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Six month-duration *Tephrosia vogelii* Hook.f. and *Tithonia diversifolia* (Hemsl.) A.Gray planted-fallows for improving maize production in Kenya

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An experiment including planted *Tephrosia vogelii* and *Tithonia diversifolia* fallow species and natural fallow was conducted at Maseno, Kenya, for assessing whether these fallows grown on a nutrient depleted land could produce sufficient green manure in six month period, whether their biomass retained on the same plots or transferred to continuously cropped plots with or without added P fertiliser could increase yield of consecutive maize crops and whether it is useful to regularly repeat these fallows on same plots. First fallow was established in randomized complete blocks with three replicates. At harvesting, biomass was recorded, then either incorporated *in situ* or transferred to continuous cropped plots split with and without added P fertiliser and monitored for the effect in improving consecutive maize crops. The second fallow was managed on this split plot design. The two-planted shrubs fallows produced more than 9 Mg total dry biomass and accumulated 154 to 234 kg $N \cdot ha^{-1}$, which were significantly higher compared to the production in the natural fallow. The shrubs were also superior to natural fallow for P accumulation (5-22 kg versus 2 $kg \cdot ha^{-1}$). The aboveground dry biomass harvested from planted *T. vogelii* and *T. diversifolia* and either incorporated *in situ* or transferred into continuously cropped plots increased maize yields by 2.5 folds compared to the unmanured crop, the control. Supplementing the organic materials with an additional 20 kg P inorganic fertilizer increased the 1st maize yield by about 40%. Productivity in the plots with *T. vogelii* or *T. diversifolia* aboveground biomass removal was low for the subsequent fallow and maize crops when compared to the performance in plots where biomass was incorporated. To achieve sustained yields of maize in depleted soils requires regular improved fallowing at least one season alternating with one season maize, and additional P inputs.
Keywords. Green manure, planted fallows, maize crop, phosphorus addition, rotation, yield.

Six mois de jachères plantées de *Tephrosia vogelii* Hook.f. et *Tithonia diversifolia* (Hemsl.) A.Gray en vue de la production régulière et performante du maïs au Kenya. Une recherche portant sur les jachères plantées de *Tephrosia vogelii* et *Tithonia diversifolia* ainsi que sur le recru naturel a été menée à Maseno, Kenya, pour déterminer si les jachères installées sur une terre fatiguée pouvaient produire assez de biomasse en six mois, si la biomasse retenue sur place ou transférée dans une parcelle sous culture continue de maïs et complétée ou non par un apport de phosphore pouvait améliorer le rendement de la culture et enfin s'il y a un avantage à répéter régulièrement ces jachères sur les mêmes parcelles. La première jachère était installée en blocs complets aléatoires avec trois répétitions. À sa coupe, la biomasse était quantifiée, puis soit incorporée dans la même parcelle soit transférée dans une parcelle régulièrement sous maïs, ces parcelles étant alors divisées en deux, à savoir celles avec et celles sans addition d'engrais phosphaté inorganique en vue de tester l'impact des fumures sur l'augmentation de rendement de maïs. La culture de maïs et la seconde jachère étaient ainsi conduites en parcelles divisées. Les jachères de *T. vogelii* et *T. diversifolia* ont produit plus de 9 Mg de biomasse totale qui accumulait 154-234 kg $N \cdot ha^{-1}$, rendement supérieur à celui obtenu dans le recru naturel. Les arbustes étaient également supérieurs à la jachère naturelle quant à l'accumulation du phosphore (5-22 contre 2 $kg \cdot ha^{-1}$). La biomasse aérienne récoltée de ces deux arbustes de jachère a, une fois incorporée dans le sol ou transférée dans la parcelle sous culture continue, augmenté le rendement de maïs de 2,5 fois par rapport à la culture non fumée, le témoin. L'addition de 20 kg $P \cdot ha^{-1}$ à cette biomasse a augmenté le rendement de la 1re culture de maïs de près de 40 %. La productivité des parcelles où la biomasse aérienne de *T. vogelii* et *T. diversifolia* avait été retirée était basse pour le maïs et la 2^{e} jachère en comparaison avec la performance observée dans les parcelles où cette biomasse avait été retenue ou

incorporée. Assurer une productivité durable dans les sols fatigués requiert la mise en jachère améliorée d'au moins une saison alternant avec une saison de culture de maïs avec un apport complémentaire de P inorganique.
Mots-clés. Engrais verts, jachères plantées, culture de maïs, addition de phosphore, rotation, rendement.

1. INTRODUCTION

Continuous cultivation of African farms with little or no nutrient inputs addition coupled by erosion losses has led to the depletion of soil fertility (Stoorvogel et al., 1993). A survey carried out in Western Kenya by Swinkels et al. (1997) showed that 50% of the farmers let about 10-50% of the land remain uncultivated and native vegetation allowed to regenerate (e.g. natural fallow) for at least a period of six months, mainly for soil fertility restoration. Natural fallows normally require long periods ranging from 2-20 years for soil fertility restoration to be achieved (Van Reuler et al., 1993) and this is not applicable to farmers in Western Kenya who are confronted with land shortage given average farm size ranges between 0.2-2.5 ha (Amadalo et al., 2003).

Fast growing tree and shrub species such as *Tephrosia vogelii* Hook.f. and *Tithonia diversifolia* (Hemsl.) A.Gray, *Leucaena* sp., *Sesbania sesban* (L.) Merr., which produce large amount of high quality biomass during a growth period of one to three years have been identified as an alternative to natural fallow (Kang et al., 1987; Niang et al., 2002; Rao et al., 2002) but the biomass produced is low in phosphorus compared to the crop P requirement (Palm, 1995). Using these shrubs as planted fallows for a period of one year or more in the cropping system has been studied but the fallow period is still too long for a farmer who needs at least to harvest one crop a year for his household consumption. Since the residual benefits of fallows on the productivity of subsequent crops usually lasts for one to two cropping seasons (Szott et al., 1999), the time for cropping might vary between 1/3 and 2/3 of the total crop-fallow cycle (R = 0.67; Ruthenberg, 1980). Biomass transfer experiments and one season duration fallows were then conducted in Western Kenya (Rutunga et al., 1999; Jama et al., 2000; Amadalo et al., 2003) but there was no assessment for the potential of biomass production and nutrient accumulation by fallows under the transfer strategy on the same experimental site.

