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Biomass production and nutrient accumulation by *Tephrosia vogelii* (Hemsley) A. Gray and *Tithonia diversifolia* Hook F. fallows during the six-month growth period at Maseno, Western Kenya

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Two planted fallows namely, *Tephrosia vogelii* Hook F. and *Tithonia diversifolia* (Hemsley) A. Gray, a natural fallow and a *Zea mays* L. crop were grown on N and P depleted soils at Maseno in Kenya during a period of six months. Growth performance and biomass production were assessed. Roots and aerial plant parts grew fast. Most of the shrubs had produced flowers by the 165th day after transplanting. *T. vogelii* and *T. diversifolia* yielded more above ground biomass than maize and natural fallow. The amount of roots in the shrub and natural fallows was higher in the topsoil (0–30 cm) than in the deep layer (30–45cm). *T. vogelii* produced the least root biomass compared to the *Tithonia* and natural fallows. *Tephrosia* and *Tithonia* leaves were high in N, K, Ca and Mg, *Tephrosia* roots in N and K, and *Tephrosia* stems high in Ca only. All plant parts had low P content. The six month-old fallows of *T. vogelii* or *T. diversifolia* accumulated high amount of N, K and Ca. This biomass and nutrient accumulation may even be higher where rainfall is evenly distributed and sufficient and if initial soil fertility status is not very highly depleted. *Tithonia* leaves had a higher proton consumption capacity compared to other plant parts or *Tephrosia* and natural fallow materials. .
Keywords. Fallow, *Tephrosia vogelii*, *Tithonia diversifolia*, *Zea mays*, biomass production, nutrient accumulation, proton consumption capacity, tropical soil, Nitosols, Kenya.

Production de biomasse et accumulation d'éléments nutritifs par *Tephrosia vogelii* (Hemsley) A. Gray et *Tithonia diversifolia* Hook F. lors d'une jachère de six mois à Maseno, Kenya. Deux jachères plantées de *Tephrosia vogelii* Hook F. et *Tithonia diversifolia* (Hemsley) A. Gray, un recru d'herbes et une culture de *Zea mays* L. ont été aménagés pour une durée de six mois à Maseno au Kenya, sur un site pauvre en N et P. Les observations faites au cours de cette étude ont montré que les racines et la partie aérienne des plants avaient une croissance rapide. La plupart des plants d'arbustes avaient fleuri 160 jours après la transplantation en champs. Les jachères de *T. vogelii* et de *T. diversifolia* ont produit plus de biomasse aérienne que la culture de maïs ou le recru d'herbes. La quantité de racines dans les jachères d'arbustes et le recru d'herbes étaient plus élevées dans la couche superficielle (0–30 cm) du sol. Comparé au *Tithonia* et à la jachère naturelle, *T. vogelii* a produit le moins de racines. Les feuilles de *Tephrosia* et de *Tithonia* avaient une teneur élevée en N, K, Ca et Mg, les racines de *Tephrosia* une teneur élevée en N et K, alors que les tiges de *Tephrosia* avaient une teneur élevée en Ca seulement. Toutes les parties des végétaux avaient une teneur faible en P. La jachère de six mois avec *T. vogelii* ou *T. diversifolia* a permis de mobiliser une grande quantité de N, K et Ca. Cette accumulation de biomasse et d'éléments nutritifs peut être augmentée sur des sites à précipitation régulière et aux sols non fortement degradés. La biomasse foliaire de *Tithonia* a une plus grande capacité de neutralisation des protons que les autres parties de la plante et le matériel produit par *Tephrosia* et la jachère naturelle.
Mots-clés. Jachère, *Tephrosia vogelii*, *Tithonia diversifolia*, *Zea mays*, production de biomasse, accumulation d'éléments nutritifs, capacité de neutralisation des protons, sol tropical, Nitosol, Kenya.

1. INTRODUCTION

Western Kenya highland region has been under continuous cultivation for long time (from the late 1930's: Dickinson, Jensen, 1998) and this has led to the depletion of soil fertility. The classical solution to the soil nutrient depletion would consist in the use of mineral fertilizers (von Uexkull, 1986), brown and green manure (Mugwira, Murwira, 1997; IBSRAM, 1989; Fungameza, 1991) or better a combination of organic and inorganic inputs (Jama *et al*., 1997; Rutunga, 1997). Inorganic fertilizers are expensive and many farmers in the region lack financial resources so that they are unable to use sufficient amounts of external nutrient input on the food crops (ICRAF, 1996; Sanchez *et al.*, 1997; Smaling *et al*., 1997). Use of local inputs such as farmyard manure, tree and shrub biomass that are easily available in the farms may be a realistic option to improve soil fertility. In highly nutrient depleted soils, high amount (10 t or more on dry matter basis) of farmyard manure is needed to match the crop demand for nutrients (Rutunga, Neel, 1980; Rutunga *et al.*, 1998) and it is usually not available in such quantities.

