AGRONOMIC EVALUATION OF SOME INDUSTRIAL WASTES AS ALTERNATIVE SOURCES OF PLANT NUTRIENTS IN MOROGORO DISTRICT, TANZANIA

BY

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ABSTRACT

A study was conducted at Magadu, Morogoro, Tanzania to evaluate the industrial wastes as alternative sources of plant nutrients and/or soil conditioners. The soil of Magadu was classified by Kaaya (1989) as Oxic Haplustult. The soil was characterised in this study for its physical and chemical properties prior to planting of the test crop. The analytical data showed that the soil was strongly acidic with a pH of 5.1. Total N, available P, %OC, exchangeable Ca and Na, CEC, and DTPA extractable Zn were in the low range. Exchangeable Mg was in the medium range, while exchangeable K, DTPA extractable Fe, Mn and Cu were high. In the field a randomised complete block design was used to evaluate the wastes using maize as a test crop. The rates of waste application were 5.24, 4.8, 4.25, 4.5 and 3.7 tonnes/ha of waste tea, wattle bark chippings, waste tobacco, wood ash and saw dust respectively. Prior to soil incorporation, the wastes were analysed for their chemical properties. Maize dry matter yields were significantly higher in plots which received 5.24 tonnes/ha of waste tea followed by plots which received 4.25 and 4.5 tonnes/ha of waste tobacco and wood ash respectively. Maize grain yields were significantly higher in waste tea and wattle bark chippings amended plots than in the other waste amended plots. At the end of the growing season the soil was analysed to evaluate the residual effect of wastes on soil properties. Soil pH, available water capacity, available P, % OC, total N, exchangeable bases, CEC, DTPA extractable Zn and Cu in waste amended plots increased in the top 15 cm of soil relative to the control plots. DTPA extractable Fe and Mn, exchangeable Al and acidity were significantly reduced in all waste treatments. Total N and % OC in wood ash and saw dust amended plots were at par with those found in control plots. The results from the field suggested that when applied at agronomic rates, industrial wastes can produce satisfactory plant growth and yields. The results revealed further that waste application on a long term basis will allow good build up of soil organic matter and plant nutrients which in turn will improve on soil productivity. It is recommended that N supplement to wood ash which is rich in almost all macro and micronutrients (except N) would balance its nutrient supply to plants. A glasshouse decomposition experiment was carried out with some wastes including sawdust and wattle bark chippings in perforated plastic litter bags. The wastes were either surface applied or buried to 10 cm depth in wooden troughs. The decomposition process which was monitored at 0. 3, 6, 9, and 12 weeks of incubation revealed that soil incorporated wastes decomposed and released nutrients faster than surface applied ones.

DECLARATION

I, Stephen Mhoja Mashauri Ndaki, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and has not been submitted for a degree award in any other University.

Signature..

Date......12.02.2001......

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DEDICATION

This work is dedicated to my parents, relatives and friends.

TABLE OF CONTENTS

ABSTRACT ---------- ii

DECLARATION---------- iv

COPYRIGHT---------- v

ACKNOWLEDGEMENT ---------- vi

DEDICATION ---------- vii

TABLE OF CONTENTS ---------- viii

LIST OF TABLES ---------- xii

LIST OF FIGURES ---------- xxii

LIST OF APPENDICES ---------- xiii

LIST OF ABBREVIATIONS AND SYMBOLS ---------- xiv

INTRODUCTION ---------- 1

2.0 LITERATURE REVIEW ---------- 4

- 2.1 Effects of industrial wastes on soil properties ---------- 4
  - 2.1.1 General background---------- 4
  - 2.1.2 Effect of industrial wastes on physical properties ---------- 4
  - 2.1.3 Effect of industrial wastes on chemical properties ---------- 7
  - 2.1.4 Effects of industrial wastes on crop yield---------- 12

2.2 Decomposition of industrial wastes ---------- 14
  2.2.1 Factors affecting decomposition ---------- 16
    2.2.1.1 Soil factors ---------- 17
    2.2.1.2 Substrate factors ---------- 17

3.0 MATERIALS AND METHODS ---------- 21

3.1 Industrial waste and Soil sampling ---------- 21
  3.1.1 Industrial wastes sampling ---------- 21
  3.1.2 Soil sampling ---------- 21

3.2 Laboratory analysis ---------- 22
  3.2.1 Physical and chemical composition of soils ---------- 22
  3.2.2 Analysis of plant materials and industrial wastes ---------- 23

3.3 Decomposition in the glasshouse ---------- 24

3.4 Field experiment ---------- 26
  3.4.1 Experimental site ---------- 26
  3.4.2 Experimental design and treatments ---------- 27

3.5 Cultural practices ---------- 28

3.6 Plant sampling and preparation ---------- 28

3.7 Data analysis ---------- 29

4.0 RESULTS AND DISCUSSION ---------- 30

4.1 Properties of soils and industrial wastes used in the study ---------- 30
  4.1.1 Experimental soils ---------- 30
  4.1.2 Chemical composition and production levels of industrial wastes ---------- 34

LIST OF TABLES

Table 1: Some selected physical and chemical properties of the soils from Magadu 31
Table 2: Selected properties of industrial wastes 36
Table 3: Effect of industrial wastes on N, P, K, Ca, and Mg concentration in maize leaves at tasselling 40
Table 4: Effect of industrial wastes on drymatter and grain yields 43
Table 5a: Some selected properties of Magadu soil after harvest and waste application 49
Table 5b: Some selected properties of Magadu soil after harvest and waste application 50
Table 6: Effect of industrial wastes on bulk density and available water capacity in the 20 cm soil layer (plough layer) 59
Table 7: Effects of methods of wattle bark chippings and sawdust incorporation into soil on P release upon wattle bark chippings and sawdust decomposition 70
Table 8: Effects of methods of wattle bark chippings and sawdust incorporation into soil on N release upon wattle bark chippings and sawdust decomposition 73

4.2 Field experiment ---------- 38

4.2.1 Visual observation of Maize plants ---------- 38

4.2.2 Effect of industrial wastes on N, P, K, Ca and Mg concentration in maize leaves ---------- 39

4.2.3 Dry matter yield of maize plants ---------- 42

4.2.4 Grain yield ---------- 43

4.2.5 Effect of industrial wastes on soil properties ---------- 47

4.2.5.1 pH ---------- 47

4.2.5.2 Organic carbon, total nitrogen and available phosphorus ---------- 50

4.2.5.3 Exchangeable Ca, Mg, K, Na and CEC ---------- 53

4.2.5.4 DTPA extractable Mn, Fe, Cu and Zn ---------- 54

4.2.5.5 Exchangeable acidity and aluminium ---------- 56

4.2.5.6 Bulk density and available water capacity ---------- 58

4.3 Decomposition of wattle bark chippings and sawdust and their nutrient release --- 60

4.3.1 Residual dry matter ---------- 60

4.3.2 Residual organic carbon ---------- 64

4.3.3 Residual phosphorus ---------- 66

4.3.4 Residual total nitrogen ---------- 70

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS ---------- 76

5.1 SUMMARY AND CONCLUSION ---------- 76

5.2 RECOMMENDATIONS ---------- 78

REFERENCES ---------- 80

APPENDICES ---------- 93

LIST OF FIGURES

Figure 1: Overall changes of dry matter in sawdust with time of incubation 61

Figure 2: Overall changes of dry matter in wattle bark chippings with time of incubation 62

Figure 3: Overall changes of organic carbon in sawdust with time of incubation 64

Figure 4: Overall changes of organic carbon in wattle bark chippings with time of incubation 65

Figure 5: Overall changes of phosphorus in wattle bark chippings with time of incubation 66

Figure 6: Overall changes of phosphorus in sawdust with time of incubation 67

Figure 7a: Changes in C/P ratio of saw dust with time of incubation 69

Figure 7b: Changes in C/P ratio of wattle bark chippings with time of incubation 69

Figure 8: Overall changes of total nitrogen in sawdust with time of incubation 71

Figure 9: Overall changes of total nitrogen in wattle bark chippings with time of incubation 72

LIST OF APPENDICES

Appendix 1: Effect of wastes on maize performance 4 weeks after seedling emergence 93

Appendix 2: Performance of maize plants as affected by waste amendments 9 weeks after seedling emergence 96

LIST OF ABBREVIATIONS AND SYMBOLS

Al = Aluminium

CCE = Calcium carbonate equivalence

CEC = Cation exchange capacity

cm = Centimetre

Cu = Copper

DM = Dry matter

DTPA= Diethylenetriaminepentaacetic acid

FAO = Food and agriculture organisation

Fe = Iron

Fig. = Figure

gcm^{-3} = Gram per cubic centimetre

H_2O_2 = Hydrogen peroxide

H_2SO_4 = Sulphuric acid

ha = Hectare

HCl = Hydrochloric acid

HNO_3 = Nitric acid

K = Potassium

kg = Kilogram

LSD = Least significant difference

m = Metre

Mg = Magnesium

mg = Milligram

mm = Millimetre

N = Nitrogen

NaOH = Sodium hydroxide

OC = Organic carbon

P = Phosphorus

$P<0.05$= Probability at less than 0.05 level of significance

SUA = Sokoine University of Agriculture

CHAPTER ONE

INTRODUCTION

Most soils in the tropics are of low fertility status due to a number of reasons especially continuous nutrient depletion by crops without adequate replenishment. This in turn poses an immediate threat to food production and causes environmental degradation (Roy *et al.*, 1992). While the use of inorganic fertilisers is the quickest and surest way of counteracting nutrient depletion and boosting crop production, cost and untimely availability frequently deter farmers from using them in recommended quantities. Thus, the use of locally available organic nutrient sources along with or without mineral fertilisers is of great importance for the maintenance of soil productivity.

The attempt to improve soil fertility and to efficiently produce food and cash crops to meet the increasing demand for food and foreign exchange in developing countries in recent years has been through the use of inorganic fertilisers. This has been successful in the case of large scale farmers who can afford to purchase these materials. The fertiliser prices have been prohibitive to small holder farmers, and in addition, there has been frequent unavailability of the fertilisers in the village markets at the time farmers need them (Haru, 1996).

The above mentioned constraint dictates a change in outlook with respect to the source of plant nutrients for increased crop production in small scale farming systems. In this regard, there is a need to promote farming systems which will make use of locally available organic nutrient sources, either to supplement or in some cases substitute for the use of inorganic fertilisers. One such system is the use of industrial wastes. Those currently available in Mororogoro include sawdust and waste tobacco. Wood ash, wattle bark chippings, sawdust, and waste tea are found in Njombe and Mufindi. The production levels for wattle wastes is about 10,450 tonnes per year. However, it is difficult to establish the production levels for the other wastes.

Organic wastes have been used as a source of plant nutrients and/or as soil conditioners for centuries. Although historical interest in direct land application of these materials declined following the advent of commercial fertilisers and liming materials, additional incentives for this beneficial use have arisen in recent years. The first is from rapidly rising landfill costs for disposal of by-product wastes produced from processing industries. Secondly, the environmental ethic of sustainable management and the concept of recycling have provided incentives to replace nutrients removed from forest and agronomy harvests (Vance, 1996).

The application of industrial wastes benefits soil condition or soil properties by improving tilth, decreasing crusting, increasing organic matter and thus, improving the soil infiltration rate (William, 1994). Most industrial wastes contain valuable nutrients that could be used to improve soil fertility (Cameron, 1997).

Information on the effects of industrial waste management on soil properties and crop yield in Tanzania is very scant. Therefore, a study to characterise and evaluate the wastes for use by farmers was considered to be of great importance.

The general objective of this study was to characterise and evaluate the wastes in terms of their chemical properties and determine their role as alternative sources of plant nutrients and/or soil conditioners.

The specific objectives were:

(i) to characterise the wastes in terms of their chemical composition.

(ii) to determine the decomposition pattern and products for some of the wastes.

(iii) to evaluate the agronomic effectiveness of the wastes on maize yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Effects of industrial wastes on soil properties

2.1.1 General background

Industrial waste management practices influence agricultural sustainability by altering the organic matter status, physical and chemical properties of the soils which altogether interact for better microbial activity and diversity (Doran and Smith, 1987). Addition of wastes to agricultural land provides soil organic matter whose status correlates well with a number of important soil physical, chemical and microbiological properties.

Soil organic matter binds soil particles to form stable aggregates that resist erosion and permit water to infiltrate easily, thereby reducing erosion (Swift, 1991). Adequate quantities of soil organic matter reduce soil crusting and soil bulk density.

As soil organic matter increases, soil nutrients also increase (Johnson, 1991). Soil organic matter helps to maintain soil pH by preventing rapid changes which may adversely affect other soil chemical properties.

2.1.2 Effect of industrial wastes on soil physical properties

Hamblin and Kyneur (1993) reported that the benefits of adding organic matter through the use of organic wastes include improved soil structure, stability and cohesion, reduced bulk density and better aeration, improved exchange capacity and soil water balance. However, they also stated that the improvements are conditional on soil type, climate, local condition, past land use and types and rates of soil amendments and/or practices.

Hart and Speir (1992) recommended that the organic matter added to the soil after decomposition of wastes aids in the formation of larger and more stable aggregates. The aggregate size characterises soil structure and pore size distribution, both of which influence aeration, temperature and water holding capacity of the soil. Lal and Kang (1985) found that at any level of soil moisture, soils with high organic matter content have more available water than those with low organic matter content. Overall, soil organic matter from organic wastes improve soil structure, soil tilth, water holding capacity and it provides a favourable medium for crop growth.

Brady (1984) found that improvement of soil structure by organic matter is due to humus which is the final product of decomposition of all organic wastes. Humus has low plasticity and cohesion, hence it has favourable effects on aggregate formation and stability.

Navas *et al.* (1998) observed changes in bulk density and total porosity that were measured six months after addition of sludge. The changes confirm the beneficial effect of sludge application on both soil properties. They observed a decrease in bulk density from 1.25 gcm^{-3} in the control to 1.00 gcm^{-3} for the highest sludge application. Reductions in soil bulk density and concomitant increases in soil porosity following wastes application have also been widely reported by Cripps *et al.* (1992). Nevertheless Cameron (1997) pointed out that depending on the characteristics of the wastes and the soil, the effects on soil physical condition can be either beneficial or detrimental. Some industrial wastes may have a potential to pollute ground waters. Therefore, this highlights the need for research into specific soil-waste systems.

Aitken *et al.* (1998) pointed out that industrial wastes may either confer benefits as a result of addition of organic matter and neutralising value when applied to soils which are acidic or contain low levels of organic matter and low water holding capacity. The same author also pointed out that because of the variable nature of industrial wastes from different mills and industries, each material should be subjected to separate investigations before being recycled to agricultural land.

