THE AGRONOMIC EFFECTIVENESS OF LIQUID MANURE EXTRACTS DERIVED FROM COMFREY (*Symphytum officinale*) AND TITHONIA(*Tithonia diversifolia*).

By

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A Dissertation submitted to the University of Zambia in partial fulfillment of the requirements for the degree of Master of Science in Agronomy.

The University of Zambia

DECLARATION

I, Dina Mambwe, do hereby declare that this dissertation is my own work, and to the best of my knowledge has never been submitted for the award of a degree at this or any other University.

Signature..

Date....04.08.09....................................

CERTIFICATION OF APPROVAL

The dissertation of Miss Dina Mambwe is approved as fulfilling the requirements for the award of the degree of Master of Science in Agronomy by the University of Zambia.

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ABSTRACT

Greenhouse and field studies were conducted to evaluate manure extracts and their effect on crop yield and selected soil chemical and microbial properties. For the green house study, comfrey and tithonia plant materials were each used at rates of 0.0625, 0.0935, 0.125 and 0.156 kg per litre of water. The experiment was laid out as a completely randomized design. For the field studies, six combinations of comfrey and tithonia were used at 0 kg, 0.156 kg comfrey, 0.156 kg tithonia, 0.0781 kg comfrey + 0.0781 kg tithonia, 0.117 kg comfrey + 0.0391 kg tithonia and 0.0391 kg comfrey + 0.117 kg tithonia per litre of water. The experiment was laid out as a randomized complete block design Two sites; Kasisi Agricultural Training Centre (KATC) and Mount Makulu Agricultural Research Station (MARS) were used for the field studies, and rape and tomato were used as test crops.

Application of manure extracts increased biomass yield of rape to between 2.8g (DM) per pot (comfrey 0.0625 kg) and 12.79g (DM) per pot (tithonia 0.125 kg). The leaf biomass increased with increased biomass of comfrey, while no particular pattern was observed for tithonia. Similarly, the application of manure extracts increased the biomass yield of tomato to between 6.67g (DM) per pot (comfrey 0.0625 kg) and 13.99g (DM) per pot (tithonia 0.0938 kg).

Mixing of comfrey and tithonia residues in the preparation of their manure extracts resulted in increased tomato yield to between 5.2 tons ha^{-1} (0.0391 kg comfrey + 0.117 kg tithonia) and 9.5 tons ha^{-1} (0.156 kg comfrey) for KATC and 32.7 tons ha^{-1} (0.156 kg comfrey) and 40.2 tons ha^{-1} (0.156 kg tithonia) for MARS. Furthermore, soil pH, P, K, Ca, Mg were positively influenced by the application of manure extracts. Although the extracts had high EC values, these did not have a drastic effect on the soil.

To Annastasia for her life, you have and always will be an inspiration to me.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisor, Prof. O.A. Yerokun, for his guidance and patience. He never gave up on me, even at times when I personally felt I could not do it anymore. I should particularly thank him for encouraging and supporting me to enroll in this masters program.

I wish to extend my gratitude to my second supervisor, Dr M. Mataa for his guidance and contribution during my research and course work. Your suggestions helped at a time when I needed encouragement.

I wish to thank the Ministry of Science and Technology, for granting the financial support to do my studies. I also wish to thank ODDISSA for the financial support rendered during my research year and Kasisi Agricultural Training Centre for facilitating my field studies and some of the organic materials.

I would like to thank my class mates; Mrs. Banda, Mr Muleya, Fr. Dondo sj, Mr Chirwa and Mr. Mateyo for their support during my studies. Just having others in my position made things easier.

I would like to thank my colleagues from the soil chemistry laboratory, ZARI, who accommodated me during my research year. Thanks also to Malambo Chijoka and Kelvin Munsanje.

To Clement and Hope, you are my family and have always been there to support me. Liwanga, thanks for being so understanding and supporting me in all I did. You were there to encourage me and urge me on whenever I was at my lowest and felt I just couldn't do it.

To God Almighty, thank you for creating me and showing me my purpose in life.

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Chapter One

1.0. INTRODUCTION

Low crop productivity is a significant challenge to attaining food security among small scale farmers in rural communities of Africa. Yet the "Green Revolution"of Asia of the 1960s demonstrated that given adequate input, small scale farmers are capable of high crop productivity (FAO, 1998). It has been argued that use of low nutrient input by farmers and cultivation of old fragile soils are among the reasons for the poor performance of sub- Saharan farmers (Palm *et al.*, 1997). Hartemink (2003) reported that there was a decrease in fertiliser use from 10% of expected quantities in the 1970s to 3.4% in the 1990s in Southern Africa. There was an average fertiliser use of 8 kg nutrients per hectare of arable land and land under permanent crop in 1990. This was low compared to the world average of 93 kg ha^{-1}. Yet it has been repeatedly observed that small scale farmers appear to be unable to afford high and escalating prices of inorganic fertilisers. For instance, in Zambia between January and September 2008 fertiliser prices rose from ZMK 135,000 to 225,000 for a 50 kg bag of urea (46% N) fertiliser which is the most commonly used top dressing fertiliser. Hence alternative and affordable options are required.

It is a well established concept of plant nutrient efficiency that plants use available nutrients best when soil organic matter level is adequate. Soil organic matter itself also contributes nutrients to plants and improves soil physical properties. Since organic matter is a largely cheaper source of soil amendment, small scale farmers have been encouraged to use it judiciously. Hence the use of organic fertilisers for the improvement of crop yields is becoming a common trend. Normally this is applied as green or dry plant biomass or obtained from animal sources (manure). An emerging form of manure application is commonly referred to as manure extract or manure tea. The manure extracts are prepared by suspending the materials in a barrel of water for varying periods before use (Diver, 2002). These periods range from one hour to as long as two weeks or more depending on the decomposition rate of the materials. The extracts are then applied to the soil through drenching or sprayed on the crop leaves. Many small scale farmers prepare manure extracts from different materials and at rates that are not specific. It is important therefore to look at probable rates and combinations of these organic fertilisers to improve crop yield and at the same time improve soil fertility.

There has been concern in some quarters that inorganic fertilisers pose risks from human ingestion of residual toxins from the chemicals used. It is further argued that inorganic inputs do not align well with the concept of sustainable agriculture which the USDA (Natural Resource Conservation Service -NRCS) define as "a way of practicing agriculture which seeks to optimize skills and technology to achieve long-term stability of the agricultural enterprise, environmental protection, and consumer safety" (Gold, 2007). This has called for the need to develop effective but non toxic ways of improving soil fertility and controlling diseases/pests.

Experiments carried out on organic residues and their impact on crop yield have given varied results. In a study conducted by Lundström and Lindén, (2001), little or no differences were observed in maize grain yield upon the application of organic fertilisers. When compared to unfertilised land, it was found that meat bone meal and chicken manure increased grain yields only moderately (600 to 1500 kg ha^{-1}) at application rates of 40 to 120 kg N ha^{-1} compared to an unfertilised control. On the other hand, Mugwe *et al.* (2009) recorded increased grain yield of maize upon the application of organic residues. *Colliandra calothyrsus, Leucaena trichandra* and *Tithonia diversifolia* were applied alone or in a 1: 1 ratio with an inorganic fertiliser to give a total of 60 kg of N. The maize yield was generally higher when the organic residues were used alone than when the inorganic fertiliser was used alone.

Manure extracts of various kinds have been known to raise crop yields. The extracts are often used as a top-dressing to supplement basal applications of manure or compost. In the studies carried out in West Africa by Gachimbi *et al.* (2004), it was noted that the use of tithonia as a green manure gave lower yields relative to the combination of tithonia and an inorganic fertiliser. However, when tithonia was used as a green manure and a top dressing of tithonia extract was applied, the grain and stover yield of maize increased substantially. The plots that were treated with farm yard manure mixed with inorganic fertilisers also gave high yields. Manure extracts have in addition been known to contain plant growth inhibition chemicals (Tongman *et al.*, 1997) as well as protect crops from termites (Adoyo *et al.*, 1997).

From the foregoing observations it was imperative to look at specific effects of manure extracts in relation to soil and crop improvement. This study was therefore set up to look at specific effects of manure extracts in relation to soil and crop improvement. It was hypothesised that; 1) increasing the biomass weight of tithonia and comfrey in the preparation of their liquid extracts would result in increased rape and tomato biomass production and 2) combining tithonia and comfrey biomass in the preparation of their liquid extracts would lead to increased crop yield of tomato and improve soil nutrient levels, pH and other soil chemical and biological properties, compared to either extract used alone. The objectives of the research were therefore to; 1) determine the optimum biomass of tithonia and comfrey in the preparation of their liquid extracts and 2) evaluate the effect of tithonia and comfrey liquid extracts and their combinations on crop yield, soil nutrient levels, pH and other soil chemical and biological properties.

Chapter Two

2.0 LITERATURE REVIEW

2.1. General overview

The productivity and quality of any given soil is greatly influenced by the management practices that are done on the land (Kaffka and Koepf, 1989; Truter, 2002). On the other hand, poor management practices tend to reduce the soils' ability to support crop growth. For example, the continuous use of nitrogenous fertilisers has been known to cause soil acidity (Wong *et al.*, 2000). The application of plant and animal residues replenishes soil nutrients. Under organic systems, high nutrient levels have been shown to accumulate. However, the amounts available for crop uptake are usually less than crop requirements creating a deficit in the soil. Many small scale farmers grow crops on the same piece of land for years without replenishment of nutrients leading to the loss of nutrients, as they are exported in the harvested crops or lost through leaching or erosion. According to Sanchez *et al.* (1997), most countries in sub Saharan Africa have soils with low available nutrients. Furthermore, the depletion levels are as high as 22 kg N, 2.5 kg P and 15 kg K ha^{-1} $year^{-1}$. The situation has not been different for Zambian soils where the following have been reported; a decrease in the levels of soil organic matter, pH, cation exchange capacity and plant nutrients (Munsanje, 2007; Phiri and Mwale, 2003).

Soil fertility amendments may be done through the application of organic materials such as animal manure (chicken, cow dung), leguminous plants (eg. Leuceana (*Leuceania* spp), sesbania (*Sesbania sesban*), sunhemp (*Crotalaria* spp) or non leguminous shrubs (Hartemink, 2003). Crop residues contribute a major fraction of a crop's total dry matter production and could contain significant amounts of nutrients that can be taken up by plants and be utilised. These sources contain different levels of nutrients and will release the nutrients at different rates (Palm *et al.*, 1997). The rate of decomposition is primarily determined by the quality of the material which is governed by the relative ratios of lignin, cellulose, carbohydrates and the presence of polyphenols (Palm and Rowland, 1997).

2.2. Use of organic compared to inorganic fertilisers for crop production.

Many studies have been conducted to compare crop yields under organic and inorganic systems (Palm, 1995; Ho, 2005). Generally, lower yields have been observed under organics in the short term. However, in the long term, organic and inorganic yields are usually comparable. The benefits of organic agriculture are thus obtained in the long run due to organic matter accumulation which is accompanied by nutrient build up. Due to the low nutrient levels in most organic materials, large amounts of materials are required to achieve moderate yield increases. Some of the organic materials have alternative uses which makes their availability even scarcer (Sanchez *et al.*, 1997).

In the attempt to compare crop yields between conventional inorganic and organic farming, it is generally reported that productivity is higher under conventional systems (Palm *et al.*, 1997). A survey of maize yield on commercial and organic mixed crop-animal farms in the USA in the 1970s recorded crop yields to be 8% lower on the organic farms (Lockeretz *et al.*, 1980). However, other reports have shown that in the medium to long term, yields under organic systems attain equilibrium similar to or higher than in conventional systems. This is demonstrated by observations in Zambia at Kasisi Agriculture Training Centre (KATC) in Lusaka where during the 2000 cropping season crop yields were only about 40 – 60 % of those from conventional plots (Ho, 2005). However in successive years up to 2004 yields in organic plots approached those in conventional plots until they were comparable. This observation was explained by various reasons. In principle, the lower yields obtained in organic systems have been attributed to the generally low content of the major plant essential elements in most organic materials. This is particularly so for phosphorus (P) whose content is usually lower than that of potassium (K) and nitrogen (N). On the other hand, one of the key factors that has been attributed to reduction of crop yield under conventional agriculture is soil acidification which makes nutrients like P to be less available for plant uptake (Munthali, 2007).