Maize (*Zea mays* L.) is the second most important cereal crop in the world (IFPRI, 1991) and the main staple food crop in Kenya (Central Bureau of Statistics, 1991). Maize grain yields range from 0.4 to 2.0 $Mg \cdot ha^{-1}$ in Western Kenya (Jama et al., 1997) with an average of 1.5 $Mg \cdot ha^{-1}$ for Kenya (Central Bureau of Statistics, 1995). This low yield is essentially due to disease and pest infestation (e.g., *Striga* sp.), inappropriate husbandry techniques and low soil fertility (mainly low N and P). Where diseases, pests and erosion are controlled, maize yields can be improved through addition of N and P to the soil, using brown and green manure (Kang et al., 1987; Mugwira et al., 1997), inorganic fertilisers (Roy et al., 2006), or better a combination of organic and inorganic fertiliser inputs especially in soils with low inherent cation exchange capacity (Rutunga et al., 1998; Jama et al., 1998; Rao et al., 2002).

Janzen et al. (1990) pointed out that application of fast decomposing organic materials could 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). Mixing low quality material such as cereal residues with high quality material in equal ratio (e.g. 50%-50%) contributed more positively to crop production than did the high quality material alone (Kuo et al., 1998). Incorporating high quality *T. vogelii* or *T. diversifolia* biomass alone, or in mixtures with maize stover that are readily available on farms, may ensure better nutrient management and productive cropping but this needs to be quantified.

The objectives of this study were:

– to compare planted fallows using *T. vogelii* or *T. diversifolia* in terms of biomass produced and nutrients accumulation,
– to assess simultaneously and on the same plots the effect of *T. vogelii* and *T. diversifolia* planted fallows and biomass transfer systems on maize yields,
– to assess in planted fallow and biomass transfer systems the added benefit from mineral P fertiliser supplementation to maize yield.

2. MATERIAL AND METHODS

2.1. Site description

The study was conducted near Maseno Agroforestry Research Centre in Kenya at latitude 0°0' and longitude 34°35' E, altitude 1,500 m above the sea level, and with a slope of 4%. Given the bimodal rainfall pattern, there are two crop growing seasons: the short (September to January) and the long (March to August) rainy seasons. The study was carried out from September 1996 to August 1999. The climate of the study area is classified as humid with a ratio of mean annual rainfall to average annual evaporation (R/Eo) > 0.85 (Sombroek et al., 1980). The rainfall during the period of study was sufficient (average annual rainfall between 1,500 and 2,000 mm) but unevenly distributed. The average annual temperature varied from 20 to 23°C with minimum and maximum temperatures of 9.5°C and 35.0°C, respectively.

The soils found at the experimental site are developed from basic igneous rocks, deep (> 1.5 m depth) and well drained. They are classified as humic Nitisols based on the FAO-UNESCO system (FAO-UNESCO, 1994) and are equivalent to kaolinitic, isohyperthermic Typic Kanhaplohumults in the USDA soil taxonomy system (Soil Survey Staff, 1996). The Ap horizon extends from 0-20 cm, AB from 20-55 cm and Bt horizons from 55-165 cm. Soil primary particles were mostly clay (53% in Ap and 61 to 68% in the deeper horizons). The bulk density increases from 1.2 $Mg{\cdot}m^{-3}$ in the Ap horizon to 1.3 $Mg{\cdot}m^{-3}$ in the Bt horizons, while soil chemical characteristics include: pH (1:1 soil/water suspension) 4.1 to 5.4, organic C and total N (Okalebo et al., 1993) 18 to 3.0 $g{\cdot}kg^{-1}$ and 2.1 to 0.2 $g{\cdot}kg^{-1}$ respectively, KCl extractable bases: Ca 0.3 to 1.7, Mg 0.7 to 1.2, K 0.2 $cmol_c{\cdot}kg^{-1}$, Al 0.6 $cmol_c{\cdot}kg^{-1}$ to trace and available P (Bray-II method) 3.0 $mg{\cdot}kg^{-1}$.

2.2. Fallow phase

The fallow experiment was conducted in a randomized complete block design with three replicates. The plots were 7.0 m x 10.0 m and were separated by a 2 m wide strip and trenched to 0.6 m. There were eight treatments:

– Fallow planted plots (T1 and T2): *T. vogelii* (T1) and *T. diversifolia* (T2) fallows, grown for a period of six months after which the aboveground biomass was cut and incorporated in the same plot.
– Biomass transfer plots (T3 and T4): *T. vogelii* (T3) and *T. diversifolia* (T4) fallows, grown for a period of six months after which the aboveground biomass was cut and removed from the plots.
– Natural fallow plot (T5): regeneration of native vegetation comprising *Digitaria* sp. Haller (78%), *Senecio discifolius* L. (7%), *Crassocephalum vitellinum* Moench (6%), *Bidens pilosa* L. (3%), *Cynodon* sp. Rich. (2%), *Richardia brasiliensis* L. (1%) and *Leonitis mollissima* R.Br. (1%) as the most dominant species recorded after three months growth period.
– Biomass incorporation plots (T6 and T7): *T. vogelii* and *T. diversifolia* biomass removed from T3 and T4 were incorporated in plots under continuous maize crop.
– Continuous maize cropping plot (T8): the control.