Many investigations have shown that industrial wastes, when applied to lands, improve soil physical properties (Hall and Coker, 1983, Guidi *et al.*, 1983). Some studies have assessed the effect of waste application on the quality and quantity of runoff water from agricultural lands. Kelling *et al.* (1977), found significantly lower runoff and sediment loss from areas treated with liquid biosolids relative to untreated areas. Rainfall simulator studies by Bruggeman and Mostaghimi (1993) showed that waste application increased soil infiltration and reduced runoff, sediment and nutrient losses.

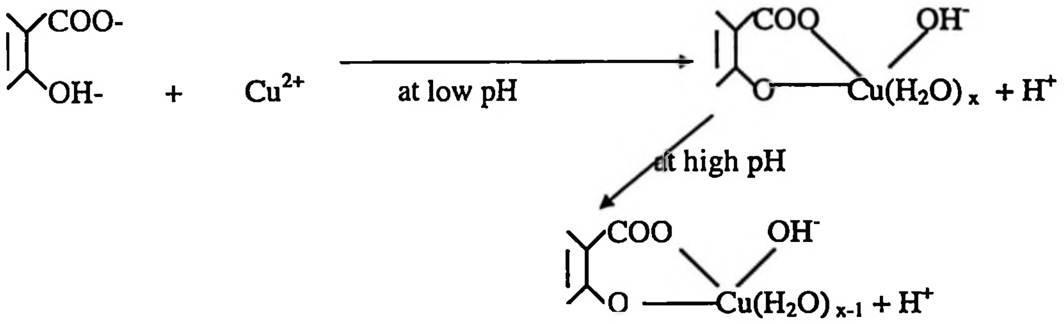
Therefore, industrial wastes help in improving soil physical environment, that is soil structure, bulk density, soil strength, hydraulic conductivity and infiltration rate. A favourable soil physical environment stimulates root growth and thus increase the capacity of the plant for efficient utilisation of nutrients and water. This results in better shoot growth and consequently high grain yields. However, each waste has its own influence on soil physical properties. This then necessitates detailed studies to clearly determine the role of each source in improving the soil physical environment.

2.1.3 Effect of industrial wastes on soil chemical properties

Application of wastes adds nutrients upon mineralization, thus reducing total dependence on expensive inorganic fertilisers. Humic substances produced after waste decomposition increase P availability in the soil. Humus enhances the utilisation of fertiliser nutrients by plants and helps in reducing leaching losses by promoting greater water retention (Navas *et al.*, 1998). Organic matter from organic wastes can form complexes with amorphous oxides of iron and aluminium, thus preventing them from crystallising. In this way availability of phosphorus can be improved because these complexes block the P-fixing sites (Nikokwe, 1992). Singh and Srivastava (1971) found an increase in the availability of native soil phosphorus as a result of organic manuring.

Brady (1984) reported that organic matter is known to facilitate availability of micronutrients such as iron, manganese, copper, zinc, and cobalt through chelation. This is important particularly in calcareous soils. However, if organic wastes may lead to excessive quantities of organic matter in the soil, this may decrease zinc or copper availability by forming metal-organic complexes which are sometimes immobilised (William and Joseph, 1970).

Reaction between humic acid and Cu can be in the following manner:



At low pH a proton is displaced from an acidic OH group of humic acid whereas at higher pH protons dissociate from water molecules covalently bound to Cu^{2+} so that a hydroxo complex is formed.

Increases in soil organic matter following Paper mill sludge have been recorded by Zhang *et al.* (1993), Palaniswami and Ramula (1994) and Philips *et al.* (1997). Effects of Paper mill sludge on other soil properties have been reported by various workers; for example Rodella *et al.* (1995), Palaniswami and Ramula (1994) and Honeycut (1988) reported that after 15 years of paper mill sludge application to a sandy soil there was an increase in soil electrical conductivity, soil pH and exchangeable Na, Ca, and K;

available P, K, Fe, Mn, Zn, and Cu and activity of Urease and alkaline phosphatase enzymes.

Logan and Esmaeilzaden (1985) tested a paper mill sludge with a C:N ratio of between 45:1 and 60:1 on soybeans, wheat, and maize. The results of this test were increased soil pH, available P, exchangeable Ca and Mg, and decreased exchangeable K. The yields for all the three test crops were also improved. On the other hand, Neilsen *et al.* (1998), reported increased yield of both Swiss chard and carrot for some organic wastes plus inorganic fertilisers relative to plots receiving commercially recommended rate of NPK-fertiliser only. They further found an elevation in leaf N, P, Zn, and Cu concentration for both crops. The elevation was found not to be toxic (i.e. below the critical level). They concluded that many locally produced organic wastes have the potential to improve soil quality and the growth of high value horticultural crops.

Reports by Muse and Mitchell (1995) revealed that wood ashes serve as a substitute for agricultural lime, and may become a practical way of recycling nutrients removed from sites during the harvesting of crops or forests. Wood ashes replace K, Ca, P, and other nutrients lost as increasing proportions of tree biomass are removed over shorter time intervals (Eriksson, 1994; Morris and Miller, 1995). Wood ash has also been recommended as a means of correcting plant nutrient deficiencies caused by natural weathering and acidic deposition (Cronan and Grigal, 1995).

Campbell (1990) reported that the most significant characteristic of wood-fired ashes relevant to their use as soil amendments is their acid-neutralising power resulting from oxides and carbonates of K and Ca. The neutralising capacity of ash is often defined by its calcium carbonate equivalent, which is quite variable and thus, need investigation before its recycling to agricultural lands (Khanna *et al.*, 1994).

Having different neutralising capacities, wood ash and agricultural limestone may also differ in their rate of reaction in soil (Vance, 1996). Some studies by Muse and Michell (1995) and Clapham and Zibilske (1992) have shown that wood ash reacts faster with soil than does agricultural limestone. This leads to high initial increases in pH values which are maintained for a shorter period in ash amended soils. One important factor affecting reaction rates for both limestone and wood ash is the fineness of their particles. Granulated ash has been found to be much less reactive in soil than ash in powder form (Clarholm, 1994). In respect of the above observations wood ash may be valuable either alone or as a complement to other fertilisers or organic by-products such as animal wastes and industrial wastes.

Thangudu *et al.* (1981) reported that available P in an acid soil significantly increased after amendments of organic matter from sewage sludge and farm manure due to the decrease in P adsorption and fixing capacity of soils by organic manures (Wagner, 1975). The organic substances (organic acids) produced during decomposition of organic wastes become responsible for the decrease in P sorption by forming stable complexes with Al and Fe. Thus, retention sites for P are eliminated or sorption sites for P are blocked through sorption of the organic anions. Similar results were found by Manu *et al*, (1988) who were studying the dynamics of P after five years of crop residue addition and found that labile P increased significantly. Lower values for exchangeable Al and Fe were found. It was speculated that the decomposition of the crop residue could result in the release of organic acids which complex Al and Fe and render them inactive as agents for phosphorus fixation.

Adsorption of phosphate by hydroxides of Al and Fe is by phosphate displacement of hydroxyl ions and penetration of phosphate ions into less crystalline Al and Fe oxides. It is known that phosphate ions react with two Fe^{3+} and Al^{3+} ions forming binuclear surface complex [Fe-O-($P=O_2$)-O-Fe], hence increase phosphate adsorption by soils. This fact can be elaborated using the following equations:

(i) $Fe(OH)_3 + 3H_2PO^-_4 \longrightarrow Fe(H2PO_4)_3 + 3OH^-$

(ii) $-AL(OH)_3 + 3H_2PO^-_4 \longrightarrow Al(H2PO_4)_3 + 3OH^-$

In a farming system where organic wastes are used as fertilisers, P adsorption by soils is slowed down because sorption sites for P are blocked through sorption of organic anions. Additionally, organic acids from the decomposing organic wastes complex Al and Fe rendering native and fertiliser P available for plant uptake.

Wang *et al*, (1984) reported that there was increased soil concentration of total N, P, K, and CEC following spent mushroom substrate application. Using the same substrate, Stewart *et al*, (1998) reported that the rate of N mineralization was low (because the organic N in spent mushroom substrate is recalcitrant) and N immobilisation might occur, whereas sulphur, potassium, calcium and magnesium were all readily released from spent mushroom substrate.

2.1.4 Effects of industrial wastes on crop yield

Erich and Ohno (1992) found increase in growth and yield of winter wheat, corn and spinach from ash amended soils. They stressed that high application rates of ash caused a decrease in growth relative to the control and the growth ceased at rates above 320 tons per hectare.

Joshua *et al.* (1998) found the density, the growth and yield of pasture being progressively higher with increasing rates of waste application in a sheep grazing study in Australia. In the effort to slow down decomposition of fast decomposing *Gliricidia sepium*, Nduwayezu (1997) found that mixtures of *Gliricidia* leaves and sawdust with C:N ratios of 21:1 and 23:1 applied on soil, synchronised the time of N release with plant requirements. This led to increase in maize yield compared to absolute control and where *Gliricidia* (C:N = 13:1) or sawdust (C:N = 297:1) were applied alone. This suggests that, in order to improve efficiency of nutrient utilisation by crop there is a need to synchronise nutrient release from organic waste with critical period of high nutrient demand by crops, example 4 -6 weeks for maize (Lehman *et al.*, 1995).

Vlamis *et al.* (1978), reported excellent yields of barley for three successive years following light to massive applications of sludge and no visual indications of toxicity on any plant parts was observed. From an agronomic point of view, they recommended that the amount needed for an average crop would be 10 tons per acre of Oakland sludge and 20 tons of Pacheco on an annual basis. They recommended different application rates of sludge from Oakland and Pachebo due to the fact that Oakland sludge had high nutrient elements than Pachebo sludge.

Stewart *et al.* (1998) found that Sweet corn and cabbage yields were increased by Spent Mushroom Substrate (SMS) when inorganic fertiliser was not used, and potato yields was increased irrespectively of fertiliser use (i.e. yield increases of 38%, 82-96% and 26 to 46% respectively for sweet corn cob, cabbage head and potato tuber fresh yields).
In Greece, Karagiannidis (1999) did a field experiment using industrial solid wastes. The results showed that the addition of 500 and 600 tons per hectare of wastes to the soil improved maize production by 8 fold and sunflower seed yield by 4.0 fold. The cotton fibre and tomato production was improved up to three fold.

Rasal *et al.* (1987) found that the application of amended Japanese mint residue compost in wheat and maize promoted higher nutrient uptake that resulted in significant increase in dry matter and grain yields. They also reported that the increased nutrient uptake and yield was possibly due to significantly higher availability of soil available N, P, and K in all amended compost treated soils. Similar findings were reported by Giusquinani *et al.*

(1995) from urban waste compost treated soils.

2.2 Decomposition of industrial wastes

The release of nutrients from industrial wastes occurs during the process of mineralization. This is the process by which the organic material is degraded into simple forms which can be taken up by higher plants or micro-organisms. It is a series of enzymatic oxidative steps performed by soil micro-organisms, which obtain energy from the sugars and amino acids in the organic material (Nikokwe, 1992). Microbial activity in decomposing residues is controlled by substrate availability and quality, temperature, and water potential. Laboratory studies indicate that water and temperature have greater effect during early stages of decomposition when soluble C and N compounds are readily available (Alexander, 1983) but C and N availability become major limiting factors during later stages.

Vigil and Kissel (1991) reported that the amount of N mineralised or immobilised during decomposition of organic wastes will influence the amount of N available for plant uptake and will ultimately have an impact on N management practices and ground water quality. They recommended that to develop the effective use and management of wastes, a detailed understanding of decomposition rate and nutrient release pattern should be of greater importance.

King (1984) reported that direct land application of raw or partially treated wastes is the best method of waste utilisation. Application rates should be based upon soil fertility, crop requirements and chemical characteristics of the wastes. Also application rates of organic wastes are generally determined on the basis of crop yield objectives and estimates of nitrogen availability from the wastes during a growing season (King, 1984). Application method will depend upon the physical characteristics of the waste and upon equipment availability. Normally, solid wastes are applied with a manure spreader or common tillage equipment. As most of the nitrogen in organic wastes is present as organic N, King (1984) recommended that information on N mineralisation rate in soil is needed to match the crop N requirement to reduce risk of adverse environmental impacts.

Time of application of organic wastes has a profound influence on decomposition and nutrient release. Rizk *et al.* (1967) reported higher concentration of N in soil when wheat straw was applied 4 or 6 weeks before planting than when was applied just prior to planting. Barthakur and Talukdah (1985), on the other hand, reported that the application of organic materials well ahead of planting season increased the availability of P. The authors, however, did not specify the period by which the materials should be applied before planting.

2.2.1 Factors affecting decomposition

The decomposition of organic wastes is largely influenced by soil and substrate factors (Parr and Papendick, 1978).

2.2.1.1 Soil factors

Moisture

Alexander (1983) reported that moisture must be adequate for decomposition to proceed. He also reported that micro-organisms grow readily in liquid media provided oxygen supply is ample. Soils having high moisture levels reduce microbial activity by hindering the movement of air and thus oxygen supply (Parr and Papendick, 1978). Nikokwe (1996) reported that unfavourable moisture conditions such as water saturation or inadequate moisture to levels of desiccation can be harmful to some micro-organisms, leading to slowed decomposition rate.

Temperature

Temperature is one of the most important environmental conditions determining how rapidly natural materials are metabolised (Palm and Sanchez, 1991). A change in temperature will alter the species composition of active flora and at the same time have a direct influence on each organism within the community (Alexander, 1983). Nikokwe (1996) reported that increasing temperature from 20°C to 60°C accelerated decomposition because micro-organisms were activated. On the other hand, Alexander

(1983) pointed out that at temperatures above about 40°C, the decomposition declines except in those special circumstances where thermophilic decay is initiated.

Oxygen supply

Air supply also governs the extent and rate of dissimilation of added substrate (Lavelle *et al.*, 1993). This effect is the consequence of the role of oxygen in microbial metabolism. Carbon dioxide is released from completely anaerobic environments through the activities of the obligate and facultative anaerobes, but aeration invariably stimulates carbon mineralization (Alexander, 1983). The decay of major plant constituents is similarly depressed as the supply of oxygen diminishes (Palm and Sanchez, 1991).

pH

pH is another major factor that determine the rate of carbon turnover (Wagner, 1975). Each bacterium, fungus and actinomycete has an optimum pH for growth and outside of which no cell proliferation takes place (Alexander, 1983). Wagner (1975) reported that decomposition typically proceeds more readily in neutral than acid soils.

2.2.1.2 Substrate factors

C:N ratio

C/N ratio has an important influence on microbial decomposition of organic substances.