2.3. Use of organic fertilisers for crop yield improvement.

The effectiveness of organic manuring may depend upon the source of biomass. One source that has shown significant success in use in Africa is tithonia (*Tithonia diversifolia).* Babajide *et al.* (2008) observed increased fruit yield in tomatoes when grown under composted tithonia in combined with inorganic fertilizer. Three rates (0, 3, 6 tons ha^{-1}) of tithonia compost were combined with three rates of urea (46% N) at 0, 30 and 60 kg N. The combinations were made in such a manner as to give a total N of 60 kg ha^{-1}. Fruit yield and other crop parameters increased with increased level of sole or combined application of tithonia compost and inorganic N fertilizer. The combination of 30:30 kg N (compost:inorganic fertilizer) was found adequate for crop growth and yield improvement (32.2 tons ha^{-1}). This was similar to the yield from the sole application of compost (27.8 tons ha^{-1}). On the other hand, the yields from the plots treated with sole urea (10.1 tons ha^{-1}) were similar to those obtained in the control were no fertilizer was added (6.2 tons ha^{-1}). Furthermore, soil physical and chemical properties improved with increased compost rate.

In an experiment carried out by Ganunga *et al.* (2005), the application of tithonia (*Tithonia diversifolia*) to maize at three different rates of 1.5, 3.0 and 4.5 tons ha^{-1} resulted in high maize yield. The yield from the lowest rate was on average 108% higher than in the plots where no fertilizers were added while the yields from the 3.0 and 4.5 tons ha^{-1} application were comparable to those where 90 tons N ha^{-1} of inorganic fertilizer was applied. Similarly, work done in the high rainfall areas of Zambia (Malama, 2001) showed a maize- grain yield increase of 180 and 233% when tithonia was incorporated into the soil, relative to the control where no fertilizers were applied. Jama *et al.* (2000) also recorded yield increase of low land rice, vegetables and maize in East and Southern Africa upon the application of tithonia biomass.

In another experiment, when tithonia and inorganic fertilisers were applied in combinations and solely on P deficient soils, it was observed that the maize grain yields and P recovered in biomass were higher for tithonia alone compared to inorganic fertilisers alone (Nziguheba *et al.*, 2005). The combinations were in such a manner as to give a standard total of 165 kg N ha^{-1}, 15.5 kg P ha^{-1} and 155 kg K ha^{-1}. Based on the results, it was concluded that economic benefits were through the application of tithonia alone although combinations were also giving high yields. In a pot experiment by Yung-Yung-Yu Shu (2005), Pea-Rice hull Compost (PRC) and Cattle dung-Tea Compost (CTC) were found to influence the yield of rice differently. The plant height, straw growth and nutrient uptake of the rice plants with the PRC treatment were the highest among all the treatments, at the maturity stage. The response was attributed to their nitrogen composition. A comparison with conventional chemical treatment indicated that effect of the composts on rice growth and nutrient uptake was conspicuous in the second crop, compared with that of routine treatment of chemical fertilizer.

Although most of the commercial agricultural production in Zambia heavily depends on the use of inorganic fertilisers and synthetic agro chemicals, a significant number of small scale farmers do not use them. These farmers contribute about 60 % of maize output, which is the major crop in Zambia (Saasa, 2003). The number of small scale farmers using organic methods of crop production has increased particularly since 1999. In the same period organic producers have developed strategies of organising themselves as a unit and in the process formed the Organic Producers and Processors Association of Zambia (OPPAZ) which has a number of roles including that of advocacy. Out of the 1,000,000 small scale farmers in the country, it is estimated that 20,000 have been certified organic producers, while 19 commercial farmers are also certified (OPPAZ, 2008).

2.4. Use of manure extracts for yield improvement

The effectiveness of manure extracts in the improvement of crop yield as well as reduction of disease incidence has also been studied extensively. There is however, limited documentation concerning specific effects of manure extracts under various systems (Kalbitz *et al.*, 2000; Welke, 2004). Research on the use of manure extracts has mostly been done in temperate regions, with a few studies in West and East Africa. The information generated from these works has been fragmented and inconsistent, making it difficult to directly implement in areas outside the study areas.

Work reported in BIOMASA (2000) showed a 26 to 30% yield increase was recorded in a number of vegetables and maize when moringa *(Moringa peregrina*) liquid extracts were used. Another study by Mudenda and Yerokun (2008) showed an increase in biomass production of maize when cow dung and chicken manure extract were used. Two rates at 15 and 30 kg/210l water of chicken and cow dung were used alongside 250 kg D Compound (10: 20: 10 kg of N: P: K) ha^{-1} and 3.0 and 6.0 tons conventional chicken and cow dung manure. The highest dry matter production was found in the pots that were treated with D compound while the 15 kg/210l chicken manure extract gave the highest yield among the manure extracts. Furthermore, it was observed that higher maize biomass yield (13.4 g per pot) was obtained when extracts prepared from 15 kg of chicken manure were used compared to the same rate of dry manure which gave maize biomass yield of 11g per pot. The yield from the pots with dry manure was attributed to the native soil fertility. Furthermore, studies by Welke (2004) demonstrated that the method of preparation of manure extracts has an influence on crop yield. It was observed that aerobically prepared cattle manure extracts improved yields of strawberries to 1.7 tons ha^{-1} relative to the anaerobically prepared extracts and control which had 1.5 and 1.36 tons ha^{-1} respectively.

In another experiment, extracts of tithonia and cassava peels increased the yield of flutted pumpkins (*T. Occidentalis*) to levels that were comparable to those under the recommended NPK fertiliser for leafy vegetable crops (Akanbi et al., 2007). It was however observed that a 1:2 dilution of extract to water gave higher yields (20.9 ton ha^{-1}) compared to 1:1 and 1:3 dilution ratios (14.7 and 19.9 ton ha^{-1}, espectively). The control were no extracts were applied gave a total shoot yield of 7.04 tons ha^{-1} while the recommended NPK rate gave a yield of 18.19 tons ha^{-1}. Analysis of the shoot nutritional contents of the fluted pumpkin plants indicated slightly higher levels in the crop treated with foliar sprays than those with soil incorporated NPK.

2.5. Influence of manure extracts on soil chemical properties.

Compared to most parts of the world, sub Saharan Africa has been found to have low plant available nutrients (Smalling, 1995). This can be attributed to weathering, leaching, depletion of organic matter (Craswell and Lefroy, 2001; Hossner and Juo, 1999), soil acidification and loss of biological life (Truter and Rethman, 2000). Traditionally, soil nutrient replenishment relied on the practice of fallow (Mugwe *et al.*, 2009). However, this can no longer be relied on considering that there is increased human population and demand for food. There is also limited land to leave for fallowing. This has led to limitation in the land that can be left under fallow. A fertile soil has been defined as one which can adequately supply nutrients, water, favourable pH and has a good structure and a rich soil borne-organism bio diversity (Gaskell *et al.*, 2008). The use of organic inputs is essential to maintain adequate physical, chemical and biological properties of soils. What follows is a discussion of how specific soil chemical parameters are affected by the application of organic inputs, particularly manure extracts.

2.5.1. Soil pH

Manure extracts have been observed to raise soil pH levels similar to a liming effect (Wong et al., 2000). In an experiment by Mudenda and Yerokun (2008) soils treated with manure extracts recorded an average rise of pH to 6.21 and 6.76 from an initial 5.9. The inorganic fertiliser treatment depressed the pH to 5.32. Martin and Duddles (1984) recorded a pH of 7.3 for chicken manure extracts compared to a pH of 6.0-6.5 under hydroponics.

Sakala *et al.* (2004) demonstrated that the source of pH rise upon the application of organic residues is the protonation of organic ligands by water molecules. In their studies, the washing of seven organic residues resulted in reduced alkalinity by 23 to 86%. A positive relationship was observed between total cations mineralised and base deficits, which suggested that the bases released were responsible for the alkalinity of the plant residues. This was explained by the high levels of organic anions and bases in the plant residues which are the sources of alkalinity.

Gower *et al.* (1995) attributed the addition of excess protons relative to output as the source of soil acidity. This was in an experiment in which soils in unpopulated areas that had higher levels of H^+ and NH_4^+ relative to Cl^-, SO_4^{2-} and NO_3^- recorded lower pH levels. In other experiments however, the mineralisation of organic matter has been found to reduce pH (Morachen *et al.*, 1972; Maurya and Gosh, 1972). Application of alfalfa residues at 16 tons ha^{-1} lowered pH from 5.3 to 5.1 over a three year period. This was attributed to the production of organic acids (Motomura, 1962).

2.5.2. Soil salinity

Soil salinity, which is measured by the presence of excessive levels of dissolved inorganic solutes (Cl^-, HCO_3^-, SO_4^{2-}, Na^+, Ca^{2+}, Mg^{2+}, K^+ and NO_3^-) is generally assessed through the Electrical Conductivity (EC) of a saturation extract (Miyamoto, 2006; Bernstein, 1975). This means therefore that the addition, and eventually decomposition of organic matter could lead to increased EC because of the mineralization of ions (Sanchez, 1976). It can be postulated that the preparation of manure extracts leads to dissolution of inorganic solutes.

High EC has been observed to reduce shoot and root growth of crops (Gutierrez *et al.*, 2008). The high EC in soils has among other reasons been attributed to irrigation water, the addition of materials with high inorganic solutes or parent material from which the soil is formed. Manure extracts have also been reported to have a similar effect (Mudenda and Yerokun, 2008). Erozel and Ozturk (1996) observed that irrigation water effected salt accumulation in the soil during the whole growing season when five different electrical conductivity levels of irrigation water were used (0.25, 1, 2, 4 and 6 dS/m). Furthermore, carrot crop was used to observe the effect of EC on crop growth. It was observed that increased EC led to reduced carrot yield, with a progressive lysimeter decrease of 410.4, 352.1, 288.5, 235.0 and 212.9 g for the 0.25, 1, 2, 4 and 6 dS/m treatments, respectively.

Shalhevet and Yaron (2004) observed that processing tomatoes produced 10% fruit yield when grown in artificially salinized plots compared to regular plots. The study further revealed that there was reduction in plant water uptake as a result of increase in soil salinity. Papadopoulos and Rendig (1983) also reported a marked reduction in the fruit yield of tomato when they grew tomatoes with saline soils of ECs of 1, 2, 3, 4, and 5 dSm^{-1}.

2.6. Plant nutrient contribution of manure extracts.

Organic residues have been observed to be a good source of nutrients, particularly for N, P and K. Nitrogen and phosphorus have been found to be the most limiting factors for general crop growth (Manu *et al.*, 1991). Nitrogen constitutes 50 % of all required nutrient inputs for crop production and is important for vegetative growth and chlorophyll formation (Akanbi *et al.*, 2005). Phosphorus is essential for energy metabolism, cell root formation and for seed and fruit formation (Van Straaten, 2007). Another essential element is K, which is important for flower formation, disease resistance and osmo-regulation. Potassium deficiency in crops is common in continuously cultivated fields which have few or no inputs of crop residues or animal manure (Hanson 1992). The importance of other elements can not be under scored. While most organic sources of fertilisers provide N, P and K, they are also a good source of Ca and Mg (Gachengo *et al.*, 1999).

Manure extracts are potentially a faster nutrient release source compared to dry manures (Mudenda and Yerokun, 2008). It has been observed that soaking of manures makes the nutrients they contain readily available compared to dry application of their leaves (Mafongoya *et al.*, 1997; Otuma *et al.*, 1998; Brinton *et al.*, 2004). Giskin and Nelson (1984) observed that 90% of foliar applied nutrients were detected even in the smallest roots of the plant within 60 minutes of application. The effectiveness of liquid application of fertilisers over dry application was found to be between 8 to 10 times more.

Several factors have been known to govern the availability of nutrients in manure extracts. Among them being the nature of the structural compounds in the materials, the duration of extraction, the sources of the materials, the age or plant part of the materials being used, the method of preparation, the concentration used, the kind of substrate and soil amended, and the crop being tested (Blunden, 1991).

It has been suggested by Tenney and Waksman (1929) that the quality of organic matter is affected by the contents of water soluble compounds, hemicelluloses, cellulose and other compounds which affect the rate of decomposition. Tithonia and comfrey for example are less lignified relative to other sources like cassava or rice peels. Akanbi *et al.* (2007) recorded a faster rate of release of nutrients in tithonia than cassava peels when the two sources were prepared over a period of seven days.

