383ab
9.	12% YWC + ash	2339a	4982a	3661a

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC = Yard waste compost.

†† Lime = Limestone.

§ Ash = Wood ash.

4.1.2.2 Natural soils

Neither YWC nor wood ash application affected peanut yields on the natural soil in either 1992 or 1993 (Table 8). The 1993 peanut yields on the 6 and 12% YWC + ash on tailings treatments (Table 7) were higher than peanut yields from all treatments on the natural soils (Table 8). These data also show the high potential for use of YWC and wood ash for reclamation of the mine tailings.

4.2 Nutrients in plants as affected by wood ash and yard waste compost

4.2.1 Nutrient concentrations in corn ear leaves

Nutrient sufficiency ranges in plants are based on amounts in specific plant parts at specific growth stages. The nutrient sufficiency ranges for corn are based on amounts in the whole plant less than 30.5 cm tall, in the leaf below the whorl prior to tasseling, and in the ear leaf at the early silk growth stage (Small, 1973; Jones et al., 1990). Ear leaf samples at the early silk growth stage were selected to evaluate the nutrient status of corn in this research. This late sampling was expected to indicate the effect of treatments on the nutrient status of plants over a longer portion of the growing season than samples at earlier growth stages.

Table 8. Peanut yield as a function of yard waste compost application on natural soils.

Treatment		Yield		
Number	Description	1992	1993	Average
		-----kg ha ⁻¹ -----		
1.	Control	3178a*	3200a	3189a
2.	Control + ash ††	4024a	3291a	3658a
3.	2% YWC † + ash	3133a	3242a	3188a
4.	4% YWC + ash	3656a	3291a	3474a
5.	6% YWC + ash	3138a	3307a	3223a

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC = Yard waste compost.

†† Ash = Wood ash.

4.2.1.1 Mine tailings

The mine tailings consists of a mixture of topsoil and subsoil and, hence, many P fixation sites could be present in the zone of fertilization. Fixation could lead to low availability of P. There is a possibility of N deficiency on the mine tailings because much of the mineralized N from soil organic matter would be positionally unavailable at lower depths below the rooting zone, i.e., surface soil with a high organic matter content with mineralizable N would be mixed with subsoil with a low organic matter content during formation of the tailings. Although, there was primary concern about treatment effects on the status of N and P in corn plants, other elements including Ca, Fe, K, Mg, Mn, and Zn, also were evaluated in this research (Tables 9 and 10).

Tissue P levels in 1992 were higher on the topsoil replacement treatment than on the YWC treatments (Table 9). Application of YWC, which contained P, did not increase P concentration in corn ear leaves at early silk growth stage. Phosphorus concentrations on all YWC treatments were below the critical level of 0.25% (Jones et al., 1990). The low P concentrations of plants on YWC treatments may have been due to P fixation in the mine tailings. The amount of P in corn ear leaves on the topsoil replacement treatment was greater than for other treatments. Higher tissue P on the topsoil treatment reflects less P fixation by topsoil than by the mine tailings. Overall there was a low P concentration in corn tissue in both 1992 and 1993 even though exceedingly

Table 9. Elemental composition of corn ear leaves sampled at early silk growth stage on tailings soils in 1992.

Treatments	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%			-----mg kg ⁻¹ -----				
Control	2.4abc	0.20bc*	1.7c	0.38dc	0.15bc	184a	51b	75b
Control + lime	2.4abc	0.27a	2.1a	0.40bc	0.24a	182a	36c	102a
Control + ash	2.5abc	0.21b	1.3c	0.45a	0.16bc	237a	59ab	97ab
Topsoil	2.1c	0.25a	1.8bc	0.36bce	0.17b	278a	34c	92ab
1 % YWC †+ash	2.8a	0.19bcd	1.7c	0.43ab	0.15bc	196a	65a	110a
2 % YWC +ash	2.2bc	0.18cd	1.7c	0.40bc	0.14bcd	212a	58ab	77b
4 % YWC +ash	2.7ab	0.18cd	2.0ab	0.34de	0.13cde	257a	52b	75b
6 % YWC +ash	2.0c	0.17cd	1.8bc	0.30f	0.10e	257a	35c	84ab
12 % YWC +ash	2.5abc	0.19bcd	1.9b	0.32fe	0.11ed	187a	38c	85ab

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC= Yard waste compost.

Table 10. Elemental composition of corn ear leaves sampled at early silk growth stage on tailings plots in 1993.

Treatment	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%			-----mg kg ⁻¹ -----				
Control	1.9a*	0.20c	1.7ef	0.45b	0.15d	48a	109a	75b
Control +lime	2.0ab	0.21bc	1.6f	0.5ab	0.26a	19c	47e	77ab
Control +ash	2.0ab	0.21bc	1.7ef	0.5ab	0.17cd	29bc	67cd	77ab
Topsoil	2.2a	0.25a	1.8de	0.4b	0.21b	37ab	64cde	78ab
1% YWC ‡+ash	2.0ab	0.21bc	1.9dc	0.5ab	0.17cd	29bc	88b	81ab
2% YWC +ash	1.8b	0.22abc	2.0bc	0.5ab	0.17cd	25c	75bc	87a
4% YWC +ash	1.8b	0.22abc	2.1ab	0.5ab	0.20bc	26bc	81bc	88a
6% YWC +ash	2.0ab	0.24ab	2.1ab	0.51a	0.20bc	23c	74bc	84ab
12% YWC +ash	1.8b	0.21bc	2.1ab	0.5ab	0.20bc	21c	55de	81ab

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

‡ YWC = Yard waste compost.

high rates were applied over the two year period (Tables 9 and 10).

Nitrogen concentrations from 2.7 to 4.0% are in the sufficiency range base on ear leaves sampled at the early silk growth stage (Jones et al., 1990). Corn ear leaves sampled in 1992 from most of the treatments, had N concentrations below 2.7% (Table 9). In 1993, corn ear leaves sampled from all treatments had a concentrations below 2.7% (Table 10). These data on N concentrations in corn plants indicate that the method of N application should be given consideration. It may be appropriate to sidedress a higher proportion of applied N in the future to ensure against low N recovery due to immobilization and leaching of the applied N.

Amounts of Ca, Fe, K, and Mn were in the sufficiency range for corn growth (Jones et al., 1990) during both growing seasons regardless of treatment (Tables 9 and 10). Zinc concentrations in corn ear leaves were above the sufficiency range of 25 to 100 mg kg⁻¹ (Jones et al., 1990) in 1992 (Table 9) but were usually within this range in 1993 (Table 10). The Mg concentrations in the ear leaves were below the sufficiency range of 0.20 to 1.0% (Jones et al., 1990) except where dolomitic limestone was applied as a treatment (Tables 9 and 10).

Zinc deficiency in corn plants may be induced by high P availability (Olsen, 1972). The Zn deficiency symptoms observed on the control + lime and control + wood ash treatments in 1992 likely were induced by the high rate

of P application in combination with a decrease in Zn availability with an increase in soil pH. Although the Zn deficiency was corrected by foliar Zn application, corn grain yields were relatively low on these treatments as compared with yields on other treatments in 1992 and all treatments in 1993 (Table 5). Zinc concentrations in ear leaves were much higher in 1992 than in 1993 (Tables 9 and 10). These high Zn levels in 1992 reflect residue from the foliar Zn which was applied a few days prior to collection of tissue samples. Even though the ear leaf concentrations were high in 1992, these Zn concentrations were below the suggested toxicity level of 300 mg kg^{-1} (Pietz et al., 1980).

Magnesium concentrations in corn ear tissue was higher on the limed soil (dolomitic limestone application) and on topsoil replacement treatments than on other treatments during the two years of this research (Tables 9 and 10). The dolomitic limestone would increase soluble Mg in the mine tailings and, as a result, increase Mg uptake. The higher tissue Mg concentration on the topsoil treatment reflects the larger amount of Mg in the topsoil than in the tailings. Even though this concentration of 0.20 mg kg^{-1} is considered low by Jones et al. (1990) no deficiency symptoms were observed on corn plants.

Limestone application decreased the Mn concentration in corn ear leaves as compared to the control in both 1992 and 1993 (Tables 9 and 10). This decrease in Mn concentration reflects formation of insoluble Mn hydroxides and

oxides as soil pH increases (Lutz et al., 1973). The high rate of YWC decreased Mn concentration in ear leaves as compared with lower rates of YWC application. Lutz et al. (1973) indicated that Mn availability is influenced by soil pH and contents of organic matter. More complexation of Mn at the higher rate of YWC application accounts for the low Mn concentrations in ear leaves.