Leucaena sp. Benth. and *Calliandra sp.* Benth hedgerow prunings as a source of green manure did ensure benefit to farmers although the technology had low adoption levels in the region (ICRAF, 1993). Improved fallow technology where leguminous shrubs such as *Sesbania sesban* (L.) Merr, *Tephrosia vogelii* Hook F. and other plants such as *Tithonia diversifolia* (Hemsley) A. Gray were grown for a period of 12 to 24 months is another means of improving crop yields (Kwesiga, Coe, 1994; Niang *et al.*, 1996; ICRAF, 1995; 1996). The period when these shrubs/plants are grown does reduce land available for crop production and so, farmers are reluctant to let their land lie fallow for one to two years. The two-year period also results in large amount of woody materials, which accumulate some nutrients that are normally taken away from the field as fuel wood or rails materials (ICRAF, 1994; 1997). One strategy to overcome these problems may be to shorten the fallow period to no more than one season and to produce sufficient high quality biomass.

Some species like *Leucaena leucocephala* (Lamk) de Wit, *Calliandra calothyrsus* Meissner and *Sesbania sesban* give high quality fodder for dairy livestock (ICRAF, 1996) and may be better used as fodder than green manure (Jama *et al.*, 1997). Species that are not useful for fodder or do not have other uses might be more appropriate as improved fallow species. *T. diversifolia* and *T. vogelii*, which are not palatable to animals, could be useful as green manure or improved fallow species.

The objective of this study was to assess the production of biomass and amount of nutrients accumulated by *T. diversifolia* and *T. vogelii* during a period of six months compared to the natural fallow.

2. MATERIALAND METHODS

2.1. Environmental characteristics of the experimental site

The site is situated close to the Kenya Agroforestry Research Centre in Maseno at latitude 0°0' and longitude 34°35' E, on the boundary of Western and Nyanza Provinces. The site is at an altitude of 1600 m above the sea level and has a slope of 4%.

The average annual temperature varies from 20°C to 23°C. The minimum and maximum temperatures are 6.5°C and 35.0°C respectively. There are two rainy seasons: the short rainy (September to January) and the long rainy (March to August) seasons. The average annual rainfall varies between 1500 mm and 2000 mm (data from ICRAF-KEFRI Maseno Centre). The rainfall during the period of study was enough, but not well distributed (**Figure 1**). 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) being > 0.85.

The soils are developed from basic igneous rocks. They are deep and well drained. The texture is mainly clay. The bulk density increases from 1.2 g/cm^3 in the Ap horizon to 1.3 g/cm^3 in the Bt horizons. Maseno soils are acid, low in available N, P and K particularly in their upper horizons (**Table 1**). They are classified as Humic Nitosols based on the FAO/UNESCO System (FAO-UNESCO, 1994), equivalent to kaolinitic, isohyperthermic Typic Kanhaplohumults in the USDA soil taxonomy system (Soil Survey Staff, 1994).

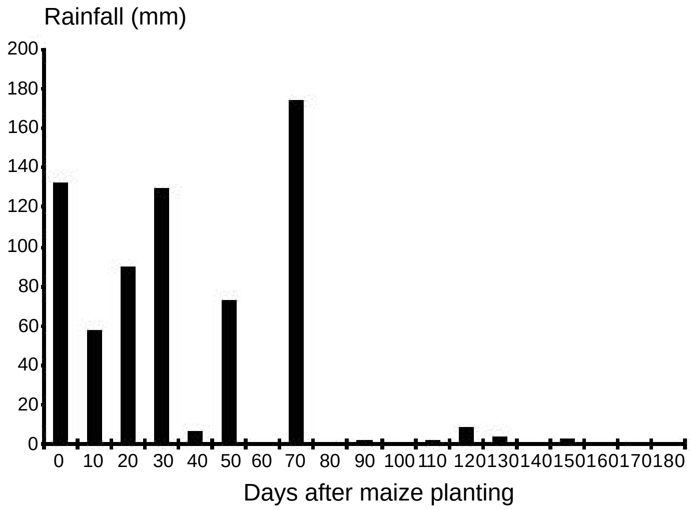

Figure 1. Rainfall during the fallow growth from September 1996 to March 1997 — *Précipitations (par décade) de septembre 1996 à mars 1997, pendant la période de jachère.*

Table 1. Physical and chemical properties of soils at the study site (Maseno, Kenya) — *Propriétés physiques et chimiques des sols au site d'essais (Maseno, Kenya).*

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 (0.05–2 mm)	26	22	18	21	22	18
% silt (2–50 µm)	21	17	22	13	12	14
% clay (< 2 µm)	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
Available 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)	0.3	1.0	1.0	1.3	1.5	1.7
Mg^{2+} (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.