2.6.1. Extraction time of manure extracts

The fast release of nutrients during the preparation of manure extracts is desirable, more so when the nutrients released are required during the early stages of plant growth (Ladd *et al.*, 1981). However, a balance in the release of these nutrients is critical. Sakala *et al.* (2004) observed a rapid release of K and Mg upon washing of organic residues. This was not the case for N which was released over a period of time. The slow release of ammonium and conversion to nitrate could potentially be desirable as the application of excess N could lead to its loss through leaching (Murwira and Kirchman, 1993).

Munsanje, (2007) observed a reduction in P and Ca during the preparation of manure extracts of tithonia. This occurred until the third day of preparation after which a steady increase was observed until the fourteenth day of preparation. On the other hand, ammonium increased steadily from day 1 with a peak at day 14 after which there was a reduction while nitrate was stable over the fourteen day period. This is supported by the observations made by Martin and Duddles (1984) who recorded stability in nitrate, relative to ammonium which increased steadily to the fourth week. From this information it was concluded that extraction time was critical to nutrient availability although the extent of the availability of nutrients to the plants beyond the fourth week of extraction is not known.

2.6.2. Method of preparation

Bertran *et al.* (2004) conducted studies in which two residues of sludge and grape stalks were mixed in two proportions of 1:1 and 1:2 (sludge: grape stalks) and composted. The results showed that the proportion of 1:2 performed better relative to the 1: 1 ratio. It was also observed that optimum results required moisture around 55% and a maximum temperature around 65°C and an oxygen concentration not lower than 5–10%. Furthermore, grinding the grape stalks made a better compost.

2.6.3. Frequency of application

At Kasisi Agricultural Training Centre (KATC), it was observed that frequent application of manure extracts over a four week period promoted increased crop response through increased vigour (KATC, 2004). On the other hand Gachengo *et al.* (1999) found that a single application of manure extracts at the beginning of the planting season was significant to provide residual effect to a second season crop. Uptake of soil nutrients by the first crop was approximated to have been 25%, with 75% being recovered by the subsequent crop. This was based on the changes in the total loss from nutrients although some of the loss was attributed to leaching.

2.6.4. Source of materials used as organic fertilisers.

Locally available non traditional plant materials could potentially be used to complement or substitute the currently available commercial fertilisers. These manures could contribute to reversing the trend of declining soil fertility and raise crop yield on small scale farms (Ganunga *et al.*, 2005). An analysis of most manures has shown them to have high nutrient levels (Anderberg, 2004). Several of these manures grow as weeds and are often not utilised by the local communities. Among the commonly used ones in the preparation of manure extracts are comfrey and tithonia.

2.6.4.1. Comfrey (*Symphytum officinale*).

Comfrey is a deep rooted crop whose roots can be as long as 3 m or more enabling it to draw and accumulate nutrients from the soil (Anderberg, 2004). It grows in almost any type of soil and is a hardy perennial which is propagated through seeds or sprouts from sections of severed roots. It can be eaten as a vegetable and has been found to have high medicinal value. The low levels of fibre in the leaves of comfrey play a dominant role in the quick break down to a thick black liquid. It is a high source of K, normally containing 2 to 3 times more K than farmyard manure (Wikipedia, 2007). Hence comfrey is especially beneficial to vegetables like tomatoes, peppers and cucumbers. Comfrey also contains N, P, Ca, Si, Fe, Mg and vitamins A, C and B12 (Organic Farming Research Foundation, 2008). Comfrey leaves have been analysed and recorded 1.8: 0.5: 5.3% for N: P: K respectively.

2.6.4.2. Tithonia (*Tithonia diversifolia*).

Tithonia, commonly known as false sunflower is a common shrub which is originally from Central America but now grows wildly in most humid and sub humid tropics of Africa. It can be used as fodder, poultry feed, fuel wood, compost or pesticide (Akanbi *et al.*, 2007; Jama *et al.*, 2007) and is easily propagated from seeds or cuttings. It grows quickly up to a height of 1 – 3 m. It has a high rate of accumulation of N and P from the soil (Swift, 2007). Nagarajah and Nizar (1982) determined the characteristic levels of nutrients in several tithonia samples. They analyzed 100 samples of tithonia leaves and tender stems from Sri Lanka which gave an average N: P: K of 3.2 –5.5: 0.2 –0.5: 2.3-5.5%. This was later supported by Jama *et al.* (2000) who reported an average N: P: K of 3.5: 0.37: 4.1 % on dry matter basis. Malama (2001) analysed tithonia from northern Zambia which gave an average N: P: K content of 2.9: 0.18: 4.2%. When incorporated into the soil, tithonia decomposes at a fast rate releasing nearly all its N into the soil within two weeks making it a ready source of N for uptake by the growing crop. Its nutrient levels are influenced by plant part, age and the position within the canopy. The parts that are best used as fertilisers are its leaves and soft twigs. Its manure extracts may be used without dilution although dilution may be made to a ratio of 15: 1 of water to extract.

2.6.4.1. Comfrey (*Symphytum officinale*).

Comfrey is a deep rooted crop whose roots can be as long as 3 m or more enabling it to draw and accumulate nutrients from the soil (Anderberg, 2004). It grows in almost any type of soil and is a hardy perennial which is propagated through seeds or sprouts from sections of severed roots. It can be eaten as a vegetable and has been found to have high medicinal value. The low levels of fibre in the leaves of comfrey play a dominant role in the quick break down to a thick black liquid. It is a high source of K, normally containing 2 to 3 times more K than farmyard manure (Wikipedia, 2007). Hence comfrey is especially beneficial to vegetables like tomatoes, peppers and cucumbers. Comfrey also contains N, P, Ca, Si, Fe, Mg and vitamins A, C and B12 (Organic Farming Research Foundation, 2008). Comfrey leaves have been analysed and recorded 1.8: 0.5: 5.3% for N: P: K respectively.

2.6.4.2. Tithonia (*Tithonia diversifolia).*

Tithonia, commonly known as false sunflower is a common shrub which is originally from Central America but now grows wildly in most humid and sub humid tropics of Africa. It can be used as fodder, poultry feed, fuel wood, compost or pesticide (Akanbi *et al.*, 2007; Jama *et al.*, 2007) and is easily propagated from seeds or cuttings. It grows quickly up to a height of 1 – 3 m. It has a high rate of accumulation of N and P from the soil (Swift, 2007). Nagarajah and Nizar (1982) determined the characteristic levels of nutrients in several tithonia samples. They analyzed 100 samples of tithonia leaves and tender stems from Sri Lanka which gave an average N: P: K of 3.2 –5.5: 0.2 –0.5: 2.3-5.5%. This was later supported by Jama *et al.* (2000) who reported an average N: P: K of 3.5: 0.37: 4.1 % on dry matter basis. Malama (2001) analysed tithonia from northern Zambia which gave an average N: P: K content of 2.9: 0.18: 4.2%. When incorporated into the soil, tithonia decomposes at a fast rate releasing nearly all its N into the soil within two weeks making it a ready source of N for uptake by the growing crop. Its nutrient levels are influenced by plant part, age and the position within the canopy. The parts that are best used as fertilisers are its leaves and soft twigs. Its manure extracts may be used without dilution although dilution may be made to a ratio of 15: 1 of water to extract.

2.7. Influence of organic fertilisers on soil microbial activities.

Robson (2000) suggests that organic farming enhances natural biological cycles in soils and crops by building up soil fertility. He recorded increased crop yield even at low nutrient levels when manure extracts were applied. This was explained by the increased micro organisms from the manure extracts which promoted the development of indigenous soil microbial populations. These aid in the incorporation of nutrients into the plant roots. The micro organisms also convert unavailable forms of nutrients to more available forms. This could mean that the observed high yield may not necessarily be attributed to the nutrient levels in the extracts alone but due to the presence of the micro organisms. It has also been postulated by Welke (2004) that yield increase could be due to the presence of growth promoting hormones and micronutrients present when manure extracts are prepared anaerobically. A similar line of thought is that the improvement of soil biological activity is more critical to soil nutrient supply capacity than just the addition of nutrients (King, 1990).

The presence of micro organisms on organic residues is well known (Burges and Raw, 1967). This implies that the decomposition begins before the organic residues are soaked in water. The addition of green manures to the soil would therefore increase microbial populations. Thomas and Shantarum (1984) recorded an increase of 49 and 53% in the population of Azobacter and other bacteria when green manures were added to soil. In other studies, aerobic microbes have been found to be dominant in manure extracts (Hoitink *et al.*, 1997).

Conversion from conventional to organic farming has been found to increase the levels of microbial activities. Doran *et al.* (1994) observed a positive correlation between agricultural management practices and activity of soil micro-organisms. Farming systems that are solely dependent on organic matter as the primary source of nutrients require the presence of micro organisms to decompose the organic matter thereby making the nutrients available for uptake by the plants. Organically farmed soils have been found to have 30 to 100% biological activity compared to conventional soils with 30 to 40% total biomass of microbes (FAO, 2000).

Chapter Three

3.0. MATERIALS AND METHODS

3.1. General Overview

The organic sources for the manure extracts used were comfrey (*Symphytum officinale*) and tithonia (*Tithonia divesrfolia*). The experiments conducted in this study were conducted in two phases. The first phase was in the greenhouse with the objective of determining the optimum rate of two sources of manure extracts (comfrey (*Symphytum officinale*) and tithonia (*Tithonia divesrfolia*)). The greenhouse study was conducted from February to May, 2008.

The second phase was a field- study. Two sites were used; Kasisi Agricultural Training Centre (KATC) and Mount Makulu Agricultural Research Station (MARS).These locations are in the medium rainfall agro- ecological zone of Zambia. The optimum rates of tithonia and comfrey determined from the first part of the study i.e. the greenhouse experiment were used in the field experiment in different combinations. The field experiment was conducted from August 2008 to February, 2009.

Two test crops were chosen on the basis of their nutrient requirements; rape var Hobson (*Brassica napus*) a low feeder and tomato var Rhodade (*Lycopersicon lycopersicum*) a higher feeder.

3.2. Greenhouse study

3.2.1. Soil preparation and analysis

Bulk soil samples were collected from the two test sites. The soils were collected from the top 20 cm and air dried. They were then screened to pass through a 2 mm sieve and all the debris removed. A general characterisation of the soils was done as indicated in Appendix 1. Soil physical and chemical analysis was done using standard laboratory methods used by the University of Zambia soil analysis laboratory (Songolo and Pauwelyn, 1998).

3.2.2. Crop management.

Tomato and rape seeds were sown in styrofoam trays using growth media. One seed was placed per slot for rape and tomato. Irrigation was provided every day until germination after which it was reduced to every other day. One week before transplanting watering was further reduced to every three days to harden the seedlings. Except for the fertiliser regime, the vegetables were managed according to standard recommended practices (Mingochi and Luchen, 2002).

3.2.3. Preparation of manure extracts.

The tithonia and comfrey leaves were collected from KATC. Tithonia leaves and twigs were used while leaves and their petioles were used for comfrey. These were cut into small pieces (approximately 15 cm) and then apportioned into the predetermined weights based on fresh weight basis. Four rates were used at 1.0, 1.5, 2.0 and 2.5 kg. These were placed into 25 l containers into which 16 l of water were added. These rates are equivalent to 0.0625, 0.0938, 0.125 and 0.156 kg l^{-1} respectively. A control of water only was included. The manures were let to decompose for a period of two weeks during which periodic stirring was done. The containers were left in the open but covered with hessian or woven polyethylene sacks. The manure extracts were sampled before the first application and analysed for N, P, K, Ca and Mg according to standard procedures (Chapman and Pratt, 1961).

3.2.4. Rape crop.

Five- litre pots were used, each being filled with 3.5 kg of the Kasisi soil. The seedlings were transplanted to the pots twenty one days after germination with three plants in each pot. The study was arranged as a completely randomised design with four replications per treatment. The first application of the manure extracts was done one week after transplanting at 400 ml per pot. The amount of manure extracts was thereafter reduced to 100 ml per pot per application repeated twice weekly for three weeks. The volume of the manure extracts was then increased to 200 ml for three weeks as the plants grew. Tap water was used to irrigate the crop every other day. The crop was attacked by aphids and these were controlled by spraying with detergent (Teepol). This was prepared in a 1l container by diluting 15 ml of the detergent and bringing it to mark with water. The rape was harvested eight weeks after transplanting which was two weeks after the last application of the extracts. This was done by cutting off the biomass above the soil. The fresh weight was immediately obtained. A sample of the biomass of known weight was placed in an oven at a temperature of 70 °C for forty eight hours. The dry weight was then calculated and the moisture content determined. The biomass results were reported on dry weight basis.

