EFFECTS OF SOME INDUSTRIAL ORGANIC WASTES ON MAIZE GRAIN YIELD AND SOME SOIL PROPERTIES

BY

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ABSTRACT

A study was conducted to evaluate paper sludge and pyrethrum marc as alternative sources of plant nutrients using maize as a test crop. The study was carried out at Magadu Morogoro, Tanzania. Kaaya (1989) classified the soil of Magadu as Oxic Haplustult. Laboratory analyses revealed the soil to be clay, compacted and acidic with low CEC (11.2 Cmol(+) kg^{-1}) Total nitrogen, (0.09 %) exchangeable Ca (1.77 Cmol (+)kg^{-1}) and Na (0.67 Cmol (+)kg^{-1} were low, exchangeable K (0.69 Cmol (+)kg^{-1}) and Mg (1.51 Cmol (+)kg^{-1} were high, extractable Fe (46.48 mg kg^{-1}) and Mn (70.06 mg kg^{-1}) were very high while Cu (1.14 mg kg^{-1}) and Zn (0.51 mg kg^{-1}) were adequate for plant growth. Four rates of paper sludge and pyrethrum marc (0, 10, 20, and 30 tons ha^{-1}) on air-dry basis were applied to soil in a randomized block design. The wastes were characterized before incorporation into the soil. Paper sludge and pyrethrum marc were alkaline and acidic in reaction respectively. Paper sludge had high C/N (37.7) C/P (245) and Ca/Mg (105.22) ratios .The high C/N and C/P ratios mean that biological immobilization of nitrogen and phosphorus would be the major limiting factors for this waste to be used as a source of plant nutrients. High Ca/Mg ratio indicates that paper sludge can be used as a liming material. Paper sludge had lower sodium adsorption ratio (SAR) (0.22) as compared to pyrethrum marc (0.62). This suggested that sufficient Ca and Mg are present to counteract the negative effects of sodium. Levels of Fe (333.4) Mn (543.71) Cu (21.00) and Zn (42.9) for paper sludge and 107.55; 901.85; 14.4 and 51.00 respectively for pyrethrum marc, were well within the limits for environmental pollution. Maize grain yield in plots amended with pyrethrum marc increased from 0.64 to 3.33 tons ha^{-1} with increasing

rate of pyrethrum marc while in plots treated with paper sludge grain yield decreased from 1.43 to 0.52 tons ha^{-1}as the rate of application of paper sludge increased. The effect of paper sludge and pyrethrum marc on soil properties was evaluated. Increasing the rates of the wastes ameliorated the bulk density from 1.50 to1.38 mg $cm^{-3}$was associated with decrease in soil bulk density. For pyrethrum marc treated plots, soil pH, OC, total N, extractable P and exchangeable Ca, Mg, and Na and CEC increased with increasing rates of the waste. Cu and Fe were significantly low relative to the control, and Zn was higher than the control. Soil pH, exchangeable Ca and CEC of the plots amended with paper sludge increased with increasing rates of the material from 5.28; 2.61; 10.57 to 7.7914.74; 14.20 respectively. Increasing the rates of paper sludge had a negative effect on exchangeable Mg, K, Na, and extractable P. Total nitrogen and organic carbon were not statistically different from the control. Cu content increased with increasing rate of paper sludge (0.71 $mgkg^{-1}$ for the lowest rate and 0.81 $mgkg^{-1}$ for the highest rate of paper sludge). Zn was not statistically different compared to the control, and Fe was significantly lower than the control. Both wastes alleviated Al and Mn concentrations remarkably.

DECLARATION

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

Signature.....

Date.....

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DEDICATION

To my relatives who believe in investing in education

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LIST OF ABBREVIATIONS AND SYMBOLS

Al	Aluminium
Al^{3+}	Aluminium ion
Ca	Calcium
CEC	Cation exchange capacity
cm	Centimetre
Cmol(+) kg^{-1}	Centimole per kilogram
Cu	Copper
CV	Coeffient of variation
DTPA	Diethylenetriaminepentaacetic acid
et al	and others
FAO	Food and agriculture
Fe	Iron
g cm^{-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
KCl	Potassium chloride
kg	Kilogram
m	Metre

Mg	Magnesium
mg	Milligram
$Mg\ m^{-3}$	Megagram per cubic metre
mm	Millimetre
N	Nitrogen
NaOH	Sodium hydroxide
OC	Organic carbon
P	Phosphorus
pH	Negative logarithim of hydrogen ion concentration
PM	Pyrethrum marc
PS	Paper sludge
$P<0.05$	Probability at less than 0.05 level of significance
SAR	Sodium adsorption ratio
SUA	Sokoine University of Agriculture
$tons\ ha^{-1}$	tonnes per hectare
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

Agriculture plays an important role in the economies of the African countries. The main contributors to these economies are the small-scale farmers who constitute about 75% of the farming population in these countries (Haru and Semu, 1996). In their farming activities the small-scale farmers use limited resources (land, fertilisers, seeds, pesticides etc) and simple farm inputs for crop production. Continuous production without external nutrient inputs decreases the fertility status of the soil. It has been recognized that the decrease in soil fertility in the small-scale farms of the African continent has led to decline in the per capita food production (Sanchez *et al.* (1997). Studies by Mnkeni (1991) showed that more nutrients are leaving the system than are being added.

The decline in soil fertility in most of the agricultural land systems is due to a net removal of nutrients from the soil in the harvested products or through soil degradation processes, namely water and wind erosion, structural degradation, salinisation, acidification and contamination (Hartemink, 1997). In India for-example, the harvested crops have been removing 9-10 million tonnes more nitrogen, phosphorus and potassium every year than the total additions through fertilisers (Tandon, 1995). It has been estimated that, an average of 660 kg N, 75 kg P and 450 kg K ha^{-1} has been lost during the last 30 years from about 37 African countries due to nutrient mining (Sanchez *et al.*, 1997). This accelerates environmental degradation which in turn poses an immediate threat to food production.

Attempts 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 have, in recent years, 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 whose prices are very high at present. However, there has been frequent unavailability of the fertilisers to the village markets at the time farmers need them (Haru and Semu, 1996). Although the use of mineral fertilisers produces quick and positive results, their high prices, lack of foreign exchange for importation of adequate quantities and poor infrastructures to enable their timely distribution to farmers deter farmers from using them in recommended quantities and balanced proportions (Semoka *et al.*, 1983).

The high cost of inorganic fertilisers has been aggravated by the elimination of subsidies through government's structural readjustment programmes. Other reasons include limited credit, unreliable delivery, adulterated fertilisers, a multitude of brands of poor quality and lack of awareness by farmers of the potential benefits (Ragland and Boonpuckdee 1987)

Industrialization and urbanization are accompanied by the accumulation of organic industrial and urban wastes in large amounts whose disposal is not only a problem, but also costly. Non judicious disposal of these industrial wastes can result in serious land and water pollution and bring about public health problems. Like most organic waste materials (e.g., animal manure, sewage sludge, municipal refuse, and

municipal solid waste compost), industrial by-products contain significant concentrations of organic carbon and plant nutrients such as N, P, K, S, Ca, Mg, Cu, Mn and Zn. In addition they may contain significant concentration of heavy metals (Zhu *et al.*, 1995). The judicious recycling of industrial wastes in agriculture brings in the much-needed organic and mineral matter to the soil. The use of agro-industrial wastes in agriculture has gained importance in crop production due to high costs of inorganic fertilisers and inadequate supply of conventional/traditional organic materials. Waste recycling not only enhances the availability of nutrients for crop production, but also helps in the abatement of environmental pollution. Since most recycable wastes are organic, they directly add organic matter and the plant nutrients contained in it. While the nutrient input improves soil fertility, the organic input has a profound and vital role to play in improving soil physical properties (e.g. soil tilth, water holding capacity, water infiltration rate), cation exchange capacity and providing a more favourable environment for micro organisms and root growth (Tandon, 1995a, and William, 1994). Thus, the use of industrial wastes in agricultural land can serve as soil amendment and also alleviate the problem of wastes disposal.

Industrial organic wastes are widely spread in Tanzania (Ndaki 2001). However, actual production levels have not been well documented. This is probably due to the fact that industrial wastes are considered by the concerned industries to be valueless end products and therefore no need to establish the amounts produced every year. Lack of legislation and poor enforcement mechanism of the few available laws on the

production and management of the industrial wastes in Tanzania, may be another reason for the poor management of the wastes in the country. On the other hand, industries responsible for production of the organic wastes are faced with serious sanitation problems of managing the wastes. The costs involved in building and operating waste treatment facilities are a burden to the economy of these industries as no financial return on the investment is provided. Thus, many factories opt for the throwaway culture of "convenience". Among the wastes produced in Tanzania are paper sludge and pyrethrum marc, which are produced by Southern Paper Mills Limited (SPM) and Tanzania Pyrethrum Processing and Marketing Company Limited (TPPMC) respectively. Both these industries are located in Mufindi district Iringa, Tanzania. SPM produces on average 51 6240 tons of paper sludge per annum and TPPMC produces on average 3600–4050 tonnes of pyrethrum marc per year.

Currently, land filling and open land dumping are the principle methods used to dispose of these wastes at SPM and TPPMC respectively. Applying paper sludge and pyrethrum marc to agricultural land to supply plant nutrients and/or act as soil amendment may be a more desirable alternative to land filling and open land dumping. However before such land treatment, it is important that, each by-product be evaluated for its chemical composition, effect on plant growth and development, economic viability, practical feasibility, and its consequences on the environment and public health.