4.2.1.2 Natural soil

Nutrient concentrations in corn ear leaves at early silk stage for plants grown on the natural are shown on Table 11 and 12. Nitrogen and P were below the sufficiency range in 1992 and 1993. Corn yields were relatively high even where concentration of these nutrients were low (Table 6). Levels of nutrients in ear leaves were not affected by rate of YWC application during the 1992 and 1993 growing seasons.

The concentrations of N and P were lower than the respective sufficiency ranges developed by Jones et al. (1990) for corn ear leaves on the natural soil in 1992 (Table 11). In 1993, the ear leaf concentrations of P were above and of N were below the levels considered sufficient by Jones et al. (1990). Deficiency symptoms were not observed in plants on the natural soils in 1993, except for N deficiency. A higher proportion of N will be sidedressed during the 1994 growing season than during the 1992 and 1993 growing season to increase the

Table 11. Elemental composition of corn leaves sampled at the early silk grow the stage on natural soils in 1992.

Treatment	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%					-----mg kg ⁻¹ -----		
Control	2.4a*	0.24a	1.9a	0.9a	0.33a	22a	68a	94a
Control + ash	1.9a	0.24a	1.8a	1.0a	0.32a	33ab	78a	108a
2% YWC †+as	2.1a	0.24a	1.9a	1.0a	0.33a	30ab	66a	101a
4% YWC + ash	2.2a	0.26a	1.9a	1.0a	0.35a	34a	79a	108a
6% YWC + ash	2.7a	0.26a	1.9a	0.9a	0.33a	32ab	71a	87a

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC=yard waste compost.

Table 12. Elemental composition of Corn ear leaves sampled at the early silk growth stage on natural soils in 1993.

Treatment	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%					-----mg kg ⁻¹ -----		
Control	2.3a*	0.27a	2.1a	0.5a	0.21b	24a	54a	84ab
Control+ash	2.2a	0.28a	2.1a	0.5a	0.22b	29a	65a	70b
2% YWC †+ash	2.3a	0.28a	2.0a	0.5a	0.24b	29a	57a	89ab
4% YWC+ash	2.0a	0.28a	2.2a	0.5a	0.30a	28a	55a	95a
6% YWC+ash	2.2a	0.30a	2.1a	0.5a	0.31a	26a	55a	94ab

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC=Yard waste compost.

efficiency of applied N utilization, i.e., to prevent N deficiency.

4.2.2 Nutrient concentrations in peanut leaves.

The nutrient sufficiency ranges for peanut plants are based on amounts in the upper most matured blades at the bloom stage (Small, 1973; Jones et al., 1990). Leaf samples at bloom stage were collected to evaluate the nutrient status of peanut plants in this research. This late sampling would be expected to indicate the effect of treatments on the nutrient status of plants over a longer portion of the growing season than plant samples from an earlier growth stage.

4.2.2.1 Mine tailings

The mine tailings consists of a mixture of topsoil and subsoil material. Hence, many P fixation sites on soil oxides and in clay minerals would be present in the zone of fertilization. Fixation could lead to low availability of P. There is low probability of N deficiency in peanut plants on the mine tailings because these plants participate in symbiotic N fixation. Nitrogen deficiency could occur in peanuts if a chemical property of tailings decreased the rate of symbiotic N fixation. Although, there was major concern about treatment effects on the status of N and P in peanut plants, other elements including Ca, Fe, K, Mg, Mn, and Zn also were considered in this research (Table 13 and 14).

Phosphorus levels of 0.25% to 0.50% are considered to be within the

Table 13. Concentration of N, P, K, Ca, Mg, Zn, and Fe in peanut leaves at the bloom stage on tailings plots in 1992.

Treatment	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%					-----mg kg ⁻¹ -----		
Control	2.4 [‡]	0.18bcd*	1.8	1.10a	0.31ab	50ab	130a	560a
Control + lime	3.0	0.19bc	1.8	0.97ab	0.40a	70a	55b	458ab
Control + ash	2.7	0.20bc	1.6	1.10a	0.29bc	43ab	89ab	497ab
Topsoil	3.4	0.27a	1.2	1.00ab	0.39a	35ab	44b	216dc
1 % YWC [†] + ash	2.9	0.19bc	1.7	0.95ab	0.36ab	53ab	126a	465ab
2 % YWC + ash	3.4	0.11d	1.7	0.74b	0.22c	28b	91ab	284dc
4 % YWC + ash	3.6	0.13cd	1.8	0.91ab	0.28bc	36ab	115a	356bc
6 % YWC + ash	3.9	0.17bcd	1.6	0.92ab	0.29bc	39ab	132a	228dc
12 % YWC + ash	4.0	0.21b	1.8	0.88ab	0.29bc	39ab	90ab	202d

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

[†] YWC = yard waste compost.

[‡] Combined samples

Table 14. Concentration of N, P, K, Ca, Mg, Zn, and Fe in peanut leaves at the bloom stage on tailings plots in 1993.

Treatment	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%					-----mg kg ⁻¹ -----		
Control	3.4c*	0.24b	2.1c	1.07e	0.37c	126a	116a	311a
Control+lime	4.4ab	0.28a	2.3bc	1.17de	0.47a	46cde	41d	279ab
Control+ash	4.1b	0.26ab	2.4b	1.32cd	0.35d	87b	81bc	292ab
Topsoil	4.4ab	0.26ab	2.5ab	1.47a	0.47a	89b	80bc	148d
1% YWC †+ash	4.2ab	0.25ab	2.4b	1.37ab	0.36cd	61c	87b	259abc
2% YWC+ash	4.4ab	0.26ab	2.5ab	1.30bc	0.38c	52cd	89b	248bc
4% YWC+ash	4.6a	0.27a	2.7a	1.40ab	0.42b	47cde	75bc	197cd
6% YWC+ash	4.4ab	0.27a	2.5ab	1.30bc	0.42b	38de	64c	164d
12% YWC+ash	4.5ab	0.27a	2.7a	1.25cd	0.45ab	33e	64c	141d

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC= Yard waste compost.

sufficiency range based on upper fully matured blades at early bloom (Jones et al., 1990). Phosphorus levels for all treatments except topsoil were below the sufficiency range in 1992 (Table 13). The low tissue P levels indicate that a high level of P application (Table 3) was necessary and that the application rates need to be increased to ensure this deficiency does not occur in the future.

Levels of Fe, K, Mn, and Zn were not affected by the rate of YWC application (Table 13 and 14). Concentrations of Fe, K, Mn, and Zn were within the sufficiency range in both 1992 and 1993 (Jones et al., 1990). Magnesium and Ca concentration were below the sufficient range for all the treatments (less than 0.30% and 1.25%, respectively). Although wood ash contains considerable amounts of nutrients, wood ash application alone did not affect nutrient concentration in peanut on the mine tailings. In 1993, plant analysis for N, P, K, Ca, Mg, and Zn indicated that plant nutrient in YWC + ash were within the adequate to high range for peanut (Table 14).

4.2.2.2 Natural soils

In 1993, YWC + ash application did not affect the nutrient concentrations in peanut tissue as compared with the ash treatment (Table 15). In 1993 YWC application increased N, P and Mg concentrations in peanut at the bloom growth stage, but did increase leaf Ca, K, Zn, Mn, and Fe concentrations (Table 16). The levels of nutrients in peanut tissue from all treatments were within the

Table 15. Concentration of N, P, K, Ca, Mg, Zn, and Fe in peanut leaves at the bloom stage on natural plots in 1992.

Treatment	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%					-----mg kg ⁻¹ -----		
Control	3.9‡	0.20a*	2.1	0.8a	0.27a	28a	103a	123a
Control+ash	4.0	0.21a	2.4	0.9a	0.31a	32a	79a	121a
2% YWC †+ash	4.2	0.23a	2.1	1.2a	0.32a	39a	78a	133a
4% YWC+ash	3.9	0.24a	2.3	1.2a	0.33a	31a	63a	121a
6% YWC+ash	4.1	0.21a	2.4	1.0a	0.40a	42a	63a	112a

* Means followed by the same letter within columns are not significantly different at 0.05 level of significance.

† YWC = yard waste compost.