3.2.5. Tomato crop.

As with the rape crop, the tomato component was arranged as a completely randomised design with four replications per treatment. Soil obtained from the University Field Station was used. Five- litre pots were each filled with 4 kg of soil. The seedlings were transplanted twenty seven days after germination. Three plants were planted per pot. An initial application of the manure extracts was done with 400 ml per pot for each of the treatments. This was done at the time of transplanting. Subsequently, two applications each week at 200 ml per were made for 3 weeks. Irrigation was done using tap water every other day. The volume of the manure extracts was then increased to 300 ml for 3 weeks. The tomato was harvested eight weeks after transplanting and two weeks after the last application of the extracts. This was done by cutting off the biomass above the soil. The fresh weight was obtained. A sample of the biomass was weighed and then dried in an oven at a temperature of 70°C for forty eight hours. The dry weight was calculated and the moisture content determined. The results were reported on dry weight basis. At the time of harvest, soil samples from the pots were collected and analysed for available N, P, K, Ca, Mg, Na, pH and EC using standard laboratory methods used by the University of Zambia soil analysis laboratory (Songolo and Pauwelyn, 1998).

3.3. Field study.

3.3.1. *Land preparation and field management*

The land was prepared by making furrows using hand hoes. These furrows were 2.4 m long and 0.7 m apart. Five furrows were made for each plot. This gave a total plot size of 8.4 m^2. Six plots were in each of the three blocks which had a total area of 50.4 m^2. The seedlings were transplanted to the field three weeks after emergence at a spacing of 0.3 m between plants within each ridge.

At the time of planting, composite soil samples were collected from the top 20 cm and characterised (Appendix 2). The samples were analysed for the following- pH-using the $CaCl_2$- method (Mc Lean, 1982); Soil organic matter –Walkely-Black titrimetric method (Nelson and Sommers, 1982); Soil texture –hydrometer method (Songolo and Pauwelyn, 1998); Electrical conductivity -saturation extract method (Rhoades, 1982); Available N- steam distillation method (Keeney and Nelson, 1982); Available P –Bray No. 1 (Olsen and Sommers, 1982); Exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+)- leaching method using ammonium acetate solution at pH 7.0 (Thomas, 1982); Soil respiration- carbon dioxide evolution rates (Songolo and Pauwelyn, 1998). Sampling and soil analysis were also done at the time of flowering and at harvest.

The study was arranged as a randomised complete block design with three replications. In each 160 litres of water 25 kg comfrey, 25 kg tithonia, 12.5 kg comfrey + 12.5 kg tithonia, 18.75 kg comfrey + 6.25 kg tithonia and 6.25 kg comfrey + 18.75 kg tithonia were weighed into 210 l drums into which 160 l of water were added. These are equivalent to 0.156 kg comfrey, 0.156 kg tithonia, 0.078 kg comfrey + 0.078 kg tithonia, 0.117 kg comfrey + 0.039 kg tithonia and 0.039 kg comfrey + 0.117 kg tithonia per litre of water, respectively. A control of water only was also included. Periodic stirring of the manures was done. After two weeks, the extracts were assumed ready for use and applied at the rate of 5 litres per plot per application. Application was done twice a week. A second batch of manure extracts was prepared when the first one finished. This gave a total of eight weeks application duration. The manure extracts were analysed each week for N, P, K, Ca, Mg, Na, pH and EC using standard analysis procedures for measuring irrigation water (Chapman and Pratt, 1961).

The vegetable seedlings were transplanted to the field twenty one days after emergence at a spacing of 0.3 by 0.7 m. This was before the onset of the rains. Therefore, irrigation was done using buckets two times every day during the first week after transplanting. This was reduced to every other, once a day. At the onset of the rainy season, irrigation was dependant on the rain. Weeds were controlled using hand hoes such that the weeds were not let to exceed approximately 10 cm in height. The tomatoes were staked at the time of flowering although the variety (Rodade) used was bunchy and short.

The number of fruits and branches per plant as well as fruit yield were recorded. Harvesting of the fruit was done when the fruit was at the pink stage. The fruit yield was obtained by weighing the tomatoes at each time of harvest. This was done on 24 plants, on an area of 5.04 m^2 and excluded plants from the boarder rows.

3.4. Statistical analysis.

Analysis of variance and correlation were done on the collected data using the GENSTAT statistical package. Means were separated using Duncan's multiple range test (Gomez and Gomez, 1984).

Chapter Four

4.0. RESULTS AND DISCUSSION

4.1. Greenhouse study

4.1.1. Rape *(Brassica napus)* crop.

4.1.1.1. Chemical composition of manure extracts used as fertilisers for rape crop.

The analysis of the manure extracts at the beginning of use gave results as indicated in Table 1. The NH_4^+ concentrations ranged from 2.8 mg l^{-1} (0.0625 kg tithonia and comfrey each) to 28.0 mg l^{-1} (0.156 kg tithonia). The NO_3^- concentrations ranged from 14.0 mg l^{-1} (0.0938 kg comfrey) to 193.2 mg l^{-1} (0.156 kg tithonia).The NH_4^+ levels were generally lower than those of NO_3^- which is contrary to findings by Martin and Duddles (1984). They recorded higher levels of NH_4^+ (655 mg l^{-1}) compared to NO_3^- (102 mg l^{-1}) within one week when they soaked 20 lbs of chicken manure in 35 gallons of water . The extracts in this study were stored in a cool room and analysed later. This could have led to the conversion of NH_4^+ to NO_3^-. Nevertheless, the NH_4^+ levels in both comfrey and tithonia extracts were comparable while those of NO_3^- were higher in the tithonia based extracts. It was also observed that NH_4^+ and NO_3^- concentrations increased with increased rate of biomass of comfrey and tithonia. However, outliers were observed for both fertilizers.

The Phosphorus levels were generally seen to increase with increased biomass concentration. This was particularly true for tithonia, which only had one outlier. On the other hand, comfrey did not exhibit any trend. The highest concentration was recorded in the 0.125 kg tithonia (32.0 mg l^{-1}) and the least in the 0.125 kg comfrey (5.5 mg l^{-1}). A comparison between the sources however, indicated little or no differences of P at each level of biomass concentration of the fertilisers except for the above mentioned treatments. The levels of K were generally comparable in the comfrey and tithonia manure extracts. Increasing the biomass of the fertiliser source was followed by an increase in the K concentration. Similarly, it would be expected that increasing the biomass of the tithonia and comfrey would lead to increased Ca and Mg concentrations. This was not the case. The Ca and Mg released among the four levels of biomass used for both tithonia and comfrey did not exhibit any particular trend. This is one of the concerns that have been raised about reliability of organic fertilisers which are subject to many factors like the part where the materials are obtained. The materials used in this experiment were collected from the same area. However, some of it was relatively younger.

Table 1: Nutrient concentration of the tithonia (*Tithonia diversifolia*) and comfrey (*Symphytum officinale*) manure extracts used as fertilizer for the rape crop in the green house study.

Source	Rate[z]	NH_4^+	NO_3^-	P	K	Ca	Mg
	(kg l^{-1})	-------------------------	(mg l^{-1})	-------------------------			
Comfrey	0.0625	2.8	25.2	7.5	486.3	207.7	53.63
	0.0938	5.6	14.0	23.5	708.5	107.6	41.0
	125	5.6	25.2	5.5	895.3	97.5	48.4
	0.156	5.6	61.6	23.5	1000.0	229.7	70.7
Tithonia	0.0625	2.8	129.0	6.0	512.5	143.4	54.8
	0.0938	22.4	168.0	18.5	669.5	362.0	37.5
	0.125	11.2	179.2	32.0	728.4	127.0	14.4
	0.156	28.0	193.2	17.0	1019.0	154.0	24.0

[Z]: weight of biomass of comfrey and tithonia used to prepare their liquid extracts in 1 litre of water.

4.1.1.2. Effect of organic fertiliser source and rate of manure extracts used on yield of rape yield.

The response of leaf yield of rape to the various rates and sources of manure extracts are shown in Table 2. The highest yield was obtained in the pots that were treated with 0.125 kg of tithonia (12.79 g per pot) while the least biomass production was in the pots that did not have manure extracts applied to them which had 0.76 g per pot. There was a progressive increase in rape crop biomass yield up to the highest rate of 0.156 kg for comfrey. This was therefore, determined as the optimum rate for comfrey to be used in the field studies. For tithonia however, an increase in yield was observed up to the 0.125 kg treatment after which a decline was observed. Since there was no significant difference between the 0.125 and 0.156 kg treatments, the 0.156 kg treatment was selected as the optimum rate for tithonia.

The observed yield patterns can be closely linked to the concentrations of N that were recorded in the manure extracts. Nitrogen is important for vegetative growth as it is used in photosynthetic and other protein- enzyme systems and this may explain the increase in biomass production of the rape. This is also supported by the differences in the biomass between the crops treated with tithonia and comfrey. Tithonia was richer in N (NO_3^-) and K compared to comfrey. A comparison of the two organic fertiliser sources generally indicated higher yields for tithonia relative to comfrey. Phosphorus, K, Ca and Ma would not however seem to have influence on the growth of the crop where the manure extracts were applied as the levels did not differ between comfrey and tithonia.

By the end of the experiment, some plants in the control pots had dried up. This was perhaps due to nutrient deficiencies. The other plants in the control pots had stunted plants. As indicated in the initial soil characterisation, the initial soil nutrient status was low. Phosphorus deficiency was prominent in the pots that did not receive any manure extracts. This was characterised by purple coloration. Slight purple coloration was also observed in the pots where the two lower rates of comfrey were being applied. This however reduced as the application of the extracts progressed. From the analysis done on the manure extracts, the plants received relatively similar levels of P. A visual assessment of growth rate indicated that the pots where tithonia manure extracts were being applied appeared to grow better than the pots were comfrey manure extracts were being applied.

Table 2: Dry weight of rape *(Brassica napus)* crop, grown under four levels each of comfrey (*Symphytum officinale*) or tithonia (*Tithonia diversifolia)* manure extracts and harvested at 8 weeks.

Treatment	Mixing Rate (kg l^{-1} of water)^{Z}	Leaf yield (g)^{y}
Control	0	0.76a^{x}
Comfrey	0.0625	2.82a^{x}
	0.0938	6.59bc
	0.125	7.53bcde
	0.156	9.31cdef
Tithonia	0.0625	10.04defg
	0.0938	10.05efg
	0.125	12.79g
	0.156	10.85fg

^{Z}: amount of biomass used per litre of water to obtain the liquid extract

^{Y}: dry matter leaf yield

^{X}: figures followed by the same letter are not significantly different (p <0.05) according to Duncan multiple range test.

4.1.2. Tomato (*Lycopersicon lycopersicum*) crop.

4.1.2.1. Effect of organic fertiliser source and rate of manure extracts on biomass yield of tomato.

Initial crop growth indicated N deficiency in most of the plots. This was characterised by yellowing of the lower leaves. As the application of the manure extracts progressed, all treatments except the control began to look uniformly healthy although the crop where tithonia was being applied appeared greener than the others. The observations made are probably linked to the N levels in the manure extracts used (Table 3). It should be noted that it is unlikely that the 0.0625 kg comfrey treatment should have higher NO_3^- levels (291.2 mg l^{-1}) than the 0.0938 and 0.125 kg which both recorded 42 mg l^{-1}. This could be because of non uniformity of the material used in the preparation of the different manure extracts.

Table 3: Nutrient concentration of the tithonia and comfrey manure extracts used as fertilizer for the tomato crop in the green house study.

Source	Rate[z] (kg l^{-1})	NH_4^+	NO_3^-	P	K	Ca	Mg
		---------- mg l^{-1} ----------					
Comfrey	0.0625	8.4	291.2	19.5	462.1	229.0	8.5
	0.0938	5.6	42.0	23,0	706.0	133.2	41.9
	0.125	5.6	42.0	22.0	941.9	101.0	6.5
	0.156	11.2	120.4	87.5	1122.0	174.8	87.6
Tithonia	0.0625	2.8	128.8	25.0	515.0	281.8	56.7
	0.0938	5.6	873.6	49.0	749.0	307.9	86.5
	0.125	42.0	145.6	45.0	947.9	292.0	10.4
	0.156	11.2	280.0	52.5	931.9	34.0	10.1

[z]: weight of biomass of comfrey and tithonia used to prepare their liquid extracts in 1 litre of water.