Establishment of fallows. *T. vogelii* and *T. diversifolia* seedlings were raised in the nursery and transplanted in the field at a spacing of 50 cm x 50 cm in early October, 1996. *T. vogelii* seedlings were inoculated twice with the *Bradyrhizobium* sp. strain No. 3384 (provenance: MIRCEN, University of Nairobi), ten days after pricking out and eight days before transplanting in the manually tilled field. Weeding was also done manually whenever the need arose in planted fallows only. Natural fallow vegetation was left growing undisturbed. Planted and natural fallows were cut in April 1997 six months after establishing. Maize variety H 512 was planted two weeks before transplanting the shrub seedlings and harvested two months before cutting the fallows; stover were separated from cobs, chopped, spread uniformly on the producing plots while cobs were removed. The details of this experiment and results are reported in Rutunga et al. (1999).

The second fallow was established from March 1998 to August 1998 on the same plots as for the 1st fallow after two consecutive maize crops. The experimental design for the 2nd fallow was a split plot due to the division of the plot into two sub-plots (size: 7.0 x 5.0 m) for P and no P applied to maize crop after the 1st fallow in April 1997 (**Table 1**). Maize and planted fallows were established at the same time: for *T. vogelii* and maize, two seeds were placed in a hole at 2 to 5 cm deep, covered with soil, then thinned to one plant at 3 weeks (*T. vogelii*) and 1 month after germination (maize); no *Rhizobium* inoculation. For *T. diversifolia*, 25 cm long cuttings obtained from mature *T. diversifolia* stems planted with 2 nodes belowground and 2 aboveground, planted at a slanting angle of about 45° (Kendall et al., 1977). Other procedures were the same as in the first fallow.

At cutting the fallows, *T. vogelii* and *T. diversifolia* aboveground biomass were chopped into short pieces (5-10 cm long) and then spread uniformly on the whole plot (for the 1st fallow) or sub-plot (for the 2nd fallow). They were then incorporated into the 0 to 10 cm soil depth through manually tilling with a hoe at one week before planting maize crop. The natural fallow biomass was applied on tilled soil as mulch without chopping to avoid digitaria shooting.

2.3. Maize crop phase

Before planting the 1st maize crop in April 1997, each plot was divided into two sub-plots for the 0 and 20 kg $P{\cdot}ha^{-1}$ provided from triple super-phosphate (19% P), changing the experimental design into a randomized split plot with 16 sub-treatments and three replicates (**Table 2**). Fertiliser was placed in planting holes as it is commonly recommended in Kenya. Maize Hybrid 512 was sown at a spacing of 30 cm x 75 cm, with two seeds per planting hole and thinned to one plant at the first weeding (30 days after sowing), giving a population of 44,444 $plants{\cdot}ha^{-1}$. A second weeding was done at 60 days after sowing (DAP). The stalkborer pest (*Chilo*

Table 1. Treatments for fallows and maize crops — *Traitements appliqués aux jachères et à la culture de maïs.*

Treatment	**1st fallow Oct. 96 - Apr. 97**	**1st and 3rd maize Apr. - Aug. 97; Sept. 98 - Feb. 99**		**2nd and 4th maize Sept. 97 - Feb. 98; Apr. - Aug. 99**	**2nd fallow/maize Mar. - Aug. 98**
	Grown species	**Biomass incorporated**	**Fertilisers applied in each sub-plot** (1)	**Fertilisers applied in sub-plots**	**Species grown in sub-plots**
T1	*Tephrosia vogelii*	All plant material	With and without P	RE (2)	*Tephrosia vogelii*
T2	*Tithonia diversifolia*	All plant material	With and without P	RE	*Tithonia diversifolia*
T3	*Tephrosia vogelii*	Litterfall, roots and stumps	With and without P	RE	*Tephrosia vogelii*
T4	*Tithonia diversifolia*	Litterfall, roots and stumps	With and without P	RE	*Tithonia diversifolia*
T5	Natural vegetation	All natural vegetation material	With and without P	RE	Natural vegetation
T6	Maize	Maize root, stover + *Tephrosia vogelii* ab(3)	With and without P	RE	Maize
T7	Maize	Maize root, stover + *Tithonia diversifolia* ab(3)	With and without P	RE	Maize
T8	Maize	Maize roots, stover	With and without P	RE	Maize

(1) Each biomass treatment plot was split into two for with and without inorganic P — *Chaque parcelle traitée avec la biomasse fut divisée en deux, avec et sans P inorganique.*
(2) RE: Residual effect of nutrient inputs applied on previous maize crop and maize roots and stover retained *in situ* — *Effet résiduel des éléments nutritifs appliqués à la culture de maïs précédente ainsi que les racines, tiges et feuilles de maïs laissés dans la parcelle*
(3) ab: aboveground biomass (litter not included) — *biomasse au-dessus du sol (litière sur sol non incluse).*

Table 2. Effective biomass incorporated into the soil after fallows/maize and corresponding amount of nitrogen (N) and phosphorus (P) — *Biomasse sèche appliquée dans le sol après les jachères/maïs et quantité d'azote (N) et de phoshore (P) correspondantes.*