‡ Combined samples

Table 16. Elemental composition of peanut leaves sampled at bloom stage on natural soils in 1993.

Treatment	Elements							
	N	P	K	Ca	Mg	Zn	Mn	Fe
	-----%			-----mg kg ⁻¹ -----				
Control	3.9c*	0.22c	2.5a	1.5a	0.38c	139a	85a	105a
Control+ash	4.0bc	0.24b	2.4a	1.4a	0.45b	40a	73ab	108a
2% YWC [†] +ash	4.2ab	0.24b	2.4a	1.5a	0.48b	35a	62bc	113a
4% YWC+ash	4.2ab	0.24b	2.4a	1.5a	0.48b	32a	48c	112a
6% YWC+ash	4.3a	0.25a	2.4a	1.5a	0.50a	31a	54bc	110a

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC=yard waste compost.

normal range (Jones, et al, 1990) in both 1992 and 1993.

4.3 Extractable phosphorus levels as related to yard waste compost application

The magnitude of P movement through the soil is closely related to the physical and chemical properties of the soil. Barrow (1980) found that the concentration of P remained higher in the soil surface where P fertilizer was applied and that the amount of extractable P in the zone of application decreased with time. Precipitation and absorptions reaction account for the decrease in extractable P with time (Barrow, 1980). Little downward movement of P occurs below the zone of P application due to soil water movement. However, the actual rate of P movement is related to the amount and the form of the applied P (Diggle et al., 1984). To maintain a sufficient P level for plants, relatively high amounts of P must be applied in soils with high buffer capacities (Fox and Kamprath, 1970). Stewart and Daniels (1992) reported that the limited P availability in mined lands reflects P fixation through reaction of H_2PO_4^- with Al, Fe, and Mn oxides and hydroxides.

The initial amount of P as triple superphosphate applied in 1992 on the mine tailings experimental areas was relatively high (289 kg ha^{-1}). In addition, P was added to the experimental areas from YWC in 1992 ranged from 12.5 to 150 kg ha^{-1} . This level of P fertilizer was based on the mine tailing properties

that affect P availability. Those properties are contents of clay and Al, Fe, and Mn oxides and hydroxides of Al and Fe, clay, and a low pH. The P fertilization rate applied to the experiment areas in 1993 was decreased as compared with 1992. Plants seemed appropriate because plants grown on the mine tailings in 1993 still had the beneficial effect of the high amount of P fertilizer applied in 1992 and the effect of crop residues from 1992.

4.3.1 Extractable phosphorus for field experiments with corn

4.3.1.1 On tailings soils

According to calibration data for the Mehlich 3 (M3) P test, $< 20 \text{ mg P kg}^{-1}$ is very low, $20 \text{ to } 30 \text{ mg P kg}^{-1}$ is low, $31 \text{ to } 50 \text{ mg P kg}^{-1}$ is medium, and $> 50 \text{ mg P kg}^{-1}$ is high (Mehlich 1984). Mehlich 3 extractable P levels for all treatments in 1992 (Table 17) were above the high range ($> 50 \text{ mg kg}^{-1}$).

Although, the amount of available P in the soil based on the M3 procedure would be expected to be high, the tissue P concentrations usually were below the critical level (Tables 5, 6). An explanation for this relationship would be that the M3 procedure extracted newly applied P that was not available to plants.

There was a larger variation among the levels of P extracted by M3 from treatment to treatment in 1992 than in 1993 (Table 17). This larger variation in extractable P in 1992 could be caused by different rates of P fixation as a result of the various treatments. By the spring of 1993, the much lower levels of M3

Table 17. Mehlich-3 extractable P in tailings soil samples with corn.

Treatment	Years	
	1992	1993
	-----mg P kg ⁻¹ -----	
Control	96abc*	54abc
Control+lime	126abc	67ab
Control+ash	120abc	44bc
Topsoil	81c	58abc
1% YWC †+ash	81c	26c
2% YWC+ash	72c	52abc
4% YWC+ash	135abc	67ab
6% YWC+ash	137abc	87a
12% YWC+ash	151ab	69ab

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

†YWC=Yard waste compost.

extractable P may reflect adsorption and precipitation of P to forms that were not extractable by the M3 method. Diggle et al. (1984) also found that tailings sands have some ability to immobilize P. Sander et al. (1992) indicated that, with time, P fertilizer reaches an equilibrium with soil. These P fixation concepts explain the lower extractable P in the soil in 1993 than in 1992.

For the two years, the correlations between rate of YWC application and M3 extractable P in the mine tailings were not significant ($P > 0.05$). These data show that the P is applied YWC was not readily extractable by the M3 procedure. Likewise, P mineralized from the applied YWC may not have been in a M3 extractable form.

4.3.1.2 On natural soils

Application of YWC increased extractable P in the natural soils in 1993 but not in 1992 (Table 18). According to the calibration data for the M3 test procedure, P levels were in the high range for all treatments for both years. Accordingly, corn yields (Tables 5, 6, 17, 18) did not increase with level of extractable P at these high P levels.

Table 18. Mehlich-3 extractable P in natural soil samples with corn.

Treatment	Years	
	1992	1993
	----- mg P kg ⁻¹ -----	
Control	63a*	54b
Control+ash	50a	67a
2% YWC †+ash	60a	67a
4% YWC+ash	58a	68a
6% YWC+ash	51a	71a

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC=Yard waste compost.

4.3.2 Extractable phosphorus for field experiments with peanut

4.3.2.1 On tailings soils

Similar extractable P results occurred in the field experiments with corn and peanuts. In 1992, extractable P in all treatments ranged from 85 to 250 mg P kg⁻¹ which was high based on calibration data for the M3 procedure (Table 19). In 1993, tailings treatments had in lower concentrations of M3 extractable P as compared with the respective treatments in 1992. These results show that P fixation reactions decreased extractable P well below the high amount of P applied in 1992 (289 kg P kg⁻¹). The decrease in M3 extractable P from the spring of 1992 to the spring of 1993 is consistent with conclusion that applied P was undergoing fixation reactions with time.

4.3.2.2 On natural plots.

Mehlich 3 extractable P levels for all treatments on the natural soils were high according to calibration data for the M3 range in 1992 (Table 20). These data also show that extractable P levels decreased from an average of 98 mg kg⁻¹ in 1992 to 49 mg kg⁻¹ in 1993. This decrease in M3 extractable P indicates that P fixation reactions occurred in the natural soil as well as in the mine tailings.

Application of YWC generally did not increase M3 extractable P in the

Table 19. Mehlich-3 extractable P in Tailings soil samples with Peanut.

Treatment	Years	
	1992	1993
	----- mg P kg ¹ -----	
Control	138bc*	61b
Control+lime	119bc	63b
Control+ash	141bc	88ab
Topsoil	196ab	60b
1% YWC †+ash	118bc	63b
2% YWC+ash	85c	61b
4% YWC+ash	144bc	71b
6% YWC+ash	143bc	84ab
12% YWC+ash	250a	123a

* Means followed by different letters with columns are significantly different at 0.05 level of significance.

† YWC=Yard waste compost.

Table 20. Mehlich-3 extractable P in natural soil samples with peanut.

Treatment	Years	
	1992	1993
	-----mg kg ⁻¹ -----	
Control	87a †	39b
Control+ash	84a	42ab
2% YWC †+ash	90a	35b
4% YWC+ash	83a	37b
6% YWC+ash	98a	49a

* Means followed by different letters within columns are significantly different at 0.05 level of significance.

† YWC=Yard waste compost.

natural soils or mine tailings over the two years (Tables 17, 18, 19, 20). Mine tailings may have some of the same characteristics as newly-cleared sandy soils. Alley and Bertsch (1983) reported that newly cleared forest soil had a large potential for P sorption. Mine tailings are inherently low in available P and have a high P fixation capacity in comparison with agricultural soil. Hence, the quantity of P fertilizer recommended on natural soil will be different from that recommended for the tailings plots.

Chapter 5

SUMMARY AND CONCLUSIONS

Mining for zircon, rutile and ilmenite is expected to occur in Atlantic Coastal Plain in the near future. The mined area is replaced with a mixture of surface and subsoil referred to as tailings. The mine tailings have chemical and physical properties that require modification to obtain normal plant growth. These properties include a low level of organic matter, high acidity, and P absorbing components, such as clay minerals and Al, Fe, and Mn hydroxides and oxides.

