PERFORMANCE OF *TITHONIA DIVERSIFOLIA* (Hemsley) A. Gray AS AN ORGANIC SOURCE OF NITROGEN AND PHOSPHORUS ON THE GROWTH AND YIELD OF MAIZE (*Zea mays)* (L.) IN DEDZA, LILONGWE AND MZIMBA DISTRICTS OF MALAWI.

by

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LUSAKA

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DECLARATION

I, ROSAN PATERSON GANUNGA, hereby declare that all the work presented in this dissertation is my own work and has not been submitted for a degree at this or any other university.

Signature..........................

Date ....

ABSTRACT

Soil degradation and continuous cropping without the addition of external inputs have resulted in declining soil fertility and consequently smallholder maize yields in Malawi. As inorganic fertilisers are becoming increasingly unaffordable due to rising prices, alternative sources for soil fertility improvement have to be evaluated.

A study was conducted during the 1996/97 season in Dedza, Lilongwe and Mzimba districts of Malawi to assess the effect of *Tithonia diversifolia* on nutrient uptake and yield of maize compared to inorganic fertiliser. The following treatments were evaluated in a randomised complete block design experiment with three replicates: (1) No fertilizer, no *Tithonia* (control), (2) 40 kg P_2O_5 ha^{-1} + 92 kg N ha^{-1} (standard recommendation), (3) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P),(4) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P), (5) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P), (6) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P) + 13.5 kg P from TSP, (7) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P) + 9.7 kg P from TSP and (8) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P) + 5.95 kg P from TSP. Laboratory incubation studies were also conducted to compare the rates of mineralisation between *Tithonia* and other green manure crops.

The treatments which received the application of *Tithonia* leaves at 1.5 t ha^{-1} produced maize grain yield increases of 39% (2692 kg ha^{-1}), 122% (4360 kg ha^{-1}) and 162% (769 kg ha^{-1}) over the control (1914, 1965 and 294 kg ha^{-1}) at Bembeke, Chitedze and Champhira, respectively. Similarly, mean maize yields from the application of *Tithonia diversifolia* biomass at 1.5 t ha^{-1} (2607 kg ha^{-1}) were not significantly different from the inorganic fertiliser treatment (2734 kg ha^{-}

^{1}). Supplementation of TSP to *Tithonia* did not result in significant maize yield increases. With *Tithonia* biomass alone, maize yields ranged from 2607 to 3731 kg ha^{-1} while with TSP supplementation yields ranged from 2640 to 3665 kg ha^{-1}. The application of *Tithonia* leaves at 1.5 t ha^{-1}, raised soil phosphorus status by 8%, 74% and 12% while soil nitrogen was improved by 22%, 6% and 11% at Bembeke, Chitedze and Champhira, respectively. With the application of DAP and urea at 92:18 N:P), nitrogen status was improved by 5%, 10% and 44% while phosphorus was improved by 22%, 47% and 68% respectively at Bembeke, Chitedze and Champhira, respectively.

From the average of the three sites, the treatments which received the application of *Tithonia* leaves only at 3.0 and 4.5 t ha^{-1} resulted in the significantly highest nitrogen uptake of 20.3 and 22.2 kg N ha^{-1} while with supplemental TSP, N uptake was 22.0 and 21.5 kg ha^{-1}, respectively. The application of *Tithonia* only at 3 and 4.5 t resulted in a P uptake of 4.4 kg P ha^{-1}, respectively. With TSP supplementation the same treatments resulted in P uptake of 5.1 and 4.9 kg P ha^{-1}). The inorganic fertiliser treatment gave an uptake of 20.0 and 4.1 kg/ha of nitrogen and phosphorus respectively.

Highest ammonium and nitrate concentrations were observed at 14 days after the onset of incubation while phosphorus concentrations were highest at 28 days. Nitrate concentration was highest in the soil which was mixed with *Mucuna* (20.4 mg NO_3- kg^{-1}). Highest ammonium concentration were noticed from the soil which was mixed with *Tithonia* leaves (10.1 mg NH^4 + kg^{-1}). The soil mixed with *Tithonia* leaves also had the highest phosphorus concentration (11.0 mg kg^{-1}).

APPROVAL

This dissertation of ROSAN PATERSON GANUNGA is approved, fulfilling part of the requirements for the award of the Master of Science Degree in Agronomy (Crop Science) by the University of Zambia.

Examiner's Names and Signature	Date
1	....
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3	....

DEDICATION

To my lovely wife Phoebe and children Chisomo, Patience (Sarai) and Leadson. To the children I say, I have shown you the way, continue from here. To Phoebe, I say continue loving and supporting me tirelessly as you have done before.

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INSTITUTIONAL ACRONYMS AND ABBREVIATIONS

CIMMYT	International Maize and Wheat Improvement Centre
ICRAF	International Centre for Research in Agroforestry
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute.
kg ha^{-1}	Kilogrames per hectare
m	Metre
N	Nitrogen
P	Phosphorus
SADC	Southern Africa Development Community
Td	*Tithonia diversifolia*
t ha^{-1}	Tonnes per hectare
TSBF	Tropical Soil Biology and Fertility
TSP	Triple superphosphate
WAP	Weeks after planting
mg/kg	Milligrams per kilogram

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1.0 INTRODUCTION

In Malawi, soil degradation and continuous cropping without the addition of external inputs have resulted in decline in soil fertility and consequently smallholder maize yields (Kumwenda *et al*., 1997; Zambezi *et al*., 1995). These effects have to be reversed if Malawi is to maintain food self sufficiency both at national and household levels. The decline in soil fertility in Malawi is due to several factors: (a) diminishing crop rotation cultural practice due to land shortage, (b) reduced fertiliser use due to increasing unaffordable fertiliser prices following the removal of subsidies on fertiliser and devaluation of the Malawi Kwacha, and (c) low adoption of green manure technologies which have been developed to act as organic fertiliser sources.

Several studies have been conducted to address issues of declining soil fertility. These include use of inorganic fertilisers (Bolton and Bennett, 1975), intercropping (Kumwenda *et al*.,1993), crop rotation (MacColl, 1989), agroforestry (Buntderson *et al*., 1991), green manuring (Kumwenda *et al*., 1995), and use of compost or animal manure (Anonymous, 1985). Despite their positive contribution, few of these are easy to adopt. For example, inorganic fertilisers have made the largest impact on improving maize yields over no fertiliser treatments (Zambezi *et al*., 1991). However, adoption rates of inorganic fertilisers have been low due to the collapse of the credit system from an annual increase of 32.7% in 1980/90 to -83.3% in 1993/94 due to failure to recover the loans and be recycled (Ministry of Agriculture and Livestock Development, 1994). Other constraints include low biomass production under intercropping systems and shortages of seeds, shortage of land to practice crop rotation and high labour demand in agroforestry (Saka, 1989). These problems have created a challenge to agronomists in Malawi to explore more options for soil fertility improvement. One such option is the use of *Tithonia diversifolia* biomass as a green manure.

Tithonia diversifolia is a naturally occurring bush in Malawi. It is available in over 75% of the districts in Malawi although a detailed quantitative survey has not been conducted. It is highly vegetative and a perennial. It has a high nutrient composition and mineralises fast (Palm, 1995). It is easily propagated by using cuttings just like cassava. In Kenya, Palm *et al*. (1995) reported that the application of *Tithonia* biomass at 5 t ha^{-1} to maize fields produced maize grain yields of 2 t ha^{-1} which were comparable to the application of 60 kg N of inorganic fertilisers (1.3 t ha^{-1}).

In Malawi, the shrub is commonly used for construction work, as a hedge for vegetable gardens and ornamental purposes. It has a pesticidal property for controlling stalkborer in maize. It is also used to heal wounds by squeezing the juice from the leaves onto the wounds and heal stomach pains. One farmer indicated that he uses it as an improved fallow species. In all the places visited, farmers indicated that they have observed that where *Tithonia* grows, there is improved fertility. If maize is grown after *Tithonia*, there is improved productivity. Unlike the agroforestry species of *Sesbania sesban* and *Leucaena leucocephala* which are eaten by domestic animals, *Tithonia species* are not edible by domestic animals.

No work has been done to evaluate the potential of *Tithonia* for soil fertility improvement in Malawi. The objectives of the study were therefore to: (a) assess the effect of *Tithonia diversifolia* on nutrient uptake and yield of maize when compared to inorganic fertiliser, and (b) measure the rates of mineralisation of *Tithonia* when compared to inorganic fertiliser.

2.0 LITERATURE REVIEW

Soil fertility decline has remained one of the major factors limiting productivity of maize in Malawi. Several interventions have been evaluated from the early 1950s to try address this problem. Technologies like agroforestry, crop rotation, intercropping, use of animal and green manures, inorganic fertilisers and improved fallowing have been evaluated. Results from these studies have shown positive contributions but institutions and logistics challenges continue to limit their advantages and hinder their adoption by smallholder farmers.

2.1 General attempts for soil fertility improvement

Inorganic fertilisers have made the largest impact on improving maize yields. In Malawi, Zambezi *et al*. (1991) reported maize yield increases from 0.7 t ha^{-1} (unfertilised control) to 2.8 t ha^{-1} due use of inorganic fertilisers at 80 kg ha^{-1} with MH 18 as a test variety. Use of inorganic fertilisers became popular in the 1950s when their real price fell below the cost of using organic fertilisers (Hikwa and Mukulumbira, 1995). However, despite the large body of work on inorganic fertilisers and their positive impact on improving maize yields, the main beneficiaries of inorganic fertiliser research are the large-scale commercial farmers (Conroy, 1992). In Malawi, smallholder average hybrid maize yields have stagnated at 2.8 t ha^{-1} for the last decade (Blackie and Conroy, 1993). These low yields are partly due to low fertiliser use. The low fertiliser uptake has been due to the removal of subsidies on fertiliser prices. For example, subsidies on urea fertiliser dropped from 23% in 1991/92 to 10.7% in 1993/94 and a further total removal of the subsidies in 1994 (Goldman *et al*., 1994). The credit system which increased from MK55,995,822.00 uncollected in 1989/90 to -MK101,922,748.20 in 1993/94 completely collapsed in 1994 due to failure of government to recover loans from farmers which resulted in lack of financial circulation (Ministry of Agriculture and Livestock Development, 1994; Smale and Heisey, 1994). This scenario is not a healthy one. A technology is desirable which will be affordable and highly effective in terms of soil fertility improvement if Malawi is to maintain food self-sufficiency. Hence the need for exploring more opportunities. In Zimbabwe, much work has been done on appropriate types, amounts, timing, and placement of inorganic fertilisers for food crops produced by smallholder farmers. However, fertiliser recommendations still fail to take sufficient account for the cash constraints and risks affecting resource poor farmers in marginal areas (Hikwa and Mukurumbira, 1995).

In Malawi, intercropping was also evaluated for soil fertility improvement (Ngwira *et al*., 1989). The most common intercrops are maize/groundnuts, maize/cowpeas, maize/beans and maize/pigeon-peas. Farmers practice intercropping to increase the value advantage of land and because it is known to improve soil fertility. In the studies reviewed, Ngwira *et al*. (1989) observed that the contribution of legumes to soil fertility are variable. This is as a result of differences in plant population, the amount of nitrogen which goes to the grain and the amount of biomass each is able to produce at the end of the season. Also, the slow growing legumes are often shaded by the taller cereals. Under smallholder management in low fertility conditions, poor growth of the legume is common. This limits the nitrogen contribution of the legume to levels well below the potentials found on research stations (Kumwenda *et al*., 1993; Kumwenda, 1995).

One of the promising intercrops is late maturing pigeon pea. Even though early growth of the legume is reduced when intercropped with maize, pigeon peas compensate by continuing to grow after the maize harvest and produce large quantities of biomass (Sakala, 1994). Sakala (1994) reported a pigeon pea leaf litter and flower dry matter yield of 3 t ha^{-1} when intercropped with maize. The problem with late maturing pigeon peas is that they are heavily attacked by livestock, such that in areas where domestic animals are left free during the dry season, this technology may have limited chance of adoption. This research by Sakala (1994) did not provide information about maize yield increases following pigeon pea litter incorporation or the changes in soil fertility status after pigeon pea litter incorporation. Hence, there is need to study these and other opportunities where plant materials with high biomass production are easily available.

Non-food legume green manure crops grown in association with maize have also shown positive contribution towards soil fertility improvement. Kumwenda *et al*. (1996) reported maize yields of 2.1, 2.0 and 1.0 t ha^{-1} higher than the control after the incorporation of pigeon pea, sunhemp and *Mucuna* biomass respectively. The drawback to this technology is that farmers are mostly interested in intercropping maize with a food crop, as such the adoption of such a technology would also be limited.