Henry (1991) observed that nitrogen biological immobilisation occurred when organic wastes of wide C:N ratio were applied to agricultural land. Nguluu *et al.*, (1997) found that a material with C:N ratio wider than 30:1 leads to immobilisation of N by microbial population. He also stated that the C:N ratio below which net mineralization occurs is about 25:1. On the other hand, Anderson and Swift (1983) reported that during the mineralization of materials containing little nitrogen (or wide C:N ratio), the C:N ratio tends to decrease with time. This is due to gaseous loss of carbon while the nitrogen remains in organic combination for as long as the C:N ratio is wide (Tian *et al.*, 1992). Therefore, the addition of mineral N is assumed to compensate for high C/N ratios and accelerate the mineralization of added organic substances in soils.

Alexander (1983) found nitrogen to be a key nutrient substance for microbial growth and hence for organic matter breakdown. He stated that if nitrogen is high and the element is readily utilised, the microflora satisfies its need from this source, and additional quantities are unnecessary. Similar findings were reported by Parr and Papendick (1978). They reported that carbon mineralization was stimulated by supplemental nitrogen in the decomposition of nitrogen poor substrate. They also found that nitrogen rich materials such as legume tissues are metabolised very rapidly, and the microflora responds minimally to supplemental nitrogen. Schoningh and Wichmann (1990) reported that when organic materials with high C:N ratio (more than 25) are used, even soil borne N will be immobilised by micro-organisms during decomposition of such materials. This can result in a depressed yield of the following crops, which can only be overcome by additional N fertilisation.

Lignin contents

Lignin content and lignin:N ratio are important factors influencing the substrate turnover characteristics of recalcitrant plant materials (Tian *et al.* 1992). Alexander (1983) stated that natural materials rich in lignin are less readily utilised by micro-organisms than lignin poor products. He also reported that the resistance of wood and saw dust to microbial attack is probably linked to the abundance of lignin in such materials. On the other hand, Sims and Frederick (1970) reported that the rate of decomposition is also governed by the size of the organic particles subject to attack. As a rule, the smaller particulate materials are more readily degraded than are the large particles due to the fact that the former expose larger surface area to microbial attack. In the light of the above observation, organic materials rich in lignin with larger particles are less readily utilised by micro-organisms than lignin poor products and the decomposition rate and nutrient release of the former is lower than the later materials.

Conclusively, the literature materials used in this study revealed that most of industrial wastes have positive effects on crop yields, and soil physical and chemical properties. These materials however, revealed negative effects on P and N mineralization process especially when materials with wider C/P and C/N ratios are used. Most of the wastes used in the present study had narrow C/P and C/N ratios and were considered favourable for improving soil physical and chemical conditions and consequently increase maize yields in Magadu (Morogoro) soils or in other areas with similar conditions. The effects of industrial wastes on soil properties and maize yield in this study are reported in the next chapters.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Waste and Soil sampling

3.1.1 Wastes

Waste tea, wood ash, sawdust and wattle bark chippings were collected from Tanganyika Wattle Company (TANWAT) in Njombe district. Waste tobacco was collected from the Tanzania tobacco processors in Morogoro municipality. These wastes were air dried and packed in nylon bags for storage. A sample from each type of waste was taken, and finely ground using tecator 1093 cyclotec sample mill for routine analysis.

3.1.2 Soil sampling

Representative composited soil samples (0 - 20 cm) were collected from Magadu within the Sokoine University of Agriculture farm. One composite sample was collected from each plot of 5.2 m x 5.1 after a thorough mixing of ten sub-samples collected randomly from the plot before the execution of the experiment. At the end of the experiment (i.e. after grain harvest) composite soil samples were collected for analysis of the waste residual effects on the soil properties in the same way as it was done before the start of the experiment. The experimental site has a total of 18 plots. The soil was air dried, ground and sieved to pass through a 2 mm sieve for physical and chemical analysis in the Soil Science laboratory at SUA.

3.2 Laboratory analysis

3.2.1 Physical and chemical composition of soils

The soils were analysed for their physical and chemical properties before planting and after harvest as follows:

Particle size distribution was determined by hydrometer method (Gee and Bauder, 1986) after dispersing with sodium hexametaphosphate. Bulk density was determined using the core sample method (Blake and Hartage, 1986). Available water capacity was determined using sand kaolin box for low suction values and pressure membrane for high suction values (National Soil Service, 1990).

Soil pH was determined potentiometrically using glass pH meter in water at a ratio of 1:2.5 soil: water (McLean, 1982). Organic carbon was determined by the wet oxidation method of Walkley and Black (Nelson and Sommer, 1982). Total nitrogen was determined by the Kjedahl method (Bremner and Mulvaney, 1982). Available phosphorus was extracted by the Bray and Kurtz-I method (Bray and Kurtz 1945) and determined spectrophotometrically (Murphy and Riley, 1962; Watanabe and Olsen, 1965). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) were extracted by saturating the soil with neutral 1M NH_4OAc (Thomas, 1982) and measured by atomic absorption spectrophotometer. The cation exchange capacity (CEC) was determined by the percolation method (National Soil Service, 1987). Exchangeable acidity and aluminium was determined by percolating with 1M KCl and titrating the leachate with 0.05M

NaOH (exchangeable acidity) and with 0.05N HCl (exchangeable aluminium) (Thomas, 1982).

Cu, Zn, Fe and Mn were extracted using the DTPA method (Lindsay and Norvell, 1978) and then determined by atomic absorption spectrophotometer.

3.2.2 Analysis of plant materials and industrial wastes

pH of the wastes was determined potentiometrically using a glass pH meter in the mixture of water and wastes at a ratio of 1:5 waste: water (McLean, 1982). Organic carbon was determined by the wet oxidation method of Walkley and Black (Nelson and Sommer, 1982).

Waste materials were digested in a mixture of concentrated nitric acid and hydrogen peroxide (Jones and Case, 1990) and P, Ca, Mg, Cu, Zn, Fe, and Mn were determined in the digests. Plant materials (maize leaves) were digested in a mixture of concentrated sulphuric acid and hydrogen peroxide (Jones and Case, 1990) followed by measurement of N, P, K, Ca and Mg.

Total P, Ca, Mg, Cu, Fe, Zn and Mn from HNO_3-H_2O_2 digest were measured using atomic absorption spectrophotometer. Total P, Ca and Mg from H_2SO_4-H_2O_2 digest were also measured by atomic absorption spectrophotometer. K and Na from both HNO_3-

H_2O_2 and H_2SO_4-H_2O_2 digests were measured using flame electrophotometer. Nitrogen from H_2SO_4-H_2O_2 digest of both the wastes and maize leaves was determined from the Kjeldahl digest by steam distillation (Bremner and Mulvaney, 1982).

Calcium Carbonate equivalence (CCE) in wood ash was determined by boiling 0.5 g of wood ash and 100 ml of 0.5N HCl for 5 minutes. Excess acidity was determined by titrating with 0.25N NaOH to a pH 7 endpoint (National Soil Service, 1990).

3.3 Decomposition study of industrial wastes in the glasshouse

The experiment was undertaken to determine decomposition rates of industrial wastes, namely sawdust and wattle bark chippings in decomposition litter bags as described by Nikokwe, (1992). Only sawdust and wattle bark chippings were used in the decomposition study because their large particles could not pass through the litter bag pores whose sizes were 7 mm. Fourty grams of the wastes were packed in each standard litter bag (30 cm x 30 cm) with pore size of 7 mm. To prevent loss of the fine textured waste particles out of the litter bags, a mosquito mesh was placed on the lower side of the litter bags. Three rectangular wooden troughs of 420 cm x 45 cm x 20 cm dimension were constructed. The inside of the trough was lined with plastic material to make it leakproof. The boxes were partitioned into 32 compartment (as plots) of equal size (35 cm x 45 cm x 20 cm), each enough to accommodate one litter bag. Partitioning was done by using hardboard which was lined with impervious plastic material to prevent cross contamination between the plots. The plots were loosely filled with air dried soil. Each plot was filled with 20 kg of air dried soil from field experimental site. The quantity of wastes incorporated in the soil was 40 g in each litter bag for both sawdust and wattle bark chippings. This was equivalent to applying about 5 and 65 kg N ha^{-1} from sawdust and wattle bark chippings respectively. The 65 kg N ha^{-1} was regarded as the rate of nitrogen input from wattle bark chippings at which plants were expected to perform fairly when nitrogen was added to an infertile soil such as that used in the present study. Because of very low content of nitrogen in sawdust (0.2%) it was difficult to incorporate in 20 kg air dried soil the amount of sawdust that would equivalent to 65 kg N ha^{-1} application rate. For the purpose of studying decomposition rate and release of nutrient from sawdust the same 40 g used for wattle bark chipping was adopted. The wastes were left to incubate for three, six, nine, and twelve weeks. Thirty two litter bags were filled with wastes: 16 litter bags with wattle wastes, and 16 with saw dust so as to suffice sampling at four intervals. Sampling intervals were three, six, nine and twelve weeks after the start of the experiment. Half of the litter bags (8 litter bags with sawdust and 8 with wattle bark chippings) were buried 10 cm deep in the soil contained in wooden incubation troughs while the other half of the litter bags were placed on the soil surface. Throughout the period of incubation, except 3 to 4 days prior to sampling, the soil moisture in the plots was maintained at around field capacity. The wastes were retrieved by separating the soil particles from the litter material through successive sieving using 2, 1, and 0.5 mm sieves. For 0.5 mm sieve water was simultaneously splashed on soil-litter admixture to break adhering soil aggregates and to get rid of the adhering soil particles through the sieve openings. All litter materials which had fallen to the soil in the plots were collected by using forceps and where necessary successive sieving was applied as described above (Nikokwe, 1992). The decomposed litter materials at each sampling interval after retrieval were oven dried at 65°C, ground and analysed for the following parameters:

(i) Residual dry matter (before grinding), (ii) Residual organic carbon, (iii) Residual total nitrogen and (iv) Residual phosphorus.

3.4 Field experiment

A field experiment was conducted to evaluate the agronomic characteristics of the wastes using maize (*Zea mays* var. TMV-1) as a test crop.

3.4.1 Experimental site

The experimental site was located at Magadu within the Sokoine University of Agriculture farm. The soil of the site had earlier on been classified as Oxic Haplustult (Kaaya, 1989). The longitude and latitude of the site are 37^0 39' East and 06^0 50' South respectively. The altitude of the site is 510 masl.

The climate at SUA farm is of a subhumid tropical type. The area experiences a bimodal rainfall distribution with two peaks in a year. The short and lighter rains last from November to January with a peak in December. These rains are followed by a short dry period which normally occurs in mid January or February to March. The long and heavier rains start in March and end in May with a peak in April. The onset and distribution of the rainfall are irregular and unreliable.

The mean monthly air temperature is about 24.4^{0}C. The mean monthly maximum air temperature ranges from 27.5^{0}C during the coldest months to 32^{0}C during the hottest months. The mean monthly minimum air temperature ranges from 15.1^{0}C during the coldest months to 21.5^{0}C during the hottest months.

3.4.2 Experimental design and treatments

A random complete block design (RCBD) was adopted. There were three blocks each having six plots that represent six treatments. The dimensions of each plot were 5.2 m x 5.1 m. Maize (TMV-1 variety) was used as a test crop, planted at a spacing of 75 cm x 30 cm (within and between rows respectively). Interblock and interplot spacings were 1 m and 0.5 m respectively. The whole experimental area was 566.06 m^2. Application rates of the wastes which represented the treatments were 5.24, 4.8, 4.25, 3.7, and 4.5 tonnes per hectare (on oven dry weight basis) of waste tea, wattle bark chippings, waste tobacco, sawdust and wood ash respectively. These rates were equivalent to 5.6, 5.6, 4.5, 4.5 and 4.5 tonnes per hectare on air dry weight basis respectively. Only one rate of application was assigned to each waste type with the main purpose of identifying the best waste(s) to be used as alternative source of plant nutrients and/or soil conditioners.

3.5 Cultural practices

The area was ploughed and hand harrowed. The industrial wastes were broadcasted in respective plots and then incorporated into the top 15 cm soil layer using hand hoes one week before planting maize. Planting was done on 6th March, 2000. Two seeds were sown per hill and later thinned to one plant after seedling emergence. The plots were maintained free of weeds for the entire period of growth to harvest. After maturity, the crop was harvested, and shelled. The moisture content of maize grains was determined by the use of Computer Controlled Moisture Meter and the actual weight of maize grain was calculated to 12.5% moisture content. The grain yield was expressed in tonnes per hectare.

3.6 Plant sampling and preparation

Leaf sampling was done when more than 50% of the plants had tasselled. Leaves below and opposite the ear leaf were sampled. Fifteen leaves were randomly sampled from each plot. The leaves were oven dried at 65°C to constant weight. Then they were cut to about 1-2 cm pieces and ground using tecator 1093 cyclotec sample mill to pass a 0.5 mm sieve.

A randomly selected line of the five harvestable lines from each plot was harvested (destructive harvest) for dry matter (DM) determination 45 days after planting. The plants were cut just above the soil surface, chopped to desirable size, oven dried at 65°C to constant weight and weighed for DM determination. The remaining four harvestable lines from each plot were harvested for seed (grain) yield after maturity.

3.7 Data analysis

Analysis of variance was done on dry matter yield, leaf N, P, K, Ca, and Mg, and grain yield. Also ANOVA was performed on selected soil properties after maize grain harvest. Comparison of means was done using Duncan Multiple Range Test ($p<0.05$). The analysis was done using MSTATC computer programme.

The model used for data analysis was as described by Snedecor and Cochran (1993) as follows:

$Y_{ij} = \mu + T_i + B_j + E_{ij}$

For $i = 1, 2, \ldots\ldots\ldots b$, $j = 1, 2, \ldots\ldots\ldots\ldots t$

Y_{ij} = maize dry matter yield, grain yield, leaf N, P, K, Ca and Mg, soil total N, organic carbon, available P, Ca, Mg, K, Na, and DTPA extractable Fe, Mn, Cu and Zn.

μ = the general mean or general effect

T_i = Treatment effect

B_j = Block effect

E_{ij} = Experimental error

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Properties of soils and industrial wastes used in the study

4.1.1 Experimental soils

Some selected physical and chemical properties of Magadu soil are summarised in table 1. Particle size analysis showed that Magadu soil has 50% clay, 7.2% silt and 42.8% sand separates. According to soil classification system by FAO (1977) the textural class of the soil from Magadu was found to be clay. Since maize can grow in a wide variety of soils (Purseglove, 1988), Magadu soil can be used for maize production if it is well supplied with available nutrients.

The bulk density was found to be 1.46 g cm^{-3}. According to Taylor *et al.*(1966) bulk density values of 0.9-1.2 g cm^{-3} for most soils are considered normal for recently cultivated soils. Bulk density of Magadu soil (1.46 g cm^{-3}) indicates that the soil is compacted, a condition which is likely to cause root impedance and affect the performance of maize.