This laboratory and field research was conducted to develop procedures to achieve the same level of productivity on the mine tailings as on the natural soils from which the mine tailings were derived. Two waste materials, wood ash and YWC were used to reclaim the mine tailings. The natural soil used in the field research was classified a fine-loamy, siliceous, thermic Typic Hapludults. Conclusions reached during the course of the research are summarized below:

1. Relatively high peanuts were obtained on the mine tailings amended with YWC and wood ash. The average peanut yields over various rates of YWC application on the mine tailings were 2012 kg ha⁻¹ in 1992 and 3198 kg ha⁻¹ in 1993, and the average yields on natural soil were 3487 kg ha⁻¹ in 1992 and 3282 kg ha⁻¹ in 1993. The relatively high yield on tailings soils can be attributed in

part to the increased available water from YWC application, and the increase in pH from the wood ash application.

2. Corn grain yield were relatively high on mine tailings but not as high as on the natural soil. The average corn grain yield over various rates of YWC application on the mine tailings were 5173 kg ha⁻¹ in 1992 and 5274 kg ha⁻¹ in 1993, and the average yields on natural soil were 10,588 kg ha⁻¹ in 1992 and 7938 kg ha⁻¹ in 1993. The higher corn yield on the natural soil probably reflected the higher nutrient availability in the natural soil than in the mine tailings.

3. Phosphorus concentration in corn ear leaves generally were below the critical level of 0.25% P for plants grown on YWC and wood ash treated mine tailings. Since a high level of P (>289 kg ha⁻¹) as triple superphosphate was applied to the mine tailings, the low P concentrations in plant tissue probably indicate a high amount of P fixation by absorption and precipitation reactions. Phosphorus concentrations in peanut tissue were above the critical level where the high level of P was applied to mine tailings. Adequate P in peanuts, as compared with inadequate P in corn, from the high level of P application was attributed to the lower P requirement of the peanut plant.

4. The N concentrations in peanut leaves at early bloom stage were within the sufficient range during the 1992 and 1993 growing seasons. These data show that the wood ash application increased the pH in the mine tailings

to a level that allowed root nodulation and, hence, N fixation by peanut plants. On the other hand, the N concentrations in corn ear leaves at the early silk growth stage were below the sufficiency range during both growing seasons. These data indicated that the method of N application should be given further attention in the future. Since the level of N application was relatively high, it may be appropriate to sidedress a higher portion of the N just prior to rapid plant uptake of N in the future.

5. Zinc deficiency occurred in corn plants grown on mine tailings soils. The Zn deficiency was induced by high P availability early in the growing season from application of $>289 \text{ kg P ha}^{-1}$ as triple superphosphate. Foliar application of Zn corrected the deficiency.

In conclusion, the yield results are promising on mine tailings reclaimed with the use of waste materials. However, additional research is required in the same experimental areas to determine if the waste application rates will maintain suitable soil characteristics over time. Further research also is needed to evaluate long-term N and P fertilization practices for corn and peanut production on the mine tailings.

Literature cited

- Adams, F., and D. L. Hartzog. 1980. The nature of yield responses of florunner peanuts to lime. *Peanut Sci.* 7:120-123.
- Alley, M. M., and P. M. Bertsch. 1983. Phosphorus application to newly-cleared coastal plain soils; Corn (*Zea mays* L.) response and soil test calibration data. *Commun. Soil Sci. Plant Anal.* 14:335-346
- Ayodele, O., and P. A. Agboola. 1981. Evaluation of phosphorus fixation capacity of tropical savannah soils of Western Nigeria. *Soil Sci. Soc. Am. J.* 45:462-464.
- Barber, S. A. 1980. Soil plant interactions in the phosphorus nutrition of plants. p. 591-616. *In* F. E. Khasawneh et al. (ed.) *The role of phosphorus in agriculture*. SSSA, Madison, WI.
- Barber, S. A., and J. L. Kovar. 1989. Reasons for differences among soils in placement of phosphorus for maximum predicted uptake. *Soil Sci. Soc. Am. J.* 53:1733-1736.
- Barkdoll, A. W., and R. A. Nordstedt. 1991. Strategies for yard waste. *BioCycle* 32:60-65.
- Barrow, N. J. 1961. Phosphorus in soil organic matter. *Soil Fertility* 24:169-173.
- Barrow, N. J. 1980. Differences amongst a wide ranging collection of soils in the rate of reaction with phosphate. *Aust. J. Soil Res.* 18:215-224.
- Birch, H. F. 1961. Phosphorus transformation during plant decomposition. *Plant Soil* 15:347-366.
- Black, C. A., and C. A. I Goring. 1953. Organic phosphorus in soils. *Agronomy* 4:123-152.
- Bremner, J. M., and C. S. Mulvaney. 1982. Nitrogen-total. p. 585-624. *In* A. L. Page (ed.) *Methods of soil analysis. Part 2*. 2nd ed. *Agron. Monogr.* 9. ASA and SSSA, Madison, WI.

- Bumaya, A. H. 1987. Phosphorus sorption and extractability in Andic soil incubated with plant residues of variable phosphorus content. M. S. Thesis, University of Idaho.
- Carpenter R. H. and S. F. Carpenter. 1991. Heavy mineral deposits in the upper Coastal Plain of North Carolina and Virginia. *Economic Geol.* 86:1657-1671.
- Chen, J. H. and S. A. Barber. 1990. Soil pH and phosphorus and potassium uptake. *Soil Sci. Soc. Am. J.* 54:1052-1036.
- Clap, C. E., S. A. Stark, D. E. Clay, and W. E. Larson. 1986. Sewage sludge organic matter and soil properties. p. 209-253. In Y. Chen et al. (ed.) *The role of organic matter in modern agriculture*. Martinus Nijhoff Publishers, Dordrechl, The Netherlands.
- Cope, J. T., J. G. Starling, H. W. Ivey, and C. C. Mitchell, Jr. 1984. Peanut and other crops to fertilize and lime in two long term experiments. *Peanut Sci.* 11:91-94.
- Cruse, R. M., G. A. Yackle, T. C. Colvin, D. R. Timmons, and A. C. Musselman. 1983. Tillage effects on corn and soybean production in farmed-managed, University monitored field plots. *J. Soil Water Conserv.* 38:512-514.
- Dalal, R. C. 1977. Soil organic phosphorus. *Adv. Agron.* 29:83-117.
- Dalton, J. D., G. C. Russell, and D. H. Sieling. 1952. Effect of organic matter on phosphate availability. *Soil Sci.* 73:173-181.
- Daniels, W. L., L. W. Zelazny, M. M. Alley, and K. C. Haering. 1991. The development of restoration strategies for prime agricultural soils following mineral sands mining in the Coastal Plain of the Eastern USA. *Australian Mining Industry Council*. p. 26-36.
- Daniels, W. L., and K. Haering. 1990. The feasibility of large-scale sewage sludge/compost utilization on central Appalachian surface mined lands. p. 165-170. In J., J. Sencindriver, and D. Samuel (eds.). *Proc. Mining and Reclamation Conference and Exhibition*. West Virginia University, Morgantown, WV.

- Diggle, A. J., and L. C. 1984. Movement of applied phosphorus following the mining and vegetation of minerals sands on Australia's east coast. *Aust. J. Soil Res.* 22:135-148.
- Donohue, J. S. 1982. Wood Ashes in the Home Garden. The Virginia Gardener. Virginia Cooperative Extension Service Program 1:1.
- Enwezor, W. O. 1967. Significance of the C:organic P ratio in the mineralization of soil organic phosphorus. *Soil Sci.* 103:62-66
- Erich, M. S. 1991. Agronomic effectiveness of wood ash as a source of phosphorus and potassium. *J. Environ. Qual.* 20:576-581.
- Erich, M. S., and T. Ohno. 1992. Phosphorus availability to corn from wood ash amended soils. *Water Air Soil Pollution* 64:475-485.
- Evans, A. Jr., and R. C. Sorensen. 1985. Effect of ionic strength and solution pH on phosphorus extractability and leaching in coarse textured soils. *Can. J. Soil. Sci.* 65:101-108.
- Fehrenbacher, D. J., I. J. Jansen, and J. B. Fehrenbacher. 1982. Corn root development in constructed soils on surface mined land in western Illinois. *Soil Sci. Soc. Am. J.* 46:353-359.
- Fink, R. J., and D. Wesley. 1974. Corn yield as affected by fertilization and tillage system. *Agron. J.* 66:70-71.
- Finestein, M. S., F. C. Miller, and P. F. Strom. 1986. Monitoring and evaluating composting process performance. *Journal Water Pollution Control Fed.* 58:272-278.
- Fox, R. L., and E. J. Kamprath. 1970. Phosphate sorption isotherms for revaluating the phosphate requirements of soils. *Soil Sci. Soc. Am. Proc.* 34:902-907.
- Fox, R. H. 1978. Selection of phosphorus efficiency in corn. *Commun. Soil Sci. Plant Anal.* 9:13-37.
- Grandt, A. F. 1988. Productivity of reclaimed lands-cropland. p. 131-155. In L. R. Hossnes (ed.) *Reclamation of Surface mined lands*. CRC Press Boca Raton, FL.

