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GRAIN MAIZE YIELD IMPROVEMENT USING *Tephrosia vogelii* AND *Tithonia diversifolia* BIOMASS AT MASENO, KENYA

[PRODUCCIÓN DE MAÍZ USANDO BIOMASA DE *Tephrosia vogelii* y *Tithonia divesifolia* EN MASENO KENIA]

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RESUMEN

El trabajo evaluó la respuesta del cultivo de maíz a la aplicación de biomasa de *Tephrosia vogelii* y *Tithonia diversifolia* obtenida en barbechos de 6 meses. La biomasa fue picada en piezas de 5 cm de largo e incorporada en el suelo una semana antes de la siembra de maíz. La biomasa del barbecho natural empleada como control. Adicionalmente se empleo 20kg de fósforo (P)/ha para obtener las tasas de P recomendadas. La incorporación de las herbaceas y hojarasca incrementó (p=0.05) la producción de maíz. La parcelas donde se retiró la biomasa área tuvieron menores rendimientos de maíz (40%). El P contenido en la materia orgánica fue insuficiente para cubrir las necesidades nutrimentales de las plantas. El efecto residual de la incorporación de la biomasa fue reducido en la segunda y tercera cosecha. Esto pudiera ser debido a la alta tasa de liberación de nutrimentos durante la descomposición de la biomasa, la alta tasa de captura de nutrimentos por los cultivos y también debido a la pérdida de nutrimentos mediante los procesos químicos y físicos del suelo.

Palabras clave: Biomasa, mejoramiento, maíz, Maseno, *Tithonia diversifolia*, *Tephrosia vogelii*.

SUMMARY

This study aimed at assessing the response of maize crop to application of *Tephrosia vogelii* and *Tithonia diversifolia* biomass obtained six month-old fallows. The biomass were chopped into 5-cm long pieces and incorporated in the soil one week before planting maize. The natural fallow biomass was used as a control. These organic inputs were supplied with 20 kg phosphorus (P) /ha to attain P recommended rates. Shrub aboveground and litterfall biomass incorporation significantly (p=0.05) increased maize yield. Plots where above ground biomass was removed produced lower maize yield compared to those where the aboveground biomass was retained. Addition of 20 kg P/ha to soil together with the biomass increased maize yield by 40%. P in form of organic materials was insufficient to meet plant nutritional requirement. Residual effect of the biomass was low on the second and third subsequent crops. This may be due to the high rate of nutrient release during the biomass decomposition, the high crop nutrient uptake and also the nutrient losses through soil chemical and physical processes.

Key words: Biomass, improvement, maize, Maseno, *Tithonia diversifolia*, *Tephrosia vogelii,* yield.

INTRODUCTION

Maize (*Zea mays* L.) is the most important food crop in Kenya (Buigutt, 1987; Central Bureau of Statistics, 1991) as it constitutes a major staple food. Kenya produced an average of 2.2 million tons of maize per year in 1992 and 1993-1994 (Anon., 1994; Central Bureau of Statistics, 1995) from 14000 km^2 corresponding to an average yield of 1.5 tons/ha. This low yield which ranges from 0.4 to 2.0 Mg ha^{-1} in Western Kenya (Jama *et al.*, 1997) is essentially due to disease and pest infestation (e.g., *Striga* spp.), inappropriate husbandry techniques and low soil fertility. The depletion of soil nutrients (mainly N and P) is a result of long-term continuous cropping of food crops with little or no external nutrient inputs application (Stoorvogel *et al.*, 1993) and erosion effects (Gachene *et al.*, 1997). Thus where diseases, pests and erosion are controlled, maize yields can be improved by addition of N and P to the soil, using manure, inorganic fertilisers or better a combination of organic and inorganic fertiliser inputs (Greenland, 1994).