The general objective of this study was to characterize paper sludge and pyrethrum marc in terms of their chemical composition and their role as alternative sources of plant nutrients and as soil conditioners. The specific objectives were to; (i) estimate the amounts of paper sludge and pyrethrum marc produced by the respective industries and their disposal problems. (ii) characterize paper sludge and pyrethrum marc in terms of their chemical composition. (iii) evaluate the agronomic potential of the wastes on maize gain yield. (iv) evaluate the effect of paper sludge and pyrethrum marc on soil properties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2. 1 General background of industrial wastes as fertilisers

Nutrient recycling is becoming an increasingly important element of environmentally sound sustainable agriculture. There are various reasons for recycling of municipal and industrial organic waste on agricultural land. These according to Schulz and Romheld (1997), include (i) benefits to crop due to the recycling of organic matter (ii) mineral nutrients and (iii) possible suppression of soil-borne pathogens. Simard *et al.* (1998) reported a reduced degree of potato scab coverage on potato tubers following the application of paper mill residue compost, (iv) conservation of naturally available, but limited supplies of nutrient resources (v) avoidance of alternative disposal methods, which are, environmentally damaging, expensive, or limited by space.

In developing countries the recycling of nutrients by fertilisation with municipal and industrial organic wastes could be essential for sustainable food production, by compensating for the increasing nutrient demand, as a result of population increase (Schulz and Romheld, 1997). Addition of industrial organic wastes to agricultural land provides soil organic matter whose status correlates well with a number of important soil physical, chemical and microbiological properties (Sain and Grant, 1980; Doran and Smith, 1987; Bellakki and Badamur, 1994).

2. 1.1 Effects of industrial wastes on soil physical properties

The effect of industrial wastes on soil physical properties were studied by Bruggeman and Mostaghim, (1993) and Stephens, (1969) who found that application of organic industrial wastes to soils increased water infiltration rate, water holding capacity, tilth and porosity, and reduced runoff, sediment and nutrient loss. 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 improved aeration, improved exchange capacity and soil water balance. However they stated also that the improvements are conditional to soil type, climate, local condition, past land use and types and rates of soil amendments and/practices.

Hart and Speir (1992) studied the relationship between organic matter and soil aggregates. They reported that the organic matter added to soil after decomposition of the wastes aided in the formation of larger and more stable aggregates. The aggregate size characterizes soil structure and pore size distribution, both of which influence aeration, temperature and water holding capacity of the soil. Monreal *et al.* (1995) found that by decreasing soil organic matter, erosion lowered the water holding capacity and the ability of soil to supply nutrients.

Nemati *et al.* (2000) reported that hydraulic conductivity increased with increasing sludge application rates in the loamy and silty clay soils. The authors also reported a positive correlation between aggregate stability, decreases in soil bulk density and

the rate of paper sludge application. The effect of sludge application on soil bulk density was most likely due to the production of binding substances that aggregated soil particles and produced a more open soil structure, which consequently led to an increase in total porosity and a decrease in soil bulk density. Nemati *et al.* (2000) and Martens and Frankenberger Jr (1992) suggested that, decreased bulk density upon organic applications was a result of a dilution effect of the added amendments with the denser mineral fraction of the soil.

Navas *et al.* (1998) observed changes in bulk density and total porosity that were measured six months after addition of sewage sludge. They reported a decrease in bulk density from 1.25g m^{-3} in the control to 1.00g m^{-3} for the highest sludge application. Ndaki (2001) reported a decrease in soil bulk density from 1.3g m^{-3} to 1.0g m^{-3} in the control after applying waste tea. Similar results have been reported by Cripps *et al.* (1992), Borde *et al.* (1984), and Rai *et al.* (1980). The changes confirm the beneficial effects of sludge application on soil properties. However 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. Aitken *et al.* (1998) pointed out that, industrial wastes may either confer benefits as a result of addition of organic matter and neutralizing value when applied to soils, which are acidic or contain low levels of organic matter and low water holding capacity. The same author also reported 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.

2.1.2 Effect of industrial wastes on soil chemical properties

Bellamy *et al.* (1995) found that paper sludge contains such essential major nutrients as N, P, K, Ca, Mg and S. However, the authors emphasized that of these nutrient elements N is most likely to be in growth limiting quantities. This is due to its relatively high C/N ratio, which leads to N being immobilized by soil microorganisms. The N in organic products, may be transformed into ammonium (NH_4^+) and nitrate (NO^-_3) upon mineralisation. The effects of industrial organic wastes on soil P were studied by Iyamuremye and Dick (1996) Singh and Jones (1976) and it was found that organic inputs to soil can increase P availability in P-fixing soils. Nziguheba *et al.* (1998), Hue (1992), and Othieno (1973) found that organic anions formed by decomposition of organic inputs can compete with P for the same adsorption sites and thereby increase P availability in soils. Organic inputs may allow a more complete utilization of soil P by plants. Organic matter from organic wastes can form complexes with amorphous oxides of iron and aluminium, thus preventing them from crystallising (Nikokwe, 1992). In this way availability of phosphorus can be improved because these complexes block the P-fixing sites.

Ndaki (2001) observed increase in organic carbon, total N, P, exchangeable Ca^{2+}, Mg^{2+} and CEC in soils amended with waste tea, wattle bark chippings, waste tobacco and wood ash as compared to the control. Stephens (1969) reported that, organic fertilisers can contribute small amounts of a range of nutrients and so correct multiple soil deficiencies. Camberato *et al.* (1997) and Bellamy *et al.* (1995), reported that the mixture of primary and secondary paper sludge has the potential to introduce large

amounts of C to soil due to its high cellulose content and also contains significant amounts of several major nutrients.

Soil organic matter regulates the vertical distribution of pedogenic Fe and Al solids, the soil materials that correlates best with SO^{2-}_4 retention in mineral horizons (Courchesne 1992). Courchesne (1998) also reported that the nature and distribution of pedogenic Fe, Al and Si compounds in Podzolic soils are strongly dependent on the abundance of soil organic matter due to the fact that the formation of allophane is spatially limited to organic matter-poor podzols. Organic materials are possible soil amendments to increase the availability of soil Fe and Zn and improve Fe and Zn uptake by plants (Moraghan and Mascagni 1991)

The application of de-inking paper sludge increased Mehlich-3-extractable P, K and Ca (Simard *et al.*, 1998). Nkana *et al.* (1998) found that paper pulp provided high Ca inputs, alleviated aluminium and manganese toxicity, can be applied to tropical acid soils as a lime substitute, and is rich in P and K when decomposited. Effect of paper mill sludge on soil properties have been reported by Rodella *et al* (1995), Palaniswami and Ramula (1994), Honeycut (1988), and Logan and Esmaeilzaden (1985), that after 15 years of paper mill sludge application to sand soil there was an increase in electrical conductivity, soil pH, and exchangeable Na^+, Ca^{2+} and K^+; available P, Fe, Mn, Zn and Cu and activity of urease and alkaline phosphotase enzymes. Matemba (2001) observed significant increases in exchangeable Ca^{2+} and Na^+ in plots amended with sludge compared to the control plot. He also reported an

increase in soil pH with increasing rate of sewage sludge from Morogoro and decreased soil pH following application of the same from Dar es Salaam.

Application of carbonation press mud and sulphitation press mud to acid soils have been reported by Datta and Gupta (1983) to increase soil pH and exchangeable Ca and Mg. Carbonation press mud have been reported to decrease the electrical conductivity of soils (Yaduvanshi and Yadav, 1990). Application of sulphitation press mud was found by Singh *et al* (1986) to decrease the electrical conductivity and sodium adsorption ratio of calcareous saline sodic soil. It was also found by Yuduvanshi and Yadav (1990) that sulphitation press mud decreased the electrical conductivity of clay loam soils.

Wood fired boiler ash often supplies macronutrients, Ca, Mg, K and P and the micronutrients Zn, Cu, Cl, Fe, Mn and Mo ((Naylor and Schmidt, 1989; Ohno and Erich, 1990). In addition, ash can neutralize soil acidity and therefore substitute for commercial lime products (Ohno and Erich, 1990; Naylor and Schimidt,1989; Magdoff and Bartlett,1985).

There fore, land application of organic wastes positively influences the organic matter content and soil nutrient availability and may result in improved crop yield (Simard *et al.*, 1998; Bellamy *et al.*,1995; Cabral and Vasdconcelos 1993; Zhang *et al.*,1993).

2 .1 .3 Effect of the industrial wastes on crop yield

Different industrial wastes have been found to influence yield of various crops. Ndaki (2001) reported increase in maize grain yield following application of waste tobacco, wood ash, wattle bark chippings and waste tea. Matemba (2001) observed significant increase in dry matter yield of *Amaranthus* with increasing rates of sewage sludge. The *Amaranthus* dry matter yield was maximum (2.16 tons ha^{-1}) at the highest rate of sewage sludge applied at 60 tons ha^{-1}. Application of carbonation press-mud to an acid soil increased grain yield of maize by about 1575 kg ha^{-1} (Datta and Gupta, 1983). Application of sulphitation pressmud and carbonation pressmud each at the rate of 10 tons ha^{-1} was found by Kumar and Mishra, (1991) to be optimal for rice–maize rotation. Increase in growth and yield of winter wheat, corn and spinach from ash amended soils relative to the control was reported by Erich and Ohno, (1992). The authors reported further that high application rates of ash caused a decrease in growth relative to the control and the growth ceased at rates above 320 tons ha^{-1}. Simard *et al* (1998) reported increased barley yield in treatments applied with N fertiliser and de–inked paper sludge. However Aitken *et al.* (1998) reported a decrease in grain yield of barley in the first year of application of paper mill sludge, but the yield increased in the third year after the application of paper mill sludge. The author commented that the decrease in yield in the first year would probably be due to immobilization of N by soil microorganisms. Application of 40 Mg ha^{-1} and 80 Mg ha^{-1} of paper mill residue compost in absence of fertiliser N and P respectively produced the highest marketable potato tubers (Simard *et al.* 1998). Yield increases for a range of crops on acid soils due to the calcium carbonate content of papermill

sludge have been found by Sahu (1987) and Ponda and Pattranik (1990). Wood fired ash increased yields of oat and bean grown on acidic soils (Krejsl and Scanlon 1996).