- Gaur, A. C. 1969. Studies on the availability of phosphate in soil as influenced in humic acid. *Agrochimica* 14:62-65.
- Hallock, D. L., D. C. Martens, and M. W. Alexander. 1971. Distribution of P, K, Ca, Mg, Cu, B, Mn, and Zn in peanut lines near maturity. *Agron. J.* 63:251-256.
- Hargrove, W. L. 1985. Influence of tillage on nutrient uptake and yield of corn. *Agron. J.* 77:763-768.
- Harter, R. D. 1969. Phosphorus adsorption sites in soils. *Soil Sci. Soc. Am. Proc.* 33:630-632.
- Hartikainen, H. 1984. Peat ash and basic slag as substitutes for lime with reference to phosphorus uptake by turnip rape. *J. Agric. Sci. Fin.* 56:291-298.
- Herbien, S. A. and J. L. Neal. 1990. Soil pH and phosphatase activity. *Commun. Soil Sci. Plant Anal.* 21:439-456.
- Hortenstine, C. C., and D. F. Rothwell. 1968. Garbage compost as a source of plant nutrients for oats and radishes. *Compost Sci.* 9:3-25.
- Jackman, L. 1955. Organic phosphorus in New Zealand soils under pasture. II. Relations between organic phosphorus content and some soil characteristics. *Soil Sci.* 79:229-299.
- Jansen, J. J., R. E. Dunker, C. W. Boast, and C. L. Hooks. 1984. Row crop yield response to soil horizon replacement. *Am. Soc. Surface Mining Reclam.* 1:413-430.
- Jones, J. B., V. E. Harold, and V. Regis. 1990. Plant Analysis as an Aid in Fertilizing Corn and Grain Sorghum. p. 523-524. In R.L. Westerman (ed.). *Soil testing and plant analysis*. ASA, CSSA, and SSSA, Madison, WI.
- Kamprath, E. J. 1970. Exchangeable aluminum as a criterion for liming leached mineral soils. *Soil Sci. Soc. Am. Proc.* 24:252-254.
- Lerner, B. R., and J. D. Utzinger. 1986. Wood ash as soil liming material. *HortScience.* 21:76-78.

- Lutz, J. A. Jr., and J. H. Hillard. 1973. Effect of fertility treatment on growth, chemical composition, and yield of no-tillage corn on orchard grass sod. *Agron. J.* 65:733-736.
- Magdoff, F. 1992. Organic matter levels in soils. p. 39-62. *In* Publishers, Inc., New York, NY.
- Mays, D. A., G. L. Terman, and J. C. Duggan. 1973. Municipal compost effects on crop yield and soil properties. *J. Environ. Qual.* 2:89-92.
- Mays, J., and T. W. Simpson. 1990. The Virginia yard waste management manual. Virginia Cooperation Extensive Service Publication 452-055.
- McConnell, D.B., A. Shiralipour, and W. H. Smith. 1993. Compost application improves soil properties. *BioCycle.* 4:61-63.
- McSweeney, K., I. J. Jansen, C. W. Boast, and R. E. Dunker. 1987. Row crop productivity of eight constructed minesoils. *Reclamation and Revegetation Research* 6:137-144.
- Mehlich, A. 1984. Mehlich 3 soil test extractant; A modification of Mehlich 2 extractant. *Commun. Soil Sci. Plant Anal.* 15:1409-1416.
- Mengel, K., and E. D. Kirkby. 1987. p. 425. *In* Principles of plant nutrition (4th ed.) International Potash Institute / Switzerland.
- Naidu, R., J. K. Syers, R. W. Tillman, and J. H. Kirkman. 1990. Effect of liming on phosphate sorption by acid soils. *J. Soil Sci.* 41:165-175.
- Naylor, L. M., and Schmidt, E. J., 1986. Agricultural use of wood ash as a fertilizer and liming material. *Tappi J.* 69:114-119.
- Ohno, T., and M. S. Erich. 1990. Effect of wood ash application on soil pH and soil test nutrient levels. *Agric. Ecosyst. Environ.* 32:223-239.
- Ohno, T. 1992. Neutralization of soil acidity and release of phosphorus and potassium by wood ash. *J. Environ. Qual.* 21:433-438.
- Olsen, R. A., F. S. Watanabe, and R. E. Danielson. 1961. Phosphorus absorption by corn roots as affected by moisture and phosphorus concentration. *Soil Sci. Soc. Am. Proc.* 25:289-294.

- Olsen, S. R., and F. S. Watanabe. 1970. Diffusive supply of phosphorus in relation to soil textural variations. *Soil Sci.* 110:318-327.
- Olsen, S. R. 1972. Micronutrient Interactions, p. 243-264. *In* J. J. Mortvedt et al. *Micronutrients in Agriculture*. SSSA, Madison, WI.
- Page, A. L., A. A. Elseeewi, and I. R. Straughan. 1979. Physical and chemical properties of fly ash from coal-fired power plants with reference to environmental impacts. *Residue Rev.* 17:83-120.
- Pietz, R. I., C. R., Carlson, J. R. Peterson, D. R. Zenz, and C. Lue-Hing. 1989. Application of sewage and other amendments to coal refuse material. Effects on chemical composition. *J. Environ. Qual.* 18:169-173.
- Sander, D. H., A. O. Esilaba, and B. Eghball. 1992. Soil test phosphorus availability as affected by time after phosphorus fertilization. *Soil Sci. Soc. Am. J.* 56:1967-1973.
- Sanchez, P., and G. Uehara. 1980. Management consideration for acid soils with high phosphorus fixation capacity. p. 471-514. *In* F. E. Khasawneh et al. (ed.) *The role of phosphorus in agriculture*. ASA, Madison, WI.
- Sanyal, S. K., and S. K. De Datta. 1991. Chemistry of phosphorus transformation in soil. *Adv. Soil Sci.* 16:14-18.
- Schlotzhauer, S. D., and R. C. Littell. 1987. SAS system for elementary statistical analysis. SAS Institute Inc., Cary, NC.
- Seaker, E. M., and W.E. Sopper. 1988. Municipal sludge for minespoil Reclamation: II. Effects on organic matter. *J. Environ. Qual.* 17:598-602.
- Shuman, L. M. 1988. Effect of phosphorus on extractable micronutrients and their distribution among soil fractions. *Soil Sci. Soc. Am. J.* 52:136-141.
- Small, H. G., and A. J. Ohlrogge. 1973. Plant Analysis as and Aid in Fertilizing Soybeans and Peanuts. p. 322-327. *In* L. M. Walsh, and J. D. Beaton (ed.) *Soil testing and plant analysis*. SSSA, Madison, WI.
- Stewart, B. R., and W. L. Daniels 1992. Physical and chemical properties in coal refuse from Southwest Virginia. *J. Environ. Qual.* 21:635-642.