Crop rotation of cereals and grain legumes has been promoted since independence in Malawi with the aim of soil fertility improvement (Lungu, 1973). Legumes commonly involved in crop rotation include groundnuts, beans, pigeon peas, and bambara nuts. However, the amount of nitrogen or phosphorus returned from legume rotation depend on whether the legume is harvested for seed, foliage or incorporated as green manure. In Malawi, MacColl (1989) estimated a net nitrogen return of 23 to 110 kg N ha^{-1} from pigeon pea, 23 to 50 kg N ha^{-1} from Dolicos bean, and 25 kg N ha^{-1} from groundnuts. In Nigeria, Jones (1974) and Giri and De

(1980) estimated 60 kg N ha^{-1} from groundnuts.

The yield response of a cereal crop following a legume can be substantial. In Malawi, MacColl (1989) showed that grain yield of the first crop of maize following pigeon peas averaged 2.8 t ha^{-1} each year. In Zimbabwe, Mukurumbira (1985) showed that maize yields were greater following bambara nuts (7.6 t ha^{-1}) than after groundnuts (6.2 t ha^{-1}), upland fallow (4.3 t ha^{-1}) or continuous maize (3.9 t ha^{-1}), without supplementation of inorganic nitrogen. Similar studies in Tanzania showed that maize yields after sunhemp with residues removed or incorporated were 3.65 t and 4.82 t ha^{-1}, respectively (Temu, 1982). In the latter, maize yields were an equivalent of applying 80 kg N ha^{-1} from inorganic fertiliser.

Most smallholders in Malawi cannot practice crop rotation because of population pressure. Land holdings per rural household is about 0.7 ha (Malawi Census and Statistical Office, 1985). Consequently, continuous cropping or intercropping is prevalent which account for 94% of the smallholders cultural practices. This situation is worsened by low soil fertility without supplying external inorganic inputs. This shows that under Malawi situation, soil fertility restoration techniques through shifting cultivation or crop rotation is not a viable option because land is the limiting factor.

Research was also conducted on crop rotation with legume green manure crops. Green manuring came about in the search for alternative sources of nitrogen. This was done to avoid some of the problems associated with inorganic fertilisers (Lathwell, 1990). Green manures were heavily researched from the 1920s to 1940s (Matelekamp, 1988). In the same studies reviewed, Matelekamp (1988) indicated that large scale farmers used green manures widely until the real price of inorganic fertilisers fell in the 1950s and green manuring became uneconomical. However, the rising of real price of inorganic fertilisers and concern over the sustainability of the current cropping system, have once again attracted interest in green manure use (Hikwa and Mukurumbira, 1995). Swift and Woomer (1993) reported that green manures are an important source of soil organic matter which is limiting in most tropical soils. They further indicated that, the maintenance and management of soil organic matter are central to sustaining soil fertility on smallholder farms. Some green manure crops are known to suppress plant pests like nematodes in soyabeans (Sharma *et al*., 1982). A review by Evans *et al*. (1983) indicated that the use of green manures by poor small scale farmers in developing countries will not only increase food crop yields by improving soil fertility, but it will also improve soil physical properties. Onim *et al*. (1990) indicated that in low-input agriculture, the use of green manure offers one of the few hopes for-low cost, sustainable agricultural production .

Results in Malawi (Kumwenda *et al*., 1996) indicated that soil nitrate was highest in plots where inorganic nitrogen was incorporated with legume residues compared to plots where either was applied separately. Giller *et al*. (1994) indicated that some green manure crops like cowpeas generate large amounts of organic matter and can accumulate 100-200 kg N ha^{-1} in 100-150 days in the tropics. Kumwenda *et al*. (1996) reported that maize yields after legume crops without fertiliser nitrogen ranged from 4484 to 5729 kg ha^{-1} compared to 3547 kg ha^{-1} from the continuous maize without inorganic fertilisers. The legumes evaluated were *Mucuna*, sunhemp and pigeon peas. The problem with this system is that farmers with limited land have no opportunity to release land for one season hoping to get the benefit the following season. Farmers would otherwise rotate with a food crop compared to a non-food crop green manure.

2.2 Agroforestry Systems

The major purposes of agroforestry are for (a) soil fertility improvement, (b) feed supplement for livestock, (d) provision of firewood and poles for construction work, (e) conservation of soil water and (f) control of soil erosion (Ngugi, 1993). Agroforestry technologies for soil fertility improvement include alley cropping, improved fallow and biomass transfer. The most common species commonly used in Malawi are *Leucaena leucocephala*, and *Sesbania sesban*. Further, research has identified alternative species that are adapted and produce more biomass than *Leucaena leucocephala* (Bunderson, 1994). *Gliricidia sepium* and *Senna spectabilis* have both shown potential to produce more biomass in a wider range of ecologies. Saka *et al*. (1994) reported that *Faidherbia albida* is a vigorous leguminous tree and has long been used for improving crop yields where the tree is naturally abundant. The tree retains its leaves during the dry season and sheds them at the onset of the rains. The resultant fine mulch of litter undergoes rapid decomposition, enriching the topsoil in plant nutrients and organic matter. The same review by Saka *et al*. (1994) reported results from Malawi which confirmed vigorous maize growth under *Faidherbia* tree with decreasing vigour away from the tree. Research results from Tanzania (Okorio and Maghembe, 1994) showed *Phaseolus* beans yields increasing from 200 to 400 kg ha^{-1} while maize yields increased from 300 to 950 kg ha^{-1} under *Faidherbia albida* trees.

2.2.1 Alley cropping

Alley cropping sometimes referred to as hedge planting, was developed in the late 1970s at IITA and is the best known agroforestry system developed for the soil fertility improvement (Kang *et al*., 1990). This technology aims at utilising deep rooted multi-purpose tree species to tap moisture and nutrients at depth in the soil, and below the roots of annual crops. The tree is then pruned to supply nutrients to the soil and these are used by shallow rooted annuals. In Malawi, Bunderson *et al*. (1991); Jones *et al*. (1995) showed that the application of *Leucaena* leaf prunings in an alley cropping system raised maize grain yield and increased soil pH, organic carbon, total nitrogen, sulphur and exchangeable calcium, magnesium and potassium. Hybrid maize yields averaged 2.0 to 3.5 t ha^{-1} when *Leucaena*, *Tephrosia*, *Cassia* or *Gliricidia* leaves are used as organic fertilisers without addition of inorganic fertilisers (Ministry of Agriculture and Livestock Development, 1994).

Some aspects of alley cropping are problematic. Saka *et al*. (1995) reported that *Leucaena leucocephala* (the most researched hedgerow species), suffers susceptibility to termite attack at the seedling stage, severe defoliation by the recently arrived *Leucaena* Psyllid and poor biomass production under low fertility and on soils of low pH. Saka *et al*. (1995) estimated that the cost of producing nitrogen from *Leucaena* biomass is comparable to that from inorganic sources. Tomich *et al*. (1995) noted that production of large quantities of of organic materials may become more difficult as farm sizes become smaller due to population pressure and farm subdivision. The labour required to move large quantities of biomass can also be enormous. This shows that the technology requires a lot of labour and is time consuming in the sense that growth of most multi-purpose tree species is slow. Competition between the trees and the associated crops can occur for moisture, and for nutrients and light in alley cropping (Mbekeani, 1991; Ong, 1994). *Sesbania sesban* produces very small amounts of biomass, while *Faidherbia albida* is difficult to raise from seedlings and also takes very long to show its impact on soil fertility improvement which is estimated at fifteen years (Kanyama-Phiri *et al*., 1997).

2.2.2 Improved Fallowing

Traditionally, farmers maintained soil fertility by shifting cultivation. This system involved clearing of small forested areas followed by burning of the debris before the rainy season. The burning helped control pests and diseases and accelerated decomposition of organic matter on the top layers of the soil. The land was cropped for a few years, left to fallow so that fertility could be regenerated naturally (Jewel *et al*., 1995).

In Malawi, *Sesbania sesban, Cajanus cajan* and *Tephrosia vogelii* have been found to be suitable for improved fallows. Results from ICRAF-Makoka indicate that best results in terms of maize yields are derived from improved fallows based on leguminous crops. Maize yields following two year fallow with *Sesbania sesban* increased from 1.9 to 5.6 t ha^{-1} (Kanyama-Phiri *et al*., 1997). In Eastern Zambia, improved fallows using *Sesbania sesban*, on station produced maize yields between 3 and 6 t ha^{-1} of grain for each of the four years following a two year improved fallow, compared to 1-2 t ha^{-1} in the unfertilised control (Kwesiga and Coe, 1994). Place *et al*., (1995) calculated that when inorganic fertilisers are not used, it was profitable for farmers to invest in improved fallow. Improved fallows avoid the competition between the trees and the crops. However, as the length of fallow period is reduced, the equilibrium levels of soil organic carbon and organic nitrogen declines.

2.3 Use of *Tithonia diversifolia*

Another soil fertility improvement intervention is the use of *Tithonia diversifolia*. *Tithonia* was introduced from Central America (Agnew and Agnew, 1994). Its english name is Wild Sunflower. In the Southern Africa region, *Tithonia* is a naturally occurring bush in Kenya, Zambia, Zimbabwe, Mocambique and Malawi. Information on whether *Tithonia* is present in the other countries in the region, is not available. It is available in all agro-ecological zones of Malawi although a detailed quantitative distribution survey has not been conducted. It has an erect stem, rhizomatous root system, is highly vegetative and a perennial. Agnew and Agnew (1994) described *Tithonia diversifolia* as a soft shrub with simple three lobed mostly opposite leaves. It has a large orange or yellow head on an expanded stalk. It is often used as a hedge. Beentje (1994) further described *Tithonia* as a member of the Compositae family. A woody herb which has escaped cultivation, gone into wild on the roadside, near rivers and on waste ground.

2.3.1 Socio-economic implication of *Tithonia diversifolia*

Farmers interviewed in various parts of the Central Region of Malawi indicated that the shrub is known by the following Chichewa names: Deliya (usually used as a name for females) in Dedza; Futsa (dried vegetable for future use), Mdadzandiyani (meaning who brought you here) and Zowawa (sour staff) in Lilongwe; and Zingombilo and Dzanjoka (where snakes hide) in Ntcheu. These names and their associated meanings give the impression that *Tithonia* was brought from somewhere most of the people do not know and was possibly associated with women.

Tithonia was successfully used as an agroforestry/green manure species in Kenya (Anonymous, 1995a). Results from work on phosphorus release by Anonymous (1995a) where *Tithonia diversifolia* was compared with *Cassia spectabilis*, indicated that both *Cassia spectabilis* and

Tithonia diversifolia resulted in significant maize yield increases compared to the control. Maize yields were highest where *Tithonia* was supplemented with TSP which produced 3.5 t ha^{-1} followed by *Tithonia* alone and *Cassia* supplemented with TSP which all produced 2.0 t ha^{-1}. Lowest maize grain yields were realised from the control and TSP alone and they all gave yields of 0.8 t ha^{-1}. Highest phosphorus release was also reported under *Tithonia. Tithonia* had a steady phosphorus release pattern of 1.5 mg P kg^{-1} at 3, 7 and 14 days after incubation. *Cassia spectabilis* released 0.9, 0.8 and 0.5 mg P kg^{-1} within the same dates (Anonymous, 1995a). This study by Anonymous (1995a) attributed the rapid release of phosphorus which subsequently improved soil available phosphorus to explain the high maize yields associated with *Tithonia* biomass than the effects of the other nutrients. The slower decomposition of *Cassia* was suspected to be due to the presence of polyphenols and not to lignin. Lignin content of the biomass of both species were similar (about 12%). Both *Cassia* and *Tithonia* could meet the nitrogen demand of maize based on their nutrient content, but neither met the phosphorus demand (Anonymous, 1995a). Nagarajah and Nizar (1982) reported use of *Tithonia diversifolia* in rice fields. Results indicated that complete decomposition of wild sunflower (*Tithonia diversifolia*) occurred about 3 to 4 weeks after incorporation. It was therefore, concluded that planting of rice should be done 1 to 2 weeks after incorporation of the green manures.

Further, research with *Tithonia* revealed that it has a pesticidal property (Carino *et al*., 1982). Fraction D extract from *Tithonia* was found to be more toxic to soft-bodied pest species than to those with a highly sclelotised exoskeleton. Fraction D leaf extract was able to kill 60%, 37.93% and 31.67% of *D. cingulatus, T. castaneum* and *S. zeamais*, respectively.

Anonymous (1995c) reported that the fastest ground cover was achieved through the highest leaf area index from *Tithonia diversifolia* (1.1) followed by natural fallow (1.09), then *Sesbania sesban* (0.9). The shading effect of *Tithonia* and *Sesbania sesban* suppressed weed growth and consequently dry matter yields of the weeds. In this study, *Tithonia* was established from cuttings while *Sesbania* was from seed.