There fore west recycling leads to an improvement in the overall soil productivity, of which soil fertility is a key component. Chemically, organic fertilisers can improve the CEC and buffering capacity of soils, and chelation of metallic ions. They can enhance microbial activity, and help conserve soil water; hence they increase crop yields (Stephens, 1969).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Industrial wastes

Paper sludge was obtained from Southern Paper Mills Company Limited, (SPM), Mgololo, while pyrethrum marc was collected from Tanzania Pyrethrum Processing and Marketing Company Limited, (TPPMCL) Mafinga. Both factories are located in Mufindi district Iringa, Tanzania. These industries have no well-defined ways of documenting the actual levels of wastes produced daily, monthly or annually. The amounts of wastes produced by the respective industries were calculated from the basis that with unlimited supply of fresh logs from the Sao Hill Forest, SPM is capable of processing 17 208 000 tons of logs per year, out of which 3% is given out as paper sludge. This gives on average 51 6240 tonnes of paper sludge per year. TPPMCL receives 4,500 tons of fresh pyrethrum per year. Upon the processing sequence 80–90% of the received fresh pyrethrum is given out as pyrethrum marc. Therefore, about 3600-4050 tonnes of pyrethrum marc are produced per year. Paper sludge and pyrethrum marc (500 each) were separately, made homogenous. Two samples of each waste were then taken from these well-mixed wastes, air-dried, and finely ground to pass through a 2mm sieve for chemical analyses. The unground samples were used for field experiment.

3.1.2 Characterization of the industrial wastes

The pH of the wastes was determined potentiometrically using a pH meter in water at a ratio of 1:2.5 industrial wastes: water (Mclean, 1982). Organic carbon was determined by the wet oxidation method of Walkely and Black (Nelson and Sommer, 1982). Following digestion of the wastes in a mixture of concentrated nitric acid and hydrogen peroxide (Jones and Case, 1990) total P, Ca, Mg, Cu, Fe, Zn, and Mn were determined using atomic absorption spectrophotometer (AAS). K and Na were determined using flame photometer. Nitrogen from sulphuric acid and hydrogen peroxide digest of the wastes was determined by micro Kjeldahl method (Bremner and Mulvaney, 1982).

3.2 Field experiment

3.2.1 Site location

The experiment was conducted from March to July 2002 at Magadu within the Sokoine University of Agriculture farm. The site is located at $37^{0}39'$ East and $06^{0}\ 50'$ South, Morogoro, Tanzania. The site is located at 510m asl. Kaaya (1989) classified the soil of the experimental site as Oxic Haplustult.

3.2.2 Soil sampling

Soil samples were taken at random prior to the beginning of the experiment from 0-20cm depth at 10 points per experimental replicate Samples for bulk density determination were taken using core rings. Samples for other parameters were taken

using a hand hoe and spade and were then thoroughly mixed. The composite samples were air–dried and ground to pass through a 2mm sieve. Samples for particle size analysis were sieved to pass through a 0.5mm sieve. Samples were also taken per plot at harvest time and were air-dried, sieved and used for physical and chemical analyses. The analyses were done in the Soil Science laboratory at Sokoine University of Agriculture, Morogoro, Tanzania.

3.2.3 Laboratory analyses of the experimental soil

Composite soil samples were analyzed for their physical and chemical properties, before planting and after harvesting the maize. Particle size distribution was determined by hydrometer technique (Gee and Bauder, 1986). Bulk density was determined using core-sample method (Blake and Hartage, 1986). Soil pH was determined using a pH meter in water with a 1: 2.5 soil: water ratio according to (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 micro Kjedahl method as described (Bremner and Mulvaney, 1982). Phosphorus was extracted by the Bray and Kurtz 1 method (Bray and Kurtz, 1945) and determined spectrophotometrically (Watanabe and Olsen, 1965; Murphy and Riley, 1962).

The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were extracted by saturating the soil with neutral 1M NH_4OAC (Thomas, 1982) then, Ca^{+} and Mg^{+} were determined

using atomic absorption spectrophotometer where as Na^+ and K^+ were determined using flame photometer. The cation exchange capacity (CEC) was determined by the percolation method (National Soil Service, 1987). Exchangeable acidity and aluminium were 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). The available micronutrients Zn, Cu, Mn, and Fe, were extracted by 0.005M DTPA following the method described by Lindsay and Norvell (1978) and then determined by atomic absorption spectrophotometer.

3.2.4 Plant sampling, preparation and analysis

Sampling of maize leaves was done when more than 50% of the plants had tasseled. Fifteen ear leaves from each plot were randomly sampled. The leaves were then oven dried at 65°C to constant weight, and thereafter chopped to about 1-2cm pieces and ground using tecator 1093 cyclotic sample mill. The plant materials were digested in a mixture of concentrated sulphuric acid and hydrogen peroxide (Jones and Case, 1990). Total P, Ca, and Mg of the maize leaves from H_2SO_4 - H_2O_2 digest were quantified by atomic absorption spectrophotometer, while K and Na were quantified using flame photometer. Nitrogen from H_2SO_4 - H_2O_2 digest of maize leaves was determined by micro Kjeldahl method (Bremner and Mulvaney, 1982). Cu, Zn, Fe, and Mn were determined from a digest using H_2O_2-HNO_3-$HClO_4$-HF mixture and then determined by AAS (Juo, 1979). One of the five harvestable lines from each plot was harvested (biomass harvest) for dry matter (DM) determination 46 days after planting, the plants were cut one centimeter from 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 grain yield data.

3.2.5 Experimental design and monitoring

A randomized complete block design was adapted. The experiment had three replicates of seven treatments (10, 20, and 30 tons ha^{-1} of each of paper sludge and pyrethrum marc plus the control) giving a total of 21 plots. Paper sludge and pyrethrum marc were applied on air-dry basis. Each plot size was 5.2m by 5.1m. The area was mechanically ploughed and hand harrowed. The wastes were applied on February 25th and thoroughly incorporated in the top 15 cm of the soil the same day using hand hoe. Maize (TMV–1 variety) was planted on 13th March 2002 at a spacing of 75 cm by 30 cm. Two seeds were sown per hill. The seedlings were thinned to one plant per hill 14 days after seedling emergence. The experiment was maintained weed free for the entire period of growth to harvest. After maturity, the crop was harvested and shelled for determination of grain yield. Moisture content of the grains was determined by the use of moisture meter and the actual weight of the maize grains was calculated to 12.5% moisture content. The yield was expressed in tonnes per hectare.

3.2.6 Data Management

The following soil properties (pH, bulk density, OC, total N, extractable P, exchangeable bases, Mn, Zn, Cu and Fe), leaf N, P, K, Ca, Mg, Mn, Zn and Fe and grain yield, were statistically analyzed using the ANOVA procedure of the Mstatc

soft ware. Comparison of means was carried out using New Duncan Multiple Range test.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Climate characteristics of the study area

Rainfall distribution of the experimental site is summarized in Fig 1 and Appendix 1. The area experiences a bimodal rainfall pattern. The short and lighter rains commence in late November and ends in January with a peak in December. The long and heavier rains start in March and end in May with a peak in April. The two sets of rains are separated by a short dry spell, which normally occurs in mid February to early March. The onset and distribution of the rainfall is irregular and unreliable and this was the case during this study. The mean monthly air temperature of the area ranges from 21.5^{0}C to 28.3^{0}C (Appendix 2)

4.2 Properties of the experimental soil

The physical and chemical characteristics of the study soil are shown in Table 1.

4.2.1 Soil texture

Particle size analysis of the experimental soil showed that, it contained 44.4% sand separates, 6.2% silt separates and 49.4% clay separates. Based on the percentage sand, silt and clay particles in the soil, the textural class of the soil was designated as clay according to classification system by (FAO 1990). The clay textural class of the