Table 1: Some selected physical and chemical properties of the soil from Magadu

Particle size analysis	Value	Quality description	Reference
% sand	42.8		
% silt	7.2		
% clay	50		
Textural Class	Clay	-	FAO (1977)
Bulk density (g cm^{-3})	1.46	high	Taylor *et al.* (1966)
pH (1:2.5 soil-water suspension)	5.10	acidic	Landon (1991)
Exchangeable bases (Cmol (+)kg^{-1})			
Calcium	1.83	low	Landon (1991)
Magnesium	1.71	medium	Landon (1991)
Potassium	0.77	high	Landon (1991)
Sodium	0.16	low	Landon (1991)
% base saturation	44.6	low	Landon (1991)
Cation exchange capacity (Cmol (+)kg^{-1})	10.2	low	Landon (1991)
Organic carbon (%)	1.20	low	Landon (1991)
Total nitrogen (%)	0.10	low	Landon (1991)
Bray 1 available phosphorus (mg kg^{-1})	3.48	low	Singh *et al.* (1977)
Exchangeable aluminium (Cmol (+)kg^{-1})	0.76	-	-
Total Exchangeable acidity (Cmol (+)kg^{-1})	1.43	-	-
DTPA extractable Micronutrients (mg kg^{-1})			
Manganese	71.63	very high	Lindsay and Norvell (1978)
Iron	60.69	very high	Lindsay and Norvell (1978)
Copper	1.23	adequate	Lindsay and Norvell (1978)
Zinc	0.33	deficient	Lindsay and Norvell (1978)

The soil was acidic, with pH of 5.1. According to Landon (1991), this is a low pH value that indicates a possibility for phosphate ion to combine with Fe and Al to form compounds which are not readily available to plants. The combination of phosphate ion with Fe and Al can be explained using the following equations:

(i) $Fe^{2+} + H_2PO^-_4 + H_2O \xrightarrow{\qquad\qquad} Fe(OH)H_2PO_4 + H^+$

(ii) $Al^{3+} + H_2PO^-_4 + 2H_2O \xrightarrow{\qquad\qquad} Al(OH)_2H_2PO_4 + 2H^+$

At pH values below about 5.5 Al ions are released from clay lattices and become established on clay complex. Below pH 5.5 bacterial activity is reduced and nitrification of organic matter is significantly retarded. It also indicates that all micronutrients except molybdenum would become excessively available. The optimum soil pH range for maize production is 6 to 7 (Purseglove, 1988). However, satisfactory maize production can generally be obtained in soils with pH value between 5 and 8 if proper management practices are carried out.

Exchangeable Ca, Mg, K, and Na were 1.83, 1.71, 0.77 and 0.16 Cmol(+)kg^{-1} respectively. Levels for exchangeable Ca and Na were low, while those of exchangeable Mg and K were medium and high respectively. Landon (1991) suggested <4 Cmol (+)kg^{-1} as a low value, 4-10 Cmol(+)kg^{-1} Ca as medium and >10 Cmol(+)kg^{-1} as high value for Ca in soils. He also suggested values for Mg to be <0.5 Cmol (+)kg^{-1} as low, 0.5-4 Cmol (+)kg^{-1} as medium, >4 Cmol (+)kg^{-1} as high and for K to be < 0.2 Cmol (+)kg^{-1} as low, 0.2-0.6 Cmol (+)kg^{-1} as medium and >0.6 Cmol (+)kg^{-1} as high respectively. Therefore, the soil requires special attention in terms of restoring acceptable levels of exchangeable bases especially Ca and Na.

The cation exchange capacity value was 10.2 Cmol(+)kg^{-1}, and it was in the low range. According to Landon (1991) rating system, CEC value >40 Cmol(+)kg^{-1} is considered very high, 25-40 Cmol(+)kg^{-1} as high, 15-25 Cmol(+)kg^{-1} as medium and 5-15 Cmol(+)kg^{-1} as low. Using this criterion therefore, CEC value of Magadu soil is between 5-15 Cmol(+)kg^{-1} and thus, it is in low range. Consequently, the soil will have low ability to supply the necessary plant nutrients.

Bray 1 available P and total N were in low range being 3.48 mg kg^{-1} and 0.1% respectively. According to Landon (1991) N values < 0.2, 0.2-0.5 and >0.5% are considered as low, medium, and high respectively. Critical levels of Bray 1 available P in the soil for maize production in Morogoro region is 25 mg kg^{-1} (Singh *et al.*, 1977). Therefore according to these authors, P and N values for Magadu soil are in low range. Organic carbon value was found to be 1.2%, the value which fall in the low range. Metson (1961) in Landon (1991) reported 2-4, 4-10, 10-20 percent organic carbon to be low, medium and high respectively. The analytical results for Bray 1 available P, total N and organic carbon imply that the soil is poor in plant nutrients, organic matter content and can hardly support a good crop.

The exchangeable acidity and aluminium were 1.43 and 0.76 Cmol (+)kg^{-1} respectively.

Aluminium can cause root injury to various crops. In maize, root development is restricted, and the roots become thick and stubby. Al tends to accumulate in the roots and impede the uptake and translocation of Ca and P to the tops. In view of these Magadu soil requires amendments that will not only supply plant nutrients, but also have adequate neutralising power to reduce or neutralise the exchangeable acidity and aluminium.

DTPA extractable Fe, Mn, Cu and Zn were 60.69, 71.63, 1.23 and 0.33 mg/kg respectively. According to Lindsay and Norvell (1978), 4.5-6.0 mg $kg^{-1}g$ Fe in soil is adequate for plant growth. In view of this, Magadu soil contained very high content of Fe. Manganese content was also very high. Lindsay and Norvell (1978), suggested 1 mg/kg Mn to be adequate for plant growth. The authors also suggested 0.2 and 0.5-1.0 mg kg^{-1} to be the critical levels for Cu and Zn respectively. Magadu soil was found to have adequate Cu but was deficient in Zn. Therefore, the soil calls for restoration of Zn to adequate levels using both organic and inorganic sources of the nutrient element in question.

4.1.2 Chemical composition and production levels of industrial wastes

Selected chemical properties of waste tea, waste tobacco, wattle bark chippings, sawdust and wood ash are shown in table 2. Sawdust contained lower P, N, Ca and Mg (0.16%, 0.203%, 0.45% and 0.11% respectively) than the other materials. It has higher OC and a wider C/N ratio (232:1). Total nitrogen values of waste tea, waste tobacco and wattle bark chippings were 3.85, 1.66 and 2.576% respectively. The C/N ratios for waste tea, waste tobacco and wattle bark chippings were narrower than that of saw dust, being 10:1, 14:1 and 14:1 respectively. These narrow C/N ratios suggest that the materials would decompose faster than sawdust. On the other hand, sawdust which had wider C/N ratio (232:1) would lead to biological immobilisation of nutrients in soils into which it is incorporated (Handayanto, 1994).

Singh and Jones (1976) found that organic materials with P concentration less than 0.22% led to immobilisation of P in soils into which they were incorporated. In view of this, the P values for wattle bark chippings and sawdust were below 0.22% an indication for P immobilisation. The C/P ratio for waste tea, waste tobacco, wattle bark chippings and sawdust were 123.2:1, 81.4:1, 232.3:1 and 295 respectively. The ratios, however, did not fall into the range that has net P immobilisation. Tisdale *et al.* (1993) reported that organic materials having C/P ratios >300 if incorporated into soil, had negative effect on P mineralization.

Table 2: Selected properties of industrial wastes

	Waste type				
	Waste tea	Waste tobacco	Wattle bark chippings	Sawdust	Wood ash
Phosphorus (%)	0.31	0.29	0.158	0.16	0.76
Organic carbon (%)	38.2	23.6	36.7	47.2	NA
Total nitrogen (%)	3.85	1.66	2.58	0.20	ND
C/P ratio	123.2	81.4	232.2	295	ND
C/N ratio	10	14	14	232	ND
pH (1:5)	5.29	7.50	7.76	7.83	10.65
Exchangeable bases (%)					
Calcium	1.94	1.76	1.16	0.45	22.32
Magnesium	0.24	0.56	0.34	0.11	5.48
Potassium	2.20	3.10	0.30	0.40	7.60
Sodium	0.1	0.1	0.1	0.1	0.4
$CaCO_3$ equivalence (%)	ND	ND	ND	ND	98.08
Total Micronutrients (mg kg^{-1})					
Copper	7.80	8.00	81.60	24.60	77.40
Iron	3.80	34.40	46.00	84.00	80.00
Manganese	313.60	292.80	99.80	92.80	931.20
Zinc	14.60	33.40	21.00	23.00	36.80

ND means not determined, and NA means not applicable

Based on the values for C/N ratio, C/P ratio and P concentration in the wastes one can recommend waste tea, wattle bark chippings and waste tobacco as the best materials for incorporation into Magadu soil.

Wood ash contained higher Ca (22.32%), Mg (5.48%), K (7.6%), Na (0.4%), pH (10.65), Mn (931.2 mg kg^{-1}) and Zn (36.8 mg/kg) than any other waste used in the study. Calcium carbonate equivalence of wood ash was found to be 98.08%. This value indicated that wood ash had higher acid neutralising value than the rest of the wastes and can be used as a cheaper alternative to agricultural lime. Sawdust was found to contain higher content of iron (84 mg kg^{-1}) when compared to waste tea, waste tobacco, wattle bark chippings and wood ash. The analytical results show that wood ash can replenish P, Ca, Mg, K, Fe, Mn, Zn and Cu removed from the soil through agronomic harvest of various crops (nutrient mining). The results also reveal that waste tea, wattle bark chippings and waste tobacco can contribute appreciable amounts of N, P, Ca, Mg, K, Fe, Mn, Cu, and Zn to the soil nutrient pool. However, the availability of nutrient elements in industrial wastes depends on the decomposition behaviour of the wastes in the soil and subsequent soil chemical reactions.

The industrial wastes are widely spread in the area of study. However, actual levels are difficult to establish due to the fact that no initiatives which have been made in Tanzania to recycle these wastes to agricultural lands. Tanganyika Wattle Company in Njombe produces wattle wastes of about 10,450 tonnes annually. Wood ash, waste tobacco, waste tea and saw dust are variable and difficult to establish. Generally, the levels are high and disposal is a problem which promotes burning of most wastes. The idea is to dispose these materials in a more environmentally friendly manner.

4.2 Field experiment

4.2.1 Visual observation of Maize plants

Visual observations of maize plants were made during the period of plant growth. Leaves of plants growing in plots that received 5.24 tonnes per hectare of waste tea, and 4.25 tonnes per hectare of waste tobacco had their leaves which maintained their dark green colour for the entire period of growth from emergence to maturity. The intensity of green colour of plants growing in plots that received 3.74 tonnes per hectare of sawdust and control plots decreased with time as from the 4th week of plant growth, and exhibited N, P, and Ca deficiency symptoms. The Young leaves were curved, later became necrotic and purplish in colour, and senesced early.

Plants growing on plots that received 4.5 tonnes per hectare of wood ash showed vigorous growth up to the 7th week beyond which slight N deficiency symptoms were observed. Ca deficiency symptoms were observed on plants grown in control plots and saw dust amended plots. Appendices 1 and 2 show the maize plant performance in different waste amendments after 4 and 9 weeks of growth.

Surprising and interesting changes were observed on plants growing in plots which received 4.8 tons per hectare of wattle bark chippings which changed tremendously from slightly weak plants with green leaves to stronger plants with dark green leaves in the 6th week of growth. The leaf dark green colour that was accompanied by vigorous growth was maintained up to maturity. These changes could have been due to the fact that the material at this time had decomposed and released an appreciable amount of plant nutrients to support the plant growth.

Towards taselling, plants in control plots and sawdust treated plots were comparatively chlorotic, with thin stems and light yellow lower leaves. This was probably due to N being a limiting factor in these plots. Immobilisation of N in plots treated with sawdust that had unfavourable C/N ratio could be another cause of maize leaf chlorosis.

The visual observations made in this study indicate that the chlorosis of plant leaves was due to nitrogen deficiency whereas development of purplish colour on leaves was due to P deficiency. Calcium deficiency was indicated by leaf margin chlorosis and curved young leaves.

4.2.2 Effect of industrial wastes on N, P, K, Ca and Mg concentration in maize leaves

Table 3 shows the concentrations of N, P, K, Ca, and Mg in maize leaves.

Table 3: Effect of industrial wastes on N, P, K, Ca and Mg concentration in maize leaves at tasselling (%)

Treatment	N	P	K	Ca	Mg
Waste tea	1.957a	0.241a	2.733a	0.216ab	0.224a
Wattle bark chippings	1.987a	0.239a	2.733a	0.288a	0.277a
Waste tobacco	1.734ab	0.241a	2.700a	0.238ab	0.234a
Wood ash	1.525bc	0.243a	2.700a	0.265ab	0.236a
Saw dust	1.330c	0.208a	2.617a	0.264ab	0.229a
Control	1.470bc	0.235a	2.560a	0.195b	0.255a
Grand mean	1.669	0.336	2.675	0.245	0.243
Standard error of mean	0.093	0.2436	0.060	0.028	0.018
LSD value	0.293	0.0767	0.190	0.081	0.057
Coefficient of variation	9.740	125.890	3.850	19.340	12.420

Means in the same column followed by the same letters are not significantly different according to the Duncan multiple Range Test at 0.05 level of significance.

Nitrogen concentration for all treatments ranged from 1.33 to 1.99%. According to Landon (1991), Okalebo (1993), and Tandon (1995), nitrogen concentrations between 3.5 and 5.0% are considered adequate for maize plant growth. Mackay and Leef (1962) set the range of 1.8-3.5% as low, <1.8% as deficient and 3.5% as intermediate for maize growth at the growth stage of between 30-45 days. Nitrogen concentration in maize leaves for all treatments was not adequate. However, plants grown on plots which were treated with waste tea and wattle bark chippings gave significantly higher N concentrations than the remaining treatments ($P < 0.05$). Waste tobacco, wood ash and the control treatments gave comparable value of shoot N content and they were not significantly different from each other. Nitrogen content in plant leaves from saw dust treated plots was strongly deficient (1.33%). The lowest N content from saw dust treated plots could be due to N biological immobilisation in the soil into which it was incorporated. This was attributed to the wide C/N ratio and very low N content in the material.

Phosphorus concentration in maize leaves due to waste treatments ranged from 0.21 to 0.24%. According to Okalebo (1993), adequate P concentration in maize plants at a growth stage of 30-45 days is 0.4-0.8%. Jones and Eck (1973) gave the sufficiency P range in maize leaves to be 0.25-0.4%. Landon (1991) suggested <0.3% P as low, 0.3-0.5 as sufficient and >0.5 as high. P values for all treatments were low and not significantly different from each other at 0.05 degree of significance.