Treatment (1)	**End of the 1st fallow**			**End of the 2nd fallow**		
	Biomass applied $Mg\cdot ha^{-1}$	**N applied** $kg\cdot ha^{-1}$	**P applied** $kg\cdot ha^{-1}$	**Biomass applied** $Mg\cdot ha^{-1}$	**N applied** $kg\cdot ha^{-1}$	**P applied** $kg\cdot ha^{-1}$
T1 (*Tephrosia vogelii* fallow)	8.7	127	7	8.8	116	5
T1+P	8.7	127	27	9.3	123	25
T2 (*Tithonia diversifolia* fallow)	10.7	150	7	18.0	230	21
T2+P	10.7	150	27	18.5	223	41
T3 (as T1, biomass removed)	4.2	53	3	3.8	41	2
T3+P	4.2	53	23	3.9	42	22
T4 (as T2, biomass removed)	7.0	81	4	7.5	85	8
T4+P	7.0	81	24	8.2	98	28
T5 (natural fallow)	2.6	36	2	6.8	82	7
T5+P	2.6	36	22	7.3	82	27
T6 (biomass addition from T3) (2)	4.4 (+2.2)	94	5	3.0 (+1.9)	74	3
T6+P	6.6	94	25	4.9	74	23
T7 (biomass addition from T4) (2)	3.3 (+2.2)	89	4	9.4 (+3.0)	134	12
T7+p	5.5	89	24	12.4	117	32
T8 (continuous maize alone)	2.2	23	1	0.8	9	0.4
T8+P	2.2	23	21	0.9	8	20.4

(1) These treatments were split into two for 20 kg mineral P and no mineral P added — *Ces traitement furent divisés en deux, soit avec un apport de 20 kg de P inorganique, soit sans apport de P inorganique.*
(2) Aboveground biomass (ab) removed from fallow (T3 and T4) was incorporated in continuous cropped plots T6 and T7, in addition to the maize stover retained (2.2 Mg) in 1st maize crop and 1.9 Mg for T6 and 3.0 $Mg\cdot ha^{-1}$ for T7 in 3rd maize crop as shown between brackets — *La biomasse au-dessus du sol (ab) retirée des parcelles en jachères (T3 et T4) était appliquée en parcelles de culture de maïs continue T6 et T7, en complément de la biomasse de maïs recyclée dans la parcelle (2,2 Mg) lors la 1re culture, puis 1,9 Mg pour T6 et 3,0 $Mg\cdot ha^{-1}$ pour T7 lors de la 3e culture de maïs, comme indiqué entre parenthèses.*

partellus sp.) was controlled by applying 3% malathion at two-weeks interval from 30 to 58 DAP. Maize was harvested in August at 125 DAP, cobs were removed, while stover was left *in situ*. The second maize crop was planted in September 1997 and no fertilisers were applied. The 3rd and 4th maize crops were established in September 1998 and April 1999, respectively, with P fertiliser applied only to the 3rd maize crop planted after the 2nd fallow season.

In this experiment with fallows, the amount of nutrients added was not equal for various treatments. To assess the eventual bias caused by this difference in nutrient amount for *T. vogelii* and *T. diversifolia* on maize growth, a complementary experiment named as " crop experiment two " hereafter was designed. The objective was to add the same amount of N and P from fertiliser (urea and triple super-phosphate) and organic inputs (*T. vogelii* and *T. diversifolia* leaves/soft twigs, maize stover) and to compare their effect on maize yields. The experiment was a factorial laid out in a randomized complete block design with three replicates, next to experiment with fallows, for seasons Apr.-Aug. 1998 and Sept. 1998-Feb. 1999. The elementary plot size was 5.25 m x 4.50 m. The treatments are shown in **table 3** and the rate of 72 kg N and 20 kg P·ha^{-1} per treatment was adopted being closer to the nutrient amount provided by treatment T6 and T7 in the experiment with fallows. Urea (46% N) and triple super-phosphate (19% P) fertilisers were also used as a control treatment. Land preparation, fertiliser application, crop variety and management and harvest procedures were the same as in the experiment with fallows.

2.4. Data collection and analyses

Fallows. Litterfall from *T. vogelii* and *T. diversifolia* was collected at two weeks intervals using 1 m^2 quadrants, oven dried at 60°C for 72 hours, weighed and then bulked until the fallow cutting. For all fallows, aboveground biomass comprising leaves/soft twigs and stems were weighed, while for maize cobs were separated from stover the only biomass left in the field. A 100 g representative amount was taken from each fresh aboveground biomass, chopped, oven-dried and weighed for moisture and aboveground dry matter quantity. For both planted and natural fallow, small roots (diameter < 2 mm) were sampled at 0-45 cm soil depth using a core sampling as outlined by Van Noordwijk et al. (1995). They were separated from the soil by soaking and washing using water and a 0.05 mm sieve and thus dried in the oven at 60°C to constant weight. Samples for primary taproots of *T. vogelii* and *T. diversifolia* were also collected (0 to 45 cm soil depth) weighed and dried for dry biomass determination. Small samples from each type of dried biomass were ground for the determination of N and P content following the procedures described by Anderson et al. (1993). Dry biomass and nutrients from T1 to T5 was subjected to statistical evaluation, using the two and three-way analysis of variance (ANOVA) and contrast methods.

Maize crops. The maize growth performance in experiment with fallows was assessed by recording biomass increase over time, plant health and colour and the number of plant tasselling over time. The single data for describing the time to tasseling for each plot was obtained using the standard logistic curve in square time (Curnow et al., 1983). Maize from both experiments was harvested at maturity (125 DAP) on 22.40 m^2 and 14.62 m^2 area for each sub-plot and plots, respectively and border rows excluded. The amount of dry maize grains (12.5% moisture content) and that of dry stover were determined. Maize grain yields from various treatments were statistically analysed, using the three-way analysis of variance. The treatment means were compared, using the least significant difference

Table 3. Sources of nutrient amount tested in the crop experiment two — *Sources d'apport d'éléments nutritifs testés dans le deuxième essai de culture*.