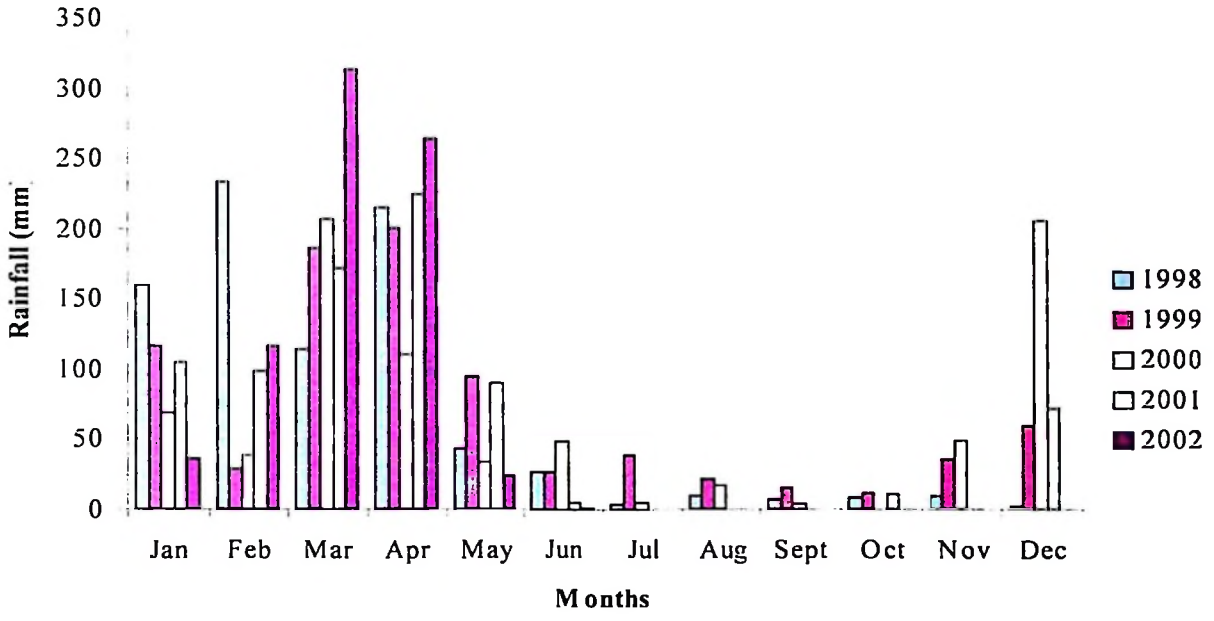

Figure 1: Monthly mean rainfall distribution

Table 1: Some physical and chemical characteristics of the experimental soil

Parameter	Value	Quality description	Critical value or range	Reference for critical values
Particle size analysis				
%sand	44.4			
% silt	6.2			
%clay	49.4			
Textural class		Clay		FAO (1990)
Bulk density (Mg m^{-3})	1.5	High		Brady and Weil (1990)
pH in water	5.1	Low	5.1	EUROCONSULT (1989)
Exchangeable bases (Cmol (+)kg^{-1}				
Calcium	1.77	Low	<4	Landon (1996)
Magnesium	1.51	Medium	<0.2	Landon (1996)
Potassium	0.69	Medium	<0.03	Landon (1996)
Sodium	0.67	Low		Landon (1996)
Base saturation (%)	41.45			
Cation exchange capacity(Cmol (+)kg^{-1}	11.2	Low	5-15	Landon (1996)
Organic carbon (%)	1.13	Low	2-4	Landon (1996)
Total nitrogen (%)	0.09	Low	<0.05	EUROCONSULT (1989)
Bray 1 extractable phosphorus ($mgkg^{-1}$)	4.8	Very low	15.0	EUROCONSULT (1989)
Exchangeable aluminium (C mol (+)kg^{-1}	0.67			
Exchangeable acidity (Cmol(+)kg^{-1}	1.45			
Total acidity (Cmol (+)kg^{-1}	2.12			
DTPA extractable micronutrients ($mgkg^{-1}$)				
Manganese	70.06	Very high	1.0	Lindsay and Norvell(1978)
Iron	46.48	Very high	<4.5-6.0	Lindsay and Norvell(1978)
Copper	1.14	High	0.2	Lindsay and Norvell(1978)
Zinc	0.51	Adequate	0.5-1.0	Lindsay and Norvell(1978)

soil influence moisture retention, transmission and cation exchange and retention capacity of the soil (Hillel, 1982) and on the performance of maize. When wet, have high water holding capacity, hard when dry and therefore can restrict root growth.

However, the magnitude of the influence on the above properties is a function of the type of clay minerals and their mineralogical composition. Most highly weathered tropical soils like Oxic Haplustults are dominated by 1:1 clay minerals and some considerable amounts of aluminium (Al) and iron (Fe) oxides and hydroxides, hence their low cation exchange capacity (CEC) values. Under good management practices, maize can be grown in a wide range of soils (Purseglove1988). In this case, maize can be grown in Magadu provided the soil is supplied with sufficient nutrients for the crop.

4.2.2 Bulk density

The bulk density of the soil was 1.5Mg m^{-3}. Bulk densities of clay, clay loam and silt loam surface soils normally range from 1.00Mg m^{-3} to as high as 1.60Mg m^{-3} (Brady 2000). Therefore, basing on this categorization, the study soil had high bulk density. The high bulk density value could be due to low organic matter content. The bulk density of 1.5 Mg m^{-3} indicates that the soil is compacted, a condition that is likely to reduce infiltration of rainwater and restrict root growth thus can lead to poor performance of maize. Foy *et al.* (1981) reported that, effects of manganese toxicity to plants, apart from occurring in soils with pH less than 5.5 sometimes do occur under less acid conditions in poorly drained or compacted soils. To minimize the

problem of soil compaction, sub-soiling coupled with an increase in the amount of soil organic matter is crucial. Due to higher costs of sub–soiling and limited availability of sub-soilers the use of organic ferilisers that improve on soil organic matter content needs to be emphasized especially for smallholder farmers.

4.2.3 Soil pH

The pH of the soil was found to be 5.1. The soil is strongly acidic (EUROCONSULT 1989) and according to Landon (1996) the pH of the study area is rated as low. The low pH of the soil could be attributed to the extensive weathering of the soil, extensive leaching and predominance of Al^{3+} (0.67 Cmol(+)kg^{-1} and H^+ (1.45 Cmol(+)kg^{-1} on the exchange sites and in the soil solution (Thomas and Hargrove, 1984). The low pH value implies that the soil would have nutritional problems for maize production. The associated problems include Al^{3+} toxicity and strong phosphorus (P) fixation. At this level of pH, it is possible for phosphorus availability to be reduced. This is because the phosphorus ions, tends to combine with Fe and Al to form insoluble compounds which are not readily available to plants. This combination of phosphate ions with Fe^{2+} or Al^{3+} can be explained as;

1) $Fe^{2+} + H_2PO_4^- + H_2O \Rightarrow Fe(OH)H_2PO_4 + H^+$

2) $Al^{3+} + H_2PO_4^- + 2H_2O \Rightarrow Al(OH)_2H_2PO_4 + 2H^+$

Also at this level of soil pH, there is an increasing possibility for excessive availability of Cu, Fe, Mn, and Zn. Micronutrients accumulation, generally increase as soil pH decreases (Shuman, 1975; McBride and Blasiak 1979). Below pH 5.5 bacterial activity is reduced and nitrification of organic matter is significantly

retarded. The optimal soil pH range for maize production is 6–7 (Purseglove1988). However, if proper management practices like supplementing with of inorganic fertilisers rich in phosphorus, addition of organic materials and liming are carried out, satisfactory maize production can generally be obtained in soil with pH values between 5.1 and 5.5 (EUROCONSULT 1989).

4.2.4 Exchangeable bases and cation exchange capacity

The respective exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were 1.77, 1.51, 0.68 and 0.67 Cmol (+) kg^{-1} respectively. According Landon to (1996) system of classification, the results from this study can be ranked as follows Ca content is low while, Mg content is high. Potassium value is high while that of Na^{+} is rated as low. The low values of Ca^{2+} and Na^{+} indicate that the soil is extensively weathered, with low pH and that most of the Ca^{2+} and Na^{+} have been leached out.

Cation exchange capacity (CEC) was 11.2 Cmol(+) kg^{-1} which according to Landon (1996) is ranked as low. This indicates that the soil is highly weathered with poor nutrient holding capacity (Msanya *et al.*,1996). The low CEC can be attributed to the low amount of organic matter and probably the nature of the clay minerals contained in the soil. This low CEC, will lead to reduction, not only of the reservoir of the major nutrients but also the capacity of the soil to retain nutrients when they are applied as inorganic fertilisers. The low level of CEC and exchangeable bases indicate that the soil has low levels of available nutrients and low nutrient reserves (Syers and Rimmer, 1994).

4.2.5 Extractable phosphorus

Bray–1–extractable phosphorus was found to be low. Any average phosphorus level of more than 7mg/kg is considered to be optimum, below which phosphorus-deficiency symptoms are likely to occur in many crops (Msanya *et al.*1996). The low level of Bray-1-P in the soil could be due to low levels of P in the parent materials and conversion of P into forms not extractable by the Bray-1-P reagents because of the strong acidic nature of the soil (Tisdale *et al.* 1993). It could also be argued that the low content of phosphorus was attributed to low organic matter in the soil, thus phosphorus might be one of the limiting factors for maize production at Magadu. Therefore the study soil cannot properly support plant growth without addition of phosphorus from external sources.

4.2.6 Organic carbon

The organic carbon content was low. Metson (1961) cited by Landon (1996) reported that organic carbon values less than 2% be considered as low. Studies done by Semoka *et al.* (1996); Mnguu (1997) and Bashiru (1992) on soils of Morogoro and Coast regions indicated that, soils from these regions are characterized by low organic carbon content. A low level of organic carbon in the study area is a reflection of low soil organic matter. This may be due to little accumulation of organic matter in the area. The low organic matter in the soil will likely affect the capacity of the soil to supply plant nutrients. The low CEC level in the soil supports this observation. In order to increase the organic carbon content of these soils for

maximum crop production, application of organic fertilizers, like farmyard manure, compost manure and industrial wastes like waste tea, waste tobacco etc need to be advocated.

4.2.7 Total nitrogen

Total nitrogen (N) of the soil of the study area was found to be low. N values of below 0.05% were categorized by EUROCONSULT (1989) low. The low content of N in the study area is probably due to low organic matter content following higher rates of organic matter transformation processes. The processes include, decomposition, mineralization and oxidation of the organic compounds, which normally take place in tropical soils, because of high temperatures and humidity, hence high microbial activities (Smith and Sanchez, 1980; Uehara and Gillman, 1981). The low content of nitrogen implies that, the soil is poor in supplying N and can therefore hardly support plant growth and development. Application of nitrogen rich fertilisers to this soil (organic/inorganic) for good crop production is inevitable.

4.2.8 Exchangeable acidity and aluminium

The exchangeable acidity and aluminium were 1.45 and 0.67 Cmol (+) kg^{-1} respectively. Aluminium toxicity is probably the most important growth limiting factor in many acid soils, particularly when pH is<5.0 to 5.5 (Landon, 1991). Root injury to many crops is a common problem associated with excessive amounts of aluminium in soils. Al^{3+} tends to accumulate in the roots and impede the uptake and translocation of calcium and phosphorus to the upper parts of plants. Excess Al^{3+} also

inhibits cell division and nodule initiation in plants. In maize, root development is retarded, consequently the roots becomes thick and stubby. Application of organic materials that will act as both, supplier of plant nutrients at the same time lower the negative effects of aluminium for Magadu soil is therefore important.

4.2.9 DTPA extractable micronutrients

DTPA extractable $Fe^{2+}$and Mn^{+} levels were very high while those of Cu^{2+} and Zn^{2+} were high and adequate respectively. According to Lindsay and Norvell (1987) 1 mg kg^{-1} Mn is adequate for plant growth. Foy *et al.* (1981) reported that, effects of manganese toxicity to plants, apart from occurring in soils with pH less than 5.5 sometimes do occur under less acid conditions in poorly drained or compacted soils. Lindsay and Norvell (1978) suggested 0.2 and 0.5-1.0 mg kg^{-1} to be the critical levels for Cu^{2+} and Zn^{2+} respectively.