The biomass and rate of the comfrey and tithonia fertilizers used contributed significantly ($p < 0.05$) to the yield of the tomato biomass (Table 4). The highest yield of tomato was obtained in the pots that were treated with 0.0938 kg of tithonia (13.99 g per pot) while the least yield (3.21 g per pot) was in the pots that did not receive any manure extract application (Table 4). The results are consistent with those of Togun *et al.* (2004) and Babajide *et al.* (2008) who observed increased yield of tomato with increased biomass of plant residues fertilisers. This was attributed to the high NPK levels in the residues. Increasing the rate of comfrey resulted in a progressive increase in tomato biomass yield. The highest rate of 0.156 kg for comfrey gave the highest biomass yield (13.34 g per pot) of tomato and was therefore selected for use in the field studies. This was not the case for tithonia which showed increased yield from the 0.0625 kg to 0.0938 kg treatments after which the yield decreased. The reduction in yield was perhaps in response to the concentration of N in the manure extracts which was higher in the 0.0938 kg manure extracts (873.6 mg l^{-1}) relative to the other two higher rates (Table 3). This could have been due to the non uniformity of the concentration of N in the tithonia used in that leaves and soft branches were used. It is possible that the treatments with lower N were predominated by the soft branches and not leaves and vice versa. It is well established that N is highly mobile and moves to younger leaves relative to the older leaves. An assumption was therefore made that there was non uniformity in the material used hence the highest rate of 0.156 kg would be used in the field.

Table 4: Dry weight of tomato (*Lycopersicon lycopersicum*) crop grown under four levels each of comfrey (*Symphytum officinale*) or tithonia (*Tithonia diversifolia)* manure extracts and harvested at 8 weeks.

Treatment	Mixing Rate (kg l^{-1} of water)^{Z}	Biomass yield (g)^{y}
Control	0	3.21a
Comfrey	0.0625	6.67bc^{x}
	0.0938	8.92cd^{x}
	0.125	8.64bcd
	0.156	13.34gh
Tithonia	0.0625	10.0def
	0.0938	13.99h
	0.125	12.38fgh
	156.25	11.73efg

^{Z}: amount of biomass used per litre of water to obtain the liquid extract

^{Y}: dry matter leaf yield

^{X}: figures followed by the same letter are not significantly different ($p < 0.05$) according to Duncan multiple range test.

4.1.2.2. Effect of manure extracts on soil chemical characteristics in the greenhouse.

Results from the analysis of the soils from the pot experiment are shown in Table 5. By the end of the study, the pH levels had increased in all the pots. These results are consistent with those of Babajide *et al.* (2008) who observed a rise in pH with increased biomass of composted tithonia. The application of urea (46 % N) on the other hand lowered soil pH. In this study, the initial pH was 7.1 but rose to 7.4 for the control where no manure extracts were applied. The highest rise in pH was by a unit of 1 which was in the pot that was treated with 0.156 kg of tithonia.

Relative to the initial P concentration at the time of planting (35 mg kg^{-1}), most of the pots that were treated with tithonia exhibited reductions in the levels of available P. It is noteworthy that the P levels in the pots that were treated with comfrey manure extracts recorded higher P levels at the time of harvest. The highest soil P concentration was recorded in the 0.156 kg of comfrey (43 mg kg^{-1}) while the least was in the pots treated with 0.0625, 0.0938, 0.125 kg of tithonia (33 mg kg^{-1}). The pots where no manure extracts were applied showed a slight increase of 3 mg kg^{-1}. This was higher than for most pots. The pots were no extracts were applied had minimal growth, which could explain the P levels in the control at the time of harvest. The levels of N were not influenced by the rate of source of the fertiliser used.

Increasing the biomass of comfrey and tithonia in the preparation of their extracts resulted in increased soil K levels except for the 0.0625 kg tithonia (0.53 cmol kg^{-1}) which had K levels that were slightly comparable to the control (0.11 cmol kg^{-1}). The soils used in the green house had relatively high inherent levels of K. This meant the addition of K from the manure extracts was luxury feeding for the crop. This could be used to explain why the K levels at the time of harvest were higher than the initial concentrations at planting for all the treatments except the control. The highest K was 1.8 cmol kg^{-1} and was in the 0.125 kg comfrey manure extracts.

The manure extracts influenced the EC of the soil at the time of harvest (Table 5). The EC had risen from 0.35mS cm^{-1} to as high as 0.847 mS cm^{-1} for the 0.156 kg of tithonia treatment. The control recorded a slight reduction to 0.34 mS cm^{-1}. Increasing the rate of comfrey was seen to increase the EC of the soil. Although the tithonia based extracts had higher EC values, no particular pattern could be distinguished among the four tithonia rates.

Table 5: Chemical analysis of UNZA soil after harvest of tomato crop that had received four levels of comfrey and tithonia manure extracts.

Source	Mixing Rate [z]	pH	NH_4^+	NO_3^-	P	K	Na	Ca	Mg	EC
	$kg\ l^{-1}$		------mg kg^{-1}------			-----------------cmolkg^{-1}---------				mS cm^{-1}
Control	0	7.4	0.16	0.03	38	0.11	0.22	7.78	1.56	0.344
Comfrey	0.062	7.9	0.14	0.05	35	0.95	0.15	3.8	1.32	0.367
	0.0938	7.9	0.14	0.08	37	1.45	0.09	4.94	1.23	0.417
	0.125	8.0	0.11	0.08	35	1.80	0.12	7.68	1.56	0.469
	0.156	8.0	0.25	0.10	43	1.77	0.40	6.39	1.90	0.765
Tithonia	0.0625	7.8	0.19	0.08	33	0.53	0.22	6.69	1.65	0.653
	0.0938	7.9	0.22	0.08	33	0.75	0.25	8.78	1.65	0.597
	0.125	8.0	0.38	0.17	33	1.15	0.19	6.14	1.40	0.58
	0.156	8.1	0.25	0.11	35	1.14	0.07	6.14	0.99	0.847
LSD		0.22	NS	NS	10.5	0.12	0.067	0.76	0.22	0.11

[z]: weight of biomass of comfrey and tithonia used to prepare their liquid extracts in 1 litre of water.

4.2. Field study.

4.2.1. Site 1- Kasisi Agricultural Training Centre.

4.2.1.1. Nutrient composition of manure extracts used as fertiliser for tomato crop in field studies.

The various combinations of manure extracts of comfrey and tithonia had an influence on the concentration of the various nutrients that were analysed for (Table 6). The highest NH_4^+ levels were obtained in the treatment of 0.156 kg tithonia (1717 mg l^{-1}). Generally it was observed that increasing the biomass of tithonia led to increased NH_4^+ concentrations. However it was also observed that the extracts from the equal biomass of comfrey and tithonia had NH_4^+ levels that were higher than those in the 0.039 kg comfrey + 0.117 kg tithonia (1356 and 1428 mg l^{-1}, respectively). The total amount of P applied to the soil from the different combinations ranged from 254 to 649 mg l^{-1}. In general, it was observed that the extracts with higher proportions of comfrey had higher P levels relative to those of tithonia. However, the extracts from the 0.039 kg comfrey + 0.117 kg tithonia recorded higher levels relative to the other three treatments except the sole preparation from comfrey. The reason for this could be that the comfrey or tithonia used in that particular treatment had exceptionally higher levels of P relative to the other plant materials that were used to prepare the other extracts.

The levels of K were highest in the treatment with 0.156 kg comfrey (6,958 mg l^{-1}). From the observations made, the concentrations of K generally increased with an increase in the proportion of comfrey, with the least being in the extracts that were solely made from tithonia. On the other hand, the concentration of Ca and Mg were generally higher in the tithonia based manure extracts compared to those of comfrey. A comparison of the concentrations across the treatments indicated higher levels of Ca than those for Mg. However, these differences were quite narrow considering the Ca: Mg balance that is in most soils. Physiologically, competition may arise between Ca and Mg for binding sites when these two elements are comparable in quantities (Marschner, 1995). The sodium concentration was the least among the bases, which would be expected. A comparison of the Na concentrations among the various combinations indicated little differences. The concentrations obtained though were quite high which can lead to soil sodicity when the extracts are applied to the soil.

The salinity hazard levels for the manure extracts were all classified as hazardous as they all had EC values above 3.0 mS cm^{-1} at 25°C (Table 7). The EC values ranged from 4.1 to 6.7 mS cm^{-1} during the five week period of use of the manure extracts. One of the key issues with the use of manure extracts is their high EC. Studies carried out have shown manure extracts to have high EC values. Such EC values could potentially cause plasmolysis in plant tissue as uptake of water could be restricted (Kamphorst and Bolt, 1979).

Table 6: Total nutrient concentration of five combinations of tithonia and comfrey manure extracts used as fertilizer for the tomato crop in the field study at KATC.

Treatment (kg/l of water)^z	NO_3^-	NH_4^+	P	K	Ca	Mg	Na
	------------	------------	------------	mg l^{-1}	------------	------------	------------
0.156kg comfrey	164	1201	649	6958	1595	808	170
0.156kg tithonia	77	1718	254	5544	2860	890	195
0.0781kg comfrey + 0.078kg tithonia	73	1428	406	6336	2456	844	179
0.117kg comfrey + 0.0391kg tithonia	134	1342	452	6608	2258	768	200
0.0391kg comfrey + 0.117kg tithonia	192	1356	623	6576	2474	732	185

^{z}: weight of biomass of comfrey and tithonia at different combinations used to prepare their liquid extracts in 1 litre of water.

Table 7: Electrical conductivity of five combinations of tithonia and comfrey manure extracts used as fertilizer for the tomato crop in the field study at KATC.

	Week of use				
Treatment (kg/l of water)[z]	1	2	3	4	5
	...........mS cm^{-1}........				
0.156kg comfrey	6.1	5.7	5.5	5.0	5.1
0.156kg tithonia	6.1	5.9	5.1	5.2	4.2
0.0781kg comfrey + 0.0781kg tithonia	6.2	5.7	4.1	4.4	4.8
0.117kg comfrey + 0.0391kg tithonia	6.7	6.1	5.4	5.4	5.4
0.0391kg comfrey + 0.117kg tithonia	6.2	6.2	5.4	6.5	4.4

[z]: weight of biomass of comfrey and tithonia at different combinations used to prepare their liquid extracts in 1 litre of water.

4.2.1.2. Changes in nutrient composition during the period of use of manure extracts.

Although there were differences in the nutrient concentration of the various combinations of manure extracts, similar patterns of nutrient levels during the five week period were observed. The analysis of NO_3^- and NH_4^+ showed that there was a rise in the amount of NH_4^+ from the first to the second week of use after which a decline was observed (Figure 1). It was interesting to note that the NO_3^- levels were stable from the first week of use right through to the fifth week. These results are consistent with those of Martin and Duddles (1984) who observed an increase in the NH_4^+ levels in a period of four weeks while the NO_3^- levels were relatively stable. This was observed at three different rates of fresh chicken manure.

Available Phosphorus was on average observed to reduce with each week of use until the third week when there was a steady increase. This trend was observed for all the manure extracts (Figure 2) except for the one prepared from 0.039 kg comfrey + 0.117 kg tithonia (Figure 3) which exhibited a sharp increase of P from the second to fifth day of use. The initial decline was probably as a result of formation of complexes between P and other compounds. The complexes were then dissociated as the weeks progressed thereby making the P available. Another possibility could be that P was less soluble and was only available after further decomposition. An initial drop was observed in the manure extracts for the other extracts. This was followed by an increase or stabilisation in the subsequent weeks. However, studies by Tian et al. (1992) and Sakala and Rowell (2004) showed rapid leaching and release of P from organic residues by 44- 95% of total plant material P upon initial washing of plant residues.

From all the collected data, the K concentrations were quite stable (Figure 4) in all the treatments with occasional deviations which could be attributed to sampling or experimental errors. This implies that most of the K was in solution by the first week of use (Sakala *et al.*, 2004). This trend has also been observed for Ca, Mg and Na (Figure 4). This means therefore that manure extracts are a good source of bases. There is little or no concern for the deterioration of the efficacy of the manure extracts if the nutrients of interest are the bases.