3.0 MATERIALS AND METHODS

3.1 FIELD EXPERIMENTS

3.1.1 Site description

Researcher managed experiments were conducted in the 1996/97 season. Field experiments were established at three sites in Dedza, Lilongwe and Mzimba districts. Dedza district is in the Central Region of Malawi and lies about 85 km south of Lilongwe City along the Lilongwe-Blantyre Road. The field study was conducted at Mrs Malamba's farm. It is about 14^{o}21'S and 34^{o}25'E. In Lilongwe, the experimental field was sited about 2 km west of Chitedze Research Sation boundary. Chitedze Research Station lies 13^{o}59'S and 33^{o}38'E. It is situated 16 km west of Lilongwe city along the Lilongwe-Mchinji/Chipata Road. The field belongs to Mr Christopher Kansinjilo of Malimbwe Village. The Champhira site was in Mzimba district (the biggest district in Malawi). Mzimba district lies in the northern region of the country but borders with Central Region. Champhira, is about 250 km from Lilongwe, going northwards and about 120 south of Mzuzu, city. This area falls under Mzimba South Rural Development Project (RDP), Champhira Extension Planning Area (EPA) and Hoho Section. The owner of the field is Mr Saka. Champhira is situated at 12^{o}24'S and 33^{o}40'E (Appendix 11).

All the sites fall under the mid-altitude ecology of Malawi which lies within 600 to 1300 meters above sea level. All these sites receive a unimodal type of rainfall (Appendix 1). The sites were selected on the basis that these are places where soil fertility is very low and *Tithonia* is ubiquitous. These are sites where for the past two years maize was grown without any fertilizers.

This was to ensure minimal residual fertilizer carry over.

3.1.2 Initial soil chemical and physical properties

Soil samples were collected from each experimental field before planting the field trials. Soil samples were collected diagonally in the field, composited, sub-samples analyzed for nitrogen by the micro-kjeldahl method (Bremner, 1965), phosphorus, calcium and magnesium by the Mehlich 3 method (Mehlich, 1984), and pH in water. The results of the analysis are presented in Table 1.

At Bembeke, the soils are cassified as Bembeke series, which originated from the basement complex, high altitude ferruginous lithosols (Malawi classification), Oxic Rhodustalf (USDA Classification) and Ferric Luvisol (FAO Classification). At Champhira, the soils are classified as Jenda series, which originated from the basement complex, weakly ferallitic (Malawi); Typic Eutrustox (USDA) and Xanthic ferralsol (FOA). The soils at Chitedze are classified as Mwanjema series which originated from biotite gneisis, in part of garnetferrous part of the basement complex, weakly ferratic (Malawi), Typic Eutrustox (USDA) and Xanthic ferralsol (FAO).

Table 1. Soil chemical properties for the experimental sites at the beginning of the season.

Property	Bembeke	Chitedze	Champhira
pH	5.3	6.5	5.8
Nitrogen (g/kg)	1.4	1.2	0.6
Phosphorus (mg/kg)	7.38	3.07	2.33
Potassium (mg/kg)	17	21	11
Calcium (mg/kg)	3.05	2.97	2.33
Magnesium (ppm)	0.29	0.38	0.15
% Silt	14	14	10 (SL)*
% Clay	16	16	18(SL)*
% Sand	70	70	72(SL)*

Key: * = Sandy loam texture class

3.1.3 Rainfall data

Monthly and total rainfall during the study period for each experimental station was collected from the nearest meteological station within the radius of five kilometres from the experimental site. For the site at Bemebeke, rainfall data was obtained from Bembeke Experimental Station while for the Chitedze site, it was obtained from Chitedze Research Station. For the Champhira site, rainfall data was obtained from Hoho Section which falls under Champhira Extension Planning Area. This data is presented in Appendix 1.

3.1.4 Initial *Tithonia* analysis

In order to know the nutrient composition of the *Tithonia* biomass used in the study, leaves were obtained from natural bushes existing in Dedza district in July 1996. Dead and fresh leaves were collected separately. The fresh leaves were air dried before analysis. Leaves were analyzed for nitrogen using micro-kjeldahl method, while phosphorus, potassium, calcium and magnesium were determined calorimetrically using ascorbic acid method at the beginning of the season. The results of these analyses are shown in Table 2.

Table 2. Nutrient composition of *Tithonia diversifolia*.

Element	*Tithonia* leaves collected green and air dried (%)	*Tithonia* leaves collected already dry (%)
Nitrogen	2.94	1.45
Phosphorus	0.25	0.09
Potassium	3.25	2.34
Calcium	0.11	0.12
Magnesium	0.07	0.08

The results of the analysis from the samples which were collected green were used to determine the quantities of *Tithonia* to be used in *Tithonia* treatments. *Tithoni*a leaf samples are also sent to the Tropical Soil Biology Fertility Program in Kenya for lignin and polyphenols analysis. The results of that analysis are presented in Table 3.

Table 3. Nutrient composition of *Tithonia* collected from different areas of Malawi (within 600 to 1300 metres above sea level).

Field name	% Polyphenols	% Lignin	% Nitrogen	% Phosphorus	% Potassium
Champhira	2.68	10.39	4.07	0.53	4.26
Lilongwe (Bunda)	5.54	7.68	2.8	0.53	3.53
Ntcheu (Katsala)	4.57	8.31	3.64	0.52	3.69
Lilongwe (Chitedze)	5.4	7.05	3.60	0.48	3.44
Dedza Boma	4.64	9.55	3.34	0.48	3.44
Dedza west (Thiwi)	3.33	10.4	3.23	0.53	4.83

3.1.5 Design and treatments

The experimental design was a randomised complete block with three replicates and eight treatments at each site. The following treatments were evaluated:

(1) No fertilizer (control),

(2) 40 kg P_2O_5 ha^{-1} + 92 kg N ha^{-1} (standard recommendation),

(3) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P).

(4) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P).

(5) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P).

(6) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P) + 13.5 kg P from TSP.

(7) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P) + 9.7 kg P from TSP.

(8) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P) + 5.95 kg P from TSP.

3.1.6 Land preparation and experimental management

All fields were hand ploughed and ridged. Ridges were spaced at 0.9 m apart. The gross plot size was 6.3 m long by 3.6 m while the net plot consisted of the two middle rows excluding the end of ridge stations. It measured 5.4 m x 1.8 m which gave a harvest area of 9.72 m^2.

Basal dressing inorganic fertilisers and organic materials were applied before planting. This was done by opening the ridge to a depth of 0.15 m, applying the materials, then covering the opening before planting. Diammonium phosphate (DAP) and Triple Superphosphate (TSP) were the basal dressing inorganic fertiliser sources. At Bembeke, the *Tithonia* leaves were air dried and incorporated in the experiment. At Chitedze and Champhira, the leaves were collected and incorporated while green. The weight of biomass at the latter sites were adjusted for the moisture content.

Hybrid maize variety, MH17, a recommended hybrid for the ecological zone, was planted. Three maize seeds were planted in stations at a spacing of 0.90 m by 0.90 m resulting in a population of 37,000 plants ha^{-1}. This is the plant population recommended by the Ministry of Agriculture and Livestock Development (1994). Planting was done on 16th, 18th and 22nd December, 1996 at Bembeke, Chitedze and Champhira, respectively. Top dressing inorganic fertilizer (Urea) was applied three weeks after planting by dollop method using fertiliser cup number 8. Two cup fulls were applied on each station. The fields were kept weed free throughout the growing season.

At Champhira, termites were controlled by applying Simuthion at 136 ml in 14 litres of water. This was done using a knapsack sprayer and spraying at the base of each planting station when attacks were detected. 2% G. Dipterex was hand applied at Bembeke and Champhira to control stalk borer because these places are prone to such problems. Application was done by scooping a quarter tea spoonful and applying it into the funnel of each maize plant. This was an application rate of 8 kg ha^{-1}. This was done at done at 4 and 6 weeks after planting. Harvesting was done when the maize was fully dry, at least with a moisture content of less than 20%.

3.1.7 Data collection and analysis:

The following data were collected: emergence count, plant height, nitrogen and phosphorus concentration in maize, dry matter production in maize, harvest count by counting all the maize stalks standing in each net plot, cob number by counting all the cobs harvested from each net plot , cob weight by weighing all the cobs harvested from each net plot, grain weight by weghing all the shelled grain from each net plot, moisture content by using Dicky John grain moisture tester. Data from soil included pH, nitrogen, phosphorus, calcium, magnesium and potassium.

3.1.7.1 Soil sampling and analysis during the growing season:

In order to monitor soil fertility changes within the experimental plots from the start of the experiment up to harvest, soil samples were taken from a 0-15 cm depth. These were collected four times from each site: (a) before planting, (b) at four leaf stage, (c) at tasselling, and (d) after harvest. Soil samples were collected from the two guard rows using an auger, then a composite sample was used for the analysis. Nitrogen was determined using the microkjeldahl method (Bremner, 1965) while phosphorus, potassium, calcium, magnesium, were determined by the Mehlich 3 method and pH using water. At the four leaf stage and at tasselling analysis was done for nitrogen and phosphorus using the procedures described above.

3.1.7.2 Plant sampling and analysis

To determine nutrient concentration in maize, samples were collected from the two outer rows of each plot. At four leaf stage of maize growth, four whole plants were collected from each plot. At tasselling and after harvest two maize plants were sampled. The samples were oven dried at 65^0C for 48 hours. The samples were then ground to pass through a 0.5 mm seive before being analyzed for nitrogen and phosphorus. Nitrogen and phosphorus uptake was determined by analysing the grains for these nutrients then multiplying by the grain yield.

Plant nitrogen and phosphorus were determined by micro-kjeldahl method using 2.5 ml of sulphuric acid /selenium mixture to digest 0.2 g ground samples. Nitrogen and phosphorus were determined calorimetrically on a spectrophotometer at 655 nm and 860 nm respectively.

3.1.7.3 Dry matter production by maize and maize stover weight

At flowering, dried maize samples were weighed for dry matter production. This was done before the samples were analyzed for N and P. Biomass production per hectare was determined by extrapolating the weight of the four maize plants to the weight of 37,000 plants per hectare. Maize stover weight was determined after harvest from the net plot. All the harvested stovers were thinly spread in the plots for further drying for three weeks before weighing.

3.1.7.4 Maize grain yields:

Maize grain yields were determined by harvesting 1.8 m x 5.4 m from each of the middle of each plot, and seed weight adjusted to 12.5% moisture content. The yields were then extraploted to kilogrammes per hectare.

The data were analyzed using MSTATC Computer Package. The means for parameters which were significantly different were compared using Duncan's Multiple Range Test. Single degrees of freedom contrasts were conducted to compare different pairs of treatments of interest.

4.0 GREENHOUSE STUDY

4.1 Preparation of soil and plant material

This work was conducted to monitor whether *Tithonia* releases nutrients early or later in the season. This was done by evaluating the same treatments which were evaluated in the field experiment under greenhouse conditions. This work was for a duration of 6 weeks. Pot management was done following the procedure by Sarrantonio (1991).

The soil used was obtained from the Chitedze farmers' field. Samples were obtained from 0-15 cm of soil from which a composite sample was obtained. The soil was then mixed with sand in a 4:1 ratio to improve on drainage. About 4.8 kg of the sand to soil mixture was filled into each pot. Plates were placed at the bottom of each pot to hold water and control leaching of nutrients from the pots. Each treatment consisted of two pots. The following quantities were applied in each pot (numbers stand for treatments) : 1 , control no fertiliser no *Tithoni*a; 2, 40 P_2O_5 + 92 kg N ha^{-1} (0.834 g DAP + 1.544 g urea); 3, *Tithonia diversifolia* at 1.5 t ha^{-1} *(Tithonia* at 14.4 g); 4, *Tithonia diversifolia* at 3.0 t ha^{-1} *(Tithonia* at 28.8 g); 5, *Tithonia diversifolia* at 4.5 t ha^{-1} *(*Tithonia at 43.2 g); 6, *Tithonia diversifolia* at 1.5 t ha^{-1} + 13.5 kg ha^{-1} TSP *(Tithonia* at 14.4 g + 0.604 g TSP); 7, *Tithonia diversifolia* at 3.0 t ha^{-1} + 9.7 kg ha^{-1} TSP *(Tithonia* at 28.8 g + 1.208 g TSP) and 8, *Tithonia diversifolia* at 4.5 t ha^{-1} + 5.95 kg ha^{-1} TSP (*Tithonia* at 43.2 g + 1.812 g TSP). *Tithonia* leaves were crushed into smaller pieces by hand before being thoroughly mixed with the soil in the pots. Inorganic fertilisers were applied by making a groove closer to the edges of the pot to avoid scotching the seed. Each pot was planted to two MH 17 maize hybrid seeds. The pots were arranged in a completely randomised design with three replicates and two pots per treatment per replicate. Water was applied to each pot at a field capacity moisture content throughout the experiment.