4.3 Production and chemical composition of paper sludge and pyrethrum marc

When in full production capacity the Southern Paper Mills Company Limited (SPM), Mgololo, Mufindi, Tanzania, owned by the government of Tanzania through National Development Corporation (NDC) produces 51,840 tons of paper sludge per annum. On the other hand the factory owned by Tanzania Pyrethrum Processing and Marketing Company Limited (TPPMC) in Mafinga, Mufindi, Tanzania produces 3600-4275 tons of pyrethrum marc per annum.

4.3.1 pH

The results indicate that, paper sludge and pyrethrum marc had of pH of 7.59 and 4.73 respectively. Upon application of these wastes to the soil, the pH of the wastes will influence the soil's low pH. Application of paper sludge wastes with a high pH will blend with the soil's low pH and improve on the final soil pH. This will also improve on other soil properties like aluminium concentration and phosphorus fixation. The low pH of pyrethrum marc may lead to intensification of soil pH. However, the degree of change of the soil's pH will depend on the neutralizing capacity from $CaCO^3$ contained in the wastes (Joam *et al.*,2000). Ndaki (2001) reported increase in soil pH from 5.1 for the control to 5.8 following application of waste tea having a pH of 5.29. Increasing pH of acidic soils improves plant available of macronutrients while reducing the solubility of elements such as Al and Mn (Hue and Licudine 1999)

Table 2: Chemical characteristics of paper sludge and pyrethrum marc

Parameter	Type of waste	
	Paper sludge	Pyrethrum marc
pH in water	7.59	4.73
Organic carbon (%)	9.80	12.88
Total nitrogen (%)	0.26	1.90
Total phosphorus(%)	0.04	0.31
C/N ratio	37.7	6.78
C/P ratio	245	41.55
Total bases (%)		
Calcium	12.45	0.39
Magnesium	0.12	0.26
Potassium	0.12	2.47
Sodium	0.14	0.74
Ca/Mg ratio	105.22	1.56
Micro–nutrients ($mgkg^{-1}$)		
Manganese	333.4	107.55
Iron	543.71	901.85
Copper	21	14.4
Zinc	42.9	51
SAR	0.02	0.62

4.3.2 Organic carbon and total nitrogen

The total organic carbon, were 9.8% and 12.88% for paper sludge and pyrethrum marc respectively. EUROCONSULT (1989) rated percentage organic carbon contained in organic materials as >3.5 very high, 2.5-3.5 high, 1.26-2.5 medium, 0.6-1.25 low and <0.6 very low. Therefore, paper sludge and pyrethrum marc had very high % OC content compared to that of the experimental soil. Thus it is expected that when paper sludge and pyrethrum marc are applied to Magadu soil or any other soil with low organic carbon can improve the organic carbon content of the soil. Zhang *et al.* (1995) reported an increase in soil organic matter following addition of papermill sludge.

The total nitrogen of paper sludge and pyrethrum marc were 0.3% and 1.9% respectively. The calculated C/N ratio of paper sludge was 37.7:1 while that of

pyrethrum marc was found to be 7:1. Nguluu *et al.* (1997), Tripepi *et al.* (1996) Handayanto (1994) and Sims 1990) reported that materials with C/N ratio greater than 30:1 promote immobilization of nitrogen by microbial populations. Therefore nitrogen deficiency is likely to occur when paper sludge is applied to soils and no nitrogen deficiency is likely to occur in pyrethrum marc amended soils provided the nitrogen content in the soil plus that contained in the waste is sufficient for maize production. This makes pyrethrum marc a better quality amendment based on C/N ratios and total N.

4.3.3 Total Phosphorus

Paper sludge contained 0.04% phosphorus and pyrethrum marc had 0.31%. Singh and Jones (1976) found that, organic materials with phosphorus concentration less than 0.22% promote phosphorus immobilization when they are incorporated in soils. In view of this, phosphorus immobilization is likely to occur when paper sludge is added to soil. The C/P ratio of paper sludge and pyrethrum marc were, 245:1 and 41:1 respectively. On the basis of critical C/P ratio of 40–50 (White 1981) strong immobilization of phosphorus is to be expected when paper sludge is incorporated into the soil. To reduce the expected phosphorus immobilization,, supplement of phosphorus rich inorganic fertilisers is important.

4.3.4 Total bases

The total amount (%) of Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} in paper sludge were 12.45, .0.12, 0.12 and 0.0.14 respectively. Pyrethrum marc contained 0.39% Ca, 0.26% Mg, 2.4% K and 0.74% Na. The high level of Ca^{2+} found in paper sludge could have beneficial effects as a source of plant nutrients. This will also improve on the % BS of the soil and possibly reduce the concentration of Al and H^{+}. The concentration of Ca^{2+} and Mg^{2+} in wastes, are important in reducing the potential effect of Na^{+} (Bellamy *et al.*, 1995). High levels of Na^{+} in the wastes can result in deflocculation and reduce permeability especially in clay soils, and inhibit plant root development.

Ca/Mg is another measure of the suitability of organic residues as sources of nutrients for plant growth and liming materials. Paper sludge and pyrethrum marc had Ca/Mg ratio of 105/1 and 1.5/1 respectively. According to McGovern *et al.* (1983), for an organic waste to qualify as a liming material, this ratio should be at a minimum of 6/1. In view of the above ratios, paper sludge can be used, as a liming material while pyrethrum marc cannot. The sodium adsorption ratio (SAR), which is a measure of the effect of Na^{+} in reducing soil permeability, was 0.02 for paper sludge and 0.62 for pyrethrum marc. Basing on the guideline limit of 5.0 (OMAF, MOE 1992), the SAR for paper sludge and pyrethrum marc were well below the limit, indicating that sufficient Ca^{2+} and Mg^{2+} are present to counteract the negative effect of Na^{+} (Bellamy *et al.*1995; Berry *et al.*1980).

4.3.5 Total micronutrients

Total micronutrients content in paper sludge were, 33.4, 543.7, 21.0 and 42.90 mg kg^{-1} for Mn^{-}, Fe^{2-}, Cu^{2+} and Zn^{2+} respectively. Pyrethrum marc had Mn^{2+} levels of 107.55 mg/kg, Fe^{2+} 901.85mg kg^{-1}, Cu^{2+} 14.40, and Zn^{2-} 51.00mg kg^{-1}. According to guideline limits for trace and heavy metals in land applied wastes other than sewage sludge developed by OMAF, MOE (1992) which are Mn^{2+} 1500, Fe^{2-} 600, Cu^{2+} 1700 and Zn^{2+} 4200 (mg kg^{-1}), the metals in paper sludge and pyrethrum marc were well within the guideline limit. Based on these limits the addition of the metals to soil would not present accumulation problems.

4.4 Effect of industrial wastes on maize grain yield

Increasing rates of application of pyrethrum marc resulted in an increase in maize grain yield (Figure 2). On the contrary, increasing the rates of paper sludge had a negative effect on maize grain yield. Grain yield from 30 tons ha^{-1} pyrethrum marc treatment was significantly higher ($P<0.05$) than all other treatments. Yield from 20 tons ha^{-1} pyrethrum marc treatment was significantly higher than that of 30tons ha^{-1} for paper sludge and the control (Appendix 3). Also, maize yield from 30 tons ha^{-1} paper sludge was lower (non significant) than the control (Appendix 3). The higher yield in pyrethrum marc amended soils was probably attributed to its high nitrogen content in the material and the build up of other plant nutrients. The narrow C/N ratio of pyrethrum marc contributed to favourable conditions for mineralization of N provided other factors were not limiting, therefore, high yield was expected. Ndaki

(2001) obtained maize yield of 3.987, 3.90, 2.850, 2.730 and 1.660 tons ha^{-1} after applying waste tea, wattle bark chippings, waste tobacco, wood ash and sawdust respectively relative to the control of 2.060 tons ha^{-1}.

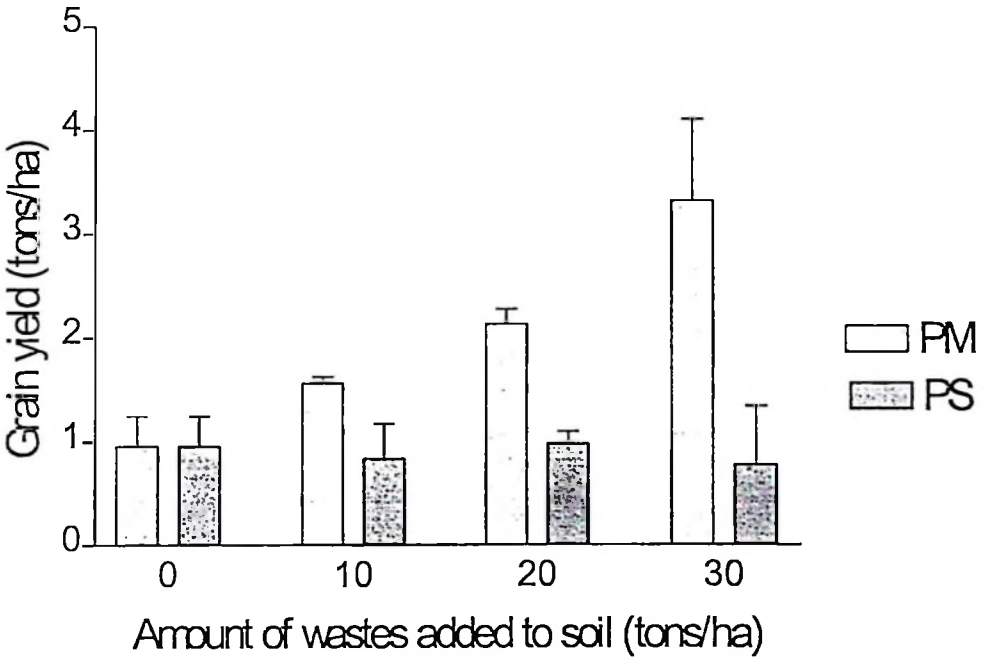

Fig. 2: Effect of organic matter application on maize grain yield

The average maize yield level in Tanzania is between 0.6-1.5 tons ha^{-1} and the potential yield is between 3.5 and 8.0 tons ha^{-1} (URT 1995, Kimaro, 1989). The yield from waste treated plots in this study ranged from 0.64-3.33 tons $^{-1}$ha, which is lower than the established potential maize yield level in the country. The results suggest that incorporation of the wastes to Magadu soil can lead to a build up of organic

matter which in turn will improve on the availability of plant nutrients and thus improve soil productivity.