The pH of the manure extracts was seen to rise with each week of use (Figure 5). This trend was observed in all the five manure extract treatments. It is interesting however to note that the pH in the extracts that were prepared from comfrey were lower than those for tithonia. Perhaps this was as a result of having more bases in the tithonia based manures than the comfrey based ones. Over the five week period of use, pH shifts from 6.5 to 7.1 and 5.5 to 6.8 were observed in the manure extracts prepared from 0.156 kg tithonia and 0.156 kg comfrey respectively. Unlike pH, the EC in all five combinations of manure extracts was seen to reduce with each week of use. In general the EC was high during the first week of use after which it stabilised in the subsequent weeks. (Figure 5)

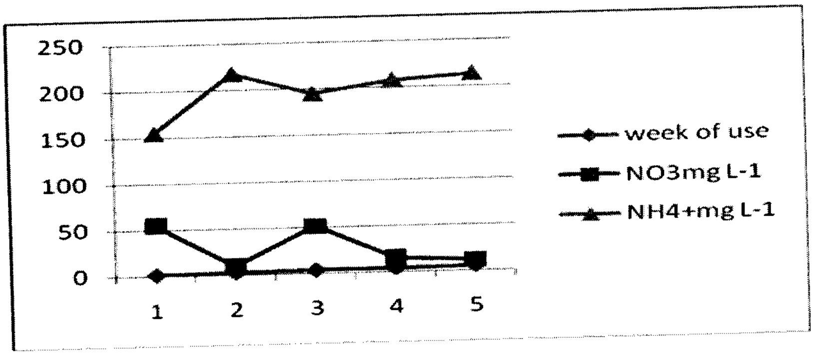

Figure 1: Nitrate and NH_4^+ concentration of manure extracts prepared from 0.156 kg of comfrey per litre of water and used as fertilizer for the tomato crop in the field study at KATC.

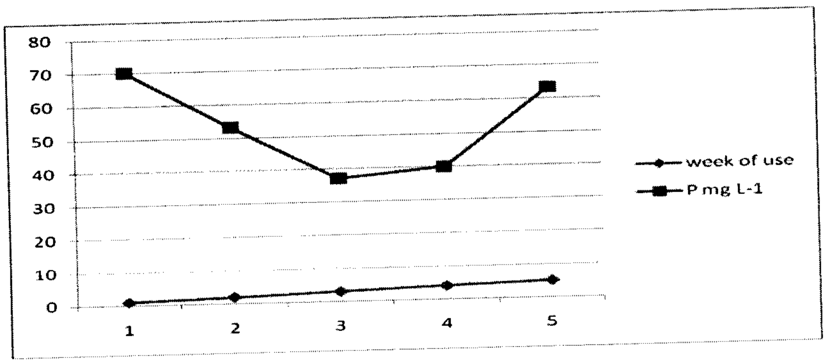

Figure 2: Phosphorus concentration of manure extracts prepared from 0.078 kg comfrey + 0.078 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at KATC.

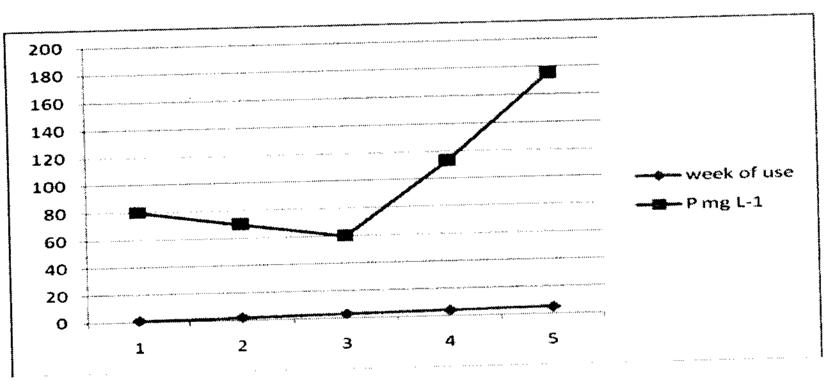

Figure 3. Phosphorus concentration of manure extracts prepared from 0.039 kg comfrey + 0.117 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at KATC.

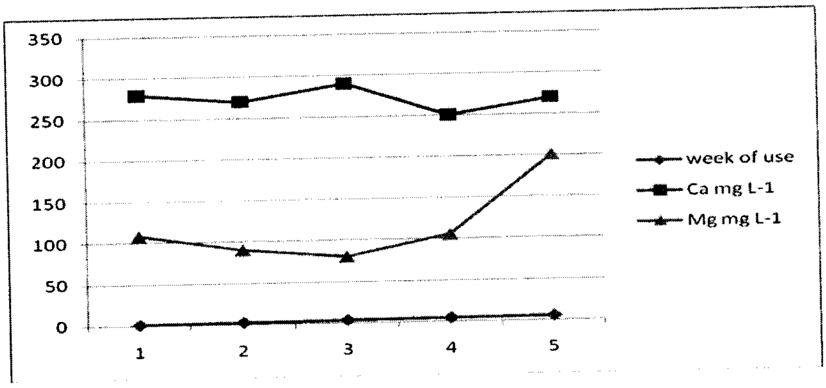

Figure 4: Calcium and Mg concentration of manure extracts prepared from 0.156 kg of comfrey per litre of water and used as fertilizer for the tomato crop in the field study at KATC.

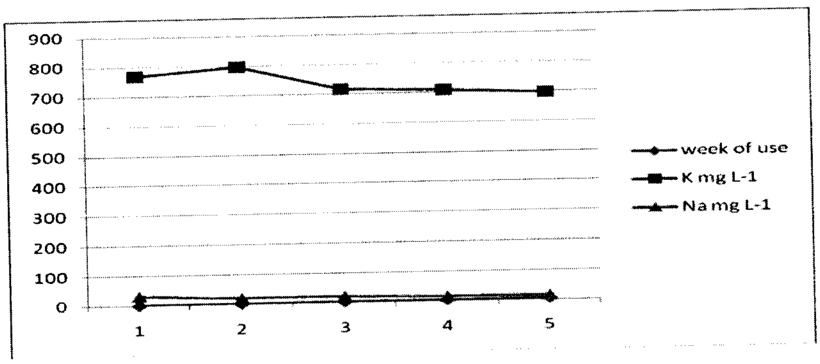

Figure 5: Potassium and Na concentration of manure extracts prepared from 0.156 kg of tithonia per litre of water and used as fertilizer for the tomato crop in the field study at KATC.

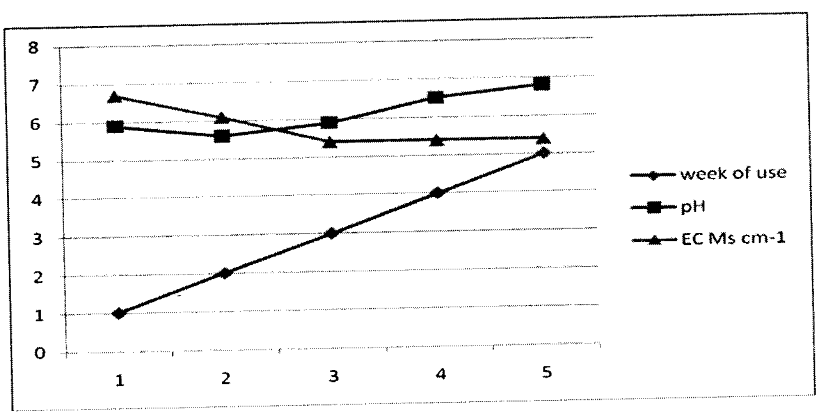

Figure 6: pH and EC readings of manure extracts prepared from 0.117 kg comfrey + 0.039 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at KATC

4.2.1.3. Effect of manure extract combinations on fruit yield of tomato.

The numbers of fruits per plant were different among the various combinations of manure extracts (Table 8). However, a correlation with fruit yield indicated a negative correlation (r= -0.028). The number of fruits per plant were not affected by the various combinations of manure extracts.

The manure extracts proved effective in raising the fruit yield of tomato. The collected data was for a single flush in that the crop was attacked by a viral infection just after the first harvest. Of the six treatments, the highest average yield was obtained in the plots that were treated with 0.156 kg of comfrey (9.5 ton ha^{-1}) while the least was obtained from the plots where no manure extracts were applied (Table 8). It should be noted however that the yields obtained in the plots that were treated with 0.156 kg tithonia and 0.117 kg comfrey + 0.039 kg tithonia were similar to those from the highest yielding treatment. The 0.078 kg comfrey + 0.078 kg tithonia and 0.039 kg comfrey + 0.117 kg tithonia treatments were similar to the control. From these results, it can be said that the manure extracts performed better when used in isolation than in combination. Perhaps there was no synergism when these manure extracts were combined. The relative concentrations of the nutrients in the manure extracts from the combinations were similar, if not higher than those in the manure extracts that were prepared from either fertiliser source alone. It would therefore have been expected that the combinations perform better than the sole treatments.

Contrary to the findings of the greenhouse, experimental units that were treated with comfrey gave higher yields relative to those that were treated with tithonia (Table 8). In terms of vegetative growth, it was observed that the plots treated with higher proportions of tithonia had rapid vegetative growth. The fruit yields were higher in plots that were treated with higher proportions of comfrey. The two phenomena can be tied to the differences in the N, P and K levels that were supplied to the crop through the different combinations of manure extracts. In general the comfrey based manure extracts had more P and K while those of tithonia had more N (Table 6). The nitrogen promoted vegetative growth while the P and K boosted fruit set and yield. Because K is important for fruiting, the need for N was more predominant than that for K in the greenhouse as the crop did not reach the flowering stage.

Table 8: Fruit yield, number of fruits plant^{-1} and branches plant^{-1} of tomato crop supplied with six combinations of comfrey and tithonia manure extracts.

Treatment(kg/l of water)^{Z}	Number of fruits plant^{-1}	Number of branches plant^{-1}	Yield (tons ha^{-1})^{Y}
0 g (Control)	4.2e	3.6	2.13a
0.156kg comfrey	3.8be	4.5	9.5c
0.156kg tithonia	3.97de	4.5	7.2bc^{X}
0.0781kg comfrey + 0.0781kg tithonia	3.27a	3.9	4.9ab
0.117kg comfrey + 0.0391kg tithonia	3.67abcd	4.8	7.8bc^{X}
0.0391kg comfrey + 0.117kg tithonia	3.87ce	4.5	5.2ab

^{Z}: weight of biomass of comfrey and tithonia at different combinations used to prepare their liquid extracts in 1 litre of water

^{Y}: fresh weight of tomato fruits

^{X}: figures followed by the same letter are not significantly different ($p < 0.05$) according to Duncan multiple range test.

4.2.1.4. Soil changes resulting from the application of manure extracts in relation to yield.

The different combinations of comfrey and tithonia manure extracts had a significant effect on the soil chemical properties (Table 9). This significance can be attributed to the differences in concentrations of the two organic fertiliser sources used. It should be noted however, that the nutrient concentrations at harvest were lower than at flowering and for some plots lower than at the time of planting. At the time of flowering, soil pH in all the treatments except the control had gone up but reduced by the time of harvest. The highest shift was in the 0.156 kg tithonia treatment from 4.3 to 4.9 at the time of flowering.

At the time of flowering, the levels of NH_4^+ and NO_3^- had gone up for the plots were manure extracts were applied. It is noteworthy that a comparison between the soils sampled at flowering and at harvest indicated little or no changes in the plots that were not treated with manure extracts. This is because application of the manure extracts was stopped before harvest. A similar trend was observed for the K, Ca and Mg. The importance of K for flowering and fruit development was clearly demonstrated by the differences in the K levels from the time of planting to the time of flowering and harvest. At the time of flowering, the amount of K had gone up in all the plots with manure extracts, with the highest amount being recorded in the plot with 0.156 kg comfrey (0.61 $cmol^{-1}$). This plot had the highest fruit yield. It is in this same plot that a drastic drop (0.19 $cmol^{-1}$) was observed relative to the other plots. This demonstrates that K was used for fruit production. No particular trend was observed for P although it can be said that a reduction was observed from the time of flowering to the time of harvest.