Practising a nutrient management system where both organic and inorganic fertilisers are applied to soils having low inherent cation exchange capacity is a worthy strategy (Kang and Wilson, 1987). *Tephrosia vogelii* and *Tithonia diversifolia* produce biomass with high N content but low P (Rutunga *et al.,* 1999). This biomass has high rates of decomposition and nutrient release patterns (Rutunga *et al*, 2001) indicating that incorporation of such a biomass in soil as green manure at the planting period may provide nutrients to the crop in the early stage of development. Janzen *et al.* (1990)

pointed out that application of fast decomposing materials might immediately benefit the current crop rather than the subsequent crop. Maize stover which is of low quality (low N and P content) is a common residue found in small-scale farms (Giller et al., 1997; Karanja *et al*, 1998). Bunyasi (1997) and Kuo and Sainju (1998) reported that mixing low quality material such as cereal residues with high quality material in ratio of 0.5:0.5 contributed more positively to crop production than did the high quality material alone. In Bunyasi's study, the ratio of 0.75 rice straw and 0.25 high quality material reduced N released from the high quality material during the first six week-period following the organic input application. Whether incorporating high quality *Tephrosia* or *Tithonia* biomass alone or with maize stover available on farms may modify the rates of nutrient release and the same time, reduce N losses hence ensure better nutrient management and productive cropping need to be assessed.

This study was undertaken to assess the effect of *Tephrosia* and *Tithonia* fallows and biomass transfer plus maize stover on maize yields compared to that of the natural fallow. The need to add mineral P fertiliser to supplement these systems was also assessed. This was achieved through two separate field experiments as explained in the sections below.

MATERIALS AND METHODS

Description of the study site

The study was conducted near the Kenya Forestry Research Institute (KEFRI), Maseno Agroforestry Research Centre at latitude 0°0' and longitude 34°35' E, in Western Kenya. The site is at an altitude of 1500 m above sea level with a slope of 4%.

There are two growing seasons viz, the short- (September to January) and the long- (March to August) rainy seasons. The study was carried out from April 1997 to August 1999. According to the agroclimatic zone map of Kenya (Sombroek et al., 1980), the climate of the study area is classified as humid with a ratio of mean annual rainfall to average annual evaporation (r/Eo) of > 0.85. The average annual temperature varied from 20°C to 23°C. The minimum and maximum temperatures were 6.5°C and 35.0°C respectively. The most dominant plant species recorded in a three month-old natural fallow were *Digitaria sp.* Haller (78%), *Senescio discifolius* L. (7%), *Crassocephalum vitellinum* Moench (6%), *Bidens pilosa* L. (3%), *Cynodon sp*. Rich. (2%), *Richardia brasiliensis* L. (1%) and *Leonotis mollissima* R.Br. (1%). The soils, which are developed from basic igneous rocks are deep, well drained, acid and low in N and P (Table 1) with a bulk density varying from 1.2 Mg/m^3 in the Ap horizons to 1.3 Mg/m^3 in the Bt horizons. The soils are classified as Humic Nitisols based on the FAO/UNESCO System (FAO-UNESCO, 1994), which is equivalent to kaolinitic, isohyperthermic Typic Kanhaplohumults in the USDA Soil Taxonomy system (Soil Survey Staff, 1996).

Experiment 1. Assessing the potential of *Tephrosia*, T*ithonia* and natural vegetation fallows and biomass transfer for improving subsequent maize crop yields

Tephrosia, Tithonia and natural vegetation biomass accumulated during the six month- fallow was managed as follows:

(i) Improved fallow system where roots + litter + above ground biomass were retained in the plots, hereto referred as *Tephrosia* (TeF), *Tithonia* (TiF) fallows and natural fallow (NF),

(ii) Roots and litter retained in the plots and the rest of the aboveground biomass removed, *Tephrosia* biomass transferred (TeR) and *Tithonia* biomass transferred (TiR),

(iii) Plots under continuous maize in which the shrub aboveground biomass removed from the TeR and TiR plots (see ii above) was brought and incorporated, called *Tephrosia* biomass incorporated (TeT) and *Tithonia* biomass incorporated (TiT) with maize stover produced in situ by the precedent maize.