4.5. Effects of industrial wastes on nutrient element in maize leaves

4.5.1 Effects of industrial wastes on N, P, K, Ca and Mg concentration in maize leaves

Nitrogen concentration for plants from pyrethrum marc amended plots increased with increasing rates of the material (Table 3). Plants grown on soils amended with 30tons ha^{-1} of pyrethrum marc gave highly significant total nitrogen concentrations than other treatments ($P<0.05$). Nitrogen concentrations in maize leaves from 20 and 10 tons ha^{-1} of pyrethrum marc treatments were significantly higher than paper sludge amended soils and the control. Chapman (1965) set the following ranges of nitrogen concentration in plants. N values <1.8% were ranked as deficient and those between 1.8 and 3.5% were ranked as low while those >3.5% were ranked adequate for maize growth for samples taken between 30 and 45 days after planting. Plants from paper sludge amended soils were deficient in N and all plants from pyrethrum marc amended soils indicated low N content. The low N content from paper sludge amended soils could be due to biological immobilization of nitrogen, which was attributed to very low N content and wider C/N ratio of the waste. In view of this rating, application

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

Treatment(tons ha^{-1})	N	P	K	Ca	Mg
0	1.34c	0.09ab	2.35b	0.03c	0.08a
10PS	1.58c	0.10ab	2.23b	0.09a	0.11a
20PS	1.53c	0.09ab	2.26b	0.10a	0.09a
30PS	1.49c	0.08b	2.24b	0.12a	0.11a
10PM	1.84b	0.11ab	2.48a	0.05b	0.11a
20PM	1.88b	0.12ab	2.43a	0.05b	0.11a
30PM	2.25a	0.15a	2.52a	0.08a	0.13a
CV (%)	12.34	22.06	5.79	0.23	16.66

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.

of paper sludge to cropland should be supplemented with inorganic nitrogen rich fertilisers to offset the deficient problem.

The influence of paper sludge and pyrethrum marc on the concentration of phosphorus in maize leaves was not statistically different in all the treatments except for soils amended with 30 tons ha^{-1} of pyrethrum marc which was fgsignificant ($P< 0.05$). Tandon (1993) suggested phosphorus values in maize plant < 0.3% as low, 0.3–0.5% as sufficient and >0.5% as high. In the light of this categorization, phosphorus concentration in maize plants was low in all the treatments. It is important therefore that, for satisfactory maize production at Magadu, incorporation of paper sludge and pyrethrum marc should be supplemented with the application of phosphorus rich fertilisers.

of paper sludge and pyrethrum marc should be supplemented with the application of phosphorus rich fertilisers.

The concentration of potassium in maize shoots ranged from 2.24 to 2.52%. Of the two wastes, the highest rate of pyrethrum marc (30tons ha^{-1}) gave significantly higher ($P<0.05$) potassium concentration than other treatments. The rest of pyrethrum marc amended plots were slightly higher than paper sludge and the control, with the control having K concentration higher (non-significant) than paper sludge amended plots. According to Tandon (1993) maize plant is said to have sufficient potassium if its concentration is in the range of 2.5–4.4.0%, the concentration of <2.5% is considered to be low and concentration > 4.4% is said to be high. In view of this, only soils amended with the highest rate of pyrethrum marc (30 tons ha^{-1}) gave sufficient concentration of plant potassium, the remaining treatments gave low potassium concentrations. The decreased levels of potassium in paper sludge amended soils relative to the control may probably be due to imbalance between calcium and potassium. Neilsen *et al.* (1997) reported imbalanced potassium nutrition in carrot and chard following application of organic wastes on sandy soils. Vound Nkana *et al.* (1998) reported potassium decrease in rye grass after application of paper pulp, the decrease persisted even after application of PK–fertiliser. Similar findings were reported by Bellamy *et al.* (1995). The results reveal the need to monitor nutrient concentrations after repeated use of organic wastes to avoid nutrient imbalance.

Calcium concentration in maize shoots from paper sludge amended soils increased with increasing rate of the material. Paper sludge amended plots gave significantly higher Ca concentration than other treatments. Pyrethrum marc amended soils gave significantly higher calcium level than the control. According to Tandon (1993) rating system, Calcium levels <0.3% are considered to be low, those between 0.3 and 0.7% are rated as sufficient and values >0.7% are said to be high. Thus, basing on this rating system, calcium concentrations in maize shoots were low in all the treatments. The significant increase in Ca in paper sludge amended soils reflected an increase in exchangeable Ca in the soil, since paper sludge contained significant amount of Calcium.

Application of paper sludge and pyrethrum marc to soil had no effect on magnesium content in maize leaves. Magnesium content in maize leaves ranged from 0.08 to 0.13%. There was no significant difference among the treatments. Tandon (1993) ranked magnesium concentration in maize plants as < 0.15mg kg^{-1} low, 0.15–0.45 mg kg^{-1} sufficient and >0.45 high. Basing on this ranking, all the treatments were in the low range. Application of magnesium containing fertilisers can improve on the level of magnesium in Magadu soil.

4.5.2 Effects of industrial wastes on plant Zn, Mn and Fe concentration

Plant Zinc, manganese and iron concentrations as influenced by paper sludge and pyrethrum marc are presented in Table 4.

Table 4: Effects of industrial wastes on Zn, Mn and Fe concentration in maize leaves (mg kg^{-1})

Treatment (tons ha^{-1})	Zn	Mn	Fe
0	12.01a	26.49bc	167.6b
10PS	12.50a	36.32abc	220.10a
20PS	12.02a	31.13bc	170.5ab
30PS	11.33a	21.14c	193.1ab
10PM	10.70a	30.27bc	170.6ab
20PM	11.83a	43.49ab	184.60ab
30PM	12.06a	53.19a	184.00ab
Cv (%)	14.76	32.29	12.95

Means in the same column followed by the same letter(s) are not significantly different according to the Duncan Multiple Range Test at 0.05 significance level.

Zinc concentration in maize leaves from paper sludge amended plots decreased (non significantly) with increasing application rate of the material, but the concentration of zinc in the leaves of pyrethrum marc amended soils increased (non significantly) with increasing rate of the wastes. The high amount of zinc in pyrethrum marc amended plots was probably due to high amount of it in the material over paper sludge. Zinc concentration in maize leaves ranged from 10.70 to 12.60 mg kg^{-1}. There was no significant difference among the treatments. Tandon (1993) suggested zinc levels <15 mg kg^{-1} in maize plants to be low, those between 15 and 70 mg kg^{-1} to be sufficient and levels higher than 70 mg kg^{-1} to be high. In view of this ranking, Zn concentration in all the treatments was low. Tandon (1995) reported that, the critical toxicity concentration of Zn for maize grown for 60 days is 60mg kg^{-1}. The amount

of Zn in maize leaves was well below this critical level, therefore, addition of paper sludge to soil cannot lead to toxic concentration in the plants.

Manganese content in plants was not affected by the application of paper sludge and pyrethrum marc. Tandon (1995) reported that, maize is among the good indicators of Mn deficiency and the critical deficient level to be 10-20 mg kg^{-1}. Basing on this ranking system manganese was found to medium in all the treatments. Edward and Asher (1982) on the other hand, reported that, the critical toxicity level of Mn in the shoots of maize is 200mg kg^{-1}. The concentration of Mn in the plants following application of paper sludge and pyrethrum marc, was therefore far below this critical toxic level, implying that short term incorporation of these wastes to soil will not result into accumulation of Mn to toxic levels in maize plants.

Iron concentration in maize leaves was slightly increased by paper sludge and pyrethrum marc application except for the 10 tons ha^{-1} paper sludge treatment. Tandon (1993) ranked iron concentration in plants as <50mg kg^{-1} low, 50–250mg kg^{-1} sufficient and >250mg kg^{-1} high. Therefore, basing on this ranking, iron concentration in all the treatments was in the sufficient range.

4.6. Effects of industrial wastes on soil properties

4.6.1 Effects of industrial wastes on soil bulk density, organic carbon, pH, total nitrogen and phosphorus

4.6.2 Bulk density

Application of paper sludge and pyrethrum marc had no significant effect on bulk density of the soil (Table 5). The bulk density in waste amended plots decreased with increasing rate of the material. The control treatment had bulk density slightly higher (non-significant) than other treatments. However, Ndaki (2001) reported a decrease in bulk density from 1.30 gm^{-3} in the control to 1.0 gm^{-3} in waste tea amended soil. Taylor *et al.* (1966) suggested that, bulk density values of 0.9 to 1.2 gm^{-3} to be normal for most recently cultivated soils. Bulk densities of all the treatments were above the critical levels suitable for maize production. However, these results suggest that repeated incorporation of wastes to magadu soil can reduce the bulk density to normal values, thus solve the problem of soil compaction and root development.