Sources of nutrient	Amount of organic and inorganic inputs (1) for reaching 72 kg N and 20 kg P per ha
Urea	72.0 kg N + 20.0 kg P
Te	2.5 Mg Te + 16.3 kg P
Ti	2.3 Mg Ti + 15.4 kg P
Mixture TeTi	1.6 Mg Te + 1.3 Mg Ti + 15.8 kg P
Urea + M	2 Mg M + 53.8 kg N + 18.5 kg P
Te + M	2 Mg M + 1.8 Mg Te + 16.3 kg P
Ti + M	2 Mg M + 1.7 Mg Ti + 15.8 kg P
TeTi + M	2 Mg M + 0.9 Mg Te + 0.85 Mg Ti + 15.8 kg P

Te: *Tephrosia vogelii* biomass — *biomasse de* Tephrosia vogelii (28.8 g N, 1.2 g P·kg^{-1}); Ti: *Tithonia diversifolia* biomass — *biomasse de* Tithonia diversifolia (31.3 g N, 1.6 g P·kg^{-1}); M: Maize stover — *Feuilles et tiges de maïs* (9.1 g N, 0.4 g P·kg^{-1})

(1) Some inorganic N and P are provided from urea and triple-superphosphate — *L'azote et le phosphore inorganique proviennent des engrais urée et triple superphosphate*.

(LSD) at probability level of 0.05 and 0.01. All statistics were performed using Genstat 3.2 computer software package (Genstat 5, 1995).

3. RESULTS

3.1. Biomass and nutrients accumulation in fallows

The dry biomass (root, litter and aboveground biomass) from the 1st fallow was highest for *T. diversifolia* followed by *T. vogelii* and the least was natural fallow (**Table 4**). Similar trend was observed in the second fallow; the amount of *T. vogelii* and *T. diversifolia* biomass, N and P were higher from the plots where all biomass was retained than from the plots where aboveground biomass had been removed. Such a removal could have led to soil fertility depletion. *T. diversifolia* materials accumulated more N and P per ha than *T. vogelii* biomass that was superior to natural fallow products; phosphorus applied one year before had no significant residual effect on the shrub biomass production and on N and P accumulation (**Tables 4** and **5**). Planted fallows were more performing than the natural fallow for biomass production and nutrient recycling and/or accumulation. Litter, roots and aboveground plant-parts were three important components in quantifying the biomass accumulated, especially for *T. diversifolia*.

3.2. Maize growth and yield

Between 0 and 60 DAP, maize grown in plots with *T. diversifolia* biomass was healthier than that in *T. vogelii* biomass plots as proven by data in **table 6**. From 60 to 70 DAP, benefits of adding shrub biomass diminished as plants displayed nitrogen deficiency symptoms especially where P fertiliser had been applied got worse at 75 DAP (silking stage). However, *T. vogelii* plots were less affected than the *T. diversifolia* ones. Maize tasseling started at 67 DAP and continued for a period of about four weeks, this unevenness being probably due to low soil fertility in unmanured plots. Biomass application shortened the time to 50% tasseling of all plants in the plot (t_{50}) by 1.0 to 4.6 days, while inorganic phosphorus application shortened the time by 2.8 days during the season, compared to the maize planted without fertiliser ($p < 0.01$). The best treatment with t_{50} of 7.4 days was with T2 treatment supplied with inorganic P. The interactions between biomass and mineral P were not significant. Maize height at the initial filling stage (90 DAP) was higher in plots where shrub biomass alone or with P fertiliser were applied. Natural fallow (T5) improved the subsequent maize growth particularly at the late stages of growth and grain yields compared to continuous maize cropping (T8).

Maize grain yield was higher with *T. vogelii* or *T. diversifolia* biomass application (T1, T2, T6, T7)

Table 4. Dry matter ($Mg \cdot ha^{-1}$) produced by fallows/maize and N and P ($kg \cdot ha^{-1}$) accumulated in the two seasons — *Biomasse sèche produite par les jachères/maïs et N et P ($kg \cdot ha^{-1}$) accumulés sur les deux saisons.*

Treatment	1st fallow						2nd fallow					
	Litter	ab [1]	All roots	Total biomass	N	P	Litter	ab [1]	All roots	Total biomass	N	P
T1	1.0	5.3	3.2	9.5	154	5.7	2.5	5.9	3.5	11.9	176	9.7
T2	3.2	4.4	4.2	11.8	191	8.1	4.0	9.8	4.8	18.6	234	21.9
T3	1.0	5.3	3.2	9.5	154	5.7	1.2	2.6	2.6	6.4	86	4.5
T4	3.2	4.4	4.2	11.8	191	8.1	4.0	7.7	3.8	15.5	201	17.2
T5	nd	2.3	1.5	3.8	54	2.6	nd	7.6	1.6	9.2	110	8.4
T6	nd	2.2 [2]	nd	2.2 [2]	20 [2]	0.9 [2]	nd	1.9 [3]	nd	1.9 [3]	17 c	0.8 [3]
T7	nd	2.2 [2]	nd	2.2 [2]	20 [2]	0.9 [2]	nd	3.0 [3]	nd	3.0 [3]	27 c	1.2 [3]
T8	nd	2.2 [2]	nd	2.2 [2]	20 [2]	0.9 [2]	nd	0.9 [3]	nd	0.9 [3]	8 c	0.4 [3]
$LSd_{0.05}$	0.6	1.1	nd	2.2	43	1.9	1.4	2.8	nd	3.0	48	3.1
0 P							2.7	6.4		11.8	158	11.6
20 $kg \cdot ha^{-1}$ P							3.2	7.0		12.9	170	13.0
$Lsd_{0.05}$							0.5	1.1 ns		1.2 ns	18 ns	1.6ns

(1) ab: aboveground biomass — *biomasse au-dessus du sol*; nd: not determined — *non déterminé*; ns: not significant — *non significatif*.