Potassium concentration in leaves was sufficient and ranged from 2.6 to 2.7% for all treatments. The treatments were not significantly different from each other. Lack of significant difference among treatments could be due to the fact that the experimental soil contained sufficient amount of potassium (soil K was 0.77 Cmol(+)kg^{-1}. Critical value for K in soil according to Landon (1991) rating system is 0.6 Cmol(+)kg^{-1}. Tandon (1995) reported that <2.5, 2.5-4.0 and >4.0% K as low, sufficient, and high ranges respectively.

Leaf calcium concentration for all treatments ranged from 0.196 to 0.288%. Plants grown in waste tea and wattle bark chippings treated plots had significantly higher leaf Ca content than other treatments. Waste tobacco, wood ash and saw dust treated plots gave comparable leaf Ca content and were ranked second from waste tea and wattle bark chippings treatments. According to Tandon (1995) rating system, <0.3%, 0.3-0.7% and >0.7% Ca are considered low, sufficient and high in maize shoots respectively. Therefore, calcium contents in the leaves were low for all waste treatments.

Magnesium content in the leaves ranged from 0.22 to 0.28 %. There was no significant difference among the treatments. Lack of significant difference among waste treatments is probably a reflection of medium concentration of Mg in the soil (1.90 Cmol(+)kg^{-1}). Landon (1991) gave 0.15-0.5% as sufficient Mg content in maize leaves. The Mg contents in leaves were sufficient for all the treatments and thus, no treatment effect was observed.

4.2.3 Dry matter yield of maize plants

Results of maize yield are presented in table 4. The highest shoot yield was obtained from plots which received being 1.93 tonnes per hectare. The shoot yields from wood ash and waste tobacco were comparable but significantly lower than that obtained from waste tea treated plots. Dry matter yields for wood ash and waste tobacco treated plots were 1.56 and 1.30 tonnes per hectare respectively.

Shoot yields from wattle bark chippings and sawdust treatments were low and not significantly different from the control at $P < 0.05$. The shoot (dry matter) yield from waste tea treated plots showed a significance different ($P<0.05$) when compared to other treatments. Dry matter yields from wood ash and waste tobacco treated plots were significantly higher ($P<0.05$) than the yields that were obtained from plots treated with wattle bark chippings and sawdust. The lower yield from sawdust treated plots was probably due to biological immobilisation of N that was attributed to the unfavourable C/N ratio of 232:1. Therefore, saw dust incorporation into soil should be supplemented with N from mineral fertilisers in order to minimise the problem of biological immobilisation of native resources of nutrients.

Table 4: Effect of industrial wastes on dry matter and grain yields

Treatment	Dry matter yield (tonnes ha^{-1}) at sixth week of growth	Grain yield (tonnes ha^{-1})
Waste tea	1.931a	3.987a
Wattle bark chippings	0.893c	3.790a
Waste tobacco	1.307b	2.850b
Wood ash	1.563b	2.730b
Saw dust	0.716c	1.660c
Control	0.731c	2.060c
Grand mean	1.190	2.852
Standard error of mean	0.089	0.179
LSD value	0.282	0.562
Coefficient of variation (%)	12.960	10.840

Means in the same column followed by the same letters are not significantly different according to the Duncan multiple Range Test at 0.05 level of significance.

4.2.4 Grain yield

Table 4 shows the maize grain yield from different waste treatments. The yield for all treatments ranged from 1.66 to 3.99 tonnes per hectare. Grain yield trends followed those of DM yield except for the wattle bark chippings where more grain yield was obtained from less dry matter.

Grain yields from waste tobacco and wood ash were significantly higher ($P<0.05$) than those from control and saw dust treatments. The yields however, were significantly lower ($P<0.05$) than yields from wattle bark chippings and waste tea treatments. The corresponding yields were 2.85 and 2.73 tonnes per hectare for waste tobacco and wood ash treatments respectively.

Grain yields for control and saw dust treatments were significantly lower ($P<0.05$) than the remaining treatments. Grain yield from saw dust treatment was rather lower than the control treatment, although not significantly different. The lower yield from saw dust treated soil or plots was probably due to biological immobilisation of nitrogen as the C/N ratio for saw dust (232:1) was wide and unfavourable for N mineralization. The results of this study suggest that saw dust application should be supplemented with mineral fertilisers in order to minimise the problem of biological immobilisation of native resources of nutrients. However, on a long term basis, saw dust application could be beneficial in improving soil physical properties.

Grain yields showed a trend similar to that which was observed in dry matter yield with an exception of yield from wattle bark chippings treatment. Dry matter yield for wattle bark chippings treatment was significantly lower ($P<0.05$) while its grain yield was significantly higher. The explanation for this different trend could be due to the fact that the material had not fully decomposed and released its nutrients at the time biomass harvest was done.

According to United Republic of Tanzania (1995), production levels for maize and rice which are major food crops are very low. Currently the average yield levels for maize are between 0.6 and 1.5 tons per hectare while the potential yields are between 4.0 and 8.0 tonnes per hectare. The yield levels obtained from waste treatments were between 1.66 and 3.99 tonnes per hectare. These levels were higher than the current average yield levels and the yields from waste tea amended plots (3.99 tonnes ha^{-1}) and wattle bark chippings amended plots (3.8 tonnes ha^{-1}) were very close to potential maize yield range for Tanzania.

Kimaro (1989), found that maize yields in Kilosa under research conditions, with all agronomic practices followed (including fertiliser application) range from 3.5 to 4.5 tonnes per hectare while that without fertiliser but with all other cultural practices followed range from 2.3 to 3.0 tonnes per hectare. Under conditions of no fertiliser application farmers obtain yields in the range of 0.5 to 1.9 tonnes per hectare. Results from waste application showed that waste tea and wattle bark chippings amended plots were in the range which is similar to the one reported by Kimaro (1989) under research conditions with all agronomic practices followed (3.5 to 4.5 tonnes per hectare). Yields of maize from waste tobacco and wood ash amended plots were similar to the yields obtained by the same author under no fertiliser with all cultural practices followed (2.3

to 3.0 tonnes per hectare). Yields from saw dust amended plots and control soil were lower than the yields which were obtained under research conditions with no fertiliser but other cultural practices followed.

On the basis of yields, waste tea and wattle bark chippings were considered best soil inputs among the wastes to be used for maize production followed by waste tobacco and wood ash. On the same basis saw dust was considered worst for the same purpose. The difference in yield due to waste applications was due to the fact that the wastes which gave higher yields had probably relatively faster decomposition and nutrient release. They also contained an appreciable amount of plant nutrients as opposed to the wastes which gave lower yields especially sawdust. On the other hand, yields obtained from sawdust amended plots were low probably due to biological immobilisation of N in the soil caused by low N content and wide and unfavourable C/N ratio in sawdust.

From the results and Magadu soil properties one can conclude that no waste was considered as a non beneficial amendment. Normally, materials poor in N like saw dust should be supplemented with inorganic fertiliser to minimise the problem of immobilisation of native soil nutrients and in turn improve soil physical and chemical properties. Wood ash is rich in almost all plant macro- and microntrients except that it has negligible or trace amount of N and thus, it requires N supplement to balance its nutrient supply to the plants. Also waste applications on a long term basis that will allow good build up of organic matter and plant nutrients are essential towards improving soil productivity.

4.2.5 Effect of industrial wastes on soil properties

Soil analysis for each treatments at completion of the experiment (four months after waste application) are presented in tables 5a and 5b.

4.2.5.1 pH

The pH of wood ash amended soils was significantly higher ($P < 0.05$) than other waste treatments. This was the largest change among the chemical properties. The increase in pH (from 5.1 to 7.5) was probably attributed to high acid-neutralising power resulting from oxides and carbonates of K and Ca. The Calcium Carbonate equivalence of wood ash used was 98.08%. Wood ash treatment increased soil pH from 5.1 to 7.5. Muse and Mitchell (1995), reported that wood ash reacted faster with soil than did agricultural limestone, resulting in higher increases in pH. Long-term (2-40 year) soil pH elevation resulting from wood ash amendments has been reported by (Muse and Mitchell, 1995; Naylor and Schmidt, 1989).

The pH values of wattle bark chippings, waste tobacco and saw dust amended soil were comparable and significantly lower ($P < 0.05$) than the value found in wood ash amended soils. The values were significantly higher than those which were observed in the waste tea amended and control soils however. The wattle bark chippings, waste tobacco and saw dust increased the soil pH from 5.1 in the control to 5.8.

According to Landon (1991) rating system the pH in wattle bark chippings, waste tobacco and saw dust amended plots after harvest was medium, while pH in wood ash amended soil was high. Soil pH in waste tea amended and control soils was in low range. Landon (1990) categorised pH <5.5 as low, 5.5-7.0 as medium and >7.0 as high.

Table 5a: Some selected properties of Magadu soil after harvest and waste application

Treatment	pH	%OC	%N	Exchangeable bases (Cmol (+)kg^{-1})				CEC(Cmol (+)kg^{-1})
				Ca	Mg	K	Na	
Wattle bark chippings	5.8b	1.38ab	0.13a	3.28b	2.40c.	1.0cd	0.23b	10.8b
Waste tobacco	5.8b	1.50a	0.12ab	2.51cd	2.54b	1.1b	0.24b	10.4c
Waste tea	5.3c	1.62a	0.13a	2.6c	2.59b	1.0cd	0.33a	10.47c
Wood ash	7.5a	1.21b	0.11c	6.10a	4.12a	1.3a	0.34a	15.7a
Saw dust	5.9b	1.48a	0.10c	2.3de	2.27d	1.1bc	0.24b	10.2c
Control	5.1c	1.23b	0.11c	2.10e	1.47e	1.01d	0.21b	10.1c
Grand mean	5.9	1.40	0.12	3.15	2.57	1.09	0.27	11.29
Standard error of mean	0.08	0.77	0.56	0.08	0.03	0.02	0.02	0.100
LSD value	0.24	0.24	0.02	0.24	0.08	0.06	0.06	0.32
Coefficient of variation (%)	28.6	9.5	8.34	4.28	1.89	3.13	9.69	1.54

Means in the same column followed by the same letters are not significantly different according to the Duncan multiple Range Test at 0.05 level of significance.

Table 5b: Some selected properties of Magadu soil after harvest and waste application

Treatment	Bray I P (mg kg^{-1})	DTPA extractable micronutrients (mg kg^{-1})				Exch. acidity	Exch. Al
		Fe	Mn	Cu	Zn	Cmol(+)kg^{-1}	Cmol(+)kg^{-1}
Wattle bark chippings	3.00c	32.23c	32.38c	1.05a	0.45bc	0.157bc	0.000b
Waste tobacco	5.60a	22.64d	32.02c	0.99a	0.50ab	0.137bc	0.067b
Waste tea	4.40ab	31.70c	39.40b	0.99a	0.56a	0.310b	0.140b
Wood ash	5.70a	22.27d	11.53d	0.94a	0.41c	0.027c	0.000b
Saw dust	3.30bc	34.50b	30.63c	0.96a	0.53a	0.153bc	0.000b
Control	3.42bc	61.00a	68.40a	0.94a	0.32d	1.45a	0.683a
Grand Mean	4.24	34.06	35.73	0.98	0.46	0.372	0.048
Standard error of mean	0.393	0.80	1.99	0.04	0.02	0.052	0.048
LSD value	1.24	2.53	6.30	0.13	0.06	0.163	0.152
Coefficient of variation (%)	16.07	4.08	9.69	6.86	5.88	23.37	158.25

Means in the same column followed by the same letters are not significantly different according to the Duncan multiple Range Test at 0.05 level of significance.

4.2.5.2 Organic carbon, total nitrogen and available phosphorus

Organic carbon of waste tea, waste tobacco and saw dust amended soils was increased significantly. The increase in organic carbon in ash amended soils was significantly lower than any other waste treatments, and there was no significant difference between this treatment and control treatment. Organic carbon of wattle bark chippings treated soils was slightly lower than that of waste tea, waste tobacco and saw dust amended soils and it was slightly higher than ash and control treatments.

Waste tea and wattle bark chippings treatments increased total nitrogen in soil significantly compared to the remaining treatments. Total nitrogen in waste tobacco amended soils was found to be significantly higher than that of wood ash, saw dust and control treatments. Total N in ash and saw dust treatments was significantly lower and there was no significant difference between these treatments and the control. Low total N in wood ash and saw dust amended soils could be due to negligible nitrogen in wood ash and wide C/N ratio (232:1). This suggests that microbial decomposition of saw dust will initially compete with plants for available N in the soil before releasing its N content.

According to Landon (1991) rating, total nitrogen values of <0.2, 0.2-0.5 and >0.5% are considered low, medium and high respectively. Organic carbon values of <4, 4-10 and >10% are considered respectively as low, medium, and high. Total N for all treatments ranged from 0.102 to 0.131 % while organic carbon ranged from 1.21 to 1.62%. Despite the fact that most of the waste treatments elevated the organic carbon and total nitrogen, the two parameters were still in low range. This means that repeated waste applications are required for beneficial build up of organic matter and nutrients.

Phosphorus was significantly higher in wood ash and waste tobacco amended soil (table 5b). P in waste tea was slightly lower than the one that was observed in wood ash and waste tobacco treated soils and was slightly higher than those of saw dust and control treatments. Phosphorus in wattle bark treated soils was lower than that of wood ash, waste tobacco, saw dust, and waste tea amended soils and the control soil. The lowest P value in wattle bark chippings amended soils could be due to low P content in the material.

Increase in available P in wood ash and waste tobacco amended soils was probably due to: (i) higher P content in the materials; (ii) the increase in pH in ash amended soils reduced the solubility of Al, Fe and Mn that are responsible for P fixation and (iii) the decomposition of the wastes resulted in the release of organic acids which complex Al and Fe and render them inactive as agents for fixation. Thangudu ***et al.***, (1981) found similar results from acid soil after amendment with organic matter from sewage sludge and organic manures. They reported that an important reason for the increase in available P by organic manure incorporation may be due to the decrease in P adsorption and fixing capacity of soils by organic manure. This was due to organic substances (acids) produced during decomposition of organic manures that became responsible for the decrease in P sorption by either forming stable complexes with Al and Fe or by blocking sorption sites for P through sorption of organic anions.

According to Singh *et al.*, (1977) the critical value of P for maize production in Morogoro is 25 mg kg^{-1}. Bray 1 P for all treatments ranged from 3.0 to 5.7 mg kg^{-1}. In the light of the above critical value P was not found to be adequate in the soil after harvest though it was relatively increased by waste application.