Maize variety H 512 was planted in the plots and its performance in terms of crop yields was compared to the continuous maize (CC) systems. There were eight treatments namely, TeF, TiF, TeR, TiR, TeT, TiT, CC and NF which were used for comparing the effects of various systems. Different rates of biomass and nutrient content were used based on the amount of biomass which was produced per plot (Table 2). The biomass for various treatments was applied in April 1997 and September 1998, using the following procedures: shrub aboveground biomass and maize stover were cut into 5-cm pieces, spread on the whole plot and then incorporated into the soil one week before planting maize. The natural fallow biomass that mainly consisted of *Digitaria sclarum* was applied as mulch without chopping.

Table 1. Physical and chemical properties of soils at the study site.

Soil properties	Horizons and depth (cm)					
	Ap 0-20	AB 20-37	BA 37-55	Bt1 55-100	Bt2 100-135	Bt3 135-165
sand (0.05-2mm) (%)	26	22	18	21	22	18
silt (2-50μm) (%)	21	17	22	13	12	14
clay (< 2μm) (%)	53	61	60	66	66	68
pH (1:1, water)	4.1	4.7	4.5	5.0	5.2	5.4
pH (1:1, KCl)	3.4	3.7	3.6	4.0	4.4	4.8
C (g/kg)	18.0	11.0	7.0	3.0	4.0	3.0
Avail. P (mg/kg)	3.0	1.0	1.0	2.0	3.0	3.0
Total N (g/kg)	2.1	1.5	1.1	0.8	0.5	0.2
CEC (cmol(+)/kg)	19	16	16	10	14	13
Ca^{2+} (cmol(+)/kg) Mg^{2+}	0.3	1.0	1.0	1.3	1.5	1.7
(cmol(+)/kg)	0.7	0.9	0.9	0.9	1.2	1.2
K^+ (cmol(+)/kg)	0.2	0.2	0.2	0.2	0.2	0.2
Al^{3+} (cmol(+)/kg)	0.6	0.5	0.4	0.03	tr*	tr

* tr: trace

Table 2. Amount of biomass incorporated in the soil and its N and P content.

Treatment	Sub-treatment*	At the end of the 1st fallow season			At the end of the 2nd fallow season		
		Biomass Mg/ha	N applied kg/ha	P applied kg/ha	Biomass Mg/ha	N applied kg/ha	P applied kg/ha
TeF	- P	8.7	127	7	8.8	116	5
TeF	+P	8.7	127	27	9.3	123	25
TeR	- P	4.2	53	3	3.8	41	2
TeR	+P	4.2	53	23	3.9	42	23
TeT	- P	4.4	74	4	3.0	50	3
TeT	+P	4.4	74	24	3.0	50	23
TiF	- P	10.7	150	7	18.0	230	21
TiF	+P	10.7	150	27	18.5	223	41
TiR	- P	7.0	81	4	7.5	85	8
TiR	+P	7.0	81	24	8.2	98	28
TiT	- P	3.3	69	3	9.4	134	12
TiT	+P	3.3	69	23	9.4	117	32
CC	- P	2.1	23	1	0.8	8	1
CC	+P	2.1	23	21	0.9	10	21
NF	- P	2.6	36	2	6.8	82	7
NF	+P	2.6	36	22	7.3	82	26

* - P means no mineral P added and +P means 20 kg P/ha from triple superphosphate.

Before sowing maize, each main plot was divided into two sub-plots with 20 kg P/ha or without added P. A split plot design was used for laying out the experiment. Triple superphosphate fertiliser was applied into the holes where 512 Hybrid maize was sown at a spacing of 30-cm interrow and 75-cm intrarow, with two seeds per planting hole. Maize was thinned to one plant at the first weeding (30 days after sowing), giving a population of 44 444 plants/ha. A second weeding was done at 60 days after sowing (DAP). Stalk borer was controlled by applying 3% malathion at two-week interval from 30 to 58 DAP. A second crop of maize was planted in September 1997 and a third in March 1998. No fertilisers were applied and maize stover was retained insitu. The fallows were repeated in March 1998 and first and second subsequent maize crops (fourth and fifth maize) planted in September 1998 and March 1999, respectively.