(2) Maize stover alone: T6, T7 and T8 were as one treatment, not used in statistical analyses; average values (T6+T7+T8) for stover + cobs were 3.1 Mg, 34 kg and 2.1 $kg \cdot ha^{-1}$ for biomass, N and P, respectively — *Feuilles et tiges de maïs seules : T6, T7 et T8 furent considérés comme un seul traitement et ne furent pas utilisés dans l'évaluation statistique ; la valeur moyenne ((T6+T7+T8)/3 et feuilles + tiges + épis ensemble) s'élevait à 3,1 Mg pour la biomasse, 34 kg pour l'azote et 2,1 $kg \cdot ha^{-1}$ pour le phosphore.*

(3) Maize stover alone, not used in the statistical analyses, ab (stover + cobs) for T6, T7 and T8 were 3.4, 5.4 and 1.5 $Mg \cdot ha^{-1}$, respectively — *Feuilles et tiges de maïs seules, non utilisées dans l'évaluation statistique, ab (feuilles + tiges + épis ensemble) pour T6, T7 et T8 s'élevaient à 3,4 ; 5,4 et 1,5 $Mg \cdot ha^{-1}$, respectivement.*

Table 5. Comparison of selected treatments during the second fallow — *Comparaison des traitements choisis pendant la seconde jachère*.

Pairs compared	Degree of freedom	F value for biomass	F value for nitrogen	F value for phosphorus
Planted fallows versus natural fallow	1/5	5.79*	7.17*	1.32 ns
Tithonia diversifolia versus *Tephrosia vogelii* fallows	1/1	44.32**	43.05**	71.54**
Biomass retained versus removed treatments	1/1	16.09**	4.68*	17.59**
Interaction fallows X nutrient	1/1	5.13*	4.98*	5.14*
No P versus with P	1/1	2.65 ns	2.38 ns	2.38 ns

* and **: significant at p = 0.05 and 0.01, respectively — *significatif à p = 0,05 et 0,01 respectivement*; ns: not significant at p = 0.05 — *non significatif à p = 0,05*.

Table 6. Accumulated DM at 30 and 60 DAP and average time to 50% tasselling of the 1st maize crop — *Matière sèche accumulée à 30 et 60 DAP et durée moyenne d'apparition de 50 % de plants fleuris dans la 1re culture de maïs*.

Treatment	**DM at 60 DAP,** $Mg \cdot ha^{-1}$	**DM at 90 DAP,** $Mg \cdot ha^{-1}$	**Days number,** average
T1	1.28	3.73	79.0
T2	1.82	3.55	77.3
T3	0.72	1.99	81.6
T4	1.22	3.20	78.9
T5	0.72	2.44	80.9
T6	1.05	2.85	80.3
T7	1.57	3.58	78.6
T8	0.44	1.60	81.9
$Lsd_{0.05}$	0.40	0.49	0.8*
0 P	0.82	2.38	81.2
20 kg $P \cdot ha^{-1}$	1.38	3.35	78.4
$LSD_{0.05}$	0.20	00.25	0.2*

* The value is SED that means standard error deviation of different treatment means — *La valeur est SED qui signifie la déviation d'erreur standard sur les moyennes de différents traitements*.

compared to the treatments where such biomass was not applied (T8) or was removed (T3), *T. diversifolia* (T4) with more litter and roots being an exception (**Tables 7** and **8**). Shrub biomass addition had greater impact than rotational (rotation benefits, litterfall and roots) effect on the performance of the 1st and 4th maize crops. The removal of large amount of biomass produced by *T. vogelii* fallow (T3) enhanced soil fertility depletion, yielding maize grain quantity as low as in the continuous maize cropping. Mineral P (20 kg) applied during the current or the previous seasons had a significant effect on maize grain yield but no significant interaction with biomass applied for the 1st and 2nd maize (**Table 7**). The amount of maize stover was positively correlated with maize grain yield ($r^2 = 90$). Application of 3.3 Mg of *T. diversifolia* (T7) or 4.4 Mg of *T. vogelii* of aboveground biomass (T6) added to 2.2 Mg maize stover, which translated to about 89-94 kg N and 4-5 kg P plus 20 kg mineral P per ha increased the 1st maize yield by 2.5 fold as compared to the production in continuous maize cropping (T8). After the first fallow season, relatively higher yields

Table 7. Analysis of variance for the grains ($Mg \cdot ha^{-1}$) of maize crops following the fallows — *Analyse de la variance pour les grains de maïs ($Mg \cdot ha^{-1}$) des cultures succédant aux jachères*.

Source of variance	Df	First maize Apr. - Aug. 97		Second maize Sept. 97 - Feb. 98		Third maize Sept. 98 - Feb. 99		Fourth maize Apr. - Aug. 99	
		Mean square	F value	Mean square	F value	Mean square	F value	Mean square	F value
Replicates	2	9.84	19.9	0.41	7.1	3.16	17.9	8.58	33.7
Treatments	7	5.45	11.0*	0.16	2.9**	6.43	36.4*	5.52	21.7*
Residual	14	0.49	4.7	0.06	5.9	0.18	76.4	0.255	50.9
P	1	8.58	80.7*	0.37	38.0	0.35	149.8*	0.94	188.6*
Treatment x P	7	0.12	1.2	0.01	1.6	0.006	2.5**	0.012	2.3**
Residual	16	0.11		0.01		0.002		0.005	
Total	**47**								

* and **: significant at p = 0.05 and 0.01, respectively — *significatif à p = 0,05 et 0,01, respectivement*.