4.2.5.3 Exchangeable Ca, Mg, K, Na and CEC

Exchangeable Ca, Mg, and K were significantly higher ($P < 0.05$) in wood ash amended soils than the other waste treatments. The higher values of exchangeable Ca, Mg and K in ash amended soils were possibly due to high content of these elements in wood ash. Wattle bark chippings treated soils showed significantly higher Ca ($P < 0.05$) than waste tobacco, waste tea and control treatments but significantly lower than Ca found in ash amended soils. Levels of Ca in waste tobacco, waste tea and saw dust amended soils were not significantly different from each other and not different from the control soils as well. Mg from waste tobacco and waste tea amended plots was significantly higher than that of saw dust, wattle bark chippings amended soil and the control. K levels of waste tobacco, saw dust, waste tea and wattle bark chippings amended plots were slightly different. Wood ash and waste tea treatments increased Na in the soil significantly when compared to other treatments.

According to Landon (1991) rating system, Ca of wood ash, waste tobacco and waste tea amended plots were found to be in the medium range while Ca in other treatments were still in low range after harvest. Mg in wood ash amended plot was in the high range after harvest while values of the same in the remaining treatments were in the medium range. K values on the other hand were in high range for all treatments after harvest.

CEC of wood ash amended soils was significantly higher ($P < 0.05$) relative to the remaining treatments. CEC values of wattle bark chippings and waste tea treatments were significantly higher than waste tobacco, saw dust and control treatments. Landon (1991) suggested CEC values of 5-15, 15-25, 25-40 Cmol (+)kg^{-1} as low, medium and high respectively. Therefore, according to this author's rating, CEC values in all treatments were in low range despite the fact that waste treatments elevated the CEC. This indicates that repeated waste applications need to be adopted so that soil organic matter builds up and the cation exchange capacity gets improved.

4.2.5.4 DTPA extractable Mn, Fe, Cu and Zn

Results of DTPA extractable Mn, Fe, Cu and Zn are presented in table 5b. DTPA extractable Mn was significantly higher ($P < 0.05$) in the control soils, followed by waste tea, wattle bark chippings, waste, waste tobacco and saw dust amended soils. DTPA extractable Mn in ash amended soil was significantly lower ($P < 0.05$) than any other treatments. The lower DTPA extractable Mn in wood ash amended soil was possibly attributed to the increased soil pH (table 5a) which in turn influenced Mn solubility and availability.

DTPA extractable Mn for all treatments ranged from 11.53 to 68.4 mg kg^{-1}. According to Lindsay and Norvell (1978) (1975), 1 mg kg^{-1} of DTPA extractable Mn is adequate for plants. In view of these authors, DTPA extractable Mn in Magadu soil was adequate.

As for DTPA extractable Mn, Fe values in the control soil was significantly higher ($P < 0.05$). DTPA extractable Fe of saw dust amended soil ranked the second after the control soil. Fe value of wattle bark chippings amended soil was slightly higher than that of waste tea amended soil and slightly lower than that of saw dust amended soil. Fe value of wood ash and waste tobacco amended soil was significantly lower ($P < 0.05$). Wood ash and waste tobacco reduced soil DTPA extractable Fe from 60.69 to 22.27 and 22.64 mg kg^{-1} respectively. The reduction in Fe in waste tobacco amended plots was probably attributed to formation of complexes by organic acids which render Fe unavailable. Increased soil pH in wood ash amended plots led to precipitation of Fe and thus, reduced its availability.

Lindsay and Norvell (1978) reported 4.5-6.0 mg kg^{-1} of DTPA extractable Fe in soil to be adequate for plant growth. Fe for all treatments ranged from 22.27 to 61.00 mg kg^{-1} and was adequate according to Lindsay and Norvell (1978).

Values for DTPA extractable Cu were comparatively the same and no significant difference was observed among the treatments. The values for all treatments ranged from 0.95 to 1.05 mg kg^{-1} and was adequate according to Lindsay and Norvell (1978).

Lindsay and Norvell (1978) suggested 0.2 mg kg^{-1} of DTPA extractable Cu in soil to be adequate for plant growth.

DTPA extractable Zn of waste tea and saw dust amended soils was significantly higher than the rest of the waste treatments. Zn of waste tobacco amended soil was slightly lower than that of waste tea and saw dust amended soil. DTPA extractable Zn in the control soil was significantly lower than all waste treatments. The values for all treatments ranged from 0.31 to 0.56 mg kg^{-1}. Critical value for DTPA extractable Zn was suggested by Lindsay and Norvell (1978) to be 0.5-1.0 mg kg^{-1}. According to these authors, waste tobacco and waste tea amended soils were found to contain adequate Zn while wattle bark chippings, wood ash, saw dust amended soil and control soil were found to be deficient in Zn. So, blending of the wastes and/or supplementary of Zn from inorganic source will restore soil Zn to acceptable levels in waste treatments which showed Zn deficiency.

4.2.5.5 Exchangeable acidity and aluminium

Values for exchangeable acidity and Al were found to be lower in all waste treatments than the control soil (table 5b). Wood ash treatment reduced exchangeable acidity from 1.43 Cmol (+)kg^{-1} in control soil to 0.027 Cmol (+)kg^{-1}. No exchangeable Al was detected in wattle back chippings, wood ash and saw dust amended soils four months after amendment. Waste tea amended soil had significantly higher exchangeable acidity and Al than any other waste treatments.

Generally, lower values for exchangeable acidity, and Al, Fe and Mn were found in all waste amended soils. This phenomenon could have been due to the fact that organic acids released during waste decomposition complexed Al, Mn and Fe and render them unavailable. Increased soil pH due to waste application also influenced the solubility and availability of these micronutrients. The increase in pH from 5.1 to 7.5 revealed that wood ash can be used as a liming material. It contains calcium (calcium carbonate) in forms which when dissolved will neutralise soil acidity. The quality of wood ash as a liming material, is measured by how effectively it neutralises soil acidity and its purity is expressed as calcium carbonate equivalence. Analytical results show that wood ash has calcium carbonate equivalence of 98.08%, this is the measure of how much of the wood ash can react with the soil to neutralise acidity under ideal conditions compared to pure calcium carbonate. In light of increased soil pH, reduced exchangeable acidity from 1.43 to 0.027 Cmol(+)kg^{-1} and high calcium carbonate equivalence (98.08%), it can be concluded that wood ash can effectively neutralise soil acidity. On the other hand, reduction of Al, Fe and Mn in wood ash amended plots was probably due to precipitation of these elements attributed to increased soil pH following wood ash application.

4.2.5.6 Bulk density and available water capacity

Table 6 shows the bulk densities and available water capacities of Magadu soil from different waste treatments.

The bulk densities for all treatments ranged from 1.00 to 1.30 g cm^{-3}. The bulk density from the control plot was significantly higher ($P < 0.05$) than the values of the same in the remaining waste amended plots. Waste tea and wattle bark chippings treatments reduced the bulk density significantly from 1.30 g cm^{-3} in the control plot to 1.00 g cm^{-3}. Waste tobacco and saw dust treatments reduced the bulk density from 1.30 g cm^{-3} to 1.10 g cm^{-3}, while wood ash treatment reduced the same parameter to 1.20 g cm^{-3}. These results reveal that application of wastes can solve the problem of compaction especially in acid soils.

The available water capacities for all treatments ranged from 26 to 34 mm. Wattle bark chippings and waste tea treatments gave significantly higher ($P < 0.05$) available water capacities than the rest of the treatments. The corresponding values were 34.00 and 32.00 mm respectively. Available water capacities of saw dust (30.00 mm) and waste tobacco (29.00 mm) were significantly higher than the values of the same in wood ash and control treatments. Available water capacity of wood ash amended plots was significantly lower and not significantly different from the control plots.

Table 6: Effects of industrial wastes on bulk density and available water in the 20 cm soil layer (plough layer)

Treatment	Bulk density (g cm^{-3})	Available water capacity (mm)
Waste tea	1.00c	32.00a
Wattle bark chippings	1.00c	34.00a
Waste tobacco	1.10bc	29.00b
Wood ash	1.20ab	26.00c
Saw dust	1.10bc	30.00b
Control	1.30a	26.00c
Grand mean	1.12	29.50
Standard error of mean	0.052	0.71
LSD value	0.16	2.23
Coefficient of variation (%)	8.04	4.15

Means in the same column followed by the same letters are not significantly different according to the Duncan multiple Range Test at 0.05 level of significance.

Similar results were observed by Navas *et al.* (1998) and, Hamblin and Kyneur (1993). Navas *et al.* (1998) reported changes in bulk density and total porosity that were measured six months after addition of sludge. They reported a decrease in bulk density from 1.25 g cm^{-3} in the control to 1.00 g cm^{-3} for the highest sludge application. Hamblin and Kyneur (1993) reduced bulk density and improved water holding capacity in soil following waste application.

Taylor *et al.* (1966) suggested that bulk density values of 0.9 - 1.2 g cm^{-3} for most recently cultivated soils are considered normal. According to Taylor *et al.* (1966) all the bulk density values from waste amended plots were found to be favourable for crop production. Bulk density in the control plots was higher than the critical value suggested by Taylor *et al.* (1966). Therefore, application of industrial wastes to Magadu soil will reduce the bulk density values to favourable levels and thus, soil compaction will also be reduced.

4.3 Decomposition of wattle bark chippings and saw dust and their nutrient release

The decomposition of wattle bark chippings and sawdust was rated using the following parameters: change or decrease in dry matter, organic carbon, total nitrogen, and phosphorus. The changes or decreases were expressed as percent residual value relative to 100% as the reference starting point.

4.3.1 Residual dry matter

The decline in dry matter from the decomposition of sawdust and wattle bark chippings over twelve weeks of incubation is shown in figures 1 and 2 respectively.

The overall incubation time influenced the decomposition process, resulting in lower residual dry matter with longer incubation periods (figures 1 and 2). The decomposition of saw dust was slower than that of wattle bark chippings. At the end of incubation (12 weeks), only 25% and 32% of surface applied and soil incorporated saw dust dry matter were lost respectively. The slow rate of decomposition of sawdust was probably due to resistance of sawdust to microbial attack that is linked to the abundance of lignin and its unfavourable wide C/N ratio.

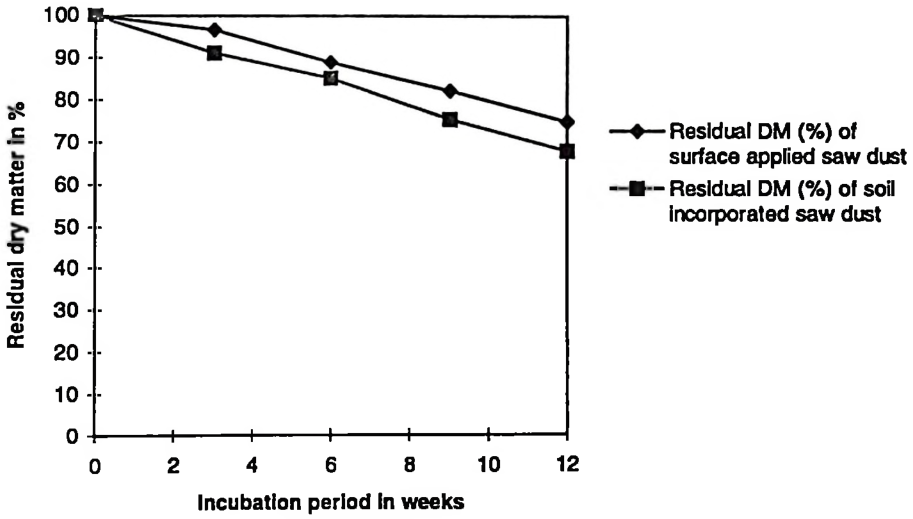


Figure 1: Overall changes of dry matter in sawdust with time of incubation.

The decomposition of wattle bark chippings was fast during the initial period up to the third week of incubation by which time nearly 14% and 24% of surface applied and soil incorporated material had decomposed respectively. The decomposition was much slower thereafter (figure 2).

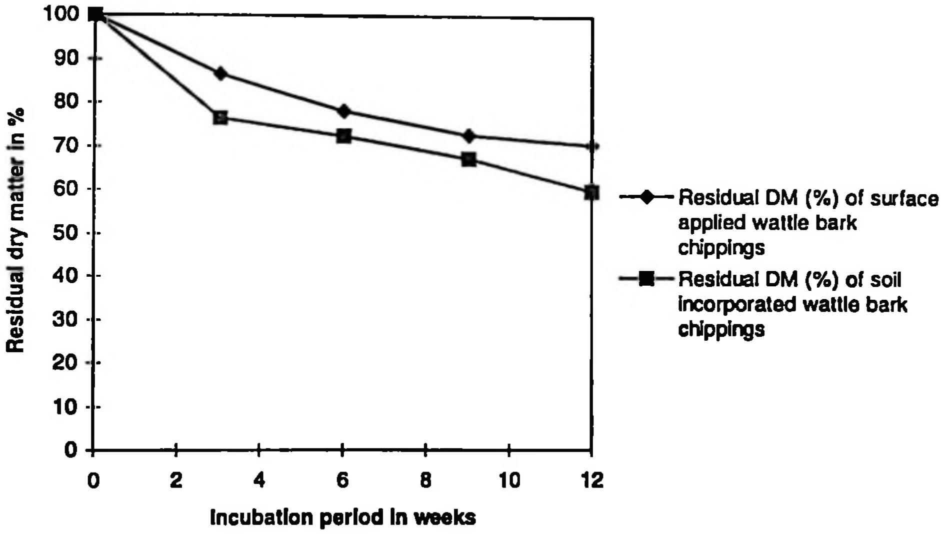


Figure 2: Overall changes of dry matter in wattle bark chippings with time of incubation.

Placement methods also influenced the rate at which saw dust and wattle bark chippings decomposed. Incorporated wastes decomposed faster than surface applied wastes at 0.05 level of significance (fig. 1 and 2). The observed difference in the rate of decomposition between surface applied and soil incorporated wastes may have been due to more contact between the wastes and the soil in the case of soil incorporated wastes. Thus soil incorporated wastes had greater contact with soil micro-organisms which were responsible for the breakdown of the wastes. Probably soil incorporated wastes stimulated microbial growth to a greater extent than did the surface applied wastes.

The intermittently lower moisture status of the surface soil as a result of surface losing moisture faster than the substrate could be the additional explanation for reduced rate of decomposition of surface applied wastes. Similar findings on the difference in rates of decomposition of surface applied and soil incorporated organic materials have been reported by Nikokwe (1996), Parker (1962), Brown and Dickey (1970) and Bent (1986). Parker (1962) reported 65% and 50% decomposition after 20 weeks of incubating buried and surface applied organic materials respectively. Brown and Dickey (1970) reported weight losses of 93 and 31% for plant residues which were placed 12 cm deep in soil and on the soil surface respectively for 18 months. Bent (1986) on the other hand, observed weight losses amounting to 80-90 and 36% after 12 months of incubating soil incorporated and surface applied barley straw respectively. He further reported that surface applied barley straw was dry on several sampling dates as compared to soil incorporated straw.