- Starpley, A. N., S. J. Smith, and R. G. Menzel. 1985. Limitations of phosphorus water control criteria. *J. Soil water Conserv.* 40:283-284.
- Struthers, P. H., and D. H. Sieling. 1950. Effect of organic anions phosphate precipitation by iron and aluminum as influenced by pH. *Soil Sci.* 69:205-213.
- Swenson, R. M., Cole C. V., and D. H. Sieling. 1949. Fixation of phosphate by iron and aluminum and replacement by organic and inorganic ions. *Soil Sci.* 67:13:22.
- Terman G. L., J. M. Soileau, and S. E. Allen. 1973. Municipal waste compost: effects on crop yields and nutrient content in greenhouse pot experiments. *J. Environ. Qual.* 2:84-88.
- Tisdale, J. M., and J. M. Oades. 1982. Organic matter and water stable aggregates in soils. *J. Soil Sci.* 33:141-163.
- Torbert, J. L. 1982. The fate of applied phosphorus on Piedmont soil and its effects on Loblolly Pine growth twenty years after application. M. S. Thesis, Virginia Polytechnic Institute & State Univ., Blacksburg, VA.
- Triplett, G. B., Jr., and D. M. Van Doren, Jr. 1969. Nitrogen, phosphorus and potassium fertilization of non-tilled maize. *Agron. J.* 61:637-689.
- Tukaki, J. L., and R. L. Mahler. 1990. Evaluation of nutrient solution phosphorus concentration on potato plantlet tuber production under greenhouse condition. *J. Plant Nutri.* 13:149-168.
- United States. 1977. Public Law 95-87. Surface mining control and reclamation act. United States Status at Large code. Vol 30, U.S. Government Printing office, Washington, DC.
- Vyas, K. K. 1964. Availability and uptake of phosphorus by wheat under different moisture and organic matter levels. *Curr. Sci.* 33:756-757.
- Yuan, T. L. 1980. Vertical distribution in soil of sprinkler applied phosphorus. *Soil Sci. Soc. Am. J.* 52:868-873.

APPENDIX

Table A1. Experimental Design at Brink Research Site.

Corn in Tailings soils

R1	2	3	6	9	8	4	7	5	1
R2	6	7	9	5	2	4	8	1	3
R3	3	1	7	8	9	4	2	6	5
R4	6	7	3	9	2	4	5	1	8

Peanuts in Tailings soils

R1	5	2	9	8	1	4	3	6	7
R2	3	1	8	2	9	4	5	6	7
R3	1	3	5	9	7	4	2	6	8
R4	8	7	5	3	1	4	9	2	6

Corn in Natural Soil

R1	3	4	1	5	2	5	1	2	3	4	R2
R4	1	5	2	3	4	2	4	1	3	5	R3

Peanuts in Natural Soil

R1	4	2	5	1	3	5	1	4	2	3	R2
R4	5	3	2	4	1	2	1	3	5	4	R3

Treatments in Tailings soils: 1) Control; 2) Control + lime; 3) Control + ash; 4) Topsoil; 5) 1% YWC + wood ash; 6) 2% YWC + wood ash; 7) 4% YWC + wood ash; 8) 6% YWC + wood + ash; 9) 12% YWC + wood ash.

Treatments in Natural Soils: 1) Control; 2) Control + wood ash; 3) 2% YWC + wood ash; 4) 4% YWC + wood ash; 5) 6% YWC + wood ash

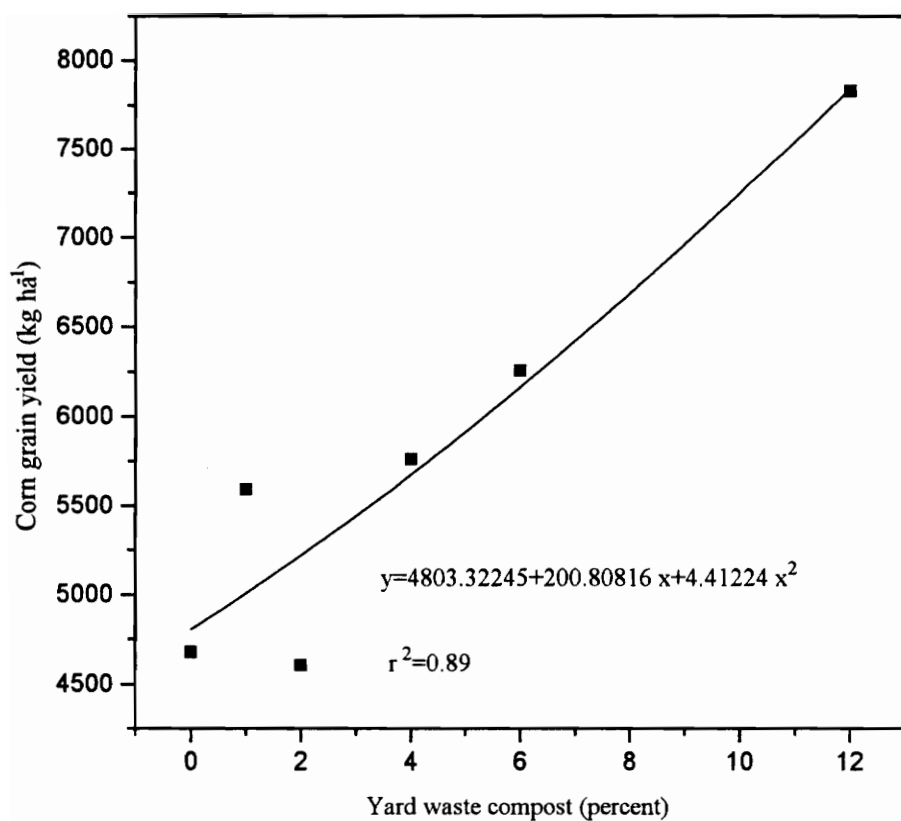


Figure 1a. The relationship between corn grain yield (means) with yard waste compost on mine tailings in 1993.

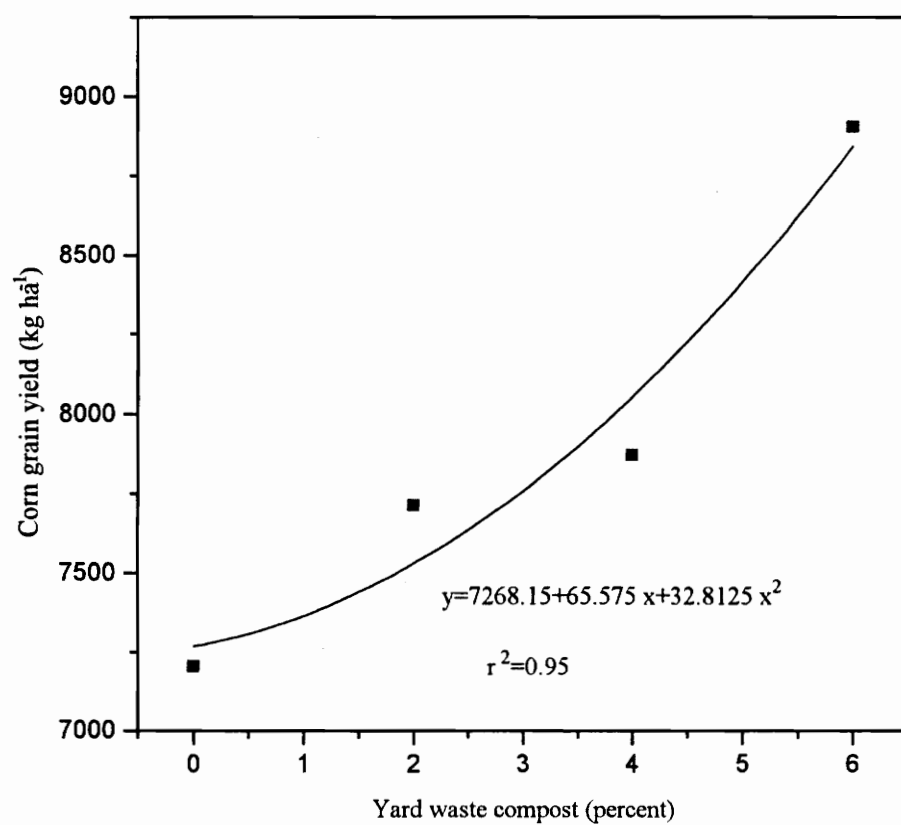


Figure 2a. The relationship between corn grain yield (means) with yard waste compost on natural soil in 1993.