4.6.3 Organic carbon

Organic carbon in pyrethrum marc amended soils increased with increasing rate of the waste, while the organic carbon from 30 tons ha^{-1} paper sludge was the lowest for paper sludge amended plots. The organic carbon in pyrethrum marc treated soils ranged from 2.49 to 2.76% and that of paper sludge amended soils ranged from 1.40-

Table 5: Effects of industrial wastes on soil properties

Treatment(tons ha^{-1})	Bulk density gm^{-3}	%OC	pH	%N	P(mg kg^{-1}	Exchangeable bases (Cmol(+)kg^{-1}				CEC(Cmol(+)kg^{-1}
						Ca	Mg	K	Na	
0	1.50a	1.37b	5.28c	0.09c	0.31c	2.61c	1.64c	0.66b	0.71d	10.53c
10 PS	1.49a	1.64b	6.95ab	0.11c	0.06c	10.50b	1.85c	0.72b	1.55c	11.47bc
20 PS	1.47a	1.64b	7.45a	0.09c	0.07c	12.99a	1.76bc	0.71b	0.92cd	12.80abc
30 PS	1.46a	1.40b	7.79a	0.12c	0.06c	14.74a	1.59c	0.69b	0.77d	13.20ab
10 PM	1.46a	2.43a	6.20bc	0.19b	8.51bc	2.82c	2.20ab	2.14ab	2.48b	13.53ab
20 PM	1.44a	2.68a	6.38bc	0.20b	24.85ab	3.02c	2.56a	2.80ab	2.79b	13.73ab
30 PM	1.38a	2.76a	6.53b	1.26a	35.03	3.59c	2.60a	4.13a	3.73a	14.93a
CV (%)	2.87	21.80	7.13	19.13	10.9	15.48	13.73	25.80	21.51	10.74

Means in the same column followed by the same letter(s) are not significantly different according to the Duncan Multiple Range Test at 0.05 level of significance.

1.64%. Although there was an increase in organic carbon in soils treated with paper sludge relative to the control the increase was statistically non significant ($P<0.05$). The results show that repeated application of the wastes to Magadu soil will improve on the soil's low organic carbon, therefore improve on the other soil properties like water retention, bulk density, pH, and cation exchange capacity. The tremendous increase in %OC following application of pyrethrum marc was probably due to increased microbial biomass as a result of good biological environment caused by the wastes.

4.6.4 Soil pH

The pH of soils amended with paper sludge and pyrethrum marc increased as the amount of application of the wastes was increased. The pH in paper sludge amended soils ranged from 6.95 to 7.79 and that of pyrethrum marc amended soils ranged from 6.20 to 6.53. The pH of paper sludge amended soils was significantly higher ($P<0.05$) than those of pyrethrum marc amended soils and the control. Soil pH in soils amended with pyrethrum marc was slightly higher than the control except soils amended with 30 tons ha^{-1} of pyrethrum marc, whose pH was 6.53. This was significantly different from the control. The increase in pH for paper sludge and pyrethrum marc amended soils was probably attributed to high–neutralizing power probably resulting from formation of and carbonates of potassium and calcium. Ndaki (2001) reported increased pH in Magadu soil from 5.1 to 7.5 after application of wood ash. The optimal soil pH range for maize production is 6–7

(Purseglove1988). The application of paper sludge to agricultural land can serve as liming material, thus can be used as an alternative to commercial lime.

4.6.5 Total nitrogen

Total nitrogen in pyrethrum marc amended soils increased with increasing rate of the wastes and the increase was significantly different from paper sludge amended soils and the control. The amount of total nitrogen in paper sludge amended soils decreased with increasing rate of the material. There was no significant difference between soils treated with paper sludge and the control. Ndaki (2001) observed increase in soil nitrogen after incorporation of waste tea, waste tobacco, and wattle bark chippings similar to acidic soil. Low total nitrogen as a result of paper sludge application to soil could have been attributed to microbial immobilization of nitrogen due to its high C/N ratio (27:1). Decrease in soil nitrogen following application of paper sludge was also reported by, Aitken *et al.* (1998), Simard *et al.* (1998) and Bellamy *et al.* (1998). Landon (1996), rated total nitrogen values in soils of <0.2 as low, 0.2–0.5 as medium and >0.5 as high. Only 30 tons ha^{-1} of pyrethrum marc amended soils gave total N > 0.2, (medium). Although all the remaining treatments except 30 tons ha^{-1} pyrethrum marc elevated total nitrogen, level was still in the low range. This suggests that application of the two wastes to cropland should be supplemented with inorganic nitrogen rich fertilsers for better crop performance. Nitrogen content in soils amended with pyrethrum marc increased tremendously due to increased biomass due to conducive environment caused by the waste material.

4.6.6 Phosphorus

The rate of application of paper sludge and pyrethrum marc affected soil phosphorus differently. The amount of soil phosphorus in pyrethrum marc treated plots increased as the rates of the wastes were increased. The increase in the concentration of phosphorus in soils amended with paper sludge was related to the decrease in the rate of application of the waste. Soils amended with pyrethrum marc had significantly higher phosphorus than paper sludge amended soils and the control. There was no significant difference in phosphorus concentration between paper sludge treated soils and the control. Soils amended with higher rates of paper sludge (30 and 20 tons ha^{-1}) had lower phosphorus (non-significant) than the control. The low phosphorus level in paper sludge amended plots may be due to low phosphorus in the material and high C/P ratio (27/1). This would have promoted immobilization of P. White (1981) reported that strong immobilization of phosphorus should be expected when organic materials with C/P ratio greater than 50 are applied to soil. This explains why the lower rate of paper sludge was less affected.

4.6.7 Exchangeable Ca, Mg, Na, K and CEC

Soil analyses at harvest showed that the amounts of exchangeable bases in the soil were affected by the application of the industrial wastes. The increase in rate of application of the wastes resulted in an increase in Ca. Exchangeable calcium in paper sludge amended soils increased significantly ($P<0.05$) over the other treatments. Increase in calcium content in pyrethrum marc amended plots was not

different from the control. Simard *et al.* (1998) found that calcium levels in soils increased with increasing rates of paper sludge up to 30tons of paper sludge per hectare. The higher levels of calcium in paper sludge amended soils may be related to high amounts of the element in the material (12.45%). Vound Nkana *et al.*(1998) suggested that the increase in calcium concentrations in soils amended with paper pulp sludge to be caused chiefly by dissolution of calcium from paper pulp sludge. According to Landon (1996) ratings, exchangeable calcium values of <4 Cmol(+) kg^{-1} were ranked as low, those between 4 and 10 Cmol (+) kg^{-1} were ranked as medium, while values above 10 Cmol(+) kg^{-1} were ranked as high. With regard to this ranking, paper sludge amended soils fall under high status and pyrethrum marc treated soils contain low levels of exchangeable calcium.

Application of pyrethrum marc to soil resulted into elevated levels of exchangeable magnesium. The increase in the level of magnesium was associated with the increase in the rate of pyrethrum marc applied. The amount of magnesium in paper sludge amended soil decreased as the rate of the waste was increased and it was not significantly different from the control. The amount of exchangeable magnesium in pyrethrum marc amended soils was significantly higher ($P<0.05$) than other treatments. The enhanced mobilization of magnesium in pyrethrum marc amended soils can be explained by the displacement from exchange sites upon adsorption of dominant Ca (Voundi Nkana *et al.* (1999). Simard *et al.* (1998) suggested that the low values of magnesium concentrations in the 0-20cm layer of soils from plots amended with 45Mg ha^{-1} raw de-inking paper sludge should possibly be attributed to

higher amounts of organic ligands supplied with the material. Landon (1996) ranked magnesium levels in soils as <0.2; 0.2-0.5 and >0.5 Cmol(+) kg^{-1}, low, medium and high respectively. According to this ranking system, all treatments had high values of exchangeable magnesium.

The amount of potassium in paper sludge amended soils decreased as the amount of applied waste increased. The concentration of potassium in plots treated with pyrethrum marc increased with increasing rate of the material. Potassium concentration of 30 tons ha^{-1}, from pyrethrum marc was significantly higher than from paper sludge amended soils and the control. The concentration of potassium in other pyrethrum marc treatments was slightly different from the control and paper sludge amended soils. Landon (1996) ranked potassium values in soils of 0.03-0.2; 0.2-0.4 and 0.4-0.8 Cmol (+) kg^{-1} as low, medium and high respectively. Basing on the ranking given above, all the treatments in this study gave high values of exchangeable potassium.

Incorporation of paper sludge and pyrethrum marc into soil resulted in increased levels of exchangeable sodium. While the effect of pyrethrum marc on the level of exchangeable sodium was associated with increased rates of the waste, the amount of increase of exchangeable sodium in paper sludge treated soils was negatively influenced by the increase in the rate of paper sludge. The amount of exchangeable sodium in pyrethrum marc amended soils was significantly higher ($P<0.05$) than that of paper sludge amended soils and the control. The enhanced release of sodium after

from exchange site the application of the industrial wastes can be attributed to displacement of sodium from exchange sites by calcium.

Paper sludge and pyrethrum marc elevated cation exchange capacity (CEC) values relative to the control. The increase in CEC in plots treated with industrial wastes was associated with the increase in the rate of application of the waste. Cation exchange capacity of 30tons ha^{-1}, pyrethrum marc amended soils was highly significant ($P<0.05$) relative to paper sludge amended soils and the control. Cation exchange capacity of paper sludge amended soils was slightly different from the control except for that of 30ton ha^{-1} which was significantly higher than the control. Landon (1996) suggested CEC values of 5-15, 15-25, and 25-40 Cmol(+) kg^{-1} as low, medium and high respectively. Although CEC values in all wastes treated soils were elevated relative to the control, they were still in the low range. Despite the application of the wastes, the soil is still poor in chemical fertility, which can be rectified by supplementing with inorganic fertilisers or, repeated application of the wastes need to be adopted so that organic matter can build up and the CEC get improved.

The increase in soil nutrient contents may be explained by mineralization of paper sludge and pyrethrum marc supplying the C source and the nutrients necessary for microbial growth. Simard *et al.* (1996) found that soil alkaline phosphotase activities were increased by raw de-inking sludge. Also biological decomposition of paper

sludge and pyrethrum marc can produce a variety of organic acids that interact with soil minerals and increase soil nutrients solubility.