Data collection and analices

Maize growth, yield and nutrient accumulation were assessed over time by sampling the first subsequent maize crop at the 7-8 leaves, V15-16 corresponding at 15-16 leaves, R3 corresponding to initial grain filling at R6 corresponding to grain maturity/drying. For the determination of dry matter accumulation and nutrient (N, P, K, Ca and Mg) uptake over time, six maize plants (aboveground portion) were sampled randomly from each treatment at each development stage. The samples were washed with distilled water, chopped into 5-cm pieces, oven dried at 65°C for a period of 72 hours, weighed and then ground to pass through 0.5 mm sieve. The ground samples were analysed for N, P, K, Ca and Mg, using the methods described by Okalebo et al. (1993). Data were interpreted for biomass and nutrient accumulation, using the nutrient sufficiency ranges given by Jones et al. (1990), Munson and Nelson (1990); Baldock and Schulte 1996).

The average plant heights were measured at the maize initial grain filling stage (90 DAP). At maturity (125 DAP), the aboveground portion of the maize plants was harvested from an area of 4.20 m x 6.75 m in each sub-plot. Maize cobs were separated from the stover, air-dried and shelled. Stover samples were washed with distilled water and air-dried. Maize grains, cores and stover were weighed and used to quantify yields at 12.5 % moisture content. Sub-samples were taken, ground and used for nutrient determination (Anderson and Ingram, 1993; Okalebo et al., 1993). Percentage Nitrogen Recovery (NIR %) was estimated using the formula:

NIR % = 100* (N uptake of treatment - N uptake of control)/ N initially applied.

Maize N and P uptake, stover and grain yields were analysed for assessing the effect of treatments, using the analysis of variance (ANOVA) for a split plot design. The treatment means were compared, using the least significant difference (LSD) (Gomez and Gomez, 1984). Correlation between nutrient uptake, biomass accumulation and maize grain yield was assessed. All statistics were performed using Genstat 3.2 computer software package (Genstat 5, 1995). To compare the treatment effects over different seasons, yields were converted to relative increase compared to control:

Yield increase (%)=(Yieldtreatment-yieldcontrol) /yieldcontrol (Gachengo et al., 1999).

RESULTS

Experiment 1. Assessing the potential of Tephrosia, Tithonia and natural vegetation fallows and biomass transfer for improving subsequent maize crop yields

Effect of fallows and biomass transfer on maize growth and yield

In nitrogen and phosphorus-depleted soils such as those found at the Maseno site (Table 1), addition of only one of the two elements for instance P resulted in maize N deficiency, due to an imbalance of N:P ratio. Dark green stunted maize, a symptom of phosphorus deficiency (Berger, 1962), was observed in the control plots which had not been applied with P.

Yellowish stunted maize, which is a symptom of N deficiency was observed in the plots where only P was applied. The addition of P improved maize growth performance where shrub and natural fallow biomass was added. Tithonia did better than Tephrosia biomass during the early stage of maize growth (0 to 60 DAP).From 60 to 70 DAP, the efficiency of the two shrub biomass was similar. Maize in all the plots had turned yellowish especially where P fertiliser had been applied. At silking stage (75 DAP), maize appeared more yellowish in Tithonia than in Tephrosia and natural fallow plots.

Maize plants at the initial grain filling stage (90 DAP) were taller in plots where shrub biomass alone or with P fertiliser were applied than in other plots. Natural fallow (NF) Improved the subsequent maize growth particularly at the late stages and grain yields compared to continuous maize cropping (CC) (Table 3).

The effect of *Tithonia* biomass incorporated (TiT) on maize crop performance was significantly higher than that of *Tephrosia* (TeT). The yields of maize stover and grains produced in the treatments without phosphorus fertiliser were significantly low P<0.05) when compared with those that received P fertilizer. However, there was no significant interaction between various biomasses and P fertilizer. Maize biomass yield was positively correlated with maize grain yield (r=90). Application of 3.3 Mg of *Tithonia* (TiT) or 4.4 Mg of *Tephrosia* (TeT) aboveground biomass (i.e., about 80 kg N and 4 kg P/ha) plus 20 kg P/ha in form of triple superphosphate increased maize yields by about 2.5 fold compared to the yields in the natural fallow and continuous maize cropping.