The results of this study also showed that there was significant difference ($P<0.05$) between the two sources of wastes, namely saw dust and wattle bark chippings. Wattle bark chippings decomposed faster than sawdust did. The difference in decomposition rate between the two wastes could be due to the fact that wattle bark chippings contained more water-soluble fractions which are rapidly metabolised than did the saw dust. Similar findings were reported by Alexander (1983) who reported that the resistance of wood and sawdust to microbial attack was linked to the abundance of lignin in such materials. It should be noted that more than 50% of the wastes (saw dust and wattle bark chippings) were still undecomposed after 12 weeks of incorporation. This is an indication of an important possible residual effect of these wastes.

4.3.2 Residual organic carbon

The overall changes of organic carbon in sawdust and wattle bark chippings with time of incubation are shown in figures 3 and 4 respectively. The residual organic carbon followed a trend similar to that of residual dry matter. It decreased with time of incubation. The residual organic carbon in both sawdust and wattle bark chippings decreased gradually with time of incubation. By the 12th week saw dust had lost only 18 and 22.6% of surface applied and soil incorporated sawdust respectively; 23.6 and 23.9% of surface applied and soil incorporated wattle bark chippings dry matter were lost respectively.

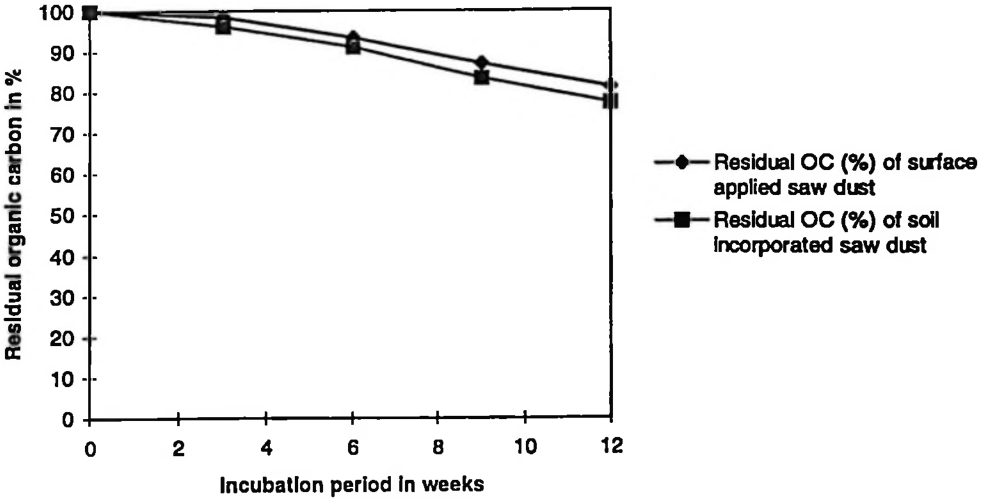


Figure 3: Overall changes of organic carbon in sawdust with time of incubation.

As for residual dry matter, placement methods influenced the rate at which the two wastes decomposed. Incorporated sawdust and wattle bark chippings lost organic carbon significantly faster ($P<0.05$) than the surface applied one. The reason for faster loss of organic carbon in the soil incorporated wastes is given in section 4.3.1. These results are in agreement with those reported by Amato *et al.* (1987) who reported that within 10 weeks of incorporation, about 28% of wheat-derived ^{14}C had disappeared. Between 10 weeks and 2 years from incorporation, residual organic ^{14}C declined more slowly, and after 2 years accounted for about 30% on average of input ^{14}C.

The results revealed that most of the input organic carbon in the two wastes remained intact and thus, would have good residual effect in the following seasons.

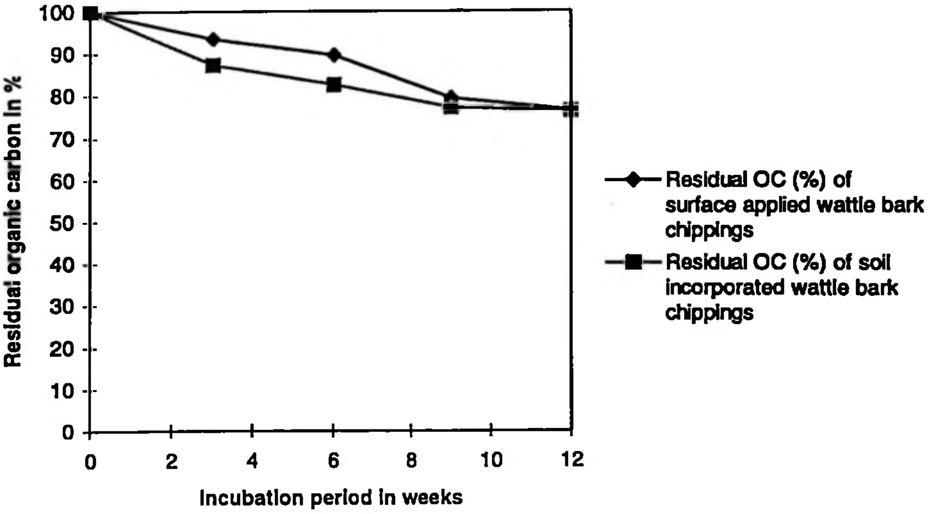


Figure 4: Overall changes of organic carbon in wattle bark chippings with time of incubation.

4.3.3 Residual phosphorus

Figures 5 and 6, respectively show the overall changes of phosphorus in wattle bark chippings and sawdust with time of incubation.

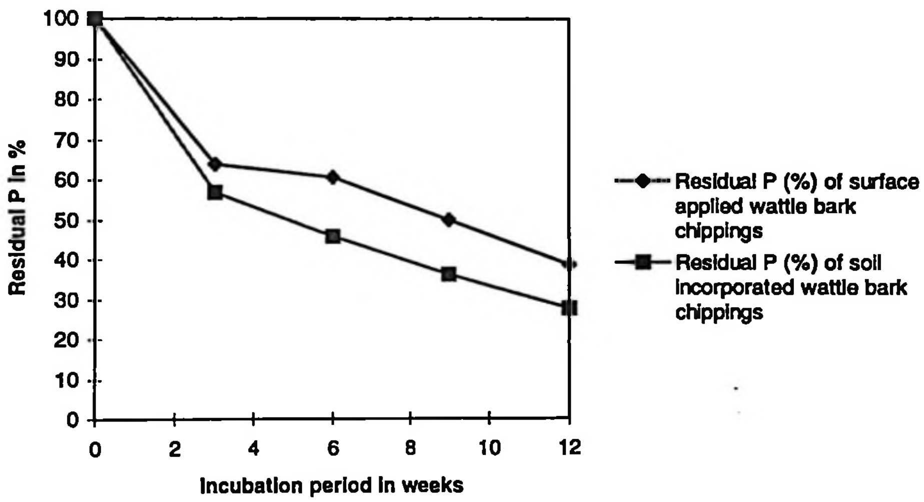


Figure 5: overall changes of phosphorus in wattle bark chippings with time of incubation.

The trend in decrease of phosphorus was observed to be similar to that of residual dry matter and organic carbon. Residual P in wattle bark chippings decreased sharply during the first three weeks (fig. 5). About 36 and 43% of P were respectively lost at the end of the third week of incubation for both surface applied and soil incorporated wattle bark chippings. As shown in figure 5, it is evident that 61.5 and 72% of P in surface applied and soil incorporated wattle bark chippings were lost up to the end of the 12th week respectively.

The decomposition of soil incorporated sawdust was faster up to the third week of incubation by which time nearly 39% of the material had decomposed. The rate of decomposition was much slower thereafter. The decomposition of surface applied saw dust, on the other hand was faster during the initial period up to the sixth week of incubation. About 39.6% of the material had decomposed up to this period. The decomposition rate after the sixth week was very slow, about 45% of the material had decomposed up to end of incubation period.

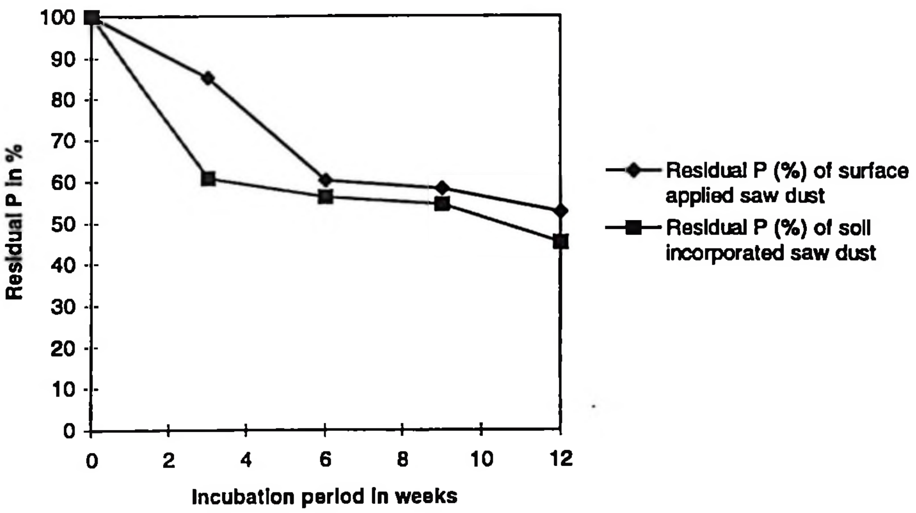


Figure 6: Overall changes of phosphorus in sawdust with time of incubation.

The amounts of P released from wattle bark chippings and sawdust from the third week to twelfth week of incubation are presented in table 7. These values were calculated as the differences between input P in the two wastes (4.013 kg P ha^{-1} for wattle bark chippings and 4.06 kg P ha^{-1} for saw dust) and residual P. During decomposition of surface applied sawdust released 1.93 kg P ha^{-1} at the end of 12th week, while soil incorporated saw dust released 2.23 kg P ha^{-1} at the same period. These values correspond to 47 and 55% of the input P of surface applied and soil incorporated sawdust respectively. 2.47 kg P ha^{-1} and 2.91 kg P ha^{-1} were released during the decomposition of surface applied and soil incorporated wattle bark chippings respectively. The values correspond to 61.4 and 72.6% of input P in surface applied and soil incorporated wattle bark chippings respectively.

During decomposition, the C/P ratio increased significantly more in soil incorporated wastes than in surface applied one (figures, 7a and 7b). The higher levels of C/P ratios in incorporated wastes had been attributed to more P been utilised by soil micro-organisms in soil incorporated wastes than in surface applied wastes. The phenomenon was caused by higher rate of decomposition which was probably enhanced by greater contact between incorporated wastes and soil micro-organisms.

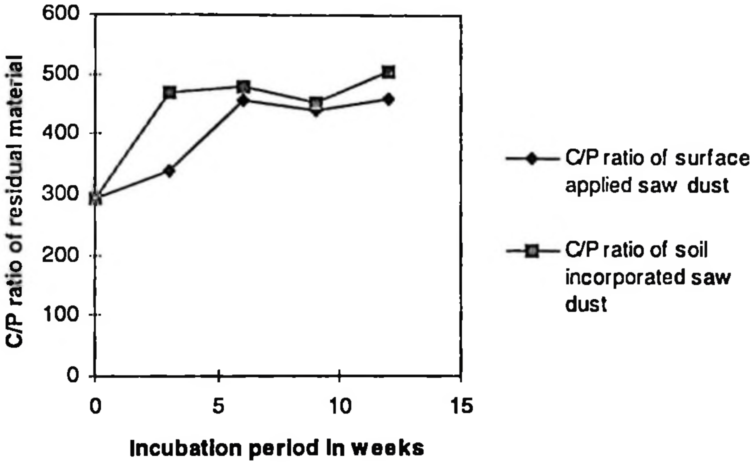


Figure 7a: Changes in C/P ratio of sawdust with time of incubation.

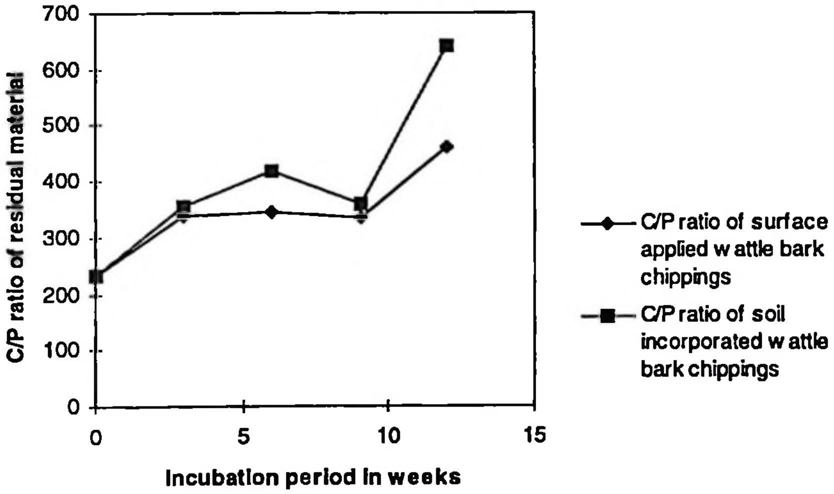


Figure 7b: Changes in C/P ratio of wattle bark chippings with time of incubation.

The increase in C/P ratio of litter material with time of incubation indicates a potential immobilisation effect of P in the subsequent season. Therefore, addition of inorganic P will be an added advantage in restoring nutrient balance.

Table 7: Effect of method of wattle bark chippings and sawdust incorporation into soil on P release upon wattle bark chippings and sawdust decomposition

	P released after given weeks of incubation (Kg ha^{-1})			
Method of placement	3	6	9	12
Surface application:				
Wattle bark chippings	1.45	1.58	2.01	2.47
Sawdust	0.60	1.61	1.70	1.93
Soil incorporation:				
Wattle bark chippings	1.73	2.17	2.57	2.91
Sawdust	1.60	1.70	1.85	2.23

4.3.4 Residual total nitrogen

The changes of total nitrogen in sawdust and wattle bark chippings are presented in figures 8 and 9 respectively. The residual total nitrogen in saw dust decreased faster during the first weeks, losing 41% and 48% of surface applied and soil incorporated saw dust after nine weeks of incubation respectively. The decrease in residual total nitrogen was slow after the ninth week.