Table 8. Grain yield (Mg·ha^{-1}) of maize crops following the fallows — *Rendement du maïs en grains (Mg·ha^{-1}) au cours des cultures succédant aux jachères.*

Treatment	First maize Apr. - Aug. 97	Second maize Sept. 97 - Feb. 98	Third maize (1) Sept. 98 - Feb. 99	Fourth maize Apr. - Aug. 99
T1	2.92	0.62	3.25	2.43
T2	3.37	0.29	3.45	3.18
T3	1.38	0.22	1.50	0.72
T4	2.65	0.44	2.45	2.02
T5	1.95	0.32	1.55	0.90
T6	3.27	0.27	1.02	1.30
T7	3.73	0.37	1.76	2.31
T8	1.38	0.06	0.52	0.51
$LSD_{0.05}$	0.32	0.31	1.00	1.05
0 P	2.12	0.23	1.83	1.48
20 kg P	2.97	0.41	2.04	1.86
$LSD_{0.05}$	0.19	0.06	0.36	0.12

(1) Due to the drought occurred at the maize filling stage, there were few grains for the crop and this result stands for maize stover and grains together — *À cause de la sécheresse qui survint au stade de remplissage du grain, il y eut peu de grains produits et les résultats présentés ici concernent les feuilles, les tiges et les grains ensemble*.

were obtained in the plots with *T. vogelii* fallow (T1) as compared to where *T. diversifolia* fallow had been grown (T2). This trend reversed in the maize grown after the 2nd fallow season. The effect of planted shrub biomass and mineral P on maize performance was declining over the seasons following their application. However, the grain yields were too low for the 2nd and 3rd maize due to unfavourable climatic conditions, and high for the 4th maize (**Table 8**).

Results from crop experiment two showed that there were no significant differences between the different organic biomass on maize stover and grain yields in both seasons (**Table 9**). This indicated that *T. vogelii* and *T. diversifolia* leaves and soft twigs were equally efficient when their biomass were applied to supply adequate amounts of N and P nutrients to the maize crop, which implied that any of both shrubs could be used for enhancing maize performance in Western

Table 9. Maize yields obtained (Mg·ha^{-1}) with application of 72 kg N and 20 kg P per ha provided by *Tephrosia vogelii*, *Tithonia diversifolia* and maize stover biomass and mineral fertilisers — *Rendement du maïs (Mg·ha^{-1}) obtenu par l'apport de 72 kg N et 20 kg P par ha fournis par la biomasse de* Tephrosia vogelii*, de* Tithonia diversifolia*, de résidus de maïs et par l'engrais*.

Factor	Yield of maize with fertiliser inputs Apr. -Aug. 98		Yield of subsequent maize without fertilisers Sept. 98 - Feb. 99
	Stover	Grains	Stover + cobs (1)
High N materials (1)			
Tephrosia vogelii biomass (Te)	2.8	2.7	1.0
Tithonia diversifolia biomass (Ti)	2.6	2.4	1.2
TeTi	3.2	2.8	1.0
Urea	2.6	2.6	0.8
$LSD_{0.05}$	0.8 ns	0.7 ns	0.4 ns
Maize stover (2)			
0 Mg·ha^{-1}	2.8	2.6	1.0
2 Mg·ha^{-1}	2.8	2.7	1.0
$LSD_{0.05}$	0.6	0.5	0.3
$LSD_{0.05}$ (a x b)	1.5 ns	1.0 ns	0.5 ns

(1) Due to the drought that occurred at the maize filling stage, very few grains were obtained and thus cobs were weighed together with stover — *À cause de la sécheresse qui survint au stade de remplissage du grain, il y eut peu de grains produits et les résultats présentés ici concernent les feuilles + tiges + épis ensemble;* ns: not significant — *non significatif.*

Kenya. Total 20 kg N per ha provided by stover look as if they were as efficient as N amount from shrub biomass in raising maize production.

4. DISCUSSION

4.1. Biomass production and nutrient accumulation by fallow systems

The biomass produced by *T. vogelii*, *T. diversifolia* and natural fallow during the second fallow was higher than that in the first fallow. This was due to the combined residual effect of organic material and inorganic P applied to the previous first maize crop coupled by the higher rainfall received during that season. According to Fungameza (1991) and Drechsel et al. (1996), the amount of biomass produced by *T. vogelii* and *T. diversifolia* is influenced by fertility status of the soil and the amount of rainfall. Rao et al. (2002) also found that P fertiliser addition significantly improved *Sesbania* biomass production on Maseno P-deficient soils. Roots and litter are important contributors of biomass and nutrient in case fallow incorporation is compared to biomass transfer technology. Some roots decompose slowly (Rutunga et al., 2001), litter has already started to release nutrients and this may contribute to better synchrony of biomass use than with the biomass transfer system alone.

There was high amount of N accumulated by planted shrubs particularly in the aboveground biomass. High N content in *T. vogelii* and *T. diversifolia* leaves was also reported by Nagarajah et al. (1982), Drechsel et al. (1996) and Amadalo et al. (2003). The plant tissue N is provided by soil mineral N and N_2 fixed through symbiotic relationships for legumes such as *T. vogelii* (Sprent et al., 1990). Since *T. vogelii* was not well nodulated (Rutunga et al., 1999) and *T. diversifolia* is not a legume, the mechanism used by the two shrubs to extract more nitrogen from the soil than do the natural vegetation and maize need to be assessed. The P concentration in *T. diversifolia* leaves though higher than that in *T. vogelii* and natural fallow materials were lower than the value of 2.7-3.8 $g \cdot kg^{-1}$ recorded by Jama et al. (2000), such a low P accumulation may have been influenced by the inherently lower levels of available P in the soils as compared to those at Jama's sites.

4.2. Maize production

The severe N deficiency observed in the first maize crop at silking stage in plots with *T. diversifolia* biomass could be explained by the released N dynamics during the cropping season. Since *T. vogelii* and *T. diversifolia* aboveground biomass release about 52 and 80% of their total N, respectively, within the first 30 days after their incorporation into the soil (Rutunga et al., 2001), it could be argued that the amount of N from *T. diversifolia* biomass yet available in soil was by this time strongly reduced through plant uptake, leaching and to a lesser extent, denitrification (Aulakh et al., 1991). Soils where *T. diversifolia* biomass was applied showed that at 53 days after planting maize, mineral N had decreased from 0 to 15 cm soil depth and increased from 30 to 60 cm depth (Rutunga, 2000). There is a need to assess the contribution of denitrification or reorganisation to the decline in N obtained from *T. diversifolia* and the strategy for improving N use efficiency through a better synchrony of nutrient supply and demand.