Table 3. Maize dry matter and grain yields (Mg/ha) for various treatments at different stages of growth.

Treatment	1st maize crop following the first fallow season						4th maize*
	DM** at V7-8	DM at V15-16	DM at R3***	Stover at R6	Cores at R6	Grains at R6	Biomass at R6
TeF	0.16	1.28	3.73	3.35	0.41	2.92	3.25
TeR	0.09	0.72	1.99	1.56	0.33	1.37	1.49
TeT	0.19	1.05	2.85	2.87	0.55	3.27	1.02
TiF	0.03	1.82	3.55	3.81	0.47	3.37	3.45
TiR	0.16	1.22	3.20	2.80	0.40	2.65	2.45
TiT	0.27	1.57	3.58	3.07	0.65	3.73	1.76
CC	0.08	0.44	1.60	1.60	0.22	1.38	0.52
NF	0.10	0.72	2.44	1.87	0.34	1.95	1.55
LSD0.05	0.05	0.40	0.49	0.43	0.10	0.32	1.00
No P	0.11	0.82	2.38	2.50	0.38	2.12	1.83
Plus P	0.23	1.38	3.35	2.73	0.46	2.97	2.04
LSD0.05	0.03	0.20	0.25	0.21	0.06	0.19	0.36

*The fourth maize is the first maize following the second fallow season: only total biomass was recorded as there was drought at the maize filling stage. ** DM: dry matter; V7-8 and V14-15: vegetative stages of growth at 7 to 8 leaves and 14 to 15 leaves, respectively; *** R 3 and R6: initial grain filling and maturity/drying stages.

Adding about 20 kg P/ha to the soil raised P concentration in the plants biomass from 4.0 to 8.0 g P/kg at V7-V8 and 2.5 to 4.0 g P/kg at R3 (data not shown). At harvest, addition of inorganic P increased N, P and K accumulated in maize biomass by 13%, 1.2% and 16%, respectively. Average percentage N recovery from *Tephrosia* (TeF +TeT)/2 and *Tithonia* (TiF+TiT)/2 biomasses was about 32 and 41%, respectively (Table 4). Percentage P recovery from mineral fertiliser was 6% while that from various biomass was about 60 %.

Residual effect on the second maize crops following the first and second fallow seasons

Maize planted in plots that were under the shrub fallow or where biomass were incorporated were more stunted than those in plots which were under continuous cropping and natural fallow plots.

Table 4. Nutrients accumulated in maize stover and grains at harvest (125 DAP).

Treatments	N (kg/ha)			P (kg/ha)		K (kg/ha)	
	Stover	Grains	%NIR#	Stover	Grains	Stover	Grains
TeF	33	40	45	1.4	3.5	95	25
TeR	16	19	0	0.7	1.6	49	12
TeT	30	44	47	1.3	3.9	88	28
TiF	37	46	40*	1.6	4.0	108	29
TiR	28	36	67*	1.2	3.2	81	23
TiT	33	51	69	1.4	4.5	96	32
CC	16	19	0	0.7	1.7	47	12
NF	19	27	Na**	0.8	1.6	57	17
$LSD_{0.05}$	4.0	4.3	Na	0.2	0.4	14	3
Without P	26	29	Na	1.1	2.5	73	18
With P	28	40	Na	1.2	3.6	82	25
$LSD_{0.05}$	1.9	2.6	Na	0.09	0.2	6	2

NIR: nitrogen recovery; *: Na: not applicable; ** N recovery in TiF and TiT was calculated using roots as bringing the equivalent amount of nutrients as maize stover.

Tasseling was irregular and delayed in all treatments. In general, there was no significant interaction between biomass and phosphorus applied in the previous season. However, the residual effect of 20-kg P/ha applied as TSP on preceding crop was still significant in terms of maize growth and biomass yield (Table 5).