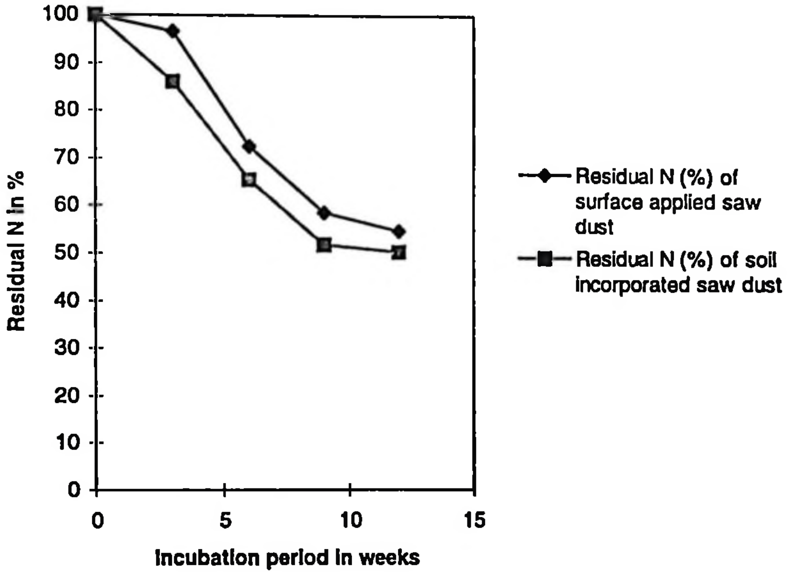


Figure 8: Overall changes of total nitrogen in sawdust with time of incubation.

Residual total nitrogen in wattle bark chippings decreased gradually and there was no different in the decrease rate between surface applied and soil incorporated chippnigs up to the sixth week of incubation (figure 9). The decrease for soil incorporated chippings was faster than that of surface applied chippings thereafter. About 23 and 27% of surface applied and soil incorporated wattle bark chippings were lost after 12 weeks of incubation respectively.

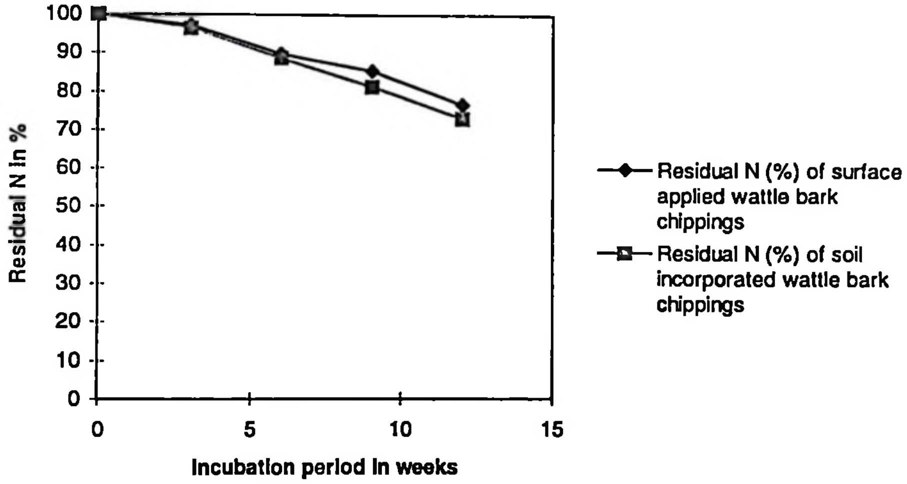


Figure 9: Overall changes of total Nitrogen in wattle bark chippings with time of incubation.

As shown in figures 8, and 9 soil incorporated wastes lost nitrogen much faster than surface applied wastes did. This was indicated by lower residual N in the incorporated wastes relative to surface applied wastes.

Table 8 show the amounts of nitrogen (kg N ha^{-1}) released from sawdust and wattle bark chippings for third, sixth, ninth and twelfth weeks of incubation respectively. The initial input N for saw dust was 5.16 kg N ha^{-1} and 65.4 kg N ha^{-1} for wattle bark chippings. The amounts of nitrogen released from sawdust after 12 weeks of incubation was 2.30 and 2.57 kg N ha^{-1} for surface applied and soil incorporated saw dust respectively. These values correspond to 44 and 48% of the initial input N of surface applied and soil incorporated saw dust respectively. About 15.3 and 17.6 kg N ha^{-1} were released from surface applied and soil incorporated wattle bark chippings respectively. The values correspond to 23.3 and 26.9% for both surface applied and soil incorporated chippings.

Table 8: Effects of method of sawdust and wattle bark chippings incorporation into soil on N release upon sawdust and wattle bark chippings decomposition

	N released after given weeks of incubation (Kg ha^{-1})			
Method of placement	3	6	9	12
Surface application:				
Sawdust	0.18	1.42	2.14	2.30
Wattle bark chippings	1.80	6.70	9.60	15.30
Soil incorporation:				
Sawdust	0.71	1.78	2.49	2.57
Wattle bark chippings	2.40	7.40	12.30	17.60

The small amounts of phosphorus (table 7) released by the two wastes are the reflection of the low phosphorus content in the wastes. Consequently, incorporation of saw dust and wattle bark chippings into soils which are deficient in phosphorus should be supplemented with phosphatic fertilisers.

As shown in table 8, nitrogen released from soil incorporated sawdust up to the 12th week of incubation is about 50% of the initial N input (5.16 kg N ha^{-1}). The amount does not meet plant requirement for N. This is due to inherent low N content in sawdust. On the other hand, N released from both surface applied and soil incorporated wattle bark chippings correspond to 23.3 and 26.9% of the initial N input (65.4 kg N ha^{-1}) respectively. The corresponding values are 15.30 and 17.60 kg N ha^{-1} respectively. This implies that the rate of release of N from wattle bark chippings is slow and it can be beneficial to subsequent crops in the following seasons.

When organic materials are added to the soil as organic source of nutrients, the nutrients may be lost because they may not be available for plant uptake. This is especially so for nitrogen which can be lost due to leaching, volatilisation or denitrification. There is need, therefore, to synchronise nutrient availability with plant demand. One way of achieving this is to regulate the timing at which the organic material is added to the soil to maximise the nutrient use efficiency. The result of the present study revealed that the two wastes released about 50% of their phosphorus and nitrogen (in case of saw dust) after 9 weeks of incubation. More P and N were released subsequently. This implies that wattle bark chippings and saw dust should be applied 9 weeks in the field before the time of maximum nutrient demand by the crops. This will match with peak release of nutrients by the wastes and peak uptake by crops. Lehman *et al.* (1995) reported that the critical period of high nutrient demand of maize is 4-6 weeks after planting. This means that the two wastes should be applied 3-5 weeks before planting maize in the field.

From the observed decomposition and nutrient release patterns, it is evident that soil incorporated wastes released more nutrients at any one time than the surface applied. It is therefore, recommended that saw dust and wattle bark chippings should be incorporated into soil to maximise their decomposition and nutrient release patterns.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSION

The experimental soil is a compacted acidic soil with low fertility status. It is low in N, P, %OC, exchangeable bases, and percent base saturation. The soil therefore, is unsuitable for maize production.

Waste tea, wattle bark chippings and waste tobacco were rich in N, with corresponding values as 3.85, 2.58, 1.66% respectively. Nitrogen content in saw dust was low (0.203%. Wood ash contained significantly high P, Ca, Mg, K, Mn, and Zn. The calcium carbonate equivalence of wood ash was 98.08%.

The waste amendments influenced dry matter and grain yields greatly. Waste tea amended plots resulted in significantly higher dry matter compared to other amendments. Dry matter yields from waste tobacco and wood ash amended plots were higher than those which were obtained from wattle bark chippings, saw dust amended and control plots but lower than the yield from waste tea amended plots. Maize grain yields were significantly high in waste tea and wattle bark chippings. The grain yields from waste tobacco and wood ash amended plots were significantly higher than those which were obtained from saw dust amended and control plots. Maize grain yield in saw dust treated plots was lower than the control plots. The poor performance of saw dust could be attributed solely to low N content (0.203%) in the material. and a wide C/N ratio which could have promoted immobilisation of N.

The wastes had a profound effect on soil properties after a single growing season. Application of wastes on strongly acid soil of Magadu resulted in increased total N, %OC, available P, and DTPA extractable Cu and Zn. DTPA extractable Fe and Mn, exchangeable acidity and aluminium were reduced by waste treatments relative to the control plots. Wood ash neutralised exchangeable acidity from 1.43 to 0.027 Cmol(+)kg^{-1}.

In the decomposition experiment, dry matter, organic carbon, total nitrogen and total phosphorus in wattle bark chippings and sawdust decreased with time of incubation. The decreasing trend in the value of these parameters reflected changes in substrate composition as incubation time increased. The period of fast disappearance of DM, OC, total N and P was attributed to degradation of readily decomposable components of the two wastes. Resistance (recalcitrant) compounds were left behind as readily decomposable materials were depleted and thus contributing to subsequent slower rate of decomposition.

Methods of placement influenced the rate at which saw dust and wattle bark chippings decomposed. Soil incorporated wastes decomposed significantly faster than those which were surface applied. This could be due to enhanced contact between the soil incorporated wastes and soil micro-organisms which were responsible for the breakdown of the wastes. Therefore, soil incorporation of the wastes into soil is an attractive method of waste placement.

Waste tea and wattle bark chippings were found to be the most effective amendments on higher yield basis, whereas wood ash was found to be more effective in neutralising soil acidity.

5.2 RECOMMENDATIONS

From the results of this study, the following further research areas are suggested.

1. In the present study, a single rate of waste application for each waste was used to identify the most effective amendments. Further research is needed to establish the most optimum rates of waste application to improve plant growth and yields in acid soils and at the same time minimising the risks of soil and plant contamination.

2. By demonstrating that industrial wastes can be used safely and beneficially on crop lands, this study has had a significant positive effect on maize dry matter and grain yields. There was positive residual effect on soil physical and chemical properties after harvest as well. However, it is recognised that the work completed to date at Magadu has been short-term, and that long-term effects through repeated annual waste treatments, at the same location or other locations with similar conditions, are needed to document

waste effects on soil properties and crop performance.

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APPENDICES

Appendix 1: Effect of wastes on maize performance 4 weeks after seedlings emergence

Effect of wattle bark chippings on maize performance.

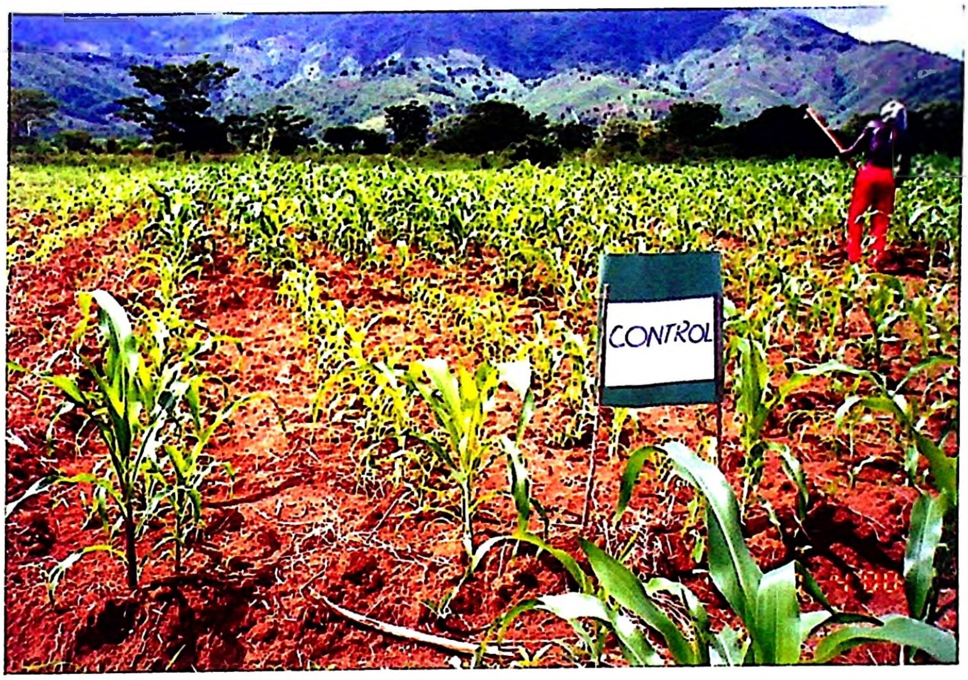
Maize performance in waste tea amended plot.

Appendix 1 continues

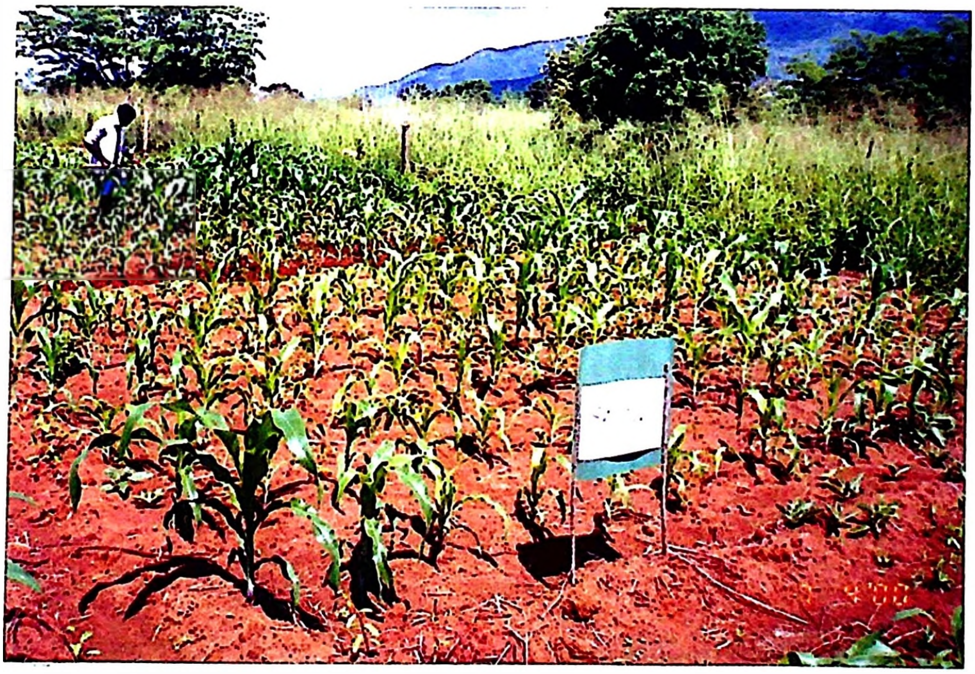
Effect of waste tobacco on maize performance

Effect of wood ash on maize performance

Appendix 1 continues



Maize performance in control plot



Effect of saw dust on maize performance.

Appendix 2: Performance of maize plants as affected by waste amendments 9 weeks after seedlings emergence

Maize performance in waste tea amended plot.

Maize performance in wattle bark chippings amended plot

Appendix 2 continues

Maize performance in waste tobacco amended plot

Maize performance in wood ash amended plot

Appendix 2 continues

Maize performance in saw dust amended plot

Maize performance in control plot