Although no significant differences were observed among the treatments for their EC values, a clear trend was observed in which the EC reduced from the time of flowering to the time of harvest. This could be attributed to loss of soluble ions through leaching or plant uptake from the time of flowering to the time of harvest.

Table 9: Chemical analysis of Kasisi Agricultural Training Centre soil at flowering (sampling # 1) and at harvest (sampling # 2) of tomato crop that had received six combinations of comfrey and tithonia manure extracts.

Treatment	Sampling #	pH	NO3-	NH4 +	P	K	Na	Ca	Mg	EC
			----------mg kg^{-1}----------			---------cmol kg^{-1}----------------				mS cm^{-1}
0 kg (control)	1	4.2	0.05	0.13	1.87	0.21	0.07	1.75	0.33	0.26
	2	4.4	0.05	0.14	3.6	0.17	0.04	0.59	0.38	0.06
0.156 kg comfrey	1	4.8	0.10	0.36	8.8	0.61	0.10	2.57	0.50	0.41
	2	4.7	0.09	0.25	5.4	0.19	0.06	0.60	0.37	0.11
0.156kg tithonia	1	4.9	0.137	0.48	4.5	0.51	0.08	2.97	0.6	0.47
	2	4.7	0.06	0.20	4.5	0.31	0.05	0.44	0.30	0.07
0.0781kgcomfrey+0.0781kg tithonia	1	4.7	0.137	0.36	5.7	0.54	0.07	2.5	0.47	0.46
	2	4.5	0.11	0.33	3.9	0.27	0.06	0.49	0.31	0.11
0.117kg comfrey+0.039 kg tithonia	1	4.8	0.173	0.46	6.7	0.48	0.07	2.83	0.64	0.49
	2	4.7	0.09	0.29	4.8	0.14	0.03	0.46	0.36	0.07
0.039kg comfrey+0.117kgtithonia	1	4.7	0.163	0.39	3.07	0.38	0.06	2.77	0.80	0.38
	2	4.6	0.08	0.23	4.5	0.15	0.03	0.28	0.33	0.34
LSD (5%)		0.315 [a]	NS	0.11 [b]	2.481 [a]	NS	NS	NS	NS	NS

[a] Significant for sampling # 1.
[b] Significant for sampling # 2.

4.2.2. Site 2-Mount Makulu

4.2.2.1. Nutrient composition of combinations of comfrey and tithonia manure extracts

The amounts of nutrients were generally comparable for all the five combinations of tithonia and comfrey (Table 10). It was observed that increasing the proportions of tithonia led to increased NH_4^+ and NO_3^-concentrations. The highest NH_4^+ levels (2000 mg L^{-1}) were recorded in the 0.039 kg comfrey + 0.117 kg tithonia treatment by the end of the eight weeks in which the extracts were supplied to the crop. On the other hand, increasing comfrey proportions led to increased P and K levels. The highest P levels (566 mg L^{-1}) were recorded in the 0.156 kg comfrey.

The amounts of Ca and Mg were observed to increase with increased proportion of tithonia, although no definite pattern could be distinguished. It was interesting to note however that the levels of Mg were not so much lower than those of Ca. Sakala *et al,* (2004) observed that washing of organic residues resulted in 20- 60% (65.9-370 mmol kg^{-1}) and 56-95% (121-315 mmol kg^{-1}) release of total Ca and Mg respectively. Larsen (1998) recorded 19-59 % of total Ca as extractable from a variety of tree crops and processed organic materials. This implies that Mg is more soluble than Ca and will readily go into solution.

Table 10: Total nutrient concentration of five combinations of tithonia and comfrey manure extracts used as fertilizer for the tomato crop in the field study at MARS.

Treatment(kg/l of water)^z	NO_3^-	NH_4^+	P	K	Ca	Mg	Na
	---------------------- mg l^{-1}						------------------
0.156 kg comfrey	53	1145	566	5498	1247	659	62
0.156 kg comfrey	96	1892	287	5224	1375	868	158
0.078 kg comfrey + 0.078 kg tithonia	98	1612	384	5399	1180	796	146
0.117 kg comfrey + 0.0391 kg tithonia	177	1978	515	5705	575	734	167
0.0391 kg comfrey + 0.117 kg tithonia	263	2000	452	5921	1651	920	132

4.2.2.2. Changes in nutrient composition in manure extracts during the period of use.

Nutrient concentrations during the period of use show that there was a similar pattern in behaviour of the measured nutrients. The levels of NO_3^--N were generally lower and more stable during the five weeks of use of the manure extracts than those of NH_4^+-N. The levels of NH_4^+ were high during the first week of use after which a decline was observed up to the third week when there was stability (Figures 7 and 8).The NH_4^+concentrations varied according to the proportion of the two organic fertiliser sources of manure extracts. The manure extract which was prepared from tithonia alone had the highest NH_4^+ levels while that which was prepared from comfrey alone had the least concentrations. Increasing the biomass of tithonia relative to comfrey increased the levels of NH_4^+-N. It is interesting to note however, that the NH_4^+ losses were lower in the comfrey based manure extracts relative to those of tithonia. Like previously discussed for the other manure extracts, the P concentrations were high during the initial week of use, after which a drastic reduction was recorded (Figure 9). This is not clearly understood.

Calcium and Mg data show that there was relative stability during the five week period of use (Figure 10). Generally, initial levels were high after which a reduction was observed before the concentrations stabilised. Apart from the manure extracts prepared from the equal combination of tithonia and comfrey (Figure 11), the other extracts exhibited a similar pattern where at some point the levels of Mg were comparable if not higher than those of Ca. This balance may be undesirable as it would affect the uptake of Ca which is needed by the plant in higher concentrations relative to Mg.

A similar pattern for K and Na was observed for all the manure extracts, with slight variations in the total concentrations of the two elements (Figure 12). In general the K concentrations were highest during the first two weeks of use, after which there was a gradual decline to the fourth week when stability was achieved. Sodium on the other hand was stable from the first to the fifth week of use.

The pH readings obtained in all treatments during the five week period of use had a similar pattern. A high shift in pH was observed for the manure extracts from the initial week of use to the fifth week (Figure 13), with the highest shift being in the 0.156 kg comfrey, 0.156 kg tithonia and 0.117 kg comfrey + 0.039 kg tithonia treatments with shifts of 1.1, 1.1 and 1.0 respectively. This rise was steady with a weekly increase of 0.2 units on average. The 0.078 kg comfrey + 0.078 kg tithonia recorded an initial high pH which subsequently dropped and then picked up by the last week of use. The rise in pH could be attributed to the release of bases which are a source of alkalinity.

Figure 13 shows the change in EC of the manure extracts over a period of five weeks of use. The Electrical conductivity for the manure extracts was on average categorised as high. From the first week of use through to the fifth, a reduction in EC was observed for all the manure extracts. The mechanisms of this reduction are not fully understood but could possibly be explained by the formation of complexes between the cations and anions. This could be linked to the reduction in the concentration of bases in the manure extracts with each week of use.

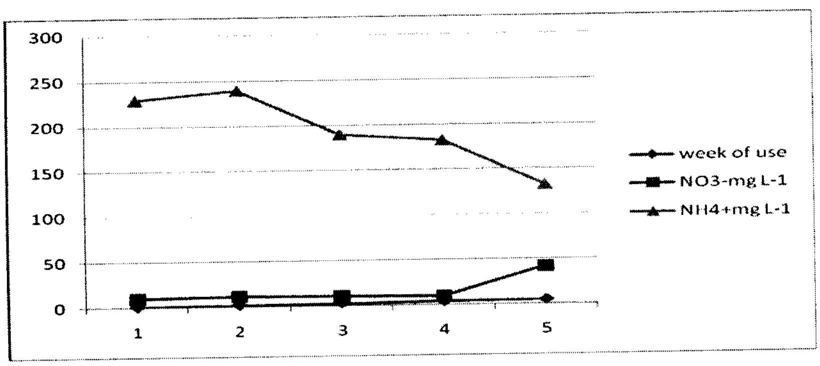

Figure 7: Nitrate and NH_4^+ concentrations of manure extracts prepared from 0.078 kg comfrey + 0.078 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at MARS.

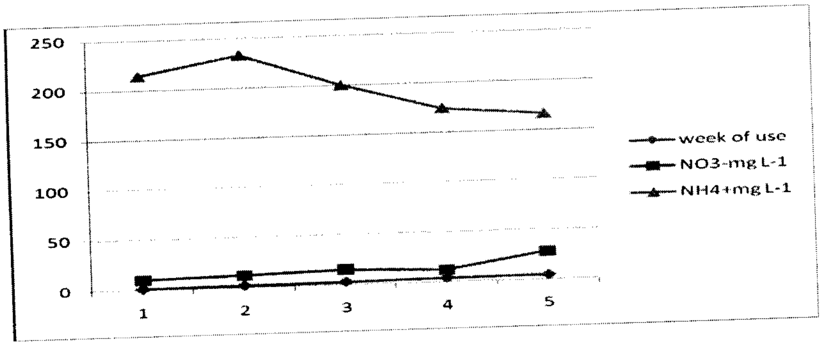

Figure 8: Nitrate and NH_4^+ concentrations of manure extracts prepared from 0.039 kg comfrey + 0.117 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at MARS.

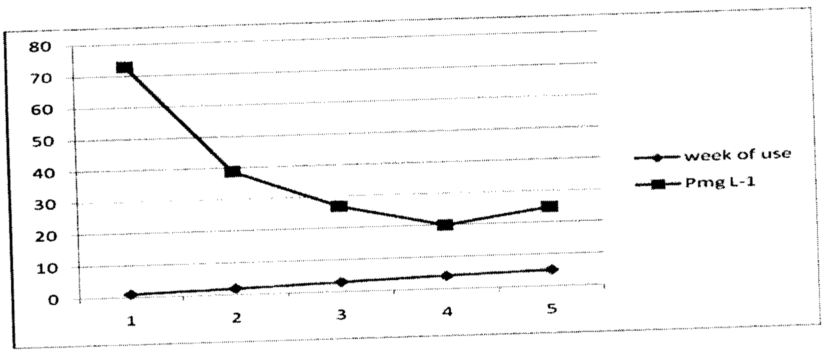

Figure 9: Phosphorus concentrations of manure extracts prepared from 0.156 kg of comfrey per litre of water and used as fertilizer for the tomato crop in the field study at MARS.

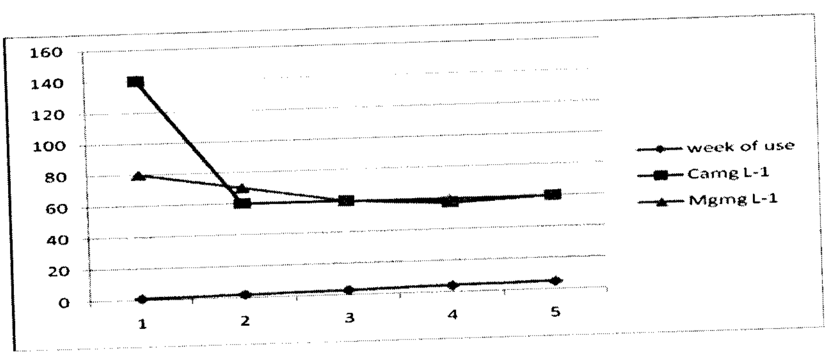

Figure 10: Calcium and Mg concentrations of manure extracts prepared from 0.156 kg comfrey per litre of water and used as fertilizer for the tomato crop in the field study at MARS.

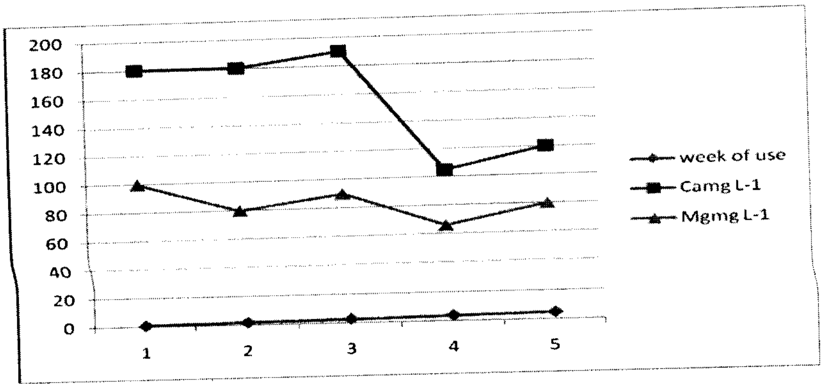

Figure 11. Calcium and Mg concentrations of manure extracts prepared from 0.078 kg comfrey + 0.078 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at MARS.