The performance of the second maize crop following the second fallow season was better than that subsequent to the first fallow period. The shrub biomass (except treatment TeR) applied in previous season had significant effect on maize yields. After the fist fallow season, relatively higher yields were obtained in the plots with *Tephrosia* fallow (TeF) compared to those in plots in which *Tithonia* fallow had been grown (TiF). This trend in maize grown was reversed after the second fallow season.

Residual effect on the third maize crop

Maize planted in *Tephrosia* and *Tithonia* biomass incorporated (TeT and TiT) and continuous maize (CC) plots grew poorly and tasseling was delayed in all the plots. Unlike the previous season, the residual effect of P on maize yield was no longer significant (Table 6). A slight yield increase ($p<0.07$) was only observed with shrub biomass particularly where *Tithonia* biomass had been applied.

Table 5. Residual effect on yields of the second maize crops following the first and second fallow seasons .

Treatments	2nd maize after the first fallow			2nd maize after the second fallow (fifth maize crop)		
	Height (cm)	Stover yield (Mg/ha)	Grain yield (Mg/ha)	Height (cm)	Stover yield (Mg/ha)	Grain yield (Mg/ha)
TeF	135	1.5	0.62	167	2.31	2.43
TeR	73	0.8	0.21	106	1.06	0.72
TeT	102	0.9	0.26	124	1.33	1.30
TiF	113	1.1	0.28	203	2.88	3.18
TiR	125	1.1	0.44	151	1.91	2.02
TiT	119	1.3	0.37	190	2.25	2.31
CC	65	0.5	0.06	79	0.69	0.51
NF	107	0.8	0.32	97	0.89	0.90
$LSD_{0.05}$	28	0.4	0.30	45	0.80	1.05
Without P	99	0.9	0.23	135	1.57	1.48
With P	111	1.1	0.41	145	1.76	1.86
$LSD_{0.05}$	6	0.2	0.06	4	0.08	0.12

Table 6. Maize stover and grain yields of the third maize crop (only for some treatments).

Treatment	Stover (Mg/ha)	Cores (Mg/ha)	Grain (Mg/ha)
TeT	1.93	0.28	1.44
TiT	2.95	0.41	2.33
CC	0.86	0.19	0.69
$LSD_{0.07}$	1.78	0.19	1.42
No P	1.93	0.31	1.51
Plus P	1.90	0.28	1.46
$LSD_{0.07}$	0.28	0.08	0.25

DISCUSSION

Maseno soils are low in N and P (Table 1) and maize biomass obtained from the control plots was low in P but relatively high in N. This unexpected high concentration of N was a limiting factor for the efficiency use of the critical plant nutrient levels in diagnosing N needs. The more severe N deficiency shown in the first maize crop at silking stage in TiF and TiT than in TeF, TeT and NF plots could be explained by the released N during the cropping season. Since *Tephrosia* and *Tithonia* aboveground biomass released about 52 and 80% of the total N content respectively within the first 30 days after their incorporation into the soil (Rutunga et al, 2001). it could be argued that some N from *Tithonia* biomass applied one week before planting maize was already used by the maize. This is confirmed by N recovery that was high (> 40%) in the maize stover and grains harvested where *Tephrosia* and *Tithonia* biomass had been applied. Also some of the N from *Tithonia* was probably lost through leaching due to high rainfall received during the growing period. Soil samples from TiF and TiT plots showed that at 53 DAP, mineral N had decreased at the 15-cm soil depth and increased in 30-60 cm depth. A healthy maize crop which was growing after a two year-old *Tithonia* fallow in a plot adjacent to the experimental plots (data not shown) was an indication that a regular application of small amounts of *Tithonia* biomass in form of litter is likely to improve N use efficiency and lead to synchronizing plant nutrient supply and demand.