4.2 Plant and soil sampling

At two weeks after planting, one plant was removed from each pot. These were used as first plant sampling. Plant and soil samples were taken at 2, 4 and 6 weeks. These were analyzed for nitrogen and phosphorus. The plant samples were oven dried for 48 hours at 65^0C, ground to pass through a 0.5 mm sieve before analysis. Plant analysis was done for samples collected at four and six weeks because samples which were collected at two weeks after planting were not adequate for analysis.

Plant height measurements were also taken from a tagged plant at 2 week intervals. This was done by measuring the plant from the base of the maize plant to the growing tip on the plant. Maize dry matter production was determined at each time of plant sampling. This was done by weighing the maize samples after oven drying.

4.3 Data analysis

Analysis of variance was done on nutrient concentration in plants, nutrient levels in the soil, maize plant height and maize dry matter production using MSTATC Computer Programme. Treatments which were significantly different were separated by Duncan' Multiple Range Test at $P \leq 0.05$.

5.0 LABORATORY INCUBATION STUDY.

5.1 Soil preparation and incubation

This study was conducted to compare the rates of mineralisation of *Tithonia diversifolia* with *Tephrosia vogelli, Mucuna (Mucuna aterrima), sunhemp (Clotalaria intermedia),* and maize stover. There were six treatments (five organic inputs plus bare soil).

The soil used in this study was obtained from the Chitedze farmer's field. The soil was collected from the top 0-15 cm from where a composite sample was obtained. This was mixed with sand in a 4:1 soil to sand mixture using a soil mixer. 500g of 4:1 soil to sand mixture was placed into a transparent plastic bag. Biomass application for all treatments was at the rate of 3 t ha^{-1}. Quantities of organic inputs to add in each bag were determined by soil weight following the procedure by Sarrantonio (1991). The mixture was placed in a plastic bag in a dark room at room temperature (25^{0}C). Water was added to the mixture to maintain field capacity moisture content.

5.2 Data collection and analysis

Ten gram sub-samples of soil were collected for nitrogen and phosphorus determination at 2 and 4 weeks. Nitrate and ammonium were determined by the potassium chloride extraction. Available phosphorus was determined by the by Mehlich 3 method. Analysis of Variance technique was employed to detect treatment differences by using MSTATC Computer Package. Treatments which were significant were separated by Duncan' Multiple Range Test at $P \leq 0.05$.

6.0 RESULTS AND DISCUSSION

6.1 FIELD EXPERIMENT

6.1.1 Maize grain yield response to *Tithonia* application

At all sites, there were significant ($P \leq 0.05$) maize yield differences among the treatments (Table 4). Application of *Tithonia* leaves at 1.5 t ha^{-1} produced maize yield increases of 39% (2692 kg ha^{-1}), 122% (4360 kg ha^{-1}) and 162% (769 kg ha^{-1}) over the control (1914, 1965 and 294 kg ha^{-1}) at Bembeke, Chitedze and Champhira, respectively. Similarly, the application of *Tithonia* leaves at 3.0 t and 4.5 t ha^{-1} or the inorganic fertilizers produced significant yield increases over the control (treatment 1) at all sites. At Chitedze, Saka *et al*.(1995) reported maize yields of 2200 and 1200 kg ha^{-1} with *Leucaena* leaves from an alley cropping system applied near and away from the hedge, respectively. This shows that similar maize yields were possible from *Tithonia* compared to *Leucaena leucocephala* which is one of the agroforestry species currently recommended for soil fertility improvement in Malawi.

Maize grain yields from the application of *Tithonia* leaves at 1.5 t ha^{-1} which supplied 44 kg N ha^{-1}, were not significantly different from the standard fertilizer rate (92:40, $N:P_20_5$) at Bembeke and Chitedze (Table 4). One of the reasons for similar maize yields was probably because *Tithonia* supplied other nutrients such as potassium (48.75 kg ha^{-1}), magnesium (1.14 kg ha^{-1}) and calcium (1.69 kg ha^{-1}) (Table 2) which are not supplied in the standard fertilizer recommendation (N:P). Also the soil test values show that K, Ca and Mg were already very low in the soil (Table 1). Wendt (1995) reported that critical values for Malawi upland soils for K is 97 ppm, Ca is 50 ppm and data from North Calorina indicated a Mg critical value of 75 ppm. These critical values are far above those reported in the initial soil analysis (Table 1), as such the contribution of these by *Tithonia* could have an impact on maize yields. Among the *Tithonia* treatments, there were significant maize grain yield differences at Champhira and Bembeke but not at Chitedze. At Bembeke, the application of *Tithonia* biomass at 4.5 t ha^{-1} with and without supplementation with TSP produced maize yields of 3841 and 3723 kg ha^{-1}, respectively.

Table 4. Effect of *Tithonia diversifolia* and inorganic fertilizer sources on maize grain yield (kg ha^{-1}).

	SITES

Treatment	**--------------- kg ha^{-1} ----------------**			
	Bembeke	**Chitedze**	**Champhira**	**Mean**
1	1914 **c**	1965 **c**	294 **d**	1400
2	3334 **ab**	3969 **b**	1000 **bc**	2734
3	2691 **b**	4360 **ab**	769 **cd**	2607
4	3262 **ab**	5808 **a**	1320 **ab**	3463
5	3841 **a**	5921 **a**	1430 **ab**	3731
6	2662 **b**	4540 **ab**	718 **cd**	2640
7	3275 **ab**	4470 **ab**	1366 **ab**	3037
8	3723 **a**	5598 **a**	1675 **a**	3665
Mean	3091	4566	1072	
F-Prob	0.001	0.0035	0.0007	
CV (%)	13.3	21.7	26.7	

Key to treatments

(1) No fertilizer, no *Tithonia* (control),
(2) 40 kg P_2O_5 ha^{-1} + 92 kg N ha^{-1} (standard recommendation),
(3) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P).
(4) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P).
(5) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P).
(6) *Tithonia diversifolia* at 1.5 t ha^{-1} (44.1 kg N + 3.75 kg P)+ 13.5kg P from TSP.
(7) *Tithonia diversifolia* at 3.0 t ha^{-1} (88.2 kg N + 7.5 kg P) + 9.7 kg P from TSP.
(8) *Tithonia diversifolia* at 4.5 t ha^{-1} (132.3 kg N + 11.25 kg P) + 5.95 kg P from TSP.

These were significantly higher than the application of 1.5 t ha^{-1} *Tithonia* with and without TSP supplementation (2691 and 2662 kg ha^{-1}, respectively). At Champhira, the application of *Tithonia* biomass at 4.5 t ha^{-1} with and without TSP supplementation gave maize yields of 1675 and 1430 kg ha^{-1}, respectively. These were not significantly higher than the application of *Tithonia* at 3.0 t ha^{-1} with and without TSP supplementation which produced 1366 and 1320 kg ha^{-1}, respectively. At Chitedze, all the *Tithonia* treatments produced maize yields which ranged from 4360 to 5598 kg ha^{-1}. Mean maize yields across sites, show that maize yields were highest at Chitedze, followed by Bembeke and lowest at Champhira. This represents a variation in inherent fertility of the sites. For example, the application of *Tithonia* biomass at 1.5 t ha^{-1} at Chitedze produced yields of 4360 kg ha^{-1} which were higher than the application of *Tithonia* at 4.5 t ha^{-1} at Champhira which produced yields of 1675 kg ha^{-1}.

Visual field observations at Champhira revealed that when *Tithonia* was applied at 1.5 t ha^{-1}, the crop started off vigorously. However, towards tasselling, the vigour was lost and leaves began to turn yellow. This suggests the need for supplemental N application at four leaf stage of maize when such low rates (1.5 t ha^{-1}) of *Tithonia* are used, especially in areas of low fertility. The maize yield results reported in this study are in line with what was reported by Anonymous (1995a) in Kenya where the application of *Tithonia* leaves at 5 t ha^{-1} supplemented with TSP produced maize grain yields which were 3500 kg ha^{-1} and was significantly higher than treatments with *Tithonia* alone and *Cassia spectabilis* supplemented with TSP which produced maize grain yields of 2000 kg ha^{-1} each. In the same report, lowest maize grain yields were obtained from the control (no biomass, no fertiliser) and TSP alone which produced 0.8 t ha^{-1} each. Palm *et al*. (1995) reported highest maize grain yields of 2 t ha^{-1} from *Tithonia* only applied at 5 t ha^{-1} and half *Tithonia* + half DAP which supplied 15 kg P + 120 kg N. These were significantly higher than half *Tithonia* only which supplied 7 kg P + 90 kg N and the control treatments which produced 1350 and 850 kg maize ha^{-1}, respectively. The application of DAP and CAN, at 60 kg N and 15 kg P per hectare produced maize yield of 1500 kg ha^{-1} and this was not significantly different from the application of *Tithonia* only at 5 t ha^{-1}.

In other studies carried out in Malawi with agroforestry species biomass, Kanyama-Phiri *et al*. (1997) observed that maize yields almost quadrupled two to three years later when intercropped with *Gliricidia sepium* in the absence of supplmental N. With *Gliricidia sepium*, maize produced 4700 kg ha^{-1} of grain compared to only 1100 kg ha^{-1} produced by a sole crop of maize. The application of 3.0 t ha^{-1} of *Tithonia*, at Chitedze produced 5808 kg ha^{-1} of maize grain, would appear that the immediate benefit derived from *Tithonia* is an added advantage over the use of long term benefits derived from *Gliricidia sepium*.

At all sites, there was a general increase in maize yield as the rates of *Tithonia* biomass application was increased from 1.5 to 4.5 t ha^{-1}. The same trend was also observed when the same *Tithonia* treatments received supplemental inorganic P, and maize yields increased remarkably (Table 4). At Bembeke and Champhira, these trends were much clearer than at Chitedze.

6.1.2 Effect of TSP supplementation to *Tithonia* leaf application on maize grain yield.

Supplementation of *Tithonia* treatments with TSP did not significantly increase maize yields at all the sites. With *Tithonia* only, average maize yields ranged from 2607 to 3731 kg ha^{-1}, while with TSP supplementation, the yields ranged from 2640 kg to 3665 kg ha^{-1} (Table 4). These results agree with those reported by Gachengo (1996) in Kenya where *Tithonia* leaves applied at 5 t ha^{-1} supplemented with 25 kg P_20_5 from TSP did not give maize yields which were significantly different from the application of *Tithonia* alone. The same report suggested that the high maize perfomance under *Tithonia* biomass was due to the other elements which are found in *Tithonia* leaves, which improved the nutrient use efficiency of nitrogen and phosphorus.

In another study, Jama *et al.* (1997) reported significantly higher maize yields of 4000 and 3800 kg ha^{-1} when *Tithonia* was supplemented with rock phosphate and TSP, respectively. Urea supplemented with Minjingu Rock and TSP produced maize yields of 1700 and 2500 kg ha^{-1}, in comparison. Urea only produced the lowest yield of 800 kg ha^{-1}. The treatments were applied to supply 60 kg N and 250 kg P, respectively. These results by Anonymous (1995a), Jama *et al*. (1997) and from the current study indicate that *Tithonia* biomass can be used with or without inorganic phosphorus sources depending on the phosphorus levels in the soil.

6.1.3 Nitrogen and phosphorus concentrations in maize plants at different growth stages.

There were significant differences ($P \leq 0.05$) in the nitrogen and phosphorus concentrations of maize plants between different treatments at tasselling, at Bembeke (Table 5) and nitrogen only at seedling stage at Chitedze (Table 6). There were no significant differences at Champhira (Table 7). At Bembeke, the highest nitrogen concentration in plants was at the 4 leaf stage from the inorganic fertiliser treatment and *Tithonia* at 4.5 t ha^{-1} supplemented with TSP (24.3 g N kg^{-1} and 20.7 g N kg-1 respectively) which were not significantly different. Phosphorus concentration was only different between the treatments supplied with inorganic source and the other treatments. The inorganic fertilisers gave 3.8 g P kg^{-1} while the other treatments had an average of 2.4 g P kg^{-1}. The comparatively low concentration of the nutrients during other growth stages and across the experimental sites could be due to the dilution effect from large plant size. This could also be due to low residual fertility of the soil which resulted in immobilisation of nutrients which are below the critical soil P level of 8 to 25 mg kg^{-1} (Wendt, 1991) which might have resulted in low uptake by the plants. The soils at Bembeke are known for phosphorus, zinc and sulphur deficiences (Matabwa and Wendt, 1993; Prof. S. Mughogho[1], personal communication). This is also known to be a P fixing site. Application of *Tithonia* biomass with and without TSP supplementation at this site did not significantly increase the phosphorus release. High quality organic materials are known to improve the availability of phosphorus to crops by binding exchangeable and solution alluminium, the key fixers of P in acid soils. Thus, the organic molecules and short-chain carboxylic acids such a oxalic acid and citric acid released during decomposition complex exchangeable and solution alluminum and detoxify them (*Yamoah et al*., 1997). It is therefore, suggested that the phophorus released was not sufficient enough to saturate the binding sites, hence, immobilisation still occured. If nitrogen was released fast, it might have been lost through leaching due to the continued rainfall pattern of the growing season (Appendix I).