The high amount of *T. diversifolia* biomass applied in T2 plots reduced the period taken for half of the maize plants to have tasselled (t_{50}) by 4.6 days. Berger (1962) pointed out that nutrient deficiencies delayed the interval from emergence to tasseling or silking and addition of fertiliser hastened the time to silking by 4 to 10 days. The effect of six-month planted-fallow on the maize performance was more through biomass addition than rotational benefits that comprise also litterfall and root effect in this study. Application of large amounts of planted shrub biomass (T1, T2, T6, T7) significantly ($P = 0.05$) increased maize grain yield, compared to the biomass from the natural fallow (T5) and continuous maize crop (T8). Similar results with *Calliandra calothyrsus*, *Sesbania sesban* and *Leuceana leucocephala* were reported by Mafongoya et al. (1997a) in Zimbabwe, Jama et al. (1998) and Rao et al. (2002) in other Maseno's experiments. A fast decomposing material such as *T. diversifolia* biomass 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). This advantage was not confirmed by crop experiment two where equal amounts of N and P from leaves/soft twigs of *T. vogelii* and *T. diversifolia*, maize stover and TSP were applied; both-shrubs biomass had similar effect on the maize grain yield (**Table 9**).

The poor performance of maize in plots where aboveground biomass was removed (T3 and T4) was less severe with *T. diversifolia* that had more litterfall (3 $Mg \cdot ha^{-1}$) and small roots (1.5 $Mg \cdot ha^{-1}$) compared to *T. vogelii* (1 Mg of litterfall and 1 Mg of small roots per ha). This was in agreement with Kang et al. (1987) who found that where biomass was continuously removed, the soil became impoverished. Maize performance in the natural fallow (T5) was slightly higher than that in the continuous cropping (T8), due to the low quality/ quantity of biomass and asyncrony in nutrient release in the natural fallow system (Rutunga, 2001). For T8 treatment the maize stover used was low in N (about 9 g N·kg^{-1} of stover) and could provide near to 20% or 2 kg N·Mg^{-1} (Sisworo et al., 1990), such a contribution was too low to have any beneficial effect on the maize growth and grain yield. Poor quality (high C/N, low nutrients) organic material was often insufficient for a productive agriculture when used alone (Giller et al., 1997), but positively improves nutrient release synchrony when combined with high quality material (Kuo et al., 1998) and this would hold as an explanation of performing effect obtained with N from maize stover in the crop experiment two.

The amounts of various biomass applied to the soil did not provide sufficient P to the maize crop and this might be due to their low P content, which was less than 2 kg P·Mg^{-1} and to the fact that organic material with less than 3 g P·kg^{-1} led to immobilisation of labile soil P (Singh et al., 1976). Lehmann et al. (1995), Palm (1995) and Rao et al. (2002) have reported such low P supply by other organic inputs. *T. diversifolia* fallow (T2) plots that had received a greater amount of N-rich biomass produced less maize grain than plots with *T. diversifolia* aboveground biomass incorporated (T7, 1st maize). No reliable explanation could be formulated except the hypothesis of high average ratio of N to P (more than 14:1) for *T. diversifolia* biomass) and eventual N or P immobilisation by roots in *T. diversifolia* fallow.

The decreasing effect of phosphorus fertiliser and biomass was clearly seen on maize grown during the seasons subsequent to their application but was biased for the grain yields obtained in some seasons. Most nutrients such as N, K, Ca and Mg were released in the first cropping season and used by maize or lost. What was left was therefore insufficient to meet the nutritional requirements of the second maize crop, in agreement with the observation made by Janzen et al. (1990) and Cadisch et al. (1998) 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 too low yield obtained for the second maize following the first fallow was also due to the excess rainfall (about 1,000 mm) received during the season, which might have enhanced loss of available nutrients. In plots with excessive moisture, nitrogen deficiency symptoms appeared more severe probably due to bacterial denitrification that becomes high under anaerobic conditions (Tiedje et al., 1984). Singh et al. (1980) also reported the reduction of maize performance by excessive soil water content. The 4th maize that was the second following the second fallow performed better because of favourable rainfall and residual nutrient contents in the soil, since the drought in the previous season may have reduced the release and leaching of nutrients and also, the nutrient removal by grain harvest.

5. CONCLUSION

During a growth period of six months *T. vogelii* and *T. diversifolia* produced high amount of biomass with high N content but low P. As fallows-incorporation or biomass-transfer systems, they provided rotational benefits and nutrients hence improved maize production. The effect of both fallows and biomass-transfer technologies depends mostly on the quantity and quality of biomass produced, the methods and time of biomass application and the processes of nutrient release and uptake by the crop (Mafongoya et al., 1997b). Application of 3.5 to 5.0 Mg·ha^{-1} of shrub dry-matter increased the maize yield by 2.5 times, compared to the maize yield in the nutrient-depleted-control plots (T8) with or without added mineral P. However, with a single application of high amount of *T. diversifolia* biomass there was a severe N deficiency on maize at the silking stage. Maize yield was increased by about 40% when inorganic P was added. The effect of biomass and inorganic P showed a decreasing trend after one cropping season and this may reflect a low amount of nutrients stored in the soil or a poor availability. Current results confirm that achieving sustained yields of maize in depleted soils such as those in Western Kenya requires regular improved fallowing and additional P inputs; given adverse climatic conditions during these experiments, it was not possible to clearly indicate the best of the two proposed frequencies, i.e. fallow-maize-fallow or fallow-maize-maize-fallow. Biomass incorporation technologies involve the impoverishment of the plots where the biomass is removed while improving the plots in which the transferred biomass is incorporated. Such an impoverishment is less severe with shrubs such as *T. diversifolia* that produce large amount of litter and roots during the growth period.

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