Biomass from TeF and TeT treatments released N progressively (Rutunga, *et al*., 2001) as the maize was growing. In NF plots, the biomass that was mulched started decomposing and releasing nutrients at the maize tasselling to grain filling stages while CC treatment showed N deficiency throughout the growth period. Ng Kee Kwong et al. (1987) and Sisworo *et al.* (1990) found that the N-use efficiency of cereal straw residues was partitioned between 5-14% and 73-84 % for the first crop and soil organic matter, respectively. Since the maize stover used in this study was low in N (about 10 g N/kg stover), CC treatment provided only about 2 kg N/ha, which was too low to have any beneficial effect on maize growth and yield. Use of poor quality organic material alone is often insufficient for productive agriculture (Giller *et al*., 1997).

Tissue P in all treatments was below the critical level of 3.5 to 4.0 g P/kg (Wild, 1988), although there was an increase in maize grain yield with fallows and biomass incorporated treatments compared to continuous maize. The low P content in maize grains may indicate that the available P was not yet sufficient to meet the crop needs estimated at 18 kg P for two tons of maize grain and three tons of stover (Palm *et al*., 1997). Okalebo (1987), Fan and MacKenzie (1994) and Mallarino (1996) found that the total P uptake by maize stalk and grain were correlated to soil available P, but the grain had a greater capacity for P luxury accumulation than the stalk. The nutrient uptake is relatively low where the nutrient supply limits the yield (Wild, 1988) and low soil P status normally leads to poor uptake of nitrate by the crop (Warren *et al.*, 1997). Since P was quickly released through the biomass decay (Rutunga *et al,* 2001), the fact that the amounts of various biomass applied to the soil did not provide sufficient P to the maize crop may be due to their low P content (less than 2 kg P/ton). The organic material with less than 3 g P/kg can immobilise the labile soil P (Singh and Jones, 1976; Swift, 1997) and make it less available to the plant. Phosphorus recovery from mineral P applied was low (6%) probably due to low net outcome between low mineral P rate and low P organic inputs added to acid soils that generally have high P fixing capacity (Sanchez, 1976; Jama *et al.,* 1997).

The low amount of P in *Tephrosia* and *Tithonia* biomass was a limiting factor in increasing crop yields. Lehmann et al. (1995) and Palm (1995) have reported such low P supply by other organic inputs. *Tithonia* fallow (TiF) plots that had received a greater amount of N, K, Ca and Mg-rich biomass produced less maize grain than *Tithonia* biomass incorporated (TiT) plots. This may have been caused by the high average ratio of N to P, which was 15:1 and 14:1 for TiF and TiT, respectively and by immobilisation of N or P by the roots. Swift (1997) reported a yield increase of 62% (from 2.0 to 3.2 Mg/ha) maize grain obtained through the supply of *Tithonia* biomass with inorganic P that decreased N:P ratio from 12:1 to 5:1.

Maize in the fertilised plots started tasseling and silking 2 to 7 days earlier and had less water in cobs at harvest than in the unfertilised plots. Berger (1962) pointed out that nutrient deficiencies prolonged the interval from emergence to tasseling or silking and addition of fertiliser hastened the time of silking by 4 to 10 days. Application of high amounts of shrub biomass (TeF, TeT, TiF and TiT) significantly (P=0.05) increased the maize stalk biomass and grain yield, compared to the biomass from natural fallow and continuous maize crop. Similar results with *Calliandra calothyrsus* and *Leuceana leucocephala* were reported by Mafongoya et al. (1997a) in Zimbabwe. Thus, the amount and quality of biomass applied are important factors for improving the maize nutrient uptake, recovery and grain yield. A fast decomposing material such as *Tithonia* may have an advantage due to the fact that the response of maize to the nutrients released, especially nitrogen appears in the early stages of crop growth (Okalebo, 1987). No comparison of *Tephrosia* and *Tithonia* efficiency on maize yield could be done in the first experiment since the rates of the shrub biomass and nutrients applied were different. In the second experiment where an equal amount of N and P from leaves (including soft twigs) of *Tephrosia* and *Tithonia* that have different nutrient release patterns were applied, both shrub biomasses had similar effect on maize yield. (Rutunga, 1999) *Tithonia* biomass improved maize growth at the early stage but the effect decreased over time, particularly at the flowering-silking period, while the effect of *Tephrosia* biomass although initially low at the early stages of maize growth increased with time. This was also observed in *Tephrosia* fallow where maize started performing well even at early stage of growth probably due to the litterfall that was already decomposing thus providing nutrients to the maize crop.