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The general nutrient concentration in the above ground harvested maize biomass followed a downward trend from planting up to harvest. Highest values ranged from 16.3 to 29 g N kg^{-1} and 1.7 to 3.1 g P kg^{-1} at four leaf stage. Lower values were recorded after harvest and these ranged from 2.4 to 8.6 g N kg^{-1} and 0.53 to 3 g P kg^{-1}. Nigarajah and Nizar (1982) reported that complete decomposition of *Tithonia* took place within 3-4 weeks after biomass incorporation. The results from the current study tie with those reported by these authors because they show that most of the nutrients were released during the first four weeks after incorporation. In a similar study, Hanway (1962) reported a rapid decrease from 30 g N kg^{-1} to 5 g N kg^{-1} in the leaves when a large proportion of the corn leaf development had occurred. This decrease was within a period of two weeks.

Similarly, percent nitrogen in the leaf sheaths declined rapidly from 40 g N kg^{-1} to 2 g N kg^{-1} within the same period indicated above. Hanway (1962) also indicated that phosphorus levels in the leaves decreased from 3 g P kg^{-1} to 0.5 g P kg^{-1} in corn leaves while in the leaf sheath, phosphorus decreased from 5 g P kg^{-1} to 0.5 g P kg^{-1}. These indicate that nitrogen and phosphorus concentrations are high during the initial growth stages.

Table 5: Effect of *Tithonia diversifolia* biomass and inorganic fertiliser sources on plant nitrogen and phosphorus concentration at 4 leaf stage, tasselling and at harvest at Bembeke.

Treatment	4 leaf stage		Tasselling		Harvest		Mean	
	N	P	N	P	N	P	N	P

------------------------g N kg^{-1}----------------------------								
1	16.3	2.0	12.8**c**	2.4**b**	3.7	0.9	12.9	1.8
2	17.8	3.1	24.3**a**	3.8**a**	5.5	0.9	15.9	2.6
3	22.7	2.9	16.6**bc**	2.3**b**	3.6	0.9	14.3	2.1
4	24.3	2.7	18.5**b**	2.6**b**	3.9	1.0	14.5	2.1
5	22.1	2.7	18.0**b**	2.4**b**	3.8	1.1	14.6	2.1
6	20.9	3.1	18.6**b**	2.3**b**	4.7	1.1	14.3	2.2
7	23.0	2.8	17.8**b**	2.3**b**	3.1	0.9	13.0	2.02
8	23.9	2.9	20.7**ab**	2.4**b**	3.9	1.1	16.2	2.2
Mean	21.0	2.8	18.4	2.6	4.0	1.0		
F-Prob	0.06	0.90	0.00	0.00	0.29	0.5		
CV (%)	14.0	15.5	18.4	13.6	27.5	18.7		

Table 6: Effect of *Tithonia diversifolia* and inorganic fertiliser sources on plant nitrogen and phosphorus concentration at 4 leaf stage, tasselling and at harvest at Chitedze.

Treatment	Leaf stage		Tasselling		Harvest		Mean	
	N	P	N	P	N	P	N	P

	---------------------g kg-1 ------------------------							
1	29.5**a**	2.8	19.5	2.1	3.3	0.8	17.4	1.9
2	29.7**a**	2.7	21.8	2.6	5.4	0.8	18.9	2
3	29.5**a**	2.3	19.7	2.4	2.9	0.5	17.4	1.7
4	25.2**b**	3	21.1	2.5	5.3	0.8	17.2	2.1
5	24.1**b**	2.1	23.7	2.7	5.6	0.7	17.8	1.8
6	25.4**b**	2.3	20.1	2.5	3.6	0.7	16.3	1.8
7	24.2**b**	2.1	23.8	2.5	8.4	0.8	18.7	1.8
8	26.5**b**	2.3	23.9	2.7	8.6	0.8	19.6	1.8
Mean	26.8	2.4	21.1	2.5	5.1	0.7		
F-Prob	0	0.33	0.44	0.18	0.2	0.83		
CV (%)	5.6	22.3	14.6	10.2	51.5	29.8		

Table 7: Effect of *Tithonia diversifolia* green manure and inorganic fertiliser sources on plant nitrogen and phosphorus concentration at 4 leaf stage, tasselling and at harvest at Champhira.

Treatment	4 leaf stage		Tasselling		harvest		Mean	
	N	P	N	P	N	P	N	P
	--------------------g kg-1 ------------------------							
1	20.	2.3	10.	1.5	3.7	0.53	11.	1.4

	5		0				4	
2	29.8	3.1	15.4	2.0	8.37	1.1	17.8	2.1
3	26.2	1.9	11.3	1.5	5.67	0.8	14.4	1.4
4	25.0	2.6	12.2	1.7	7.6	0.9	14.9	1.7
5	24.9	2.6	15.8	1.6	5.2	0.6	15.3	1.6
6	29.0	2.8	10.1	1.5	5.7	0.7	14.9	1.6
7	29.1	2.1	12.0	1.7	4.9	0.6	15.3	1.5
8	27.2	2.1	12.0	1.7	5.3	0.7	14.8	1.5
Mean	26.4	2.3	12.7	1.7	5.8	0.7		
F-Prob	0.06	0.3	0.5	0.6	0.2	0.6		
CV (%)	12.7	31.96	27.8	16.0	33.2	55.6		

Jama and Nair (1996) reported an average decomposition rate of 12% per week as rate of *Leucaena* and *Cassia* decomposition using litter bag technique in the first season and 1% per week in the second season. They also indicated that full decomposition was achieved by the end of the seventh week. In general, *Leucaena* was reported to decompose faster than *Cassia*. The same study, by Jama and Nair (1996) indicated that 80 to 85% of the nitrogen was released during the first four weeks after mulch application. High nitrogen and phosphorus rates at four leaf stage reported in the current study show that *Tithonia* releases nutients in a similar pattern as those reported by the above scientists.

Dumenil (1961) indicated that the critical nitrogen and phosphorus levels are not narrow ranges or points of values, but include a wide range of values depending on how they are defined and on the level of the other nutrients in the leaf. For example at maize silking time, 29 g N kg^{-1} and 3 g P kg^{-1} are considered critical. Results from the present study show that at tasselling which is close to silking, maize had the following nutrient concentrations: at Bembeke, nitrogen was 18.4 g N kg^{-1} and phosphorus was 2.4 g P kg^{-1}; at Chitedze, nitrogen was 22.1 g N kg^{-1} and phosphorus was 2.6 g P kg^{-1} while at Champhira, nitrogen was 12.6 g N kg^{-1} and phosphorus was 1.6 g P kg^{-1} as an average from the *Tithonia* treatments. The inorganic fertiliser treatment had nitrogen concentrations of 24.3, 21.8 and 15.4 g N kg^{-1} at Bembeke, Chitedze and Champhira, respectively. Phosphorus concentrations were 3.8, 2.6 and 2.0 g P kg^{-1} at Bembeke, Chitedze and Champhira, respectively. These results show that both the *Tithonia* and the inorganic fertiliser treatments failed to raise the nitrogen and phosphorus concentration to the critical level in maize at tasselling.

The general observation from the data is that nutrient concentrations did not take a definite pattern in connection with the grain yield. This could be due to the lack of correlation between nutrient concentration in the plants and the grain yield. These results are in agreement with what was reported by Binford *et al*. (1992) where concentrations of nitrogen in young plants only explained 24% of the variations in corn yields. In the same study, nitrogen concentration in young maize plants only explained 27% of the variability in soil nitrate concentrations. These show how poorly soil or plant analysis data fail to explain other parameters like grain yield in our case.

6.1.4 Nitrogen and phosphorus uptake by maize

Maize grain nitrogen and phosphorus uptake at harvest were significantly different between the treatments at Bembeke. At Champhira, only phosphorus uptake was different (Table 8). At Bembeke, nitrogen uptake by maize were highest where *Tithonia* was applied at 3.0 t ha^{-1} with TSP (31.7 kg N ha^{-1}) and *Tithonia* only at 3 and 4.5 t (28.3 and 33 kg N ha^{-1}, respectively). Nitrogen uptake was not significantly different between *Tithonia* at 1.5 t ha^{-1} with and without TSP and the control (22.3, 22.7 and 16.3 kg N ha^{-1},respectively). Amongst the *Tithonia* treatments, there was more nitrogen uptake when *Tithonia* was supplemented with TSP than where *Tithonia* was applied alone. This shows the need for a balanced nutrient applications. Phosphorus uptake by maize was also highest where *Tithonia* was supplemented with TSP and this was where *Tithonia* was applied at 3.0 and 4.5 t ha^{-1} (8.2 and 7.2 kg P ha^{-1},respectively).

Table 8. Effect of *Tithonia* and inorganic fertiliser on nitrogen and phosphorus uptake by maize.

Treatment	Bembeke		Champhira		Mean	
	N	P	N	P	N	P
---------------------------kg ha^{-1}-----------------------						

1	16.3 **c**	4.2 **d**	5.0	0.7**c**	10.6	2.5
2	30.7 **a**	6.8 **abc**	9.3	1.4 **bc**	20.0	4.1
3	22.6 **bc**	5.4 **bcd**	6.7	1.0**c**	14.7	3.2
4	28.3 **ab**	6.9 **abc**	12.3	2.0 **bc**	20.3	4.4
5	33.0 **a**	6.8 **abc**	11.3	2.0 **ab**	22.2	4.4
6	22.3 **bc**	4.5 **cd**	6.3	1.0 **bc**	14.3	2.8
7	31.7 **a**	8.2 **a**	12.3	2.0 **bc**	22.0	5.1
8	33.0 **a**	7.2**ab**	10.0	2.5 **a**	21.5	4.9
Mean	27.25	6.2	9.2	1.5		
Probability	0.0019	0.05	0.06	0.007		
C.V. (%)	15.9	23.6	33.7	31.5		

[*] Data for Chitedze is not presented because maize samples were mixed up by mice.

The results from the present study have shown that the *Tithonia* treatments resulted in nitrogen uptake of 14.3 to 22.2 kg N ha^{-1} while inorganic fertilisers resulted in an uptake of 20 kg N ha^{-1}. These agree with those reported by Varvel and Peterson (1986) who reported a nitrogen uptake of 5.8 kg N ha^{-1} by maize grown under rotation with soyabeans and 25.9 kg N ha^{-1} from fertilised corn fields supplied with 90 to 180 kg N ha^{-1}.

At Champhira, nitrogen uptake was not significantly different amongst the treatments. However, phosphorus uptake was significantly different amongst the treatments. There was a general increase in P uptake from the treatments where inorganic phosphorus was supplemented (treatments 6, 7 and 8). Phosphorus uptake was 1.0, 1.2 and 2.4 kg P ha^{-1}. These results show the need for integrating high quality organic materials with inorganic fertilisers to enhance phosphorus uptake.

6.1.5 Nitrogen and phosphorus concentrations in maize grain

There were no significant differences in nitrogen and phosphorus concentrations in maize grains amongst the treatments at all sites (Table 9). Nitrogen levels ranged from 8.8 to 8.9 g N kg^{-1} while phosphorus levels ranged from 1.7 to 1.9 g P kg^{-1}. Pierre *et al*. (1977) reported that the critical nitrogen for maize was found to lie within a range of 10 to 15 g N kg^{-1}.

Table 9: Effect of *Tithonia diversifolia* and inorganic fertilisers on nitrogen and phosphorus concentration in maize grain.

Treatment	SITES		MEAN
	Bembeke	Champhira	

	N	P	N	P	N	P
	-------------------g kg^{-1}-----------------------					
1	9.2	2.1	8.5	1.3	8.8	1.7
2	8.6	2.0	9.3	1.4	8.9	1.7
3	9.0	2.0	8.7	1.3	8.8	1.7
4	8.5	2.2	8.5	1.3	8.5	1.7
5	8.3	1.8	8.8	1.5	8.6	1.6
6	9.4	1.7	7.9	1.5	8.6	1.6
7	8.8	2.4	9.1	1.5	8.9	1.9
8	8.6	1.9	7.9	1.4	8.29	1.6
Mean	8.8	2.0	8.6	1.4		
Probability	0.73	0.36	0.23	0.78		
CV (%)	8.9	18.1	8.3	13.3		

Data for Chitedze is not presented because maize samples were mixed up by mice.