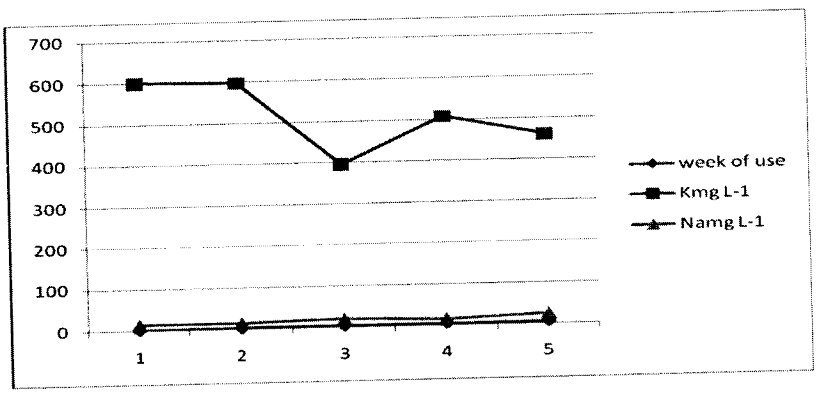

Figure 12: Potassium and Na concentrations of manure extracts prepared from 0.078 kg comfrey + 0.078 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at MARS.

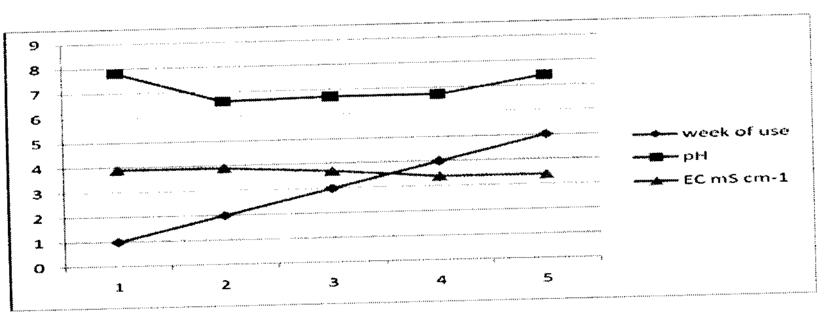

Figure 13: pH and EC readings of manure extracts prepared from 0.078 kg comfrey + 0.0781 kg tithonia per litre of water and used as fertilizer for the tomato crop in the field study at MARS.

4.2.2.3. Effect of manure extract combinations on fruit yield of tomato

During the vegetative growth stage of the crop, all the experimental units treated with manure extracts appeared to grow at the same rate. This was not the case in plots where no manure extracts were applied. However, no nutrient deficiencies were observed in all the plots. Towards fruit maturity, late blight was evident on the fruits but not the leaves. Some of the plots that were treated with manure extracts exhibited profuse branching, with some plants having many small fruits. However, the numbers of fruits and branches per plant were not affected by any of the treatments as indicated in Table 11.

The effect of manure extract combinations on the yield of tomato fruits was statistically significant. However, further separation of the means indicated that only the plot where no manure extracts were applied produced yields that were different (Table 11). Although the yields among the treatments were not statistically different, there were differences in terms of total tonnage. The treatment of 0.156 kg tithonia gave the highest yield (40.2 tons ha^{-1}). This would be expected, considering that the 0.156 kg tithonia manure extracts recorded the highest N amount of 1718 mg l^{-1}. On the other hand, the plots treated with 0.156 kg comfrey had the least yield of 32.7 tons ha^{-1} among the plots treated with manure extracts. This plot received the least N amount of 1201 mg l^{-1}. A pattern was observed in relation to the combination of manure extracts and yield. Increased proportion of tithonia in the various combinations resulted in increased fruit yield.

It should however be noted that even though the yield obtained in the plot where no manure extracts were added was the least (22.4 tons ha^{-1}), it was quite high considering that the average yield under conventional farming is 25 to 50 tons ha^{-1}. The field used for the study had previously been cultivated with pigeon peas which could have contributed to increased soil fertility residual effects. The initial NH_4^+ and P amounts were 0.17 and 43 mg kg^{-1} respectively.

Table 11: Fruit yield, number of fruits $plant^{-1}$ and branches $plant^{-1}$ of tomato crop supplied with six combinations of comfrey and tithonia manure extracts.

Treatment(kg/l of water)^{z}	Fruits $plant^{-1}$	Branches $plant^{-1}$	Yield(tons ha^{-1})^{y}
0 g (Control)	13.3	4.23	22.4a
0.156kg comfrey	16.3	4.47	32.7b
0.156kg tithonia	19.0	3.73	40.2b
0.0781kg comfrey + 0.0781kg tithonia	18.7	4.23	36.9b
0.117kg comfrey + 0.0391kg tithonia	14.7	4.27	37.1b
0.0391kg comfrey + 0.117kg tithonia	20.0	4.67	38.5b
	NS	NS	

Z: weight of biomass of comfrey and tithonia at different combinations used to prepare their liquid extracts in 1 litre of water

Y: fresh weight of tomato fruits

X: figures followed by the same letter are not significantly different ($p < 0.05$) according to Duncan multiple range test.

4.2.2.4. Soil changes resulting from the application of manure extracts in relation to yield.

During the course of the cropping season, the effects of the manure extracts on the soil were becoming more noticeable as differences were recorded for some of the parameters among the treatments (Table 12). The soils used had relatively high initial soil fertility.

Significant differences ($p < 0.05$) were observed when sampling was done at the time of harvest. A general increase of 0.1 or 0.2 units was observed for pH from the initial 7.1 when the second soil sampling was done at the time of flowering. It would therefore be expected that the continued use of manure extracts would raise pH. This was not the case.

At the time of harvest, a drop in pH by an average 0.5 units was observed in all plots, including the plots where no manure extracts were applied. This can be explained by the release of H^+ ions. Another reason would be that the reduction of bases from the time of flowering to the time of harvest could have lowered the soil pH, as suggested by Truter (2002). This could have been through leaching or plant uptake. Based on the proximity of the field site to the local cement plant, it would be expected that the soil pH would further increase at the time of harvest. This is because there is emission of alkaline dust particles from the cement plant.

The nitrate concentrations did not change from the time of flowering to the time of harvest. The ammonium concentrations on the other hand increased from the time of flowering to the time of harvest except for the 0.039 kg comfrey +0.117 kg tithonia which recorded a decrease. Similarly, the amount of P increased in all the plots from the time of flowering to the time of harvest. The highest P concentration was observed in the 0.156 kg tithonia and 0.117 kg comfrey+0.039 kg tithonia treatments which each had P levels of 40.0 mg kg^{-1}. Calcium, Mg, K and Na on the other hand decreased from the time of flowering to the time of harvest. This was more so for Ca than for the other bases with the lowest levels being recorded in the 0.156 kg comfrey and control which had 10.1 and 10.37 cmol kg^{-1}, respectively. The EC data was within the ranges of 0.34 $mScm^{-1}$ (0.156 kg comfrey) and 0.40 $mScm^{-1}$ (0.117 kg comfrey+0.039 kg tithonia). These values are acceptable for general crop growth with salinity effect being usually negligible (Appendices 5 and 6. However, tomato plants have a salinity tolerance level of 0.25 mS cm^{-1}(Hoffman 1981). Although the levels obtained in this study were slightly higher, they are still within acceptable levels.

Table 12. Chemical analysis of Mount Makulu Agricultural Research Station soil at flowering (sampling # 1) and at harvest (sampling # 2) of tomato crop that had received six combinations of comfrey and tithonia manure extracts.

Treatment	Sampling #	pH	NO_3^-	NH_4^+	P	K	Na	Ca	Mg	EC
			------------mg kg^{-1}------------			---------------cmol kg^{-1}---------------				$mScm^{-1}$
0 kg (control)	1	7.4	0.08	0.15	32	0.65	0.02	14.87	3.01	0.34
	2	6.6	0.08	0.28	35.0	0.45	0.02	10.37	3.17	0.39
0.156 kg comfrey	1	7.3	0.07	0.15	38.7	0.78	0.02	17.53	3.9	0.36
	2	6.7	0.07	0.29	41.0	0.55	0.01	10.1	3.13	0.34
0.156 kg tithonia	1	7.5	0.07	0.14	32.7	0.73	0.02	15.2	3.23	0.42
	2	6.9	0.06	0.23	42.0	0.62	0.02	12.57	3.36	0.36
0.0781 kg comfrey + 0.0781 kg tithonia	1	7.4	0.07	0.15	33.3	0.69	0.02	16.83	2.73	0.4
	2	6.8	0.05	0.19	39.3	0.77	0.01	12.1	3.33	0.37
0.117 kgcomfrey+0.039 kg tithonia	1	7.3	0.08	0.18	35.3	0.76	0.02	20.7	3.93	0.39
	2	6.9	0.06	0.22	42.0	0.79	0.02	11.27	3.23	0.40
0.039 kg comfrey +0.117 kg tithonia	1	7.4	0.07	0.24	32.7	0.79	0.02	19.67	3.93	0.42
	2	6.8	0.07	0.19	38.7	0.55	0.03	11.5	3.2	0.34
		0.163[b]	NS	0.032[a]	NS	0.054[a]	NS	NS	NS	NS

[a] Significant for sampling # 1.
[b] Significant for sampling # 2.

5.0. CONCLUSION

The main conclusion to be drawn from this investigation is that manure extracts of comfrey and tithonia could potentially be used as fertilisers to raise the crop yield of tomato and rape. The optimum rates for tithonia in the preparation of its manure extracts for rape and tomato crop were determined as 0.156 kg per litre (12.79g per pot) and 0.0938 kg per litre (13.99g per pot), respectively. The optimum rates for comfrey in the preparation of its manure extracts for rape and tomato crop were determined as 0.156 kg per litre (9.31g per pot) and 0.156 kg per litre (13.34g per pot), respectively. Similarly, combining these two organic fertilisers in the preparation of their manure extracts resulted in fruit yield increase of tomato at both sites used. However, the specific effects of the five combinations of comfrey and tithonia that were used could not clearly be distinguished in terms of which one is better. Manure extracts can also improve soil fertility. Since the nutrients are quickly and readily made available to the crop, there is a risk of the nutrients being leached. Furthermore, the manure extracts were seen to have high pH and EC, although these did not seem to have a drastic effect on the soil.

6.0. RECOMMENDATIONS

There is need to do further research. A starting point would be looking at application of these two manures at different growth stages of the crop. This would enable the two manure extracts complement each other based on their different nutrient levels. A second crop would help determine the long term effect of these manure extracts on subsequent crops.

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Appendices

Appendix 1: Soil chemical characteristics for the two sites used in the green house experiment.

Soil	Texture	pH	NH_4^+ (mg kg^{-1})	NO_3^- (mg kg^{-1})	P (mg kg^{-1})	K (cmol kg^{-1})	OM (%)
Kasisi	Sandy clay	4.7	0.12	0.04	5.0	0.02	1.4
Field station	Sandy clay loam	7.1	0.22	0.09	35	0.10	1.7

Appendix 2: Soil Characterisation at time of planting for field studies at Kasisi Agricultural Training Centre and Mount Makulu Research Station.

Soil	Texture	pH	NH_4^+ (mg kg^{-1})	NO_3^- (mg kg^{-1})	P (mg kg^{-1})	K (cmol kg^{-1})	OM (%)
Kasisi	Sandy clay	4.3	0.13	0.05	6.0	0.10	1.98
Mount Makulu	Sandy clay loam	7.1	0.17	0.09	43	0.62	2.3

Appendix 3: Salinity hazard levels of irrigation water based on EC values.

Electrical Conductivity (mS cm^{-1} at 25°C)	Salinity Hazard
Below 0.75	Low
0.75-2.0	Medium
2.0-3.0	High
Above 3.0	Very high

Appendix 4: Salinity classes of soils based on their EC values.

Conductivity of extract	Salinity class
0-2 mS cm^{-1} at 25°C	Free
2-8 mS cm^{-1} at 25°C	Slight
8-15 mS cm^{-1} at 25°C	Moderately strong
Above mS cm^{-1} at 25°C	Strong