The poor maize performance under biomass transferred systems (TeR and TiR) was less severe with *Tithonia* that had more litterfall (3 Mg/ha) and more small roots (1.5 Mg/ha) compared to *Tephrosia* (1 Mg of litterfall and 1 Mg of small roots/ha). This is in agreement with the observation made by Kang and Wilson (1987) that where biomass was continuously removed, the soil became impoverished. Maize performance in the natural fallow (NF) was slightly higher than that in the continuous cropping (CC) but less than that in the fallow and biomass incorporated treatments. This was due to the low quality/quantity of biomass and the asyncrony in nutrient release in the natural fallow system (Rutunga *et al.*, 2001).

The residual effect of biomass and phosphorus application significantly increased the maize yield compared to the control although this increase was below the optimum. The low residual effect obtained from the treatments with shrub biomass (TeF, TeT, TiF, TiT) for the second maize following the first fallow season was due to the high biomass decomposition rate and excess rainfall (about 1000 mm) received during the season. Most nutrients such as N, K, Ca and Mg were released in the first cropping season (Rutunga, *et al.*, 2001) and used or lost. What was left was therefore insufficient to meet the nutritional requirements of the second and third maize crop. This is in agreement with the observation made by Cadisch *et al*. (1998) and Janzen *et al.* (1990) that the contribution of N from plant residues applied to a previous crop was 1-4 % of the N content of the material originally applied.

The residual effect of P was less due to the low rate and fixation by the soil of P applied in form of TSP. Sanchez *et al.* (1997) pointed out that the higher the P application rate, the strong the residual effect. Warren (1992) observed that moderate P rates of about 20-kg P/ha had a significant effect on maize yield for one to two crops following the application in the drier parts of Embu District, Kenya. At the site of this current study, P loss that may have taken place through crop harvest (Smaling *et al*., 1997) and erosion (Gachene *et al*., 1997) was reduced since all the maize stover was retained in the plots while erosion control measures were put in place.

Maize crop is sensitive to water deficit at flowering stage (Salter and Goode, 1967), and as such the one to two-weeks period of water stress experienced during the experimental seasons resulted in a reduction in crop response to biomass application. On the other hand, maize performance may be reduced by excessive soil water content (Chaudhary *et al.,* 1975; Singh and Ghildyal, 1980) and this was observed in the present study during the second season which had a lot of rain. The yields of the second maize from treatments TeT, TiT and CC were generally lower than those of the third and fifth maize crops (Tables 5 and 6). In plots with excessive moisture, nitrogen deficiency symptoms were more severe probably due to N losses through denitrification and leaching (Tiedje *et al.*, 1984).

CONCLUSION

The results from this study showed that there is a potential for six month-planted fallow and biomass incorporated technologies for improving maize production. The effect of the two technologies depend mostly on the quantity and quality of biomass (amount of nutrients recycled or eventually fixed) produced, the methods and time of biomass application and the processes of nutrient release and uptake by the crop (Mafongoya *et al*., 1997b). Incorporating *Tephrosia* and *Tithonia* biomass one week before planting improved the maize yield. The effect was greater (an increase of about 40%) when inorganic P was added. However, there was severe N deficiency on maize at silking stage with a single application of high amount of *Tithonia* biomass. Application of 3.5 to 5.0 Mg/ha of dry matter increased the maize yield by 2.5 times, compared to the maize yield in the unfertilised nutrient-depleted-plot. The effect of biomass started decreasing after one cropping season and this may reflect a low amount of nutrients stored in the soil. To achieve sustained yields of maize in depleted soils of Western Kenya requires regular fallowing and additional P inputs. Biomass incorporated technologies involve the impoverishment of the biomass transferred plot, while improving the biomass incorporated plot.

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