The results from this study indicate that both *Tithonia* and inorganic fertiliser treatments did not raise the N levels in the grain to the critical levels. However, both *Tithonia* and inorganic fertilisers supplied similar amounts of nitrogen to the maize grain. Therefore, the application of *Tithonia* was as good as inorganic fertiliser. These results agree with what was reported by

Nziguheba *et al*. (1997) that *Tithonia* is a high quality organic resource in terms of nutrient release and supplying capacity because of the high nitrogen content and and its capacity to improve phosphorus availability, high soluble fractions and moderate lignin content (Table 3). The low nitrogen and phosphorus levels in maize plants at tasselling, explains the N and P in the grain because these are the nutrients which are translocated to the grain during grain filling stage (sink source relationship).

6.1.6 Changes in soil nitrogen and phosphorus

There were no significant differences in nutrient status in the soil amongst the treatments at each sampling time at Bembeke (Table 10). At Chitedze (Table 11) and Champhira (Table 12, there were significant differences in soil phosphorus at the four leaf stage and at tasselling, respectively. At the four leaf stage, phosphorus levels were highest when *Tithonia* biomass was applied at 1.5 t ha^{-1} and supplemented with TSP (5.28 mg P kg^{-1}), followed by the other *Tithonia* treatments and inorganic fertiliser. Lack of significant differences in soil nutrients suggests that most of the nutrients released either from the organic materials or inorganic fertiliser were taken up by the plant or some were lost through leaching especially nitrogen. Some of the phophorus might have also been fixed due to the inherent phosphorus levels.

Table 10: Effect of *Tithonia diversifolia* biomass and inorganic fertiliser sources on soil nitrogen and phosphorus at 4 leaf stage, tasselling and at harvest at Bembeke.

Treatment	4 Leaf stage	Tasselling	Harvest	Mean

	N	P	N	P	N	P	N	P
----------------------g N kg^{-1} and mg P kg^{-1} -----------------								
1	0.8	7.3	1	13	5.2	10	2.4	10
2	0.8	11	1.6	14	5.3	12	2.6	13
3	1.4	11	1.7	13	5.9	10	3	11
4	0.8	11	1.7	13	5.2	10	2.6	12
5	0.8	10	1.7	13	5.2	9.1	2.6	11
6	1.1	12	1.5	14	6	13	2.9	13
7	1.3	11	1.6	14	5.2	13	2.7	13
8	0.9	11	1.6	13	4.6	10	2.4	12
Mean	1	11	1.6	13	5.4	11		
F-Prob	0.9	0.2	0.7	1	0	0.6		
CV (%)	60	18	8.6	13	9.4	24		

Table 11: **Effect of *Tithonia diversifolia* and inorganic fertiliser sources on soil nitrogen and phosphorus at 4 leaf stage, tasselling and at harvest at Chitedze.**

Treatm	4 Leaf	Tasselling	Harvest	Mean

ent	stage							
	N	P	N	P	N	P	N	P
	------------------g N kg^{-1} and mg P kg^{-1}--------------							
1	0.8	2.0**c**	1.4	2.7	5.1	3.1	2.4	2.8
2	1.0	3.4 **bc**	1.5	3.7	5.6	5.2	2.7	4.1
3	1.1	4.0 **ab**	1.5	3.5	5.1	7.1	2.6	4.9
4	1.1	3.2 **bc**	1.5	3.2	5.1	4.0	2.6	3.5
5	1.2	3.6 **b**	1.6	3.5	5.8	3.6	2.8	3.6
6	1.1	5.2**a**	1.6	3.9	5.5	4.5	2.7	4.6
7	1.3	3.4 **bc**	1.3	3.6	4.9	5.5	2.5	4.2
8	1.1	3.9 **ab**	1.5	3.7	5.5	2.8	2.7	3.5
Mean	1.1	3.6	1.5	3.5	5.3	4.4		
F-Prob	0.69	0.01	0.15	0.76	0.92	0.36		
CV (%)	23.9	21.13	8.79	23.5	16.32			

Table 12 : **Effect of *Tithonia diversifolia* green manure and inorganic fertiliser sources on soil nitrogen and phosphorus at 4 leaf stage, tasselling and at harvest at Champhira.**

Treatment	At 4 leaf stage	Tasselling	Harvest	Mean

ent								
	N	P	N	P	N	P	N	P
	-----------------------g N kg^{-1} and mg P kg^{-1}---------------------							
1	0.6	2.3	0.7	2.7 **d**	6.4	3.2	2.5	2.7
2	1.3	4.6	0.7	4.2 **bc**	9.0	5.1	3.7	4.6
3	0.8	2.4	0.7	3.1**cd**	7.0	3.7	2.8	3.1
4	0.60	2.4	0.9	3.3**cd**	7.9	4.3	1.6	3.3
5	0.7	2.6	0.7	3.9 **bcd**	7.9	3.7	3.1	3.4
6	0.7	2.8	0.7	4.3 **bc**	8.5	5.8	3.3	4.3
7	0.3	3.4	0.8	4.6 **b**	8.1	4.9	3.1	4.3
8	0.9	2.5	0.9	5.8**a**	8.17	4.5	3.3	4.3
Mean	0.7	2.9	0.8	4.0	7.9	4.4		
F-Prob	0.15	0.35	0.15	0.0017	0.54	0.68		
CV (%)	46.8	46.3	10.43	16.6	19.1	40.6		

Despite the lack of significant differences among the treatments to soil nitrogen and phosphorus, there were significant maize grain yield differences among the treatments (Table 4). These results concur with what was reported by Nziguhemba *et al*. (1997), who reported that the application of P as a high- quality source, *Tithonia* or an inorganic source either alone or in combination increased labile P as determined by resin extration. This study by Nziguhemba *et al*. (1997) revealed that there was a longer lasting effect from *Tithonia* than TSP on P sorption and further suggested that *Tithonia* reduced P sorption through the release of organic anions that competed for P sorption sites. Chilimba[2] (personal communication) indicated that P values by Mehlich 3 method of extraction of less than 8 ppm are considered very low; 9 to 18 ppm, low; 19 to 25 ppm as adequate; 26 to 33 ppm as high and over 33 ppm as very high. Results from this study show that both the inorganic fertiliser and the *Tithonia* treatments supplied low rates of the above standards in Malawi. The inherent low soil fertility of these sites might have contributed to availability of the applied P.

It was however observed at all sites that there was an improvement in soil nitrogen and phosphorus from planting to the time of harvesting. This could be due to the reduction in uptake by the plants which declined as the maize was going towards maturity. This indicates that apart from the rapid release of nutrients by *Tithonia*, it is able to release these nutrients for a longer period even after peak plant demand which results in the improvement in soil fertility (Nziguheba *et al*., 1997). Singh (1984) indicated that the major effects of adding prunings to the soil is reflected in the amounts of nutrients mostly nitrogen and phosphorus released from the decomposing materials. With the application of *Tithonia* leaves at 1.5 t ha^{-1}, soil phosphorus status improved by 8%, 74% and 12% while nitrogen improved by 22%, 6% and 11% at Bembeke (Table 9), Chitedze (Table 10) and Champhira (Table 11), respectively. From the treatments which received the application of DAP and urea at 92:18, N:P), nitrogen

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Mr. A. D. C. Chilimba, Principal Soil Scientist, Chitedze Research Station, Lilongwe, Malawi status improved by 5%, 10% and 44% while phosphorus improved by 22%, 47% and 68% respectively at Bembeke, Chitedze and Champhira, respectively. These percentages were calculated by using the treatment means against the control. Banda (1993) reported improvements in soil nitrogen of 18%, 31% and 26% from *Leucaena*, *Flemingia* and *Sesbania* respectively at Chalimbana in Zambia. He, however reported a negative phosphorus contribution from *Sesbania* and *Leucaena* but a positive effect of *Flemingia*. *Tithonia* had positive contribution for both nitrogen and phosphorus because of the possibility it has to solubilise soil phosphorus despite itself having low P content.

6.1.7 Maize dry matter production at tasselling and stover weight after harvest.

At all sites, both the *Tithonia* treatments and inorganic fertiliser treatment produced higher maize dry matter yields at tasselling than the control ($P \leq 0.05$) (Table 13). The means for all the sites show that the application of *Tithonia* leaves at 1.5 t ha^{-1} produced 4262 kg ha^{-1} compared to the control (2292 kg ha^{-1}). Applying 40 kg P_2O_5 + 92 kg N from DAP and urea produced maize dry matter yields of 4318 kg ha^{-1}. Interestingly, the application of the lowest rate of *Tithonia* (1.5 t ha^{-1}) produced maize dry matter yileds which were similar to the standard fertiliser rate of 92:18, N:P.

Maize stover yields after harvest were highest in the treatments which received *Tithonia* biomass application.

Table 13: Effect of *Tithonia diversifolia* and inorganic fertilisers on maize dry matter production at tasselling and maize stover yield.

Treatment	SITES						MEAN	
	Bembeke		Chitedze		Champhira			
	MDY	MSY	MDY	MSY	MDY	MSY	MDY	MSY
	-------------------kg ha^{-1} -----------------------							
1	2718 **c**	2940 **d**	2436 **c**	2341 **c**	1727 **d**	1432 **c**	2294	2223
2	4408 **abc**	3840 **abc**	4730 **ab**	6113 **ab**	4005 **bc**	2552 **bc**	4318	4168
3	4636 **abc**	3141 **cd**	4532 **ab**	5415 **b**	3617 **bcd**	1991 **bc**	4262	3516
4	4311 **abc**	4803 **a**	4425 **ab**	7126 **ab**	4808 **ab**	5469 **a**	4516	5783
5	3583 **bc**	4716 **a**	3700 **b**	8454 **a**	6530 **a**	6148 **a**	4604	6439
6	4595 **abc**	3458 **bcd**	3583 **b**	6742 **ab**	4655 **ab**	3144 **b**	4278	4448
7	6669 **a**	4087 **abc**	5222 **a**	6567 **ab**	3458 **bcd**	5205 **a**	5116	5286
8	5727 **ab**	4559 **ab**	4104 **ab**	7790 **ab**	2525 **cd**	6253 **a**	4119	6201
Mean	4581	3948	4091	6319	3916	4024		
Prob	0.039	0.008	0.003	0.003	0.002	0.000		
CV (%)	26.5	14.7	15.7	21.2	26.5	19.2		

KEY: MDY: Maize dry matter yield, MSY: Maize stover yield.

At Bembeke, highest yields were obtained when *Tithonia* leaves were applied at 3.0 t ha^{-1} which produced stover yields of 4803 kg ha^{-1}. These were not significantly different from the treatments which received the application of inorganic fertiliser (3840 kg ha^{-1}) and *Tithonia* only at 4.5 t ha^{-1} (4713 kg ha^{-1} of maize stover).

The application of *Tithonia* leaves only at 1.5 t ha^{-1} produced stover yields which were comparable to inorganic fertiliser. At Chitedze, *Tithonia* only at 4.5 t ha^{-1} produced 8454 kg ha^{-1} stover. This yield was not significantly different from the other *Tithonia* treatments and inorganic fertiliser treatment but was significantly higher than from the control (treatment 1).

At Champhira, *Tithonia* application at 3.0 t and 4.5 t ha^{-1} with TSP supplementation produced maize stover yield 5205 and 6253 kg ha^{-1}, respectively. *Tithonia* application at 3.0 and 4.5 t ha^{-1} without TSP supplementation produced maize stover yields of 5469 and 6148 kg ha^{-1}, respectively. These were not significantly different amongst themselves. The *Tithonia* treatments with and without TSP however produced significantly higher maize stover yields than the inorganic fertiliser (2552 kg ha^{-1}), control (1432 kg ha^{-1}) and the *Tithonia* treatments at 1.5 t ha^{-1} with and without TSP which produced 3144 and 1991 kg ha^{-1}, respectively (Table 12). At this site (Champhira), it is interesting to note that the control, the inorganic fertiliser and *Tithonia* treatments, at 1.5 t ha^{-1} were not significantly different in the amount of maize stover produced. These were however significantly lower than the *Tithonia* treatments at 3 and 4.5 t ha^{-1} with and without TSP. This is a site which is typified by the low fertility red soils (weakly ferallitic). Visual field observations indicated that there were severe nutrient deficiencies of nitrogen, phosphorus and sulphur in the control and inorganic fertiliser plots. Use of DAP and urea resulted in a total crop failure in these soils. Even use of *Tithonia* leaves at 1.5 t ha^{-1} required supplemental inorganic N fertiliser at the four leaf stage in order to achieve optimum maize yields. In this *Tithonia* treatment (1.5 t ha^{-1}), the crop started vigorously, but at tasselling severe yellowing of the leaves started. However, the maize grain yields and the stover yields at Champhira are a clear indication that the potential of *Tithonia* for improving soil fertility is possible even in the poorest soil where maize has been failing.