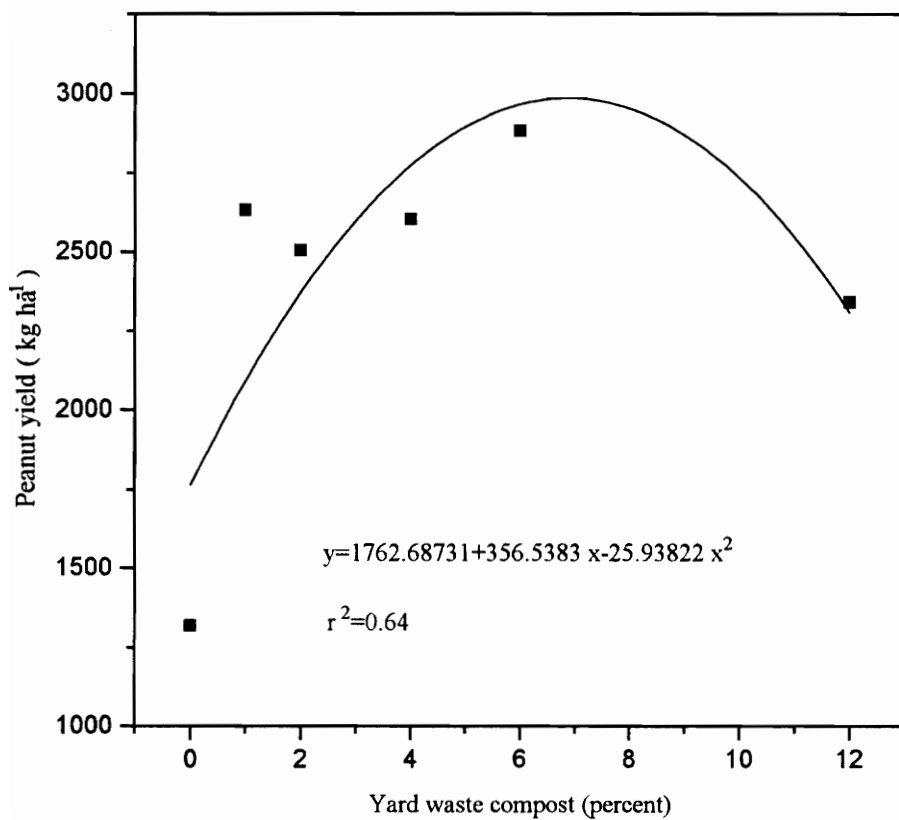


Figure 3a. The relationship between peanut yield (means) with yard waste compost on mine tailings in 1992.

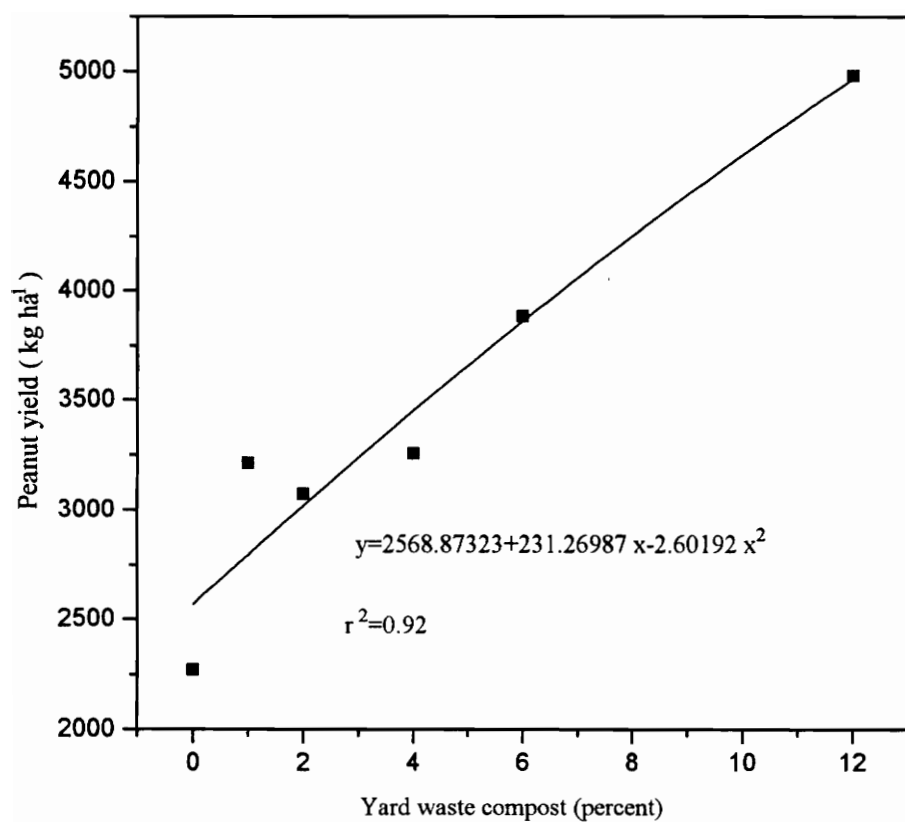


Figure 4a. The relationship between peanut yield (means) with yard waste compost on mine tailings in 1993.

Table B1. Corn yield as affected by yard waste compost on mine tailings in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		-----kg ha ⁻¹ -----			
1.	Control	4380	4863	4812	1782
2.	Control + lime	2936	3124	2453	3413
3.	Control + ash	4618	2886	3175	4474
4.	Topsoil	6017	7699	7649	5007
5.	1% YWC [†] + ash	4524	6494	5584	5434
6.	2% YWC + ash	7460	6180	6350	5296
7.	4% YWC + ash	6544	6205	6235	4907
8.	6% YWC + ash	7266	5340	6494	2936
9.	12% YWC + ash	7749	6595	5340	6017

† YWC = yard waste compost.

Table B2. Corn yield as affected by yard waste compost on mine tailings in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		-----kg ha ⁻¹ -----			
1.	Control	5723	5772	2645	7263
2.	Control + lime	5243	4858	6589	7359
3.	Control + ash	6637	5435	2068	4569
4.	Topsoil	721	818	2886	1058
5.	1% YWC [†] + ash	6108	5339	3992	6926
6.	2% YWC + ash	6553	4136	7022	1010
7.	4% YWC + ash	7166	8657	5339	1876
8.	6% YWC + ash	5483	8417	6060	5050
9.	12% YWC + ash	5290	7984	8802	9234

† YWC = yard waste compost.

Table B3. Corn yield as a function of yard waste compost on the natural soil in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		-----kg ha ⁻¹ -----			
1.	Control	11778	9933	9745	10949
2.	Control + ash	9054	10855	10855	11916
3.	2% YWC [†] + ash	10855	9607	9607	10485
4.	4% YWC + ash	9701	11458	10347	9839
5.	6% YWC + ash	12192	10021	11458	9977

† YWC = yard waste compost.

Table B4. Corn grain yield as a function of yard waste compost on the natural soil in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		-----kg ha ⁻¹ -----			
1.	Control	7711	8311	8496	7450
2.	Control + ash	7988	8126	6510	6187
3.	2% YWC [†] + ash	8680	8819	6187	7157
4.	4% YWC + ash	7018	9234	7438	6787
5.	6% YWC + ash	9696	9142	8450	8311

[†] YWC = yard waste compost.

Table B5. Peanut yield as affected by yard waste compost on mine tailings in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		-----kg ha ⁻¹ -----			
1.	Control	1867	1711	850	1151
2.	Control + lime	867	1667	1464	401
3.	Control + ash	1286	1791	1336	852
4.	Topsoil	905	1388	1407	1619
5.	1% YWC [†] + ash	2722	2464	3512	1822
6.	2% YWC + ash	2151	2486	3099	2282
7.	4% YWC + ash	2646	2743	2199	2817
8.	6% YWC + ash	1899	3056	2024	3551
9.	12% YWC + ash	1901	2297	2631	2526

† YWC = yard waste compost.

Table B6. Peanut yield as affected by yard waste compost on mine tailings in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		-----kg ha ⁻¹ -----			
1.	Control	3838	1723	1864	1486
2.	Control + lime	2786	3413	1292	1422
3.	Control + ash	2388	1680	2367	2634
4.	Topsoil	3647	2864	3609	3609
5.	1% YWC [†] + ash	2992	2344	3791	3716
6.	2% YWC + ash	3472	2528	3059	3231
7.	4% YWC + ash	2931	2434	3768	3886
8.	6% YWC + ash	4239	3363	3820	4107
9.	12% YWC + ash	4009	7119	4786	4009

[†] YWC = yard waste compost.

Table B7. Peanut yield as a function of yard waste compost on the natural soil in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		-----kg ha ⁻¹ -----			
1.	Control	3334	3902	2340	3134
2.	Control + ash	4768	3326	3922	4079
3.	2% YWC [†] + ash	2842	2548	3146	3994
4.	4% YWC + ash	3067	4154	3014	4387
5.	6% YWC + ash	3010	4067	3085	2390

[†] YWC = yard waste compost.