4.6.6 Effects of industrial waste on DTPA extractable, Mn, Cu, Zn and Fe

Paper sludge and pyrethrum marc caused a decrease in soil manganese content. The amounts decreased with pH increase (Table 6). DTPA extractable manganese in waste amended soils was significantly lower ($P<0.05$) than the control. The lower DTPA extractable Mn in waste amended soils was probably attributed to the increased pH. The findings are in agreement with those of Hue and Licudine (1997), which increasing soil pH of acidic soils reduces the solubility of elements such as manganese thus, reducing its negative effects. Tandon, (1995) reported that the range for manganese toxicity is 100-600mg kg^{-1}which is normally associated with a 10% reduction in dry matter yield. In view of this, incorporation of paper sludge and pyrethrum marc to soil reduced the potential Mn toxicity.

Incorporation of paper sludge and pyrethrum marc to soil resulted in reduced amount of DTPA extractable copper as compared to the control. The control treatment had significantly higher levels of DTPA extractable copper than waste amended soils. DTPA extractable copper was generally not significantly different among the treatments amended with wastes. Low levels of copper in soils amended with wastes was probably a result of

Table 6: Effect of Industrial wastes on soil Mn, Cu, Zn and Fe ($mgkg^{-1}$)

Treatment (tons ha^{-1})	Mn	Cu	Zn	Fe
0	70.06a	1.24a	0.51b	46.87a
10PS	21.72c	0.71b	0.51b	25.92b
20PS	18.36c	0.73b	0.63b	21.52b
30PS	12.82d	0.81b	0.62b	21.59b
10PM	47.64b	0.77b	1.40a	25.70b
20PM	46.27b	0.62b	1.57a	29.31b
30PM	45.48b	0.78b	1.56a	25.21b
Cv (%)	9.26	25.96	25.72	26.52

Means in the same column followed by the same letter (s) are not significantly different according to the Duncan Multiple Range Test at 0.05 level of significance.

copper being immobilized, and/or complexation with organic matter and adsorption. However, according to Sims and Johnson (1991) the normal range of copper for most soils, based on extraction by DTPA, is 0.1–2.5mg kg^{-1}. The values of DTPA extractable copper for this study are well within this range. Therefore, incorporation of paper sludge and pyrethrum marc to Magadu soil cannot lead to accumulation of the metal to toxic levels.

DTPA extractable zinc of pyrethrum marc amended soils was significantly higher ($P<0.05$) than paper sludge amended soils and the control. There was no significant

difference in zinc levels between paper sludge amended soils and the control. For all the treatments, the values ranged from 0.28 to 1.57mg kg^{-1}. Lindsay and Norvell (1978) suggested the critical value for DTPA extractable zinc to be 0.5-1.0 mg kg^{-1}. In addition, according to Sims and Johnson (1991) the normal range of zinc for most soils based on extraction by DTPA is 0.2–2.0mg kg^{-1}. DTPA extractable zinc for this study was within the said range. In view of this categorization system, paper sludge and pyrethrum marc amended soils were found to contain adequate zinc. Therefore, application of these wastes to Zn deficient soils can restore soil zinc to acceptable levels.

Paper sludge and pyrethrum marc reduced soil DTPA extractable iron significantly. The amount of DTPA extractable iron in the control soil was significantly higher ($P<0.05$) than other treatments. DTPA extractable iron of paper sludge was slightly higher than DTPA extractable iron from pyrethrum marc. The reduction in iron in wastes amended plots was probably attributed to formation of complexes by organic acids, which render iron unavailable. Increased soil pH in wastes treated plots, can also lead to precipitation of iron thus, reducing its availability.

4.6.7 Exchangeable acidity and Aluminium

Exchangeable acidity was found to be lower in both, paper sludge and pyrethrum marc amended soils than the control. Exchangeable aluminium was not detected in all wastes amended soils. This was probably attributed to increase in exchangeable Ca in the wastes treated soils. Ca released from dissolution of the wastes replaced Al on the exchange complex and Al was subsequently precipitated due to increased pH.

CHAPTER FIVE

5.0 SUMMARY CONCLUSION AND RECOMMENDATIONS

5.1 Summary and conclusion

The study soil was clay, compacted and acidic. The low pH value indicates that the soil will have nutritional problems for maize production. The associated problems include aluminium toxicity and strong phosphorus fixation. The level of P is generally low, implying that P might be one of the limiting factors for maize production. The levels of total N and % OC are also low, indicating poor chemical characteristics of the soil. The soil had low levels of exchangeable bases and CEC, therefore low in available nutrients and nutrient reserves. Generally, the soil was of low fertility status.

Paper sludge was rich in % OC, total Ca, and extractable micronutrients. It had low-test values for total N, P, Mg, K and Na. Paper sludge had a wide C/N and C/P ratios. The wide C/N and C/P ratios can cause microbial immobilization of nitrogen and phosphorus. Pyrethrum marc had adequate levels of % OC, total N, Ca, K, Mg and micronutrients. It also had very narrow C/N and C/P ratios. The narrow C/N and C/P ratios indicate that, incorporation of pyrethrum marc into soils cannot cause immobilization of nitrogen and phosphorus. Pyrethrum marc will also rapidly decompose. The level of micronutrients in both wastes, were well within the limits such that they can not cause environmental problems upon incorporation in the soil.

Paper sludge and pyrethrum marc blended well with the soil and improved soil pH greatly. The wastes reduced aluminium and manganese toxicity considerably. The addition of pyrethrum marc increased maize grain yields by 23% and had a positive effect on soil properties, conditions which qualifies it to be used as a source of plant nutrients.

Paper sludge supplied high contents of calcium, a condition that made it a strong neutralizing agent, therefore, it behaved more as a liming material rather than a source of plant nutrients. It can therefore be incorporated into the soil as a substitute for commercial limes. The study revealed that, total nitrogen and phosphorus content in soils treated with paper sludge were lower than in soils treated with pyrethrum marc, providing evidence of nitrogen and phosphorus immobilization, which were probably the major causes of the maize yield loss. Therefore, application of high rates of paper sludge should be avoided if the land is to be used for grain or cereal crops immediately thereafter, unless sufficient nitrogen and phosphorus rich inorganic fertilisers are added to reduce the C/N and C/P ratios so that nitrogen and phosphorus immobilization can be minimized. The study showed that no environmental contamination was associated with the utilization of paper sludge and pyrethrum marc in maize production.

5.2 Recommendation

(i) Research on the long-term (residual) effects of paper sludge and pyrethrum marc on environmental quality, physical and chemical properties of acid soils under maize production need to be established.

(ii) Evaluation of different combinations of paper sludge and pyrethrum marc wastes and inorganic fertilisers for economic production of maize should be conducted.

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7.0 APPENDICES

Appendix 1: Monthly mean rainfall distribution

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1991	140	3.5	68.2	221	59.4	2.9	2.9	29.6	9.6	6.7	17.7	184
1992	13.4	45.5	85	240	86.9	21.1	4.7	0.1	1.7	0	85.8	122
1993	32.1	157	118	296	85.3	12.7	4.4	3	2.2	45.8	37.4	0.8
1994	54	134.6	77.4	135.6	88.2	8.2	37	18.7	5.6	22.3	43.5	49.2
1995	142.2	98.5	202	245.2	134.2	0.0	1.3	28.9	13.1	78.7	0.6	74.4
1996	102.9	153.6	122.1	214.3	131.3	2.7	2.3	0	0	13.6	25.9	7.6
1997	13.8	61.6	146.6	238.9	34.1	38.6	9.8	2	0.9	83.6	98.6	242.3
1998	160	233.1	114.8	215.8	43.7	26.8	4.2	9.9	7.6	8.2	9.9	2
1999	116.1	29	186.2	200.7	95.3	26.8	38.7	21.3	16.1	11.5	35.7	60.6
2000	68.8	37.9	207.4	110.6	33.1	47.8	5.2	17.2	4.1	0	49.4	207
2001	104.1	99	172.5	224.6	90.4	4.6	0.6	0	0	11.1	0	72.3
2002	35.6	116.5	313.6	264.6	24.6	1.1						

Appendix 2: Monthly mean temperatures

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	25.4	27.0	27.0	25.7	24.2	21.9	21.5	22	23.3	25.3	26.5	26.4
1992	26.2	27.2	26.7	25.2	23.7	21.9	20.9	22	23.3	24.7	24.9	24.9
1993	26.4	26.0	26.0	24.3	24.2	21.7	20.7	21.6	22.9	24.2	25.8	27.6
1994	27.3	26.1	25.8	24.7	23.1	21	21.4	21.9	23.5	25.1	25.4	26.3
1995	26.3	26.2	25.7	24.5	23.3	20.7	21.4	22.6	23.4	24.8	25.8	27.5
1996	27	26.3	26.4	25.6	24	21.9	21.1	21.8	23.3	24.1	25.7	28
1997	28.2	27.8	26.7	25.6	23.7	22.2	21.8	22.6	24.1	25.1	25.9	25.6
1998	26.3	26.8	27.1	24.6	24.1	23.1	22.1	23.1	24.4	24.7	26.4	28.3
1999	27.9	26.6	26.1	25.4	24.2	22	22.4	22.1	25.9	24.9	26.3	25.1
2000	27.4	26.4	26.2	25.4	23.8	22.7	21.5	22.7	23.5	25.5	27.2	26.3
2001	26.1	25.2	26.7	25.7	24.3	23.3	22.4	23.2	24.9	27	27.9	26.8
2002	22.6	22.0	21.8	21.1	21.5	22.0						

Appendix 3: Effect of industrial wastes on maize grain yield

Treatment (tons/ha)	Grain yield (tons/ha)
0	0.78c
10PS	1.18bc
20PS	0.96bc
30PS	0.64c
10PM	1.56bc
20PM	2.14b
30PM	3.33a
CV (%)	41.21

Means in the same column followed by the same letter (s) are not significantly different according to Duncan Multiple Range Test at 0.05 level of significancy.