The application of *Tithonia* leaves resulted in high maize dry matter yields at all sites, which were comparable or higher than for the inorganic fertiliser treatment. Higher maize biomass yields reported from *Tithonia* in this study, agree with what was reported by Anonymous (1995b). When different agroforestry species were applied to the soil, highest maize crop fresh biomass yields were obtained from *Tithonia* (2530 kg ha^{-1}). *Lantana camara* treatment produced 2240 kg ha^{-1} of maize biomass. These were significantly higher than production under *Cassia spectabilis (*1500 kg ha^{-1}*), Caliandra calothyrsus (*1400 kg ha^{-1}*), Grevillea (*1300 kg ha^{-1}*)* and Guava (1300 kg ha^{-1}). The control plot, maize only performed the poorest with only 1270 kg ha^{-1}. The results reported in the current study and those by Anonymous (1995b), show that *Tithonia* is a potential candidate for improving maize productivity both under bimodal and unimodal rainfall conditions like those found in Malawi.

6.1.8 Summary

The application of *Tithonia* leaves produced maize grain yields which were significantly higher than from no fertilizer treatment. The application of *Tithonia* leaves at 1.5 t ha^{-1} produced maize grain yields which were 39%, 122% and 162% over the control at Bembeke, Chitedze and Champhira, respectively. The same rate of *Tithonia* leaves applied at 1.5 t ha^{-1} produced maize grain yields which were 12% higher than the standard fertilizer rate at Chitedze but were 24% and 30% lower at Bembeke and Champhira respectively. Supplementation of TSP to *Tithonia* did not result in significant maize yield increases compared to the application of *Tithonia* leaves alone. There were no significant maize grain yield differences among the *Tithonia* treatments at Chitedze and Bembeke.

Application of *Tithonia* leaves and inorganic fertilisers resulted in no significant differences in nitrogen and phosphorus concentrations in maize plants at the four leaf stage at Chitedze and Champhira. It was only at Bembeke where nitrogen concentration was highest in the inorganic fertiliser treatments but it was not different from the application of *Tithonia* at 4.5 t ha^{-1} which gave 24.3 and 20.7 g N kg^{-1}, respectively. Phosphorus concentration was also highest in the inorganic fertiliser treatment (3.8 g P kg^{-1}). In general, there were higher nitrogen and phosphorus levels at the four leaf stage than at tasselling and harvest.

In the soils, phosphorus concentration was highest when *Tithonia* biomass was applied at 1.5 t ha^{-1} supplemented with TSP at four leaf stage (5.28 mg P kg^{-1}) followed by inorganic fertilisers. There was a build up of 21.8% of soil nitrogen from planting up to harvest. There were no significant differences in the concentration of nitrogen and phosphorus in the grains amongst the treatments. Values ranged from 8.87 to 8.98 g N kg^{-1} and 1.77 to 1.99 g P kg^{-1}.

Highest maize stover yields were produced from where *Tithonia* leaves were applied at 4.5 t ha^{-1} supplemented with TSP which produced a yield of 6400 kg ha^{-1} maize stover. This was followed by *Tithonia* alone at 4.5 t ha^{-1} (5800 kg ha^{-1} of maize stover). Inorganic fertiliser produced maize dry matter yields which were not significantly different from *Tithonia* alone at 1.5 t ha^{-1}. Maize dry matter yields were 4318 and 4262 kg ha^{-1} for inorganic fertiliser and *Tithonia* respectively.

6.2 GREENHOUSE EXPERIMENT

6.2.1 Nitrogen and phosphorus concentrations in greenhouse maize plants.

There were no significant differences in nitrogen and phosphorus concentrations in maize plants at four weeks after planting (Table 14). This suggests that all the nutrients released were taken up by the plants . The higher nutrient concentrations recorded at 4 weeks after planting compared to those reported at six weeks could be due to dilution effect due to large plant size. At six weeks after planting (WAP), plant nitrogen concentration was significantly higher where *Tithonia* leaves were applied at 4.5 t ha^{-1} supplemented with TSP and gave 2.07 g N kg^{-1} followed by *Tithonia* alone at 3.0 and 4.5 t ha^{-1} giving 1.8 g N kg^{-1} each.

Table 14: Effect of *Tithonia diversifolia* biomass and inorganic fertiliser on maize plant nitrogen and phosphorus at 4 and 6 weeks in a greenhouse pot bioassay .

Treatment	4 WAP		6 WAP		MEAN	
	N	P	N	P	N	P
	------------------g N kg^{-1} and mg P kg^{-1}-------------------------					
1	2.5	0.1	1.0**d**	0.1	1.7	0.1
2	2.2	0.2	1.0**d**	0.1	1.6	0.1
3	2.3	0.2	1.3**cd**	0.2	1.8	0.2
4	2.6	0.2	1.8**ab**	0.2	2.2	0.2
5	2.5	0.1	1.8**ab**	0.2	2.1	0.1
6	2.4	0.4	1.1**d**	0.2	1.8	0.3
7	2.4	0.2	1.6**bc**	0.2	2.0	0.2
8	2.7	0.3	2.0**a**	0.2	2.4	0.2
MEAN	2.4	0.2	1.5	0.1		
F-Prob.	-	0.22	0.00	-		
CV (%)	14.9	55.9	12.6	15.1		

Inorganic fertiliser and the control treatments gave the lowest nitrogen concentrations of 1.07

and 1.02 g N kg^{-1}, respectively.The lower concentrations of nitrogen and phosphorus from diammonium phosphate and urea suggests that the absence of other nutrients (which are present in *Tithonia*) might have affected nitrogen and phosphorus uptake. Addition of *Tithonia* biomass provided some additional nutrients like potassium, calcium and magnesium which might have improved the nutrient use efficiency of nitrogen and phosphorus. Additionally, application of *Tithonia* biomass might have also improved the solubility of P in the soil.

However, in this green house study, we have not been able to get high nutrient concentrations which were observed in the field study at the four leaf stage. Kumwenda (1996) reported maize yield increases of 3-26% in Dedza across different sites because of the inclusion of 8 kg ha^{-1} sulphur in addition to nitrogen and phosphorus which were not varied. The same study also showed yield increments of 5-32% due to inclusion of zinc with nitrogen and phosphorus treatments. This study by Kumwenda (1996) suggested that the addition of other elements in addition to N and P can lead to higher maize yields or better crop perfomance compared to the application of N and P alone.

6.2.2 Changes in greenhouse soil nitrogen and phosphorus concentrations

The results of this study are presented in Table 15. At two weeks, there were no significant differences amongst the treatments. At four WAP, phosphorus concentration in the soil differed significantly amongst the treatments.

Table 15: **Effect of *Tithonia diversifolia* biomass and inorganic fertiliser on soil nitrogen and phosphorus at 2, 4 and 6 weeks in a greenhouse pot bioassay.**

Treatment	2 WAP		4 WAP		6 WAP		MEAN	
	N	P	N	P	N	P	N	P
	----------------------g kg^{-1}N and mg/kg P----------------------							
1	4.7	7.9	4.3	4.3**b**	2.0**c**	3.3 **c**	2.1	5.1
2	4.3	5.3	4.7	11.**b**	4.7 **ab**	8.4 **bc**	4.6	8.2
3	4.3	13.7	4.0	4.4**b**	4.3 **ab**	3.4 **c**	4.2	7.2
4	4.7	4.7	4.0	4.2**b**	3.7**b**	3.5 **c**	4.1	4.1
5	3.3	16.2	4.7	6.6**b**	3.3**b**	5.6 **c**	3.7	6.1
6	5.0	14.9	4.7	38.7 **a**	3.7**b**	24.9 **a**	4.4	26.2
7	4.3	8.7	4.0	27.9 **a**	3.3**b**	23.7 **a**	3.8	20.1
8	4.0	7.2	4.0	10.5 **b**	5.0**a**	13.8 **b**	4.3	10.4
Mean	4.3	8.6	4.3	13.5	3.8	10.8		
F-Prob	0.23	-	0.40	0.000	0.002	0.00		
CV (%)	16.3	80.6	12.58	47.2	5.1	35.45		

At this stage (4 WAP), the application of *Tithonia diversifolia* at 1.5 t and 3.0 t ha^{-1} supplemented with TSP, resulted in significantly higher phosphorus concentrations of 38.7 and 27.9 mg P kg^{-1}, respectively than the other treatments. The other treatments were not significantly different. From the greenhouse study, it was observed that supplemental P resulted in improving the P from *Tithonia* to adequate levels. This study has therefore, led us to suggest that inorganic supplemental P is required to improve the P status of the soil when *Tithonia* is used.

At six weeks after planting, highest phosphorus concentrations were also recorded from the same treatments (treatment 6 and 7). This suggests that *Tithonia* required phosphorus supplementation from inorganic fertiliser. Alternatively, *Tithonia* might have also improved the availability of soil phosphorus. Inorganic phosphorus utilisation could also be improved through a similar process. This ability could be a useful property for *Tithonia*, since you may need large quantities of *Tithonia* biomass to be applied in the field if adequate amounts of phosphorus is to be supplied.

The low phosphorus levels in the soil may be due to inherent low P levels of the soil and due to rapid plant uptake which is high at an initial stage because of rapid growth processes taking place at this stage. Nitrogen too was low possibly due to the same reasons. Palm (1995) indicated that organic inputs cannot provide sufficient balanced nutrients for crop growth due to low levels of some of them like phosphorus. Singh and Jones (1976) indicated that organic materials can either increase of decrease the P sorption of a soil depending on the type of organic material, its phosphorus content and amount added. The same study by Singh and Jones (1976) reported that organic materials of 0.31% or more P decreased P sorption capacity while those containing 0.22% or less increased the amount of P sorbed. However, this also depend on the soil characteristics at each site. The quality of *Tithonia* used in this study contained 0.25% P (Table 2) which is above the critical P level. Therefore, if there was any P immobisation, it could be due to low amounts of biomass used.

In a related study, Mukanga (1994) observed higher nitrogen levels in *Sesbania* fallow treatment plots with the highest being on the three year fallow which was 17% and 62% more than continuous fertilised maize and unfertilised maize plots, respectively. Results from this study show that there was a 100% increase in soil nitrogen and 31% increase in soil phosphorus within 6 weeks when *Tithonia* biomass was applied at 1.5 t ha^{-1}. Inorganic fertiliser increased soil nitrogen and phosphorus by 119% and 58% respectively. There was a steady increase in nitrogen concentration in the soil for the entire six week period. At 2 and 4 weeks, there were no significant differences in nitrogen concentration in the soil under the different treatments. At six weeks, highest nitrogen concentration was observed in the treatments where *Tithonia* leaves were applied at 4.5 t ha^{-1} and received supplemental P (5 mg P kg^{-1}). This was significantly different from the inorganic fertiliser treatment (4.7 mg P kg^{-1}) and *Tithonia* application alone at 1.5 t ha^{-1} (4.3 mg P kg^{-1}). The low soil nitrogen levels explains the low nitrogen concentrations which were reported from the plants.

6.2.3 Maize biomass production in a greenhouse pot bioassay.

Table 16 below shows that there were no significant differences in maize biomass production at 2 and 4 weeks after maize planting. At six weeks, application of *Tithonia* biomass at 3.0 t ha^{-1} supplemented with TSP which produced maize biomass yield of 12 g plant^{-1} was significantly higher than *Tithonia* alone at 1.5 t ha^{-1} and inorganic fertiliser. They both produced 9.1 g plant^{-1} pot^{-1}. These results agree with what was reported by Palm *et al*. (1995) where the application of *Tithonia* biomass alone at 5 t ha^{-1} produced maize dry matter yields of 6.1 g plant^{-1} pot^{-1} which was significantly higher than an NKP and another NP treatment. These treatments were not significantly different from each other and produced 4.8 and 4.0 g plant^{-1} pot^{-1},respectively.

6.2.4 Summary

There were no significant differences in nitrogen and phosphorus levels in maize plants at four weeks. Significantly different nitrogen concentrations were recorded at six weeks from the *Tithonia* treatment at 4.5 t supplemented with TSP (2.0 g N kg^{-1}) followed by *Tithonia* alone at 3.0 t ha^{-1} and 4.5 t ha^{-1}. Inorganic fertilisers were not significantly different from bare soil.

Table 16: Effect of *Tithonia diversifolia* biomass and inorganic fertiliser sources on dry matter production by maize at 2, 4 and 6 weeks in a greenhouse pot bioassay.