Table B8. Peanut yield as affected by yard waste compost on the natural soil in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		kg ha ⁻¹			
1.	Control	3184	2999	3323	3292
2.	Control + ash	3519	3298	2931	3417
3.	2% YWC [†] + ash	3598	2602	2887	3879
4.	4% YWC + ash	3899	2830	3171	3243
5.	6% YWC + ash	3568	3843	2662	3151

† YWC = yard waste compost.

Table C1. Weight of corn leaves dry matter on mine tailings in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		----- g 8 leaves ⁻¹ -----			
1.	Control	41.2	39.4	39.4	30.1
2.	Control + lime	17.0	49.4	34.4	37.9
3.	Control + ash	44.3	36.7	32.3	36.8
4.	Topsoil	48.2	12.5	38.1	34.0
5.	1% YWC [†] + ash	42.9	47.8	37.3	32.0
6.	2% YWC + ash	54.7	56.1	51.5	52.0
7.	4% YWC + ash	41.3	38.7	17.7	47.2
8.	6% YWC + ash	42.9	40.4	40.7	16.8
9.	12% YWC + ash	46.5	43.3	43.6	44.7

† YWC = yard waste compost.

Table C2. Weight of corn leaves dry matter on mine tailings in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		----- g 8 leaves ⁻¹ -----			
1.	Control	40.9	45.7	40.7	50.1
2.	Control + lime	43.6	32.6	37.5	31.9
3.	Control + ash	34.1	39.3	30.3	32.1
4.	Topsoil	22.7	35.1	39.2	34.1
5.	1% YWC [†] + ash	38.6	38.6	45.0	37.6
6.	2% YWC + ash	45.7	31.9	43.1	29.5
7.	4% YWC + ash	48.5	42.2	39.4	46.9
8.	6% YWC + ash	49.1	46.8	43.0	37.2
9.	12% YWC + ash	32.8	40.2	45.9	47.8

[†] YWC = yard waste compost.

Table C3. Dry weight of corn ear leaves on the natural soil in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		-----g 8 leaves ⁻¹ -----			
1.	Control	52.8	51.0	53.8	55.1
2.	Control + ash	52.5	56.9	49.3	45.6
3.	2% YWC [†] + ash	43.9	53.8	52.8	49.3
4.	4% YWC + ash	52.0	54.9	49.4	50.1
5.	6% YWC + ash	49.4	49.5	53.9	53.4

[†] YWC = yard waste compost.

Table C4. Dry weight of corn ear leaves on the natural soil in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		g 8 leaves ⁻¹			
1.	Control	46.0	43.5	44.5	43.1
2.	Control + ash	46.1	42.2	43.4	42.2
3.	2% YWC [†] + ash	44.0	44.6	45.0	45.0
4.	4% YWC + ash	47.2	46.1	47.3	50.2
5.	6% YWC + ash	47.4	48.3	41.0	47.0

[†] YWC = yard waste compost.

Table C5. Weight of peanut leaves dry matter on mine tailings in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		----- g 75 blades ⁻¹ -----			
1.	Control	2.0	3.8	2.8	3.2
2.	Control + lime	3.1	4.0	3.8	4.3
3.	Control + ash	3.7	2.9	2.8	2.5
4.	Topsoil	3.1	3.5	3.2	3.4
5.	1% YWC [†] + ash	2.7	2.6	2.4	2.4
6.	2% YWC + ash	3.2	3.7	3.8	3.7
7.	4% YWC + ash	3.4	3.2	2.1	2.8
8.	6% YWC + ash	3.2	2.8	3.3	2.1
9.	12% YWC + ash	2.4	2.6	2.7	4.4

[†] YWC = yard waste compost.

Table C6. Weight of peanut leaves dry matter on mine tailings in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		-----g 75 blades ⁻¹ -----			
1.	Control	4.7	4.5	5.2	4.0
2.	Control + lime	4.5	5.5	5.0	3.5
3.	Control + ash	4.3	4.2	5.0	4.4
4.	Topsoil	5.2	5.0	5.0	5.6
5.	1% YWC [†] + ash	4.8	4.1	4.3	4.8
6.	2% YWC + ash	4.9	4.2	5.2	4.9
7.	4% YWC + ash	4.5	4.2	5.3	5.8
8.	6% YWC + ash	5.4	4.9	4.8	5.8
9.	12% YWC + ash	5.2	4.3	4.7	4.9

† YWC = yard waste compost.

Table C7. Dry weight of peanut blades on the natural soil in 1992.

Treatment		Replication			
Number	Description	1	2	3	4
		g 75 blades ⁻¹			
1.	Control	4.4	5.2	4.8	4.8
2.	Control + ash	4.3	4.8	4.8	7.1
3.	2% YWC [†] + ash	4.8	5.7	5.4	4.1
4.	4% YWC + ash	5.1	5.8	4.4	5.1
5.	6% YWC + ash	4.6	4.5	4.4	5.1

[†] YWC = yard waste compost.

Table C8. Dry weight of peanut blades on the natural soil in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
		g 75 leaves ⁻¹			
1.	Control	4.3	4.6	3.3	4.5
2.	Control + ash	3.5	4.5	3.3	4.7
3.	2% YWC [†] + ash	4.4	4.2	4.5	5.5
4.	4% YWC + ash	4.9	4.4	4.7	4.9
5.	6% YWC + ash	5.5	4.2	4.3	3.8

[†] YWC = yard waste compost.

Table D1. Soil pH as affected by wood ash on mine tailings with corn 1993.

Treatment		Replication			
Number	Description	1	2	3	4
1.	Control	4.9	5.5	4.9	5.0
2.	Control + lime	6.1	6.3	6.7	5.8
3.	Control + ash	5.6	5.3	5.4	5.5
4.	Topsoil	5.9	6.0	5.7	5.6
5.	1% YWC [†] + ash	5.0	5.8	6.2	5.8
6.	2% YWC + ash	5.8	4.8	5.9	6.0
7.	4% YWC + ash	5.8	6.0	6.0	6.1
8.	6% YWC + ash	5.9	6.2	5.8	6.0
9.	12% YWC + ash	6.1	5.8	6.3	6.3

† YWC = yard waste compost.

Table D2. Soil pH as affected by wood ash on mine tailings with peanuts in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
1.	Control	4.8	5.0	5.3	4.7
2.	Control + lime	6.1	6.5	6.7	6.7
3.	Control + ash	5.6	5.1	5.1	6.5
4.	Topsoil	6.0	5.8	5.8	5.6
5.	1% YWC [†] + ash	5.6	5.8	5.8	6.1
6.	2% YWC + ash	5.4	5.6	5.6	5.8
7.	4% YWC + ash	6.1	5.9	5.9	5.9
8.	6% YWC + ash	6.2	6.0	6.3	6.1
9.	12% YWC + ash	6.4	6.2	5.0	6.1

[†] YWC = yard waste compost.

Table D3. Soil pH as affected by wood ash on the natural soil with corn in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
1.	Control	5.5	5.8	5.8	6.1
2.	Control + ash	5.6	5.6	5.7	5.8
3.	2% YWC [†] + ash	6.0	5.9	5.9	6.1
4.	4% YWC + ash	6.1	6.0	6.0	6.4
5.	6% YWC + ash	6.4	6.4	6.3	6.1

[†] YWC = yard waste compost.

Table D4. Soil pH as affected by wood ash on natural soils with peanuts in 1993.

Treatment		Replication			
Number	Description	1	2	3	4
1.	Control	6.0	5.2	5.7	5.6
2.	Control + ash	5.8	5.7	6.0	5.4
3.	2% YWC [†] + ash	5.7	5.8	6.0	6.2
4.	4% YWC + ash	6.2	6.2	6.3	6.3
5.	6% YWC + ash	6.3	6.4	6.3	6.3

[†] YWC = yard waste compost.

VITA

Regine Ndole Mankolo was born in Cameroon on February 1950. She received her primary education in Cameroon. She went in high school in "Lycee de New Bell in Cameroon" and "Lycee de Gisors in France" from 1971 to 1979. She graduated in 1983 from the University of Dschang in Cameroon as an "Ingenieur de technique agricoles." She has been serving as a Research Technician at IRA (Agronomic Research Institute) in the Farming system IRA/NCRE project.

The author began her M.S. degree study at Virginia Polytechnic Institute and State University on January 1992.

Regine Mankolo completed her Master of Sciences in May 1994 with a major in Crop Soil and Environmental Sciences.

A handwritten signature in black ink, appearing to read 'Regine Mankolo', with a stylized flourish at the end.