Treatment	2 WAP	4 WAP	6 WAP	MEAN
	-------------g plant^{-1} pot^{-1}----------------			
1	0.5	1.5	3.3 **c**	1.8
2	0.9	2.0	9.1 **b**	4.0
3	0.8	1.8	9.1 **b**	3.9
4	1.0	3.4	10.8 **ab**	5.0
5	0.7	4.0	10.9 **ab**	5.2
6	1.2	3.0	11.8 **ab**	5.3
7	0.7	2.6	12.0 **a**	5.1
8	0.8	3.6	10.2 **ab**	4.9
MEAN	0.8	2.7	9.6	
F.Prob.	-	0.17	0.0001	
CV (%)	41.0	43.3	15.3	

Soil phosphorus was different at two weeks after planting. The application of *Tithonia* biomass at 1.5 t and 3.0 t ha^{-1} supplemented with TSP resulted in phosphorus levels which were significantly higher the the other *Tithonia* treatments (38.7 and 27.9 mg P kg^{-1}), respectively. These were significantly higher than the inorganic fertiliser. This suggests that *Tithonia* improved the solubility of phosphorus in the soil despite itself having low amount of phosphorus.

There was a steady increase in nitrogen concentration in the soil for the entire six weeks. At six weeks, nitrogen concentration was significantly highest where *Tithonia* leaves were applied at 4.5 t ha^{-1} and gave nitrogen levels of 5.0 g N kg^{-1}. This suggests that high quality organic materials like *Tithonia diversifolia* releases nutrients fast and improves the nutrient status of theh soil. These characteristics are comparable to some green manure and agroforestry species which are currently advocated in Malawi.

6.3 LABORATORY INCUBATION EXPERIMENT

6.3.1 Mineralisation of nitrate, ammonium and phosphorus from diferent organic materials

At two weeks after incubation, nitrate was significantly highest from the soil which was mixed with *Mucuna* leaves (20.4 mg $No\text{-}_3$ kg^{-1}), followed by the soil mixed with Sunhemp (17.5 mg $No\text{-}_3$ kg^{-1}), then *Tephrosia* (16.9 mg $No\text{-}_3$ kg^{-1}). *Tithonia*, maize stover and the control accumulated 13.1, 12.1 and 12.6 mg $No\text{-}_3$ kg^{-1}, respectively and were not significantly different from each other (Table 17).

Table 17: **Effect of *Tithonia* and some green manure crops on soil nitrate release under laboratory incubation.**

Species	**After 14 days**	**After 28 days**	**Mean**
	-------------------mg No_{-3} kg^{-1}		----------------------
Control	12.6 **c**	3.0 **d**	7.8
Mucuna	20.4 **a**	3.8 **bc**	12.1
Tephrosia	16.9 **b**	4.2 **b**	10.5
Sunhemp	17.5 **b**	4.9 **a**	11.2
Tithonia	13.1 **c**	4.0 **bc**	8.6
Maize stover	12.1 **c**	3.4 **bc**	7.8
Mean	15.4	3.9	
Probability	0.0000	0.0003	
CV (%)	8.4	8.5	

At 28 days, all the treatments released significantly different amounts of nitrate, but they were lower than those reported at 14 days. The means for the treatments show that soil nitrate was highest under *Mucuna* (12.1 mg $No-_3$ kg^{-1}) for the whole sampling period followed by Sunhemp (11.2 mg $No-_3$ kg^{-1}), *Tephrosia* (10.5 mg $No-_3$ kg^{-1}), then *Tithonia* (8.6 mg $No-_3$ kg^{-1}) (Table 17). The soil mixed with maize stover and bare soil resulted in the lowest nitrate accumulation (7.8 mg $No-_3$ kg^{-1} each). At 28 days after the start of incubation, nitrate mineralisation declined sharply across all the treatments.This indicates that most of the nutrients were released by the 14th day.

These results are in agreement with what was observed in the field study. At the four leaf stage (three weeks after maize planting) soil nitrogen concentration was highest then declined later in the season (at tasselling and after harvest). These results are in contrast with what was reported by Kumwenda *et al*. (1996) where the incorporation of pigeon pea, sunhemp and *Mucuna* green manure resulted in soil nitrate concentrations of 22.9, 16.2 and 15.4 mg $No-_3$ kg^{-1}, respectively. These were determined at 32 days after incorpoation under field conditions. This could be due to differences in the amounts of biomass produced.

Soil ammonium concentrations were significantly different amongst the treatments during the whole incubation period (Table 18). The soils which were mixed with *Tithonia*, Sunhemp and *Mucuna* leaves accumulated significantly similar amounts of ammonium. At 14 days after the onset of incubation, the soils which were mixed with *Tithonia*, Sunhemp and *Mucuna* leaves accumulated the highest amounts of ammonium (10.1, 9.8 and 8.53 mg NH_4+kg^{-1}, rspectively).

Table 18: **Effect of *Tithonia* and some green manure crops on soil ammonium under laboratory incubation.**

Species	**After 14 days**	**After 28 days**	**Mean**
	--------------------mg NH_4 + kg^{-1} -----------------		
Control	4.7 **d**	0.1 **c**	2.4
Mucuna	8.5 **ab**	3.6 **b**	6.1
Sunhemp	9.8 **a**	6.5 **a**	8.2
Tephrosia	6.9 **bc**	3.0 **b**	5.2
Maize stover	6.5 **c**	1.0 **c**	3.8
Tithonia	10.1 **a**	4.6 **bc**	7.4
Mean	7.7	3.1	
Prob.	0.0001	0.0001	
CV (%)	11.5	34.96	

These were not significantly different from each other. The means across the four week period show that the soils mixed with *Tithonia*, Sunhemp and *Mucuna* leaves each released an average of 7.4, 8.2 and 6.1 mg NH_4+ kg^{-1}, respectively. In general, ammonium release pattern was the same as nitrate with the highest release was at 14 days after incubation, then declined at 28 days. Lowest ammonium was recorded from the bare soil (2.4 mg NH_4+ kg^{-1}) which was not significantly different from the soil which was mixed with maize stover (3.8 mg NH_4+ kg^{-1})(Table 18). The higher rates of *Tithonia* mineralisation could be attributed to its low C:N ratio of 15:1 (Bashir Jama[3], personnal communication). The low level of lignin (8.31%) and polyphenols (4.57%) (Table 3) also contributed to the fast mineralisation of *Tithonia*. *Mucuna* was reported to have lignin and polyphenol contents of 11.1% and 3.20% respectively (Kumwenda *et al*. (1996). These lignin and polyphenol levels are low enough to allow for rapid organic matter decomposition and mineralisation.

Nziguheba *et al*. (1997) indicated that lignin levels of 15% are considered moderate and cannot interfere with organic matter decomposition. As such, plants with such levels of lignins and polyphenols decompose and mineralise fast. Palm and Sanchez (1991) reported that legumes with high polyphenol and lignin content such as pigeon peas, despite high nitrogen concentrations, can result in immobilisation and delay in subsequent release of nitrogen. Soil ammonium from *Tithonia* and the other green manure crops declined after 28 days indicating that most of the ammonium were fully released. After 28 days, sunhemp still

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produced the highest amount of ammonium followed by *Tephrosia* then *Tithonia* (4.9, 4.2 and 4.0 mg NH_4+ kg^{-1}, respectively). These results show that *Tithonia* releases nutrients like ammonium in a similar pattern as other green manure crops currently recommended for soil fertility improvement in Malawi. However, other factors like adaptability to local environment and acceptability by farmers makes *Tithonia* a potential candidate for wider adoption by farmers becacuse farmers are already familiar with it and they use it for other purposes like medicinal and hedge (Agnew and Agnew, 1994) and pesticidal (Carino *et al*., 1982).

Soil phosphorus was significantly different between the treatments throughout the incubation period (Table 19). At 14 days after the start of incubation highest phosphorus was released from the soil which was mixed with Sunhemp leaves (4.9 mg P kg^{-1}), followed by *Tephrosia* (4.2 mg P kg^{-1}) and *Tithonia* (4.0 mg P kg^{-1}). After 28 days, the soil mixed with *Tithonia* leaves accumulated the highest phosphorus concentration (11.0 mg P kg^{-1}) followed by sunhemp (10.2 mg P kg^{-1}) and *Tephrosia* (7.1 mg P kg^{-1}).

The high phosphorus release from *Tithonia* could be due to low levels of lignin and polyphenol contents in *Tithonia*. The fast nutrient release from *Tithonia* treatments might have been the cause for the high maize grain yields in the field study which were significantly higher or comparable to inorganic fertiliser (Table 4).

In a related study, Anonymous (1995a) reported that *Tithonia* released largest amount of phosphorus of 1.5 mg P kg^{-1} steadily at 3, 7 and 14 days after incubation compared to *Cassia siamea* which released 0.9, 0.8 and 0.5 mg P kg^{-1} within the same period. Maize

Table 19: Effect of *Tithonia* and other green manure crops on soil available phosphorus under laboratory incubation.

Species	**After 14 days**	**After 28 days**	**Mean**
	------------------mg P kg^{-1}------------------		
Bare soil	3.0 **d**	5.1 **c**	4.0
Mucuna	3.8 **bc**	5.3 **c**	4.5
Sunhemp	4.9 **a**	10.2 **a**	7.5
Tephrosia	4.2 **b**	7.1 **b**	5.6
Maize stover	3.4 **cd**	7.0 **b**	5.2
Tithonia	4.0 **bc**	11.0 **a**	7.5
Mean	3.8	3.9	
Prob.	0.000	0.000	
CV (%)	10.1	5.1	

Maize stover resulted in immobilising some of the phosphorus because the phosphorus results were 0.1, -0.8 and -0.6 mg P kg^{-1}. The low posphorus levels of maize stover (0.07%) which is below the minimum level for mineralisation of organic materials was responsible for this immobilsation (Nziguheba *et at*., 1997; Singh and Jones, 1976). These results indicated that *Tithonia* releases nutrients fast and no wonder there were large positive maize yield responses to *Tithonia* application within the season it is applied. The current study has further revealled that some green manure crops like *Mucuna, Tephrosia, Tithonia* and Sunhemp released phosphorus for a long period. This is because at 28 days after the start of incubation, there was still an increase in the amount of phosphorus released (Table 19). Nziguheba et al. (1997) also reported long lasting P release from *Tithonia* of up to 16 weeks.

6.3.2 Summary

Tithonia diversifolia released the highest amount of phosphorus for the entire four week period. This could be due its ability to solubilise soil P which might have resulted in a better root development and consequently improved the utilisation of other nutrients. Sunhemp released the highest amount of nitrates followed by *Mucuna*. *Tithonia* released the high amounts of ammonium which were comparable to the other green manure crops.

6.4 GENERAL CONCLUSION

The application of *Tithonia diversifolia* biomass as a green manure produced maize grain yields which were equal to or higher than grain yield from the recommended inorganic fertiliser rate. The supplementation of TSP to *Tithonia* resulted in maize grain yields which were not significantly different from the application of *Tithonia* alone. However, TSP supplementation increased phosphorus concentration in the soil. Nitrogen and phosphorus concentrations in maize plants were higher when plants were young and declined later in the season. However, nitrogen and phosphorus concentrations in the soil increased as the plants grew towards maturity.

Tithonia diversifolia biomass released nitrogen and phosphorus in a similar pattern as inorganic fertilisers. Ammonium and and nitrate release by *Tithonia* was comparable to other green manure plants like *Tephrosia*, *Mucuna* and Sunhemp, but was higher than maize stover. Phosphorus release from *Tithonia* was longer lasting and much more than the listed green manure crops. The higher P in soils supplied with *Tithonia* is suggested to be due to its ability to solubilise soil P. These attributes have shown that *Tithonia diversifolia* is a potential candidate for soil fertility improvement in Malawi. Additionally, use of *Tithonia diversifolia* for soil fertility faces a better adoption rate because farmers are already familiar with it as they already use it for other purposes like hedge, construction and medicinal. *Tithonia* is also adapted to the local conditions, as such its sustainability will not be a problem.

6.5 RECOMMENDATIONS

From the observations made in this study,the following recommendations have been made:

1. Further study is required to study minimum rates of *Tithonia* for intergration with inorgnic fertilisers. This will help address problems of the large amount of biomass required. In addition, this will help establish how much inorganic nitrogen is required to be supplemented to Ti*thonia* to achieve optimum yield.
2. Research should further look at how much biomass can be produced per unit area of land. For example, if *Tithonia* is planted as a hedge which is the traditional way, how much biomass can be produced from there. Various other planting arrangements can also be evaluated to establish how to produce adequate amounts of biomass. The economics of biomass production should also be looked to compare it with the use of inorganic fertilisers.
3. A study is also required to look at the dynamics of P in the soil when *Tithonia* is applied so that it can be esatblished whether *Tithonia* solubilises P. This requires a separate study altogether.

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Appendix 1. Monthly and total rainfall (mm) for all the experimental sites for the 1996/97 season.

Site/Month	Bembeke	Chitedze	Champhira
October	83.1	-	-
November	-	10.3	-
December	190.9	188.3	33.7
January	270.0	257.1	254.3
February	302.5	139.5	244.3
March	103.2	60.2	99.8
April	90.3	131.5	-
May	2.7	-	17.0
Total	**939.5**	**786.9**	**649.1**