2.2. Establishment of fallows

Two shrub-fallows, namely *Tephrosia vogelii* (Leguminosae) provenance Yaoundé and *Tithonia diversifolia* (Compositae) provenance Maseno, and the natural fallow (NF) were assessed for biomass production and nutrient accumulation and compared to that of the continuous maize (*Zea mays* L.) crop variety H 512. The most dominant 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* (Pers.) R. Br. (1%).

The treatments were laid out plots in a randomised complete block design with three replicates. The blocking was done on a basis of a uniform crop of maize grown without fertilizer prior to the establishment of fallow. The plots were 7.0 m × 10.0-m and were separated by a 2-m wide strip and trenched to 0.6 m.

Shrub seedlings were raised in the nursery according to agroforestry procedures as outlined by Singh (1994) and Kerkhof (1988). *T. vogelii* seedlings were inoculated with the *Bradyrhizobium sp.* strain No.3384, provided by the Microbial Resources Centre (MIRCEN) of the University of Nairobi. The seedlings were inoculated twice, at ten days after pricking out and at eight days before transplanting the seedlings in the field in order to improve the plant growth (Ding Ming-Mao *et al.*, 1994). *T. vogelii* and *T. diversifolia* seedlings were transplanted at a spacing of 50 cm × 50 cm in early October, 1996. At this time, *T. vogelii* seedlings were well nodulated (more than ten rhizobia nodules on each seedling) and had four leaves which had an average length of 15 cm. *T. diversifolia* seedlings had three leaves with an average length of 7 cm. The maize was planted on 15th September, 1996 at a spacing of 75 cm by 30 cm, and two seeds per planting hole. At two weeks after planting, this was thinned to one plant per hole. Weeding was done manually whenever the need arose in *Tephrosia*, *Tithonia* and maize plots. Natural fallow plots were only dug during land preparation and left undisturbed until the end of the fallow period.

The fallow lasted for a period of six months (from October, 1996 to March, 1997) after which the fallow biomass was harvested. Maize stover and grain were harvested 4 months after planting.

2.3. Data collection and statistical analysis

The growth rate of the fallows was assessed through height and percentage ground cover measurements. The height of sixteen randomly selected shrubs was measured at 15 days intervals in each plot from the date of planting to the time of harvesting. The plant (shrub and maize) height was measured from the ground to the stem tip or to the tassel. The percentage ground cover was recorded every month at about noon, using a square ruled 50 cm × 50 cm paper that was randomly laid down in the space between four plants. Shaded squares were counted and expressed in percentage of total number (100) of paper squares.

The production of biomass was assessed through litterfall, above ground biomass (leaves + twigs + stems) and root weight. Litterfall was collected at two-week intervals, using 1-m^2 quadrants. The first collection was done at 120 days after transplanting. The litter was oven-dried at 60°C for 48 hours, weighed and then bulked for a period of two months after which, a sample was ground and analysed for N, P, K, Ca and Mg. The fallows were cut at six months after establishment. The above ground biomass was separated into the leaves/twigs and stems and weighed. A 50-g representative sample was taken for the moisture and nutrient determination. After this, the leaves + twigs and the stems from each treatment were chopped and then mixed in weight ratio of leaves + very soft twigs to stems of 2:1 for *Tephrosia* and 1.3 to 3.3:1 for *Tithonia*. These mixtures have been referred to as *Tephrosia* or *Tithonia* mixture in the text presented hereafter. For the natural fallow, all above ground biomass was mixed and called leaves. Representative samples of mixtures and NF leaves were taken following the same procedure as for leaves (twigs and stems) biomass for the same chemical analyses. For maize, stover was separated from cores and grains, weighed and sampled for chemical analyses. All the samples were dried in the oven at 60°C for 72 hours then weighed for the dry matter content and ground for nutrient determination.

The below ground biomass was separated into small roots including fine (diameter < 2 mm) and coarse (diameter > 2 mm) roots and big roots consisting of primary taproots. Small roots were sampled from each treatment following the methods described by Van Noordwijk *et al.* (1985; 1995) and Anderson and Ingram (1993). The core sampling depths in this study were at 0–15 cm, 15–30 cm and 30–45 cm. For the 30–45 cm depths, mini-pits were dug for root sampling. Twelve sampling points were made in each plot. Small roots were separated from the soil by soaking and washing using water and a 0.5 mm sieve. Fine roots (diameter < 2 mm) were manually separated from coarse roots using a 2 mm sieve. Small roots were dried in the oven at 60°C to constant weight to obtain the dry biomass. The primary taproots from 12 shrubby plants per plot were dug out to a depth of 45 cm for their fresh weight determination. After taking a sample for moisture determination, the remaining primary taproots were left in the field. The length of the lateral small roots was assessed at 75 days after planting by excavating some shrub plants.

Shoot and all root dry matter was ground for the determination of N, P, K, Ca and Mg content, following the procedures described by Anderson and Ingram (1993). Nutrients accumulated in the harvested biomass and litterfall collected over the period of 60 days were calculated by multiplying biomass nutrient concentration and biomass quantity. The proton consumption capacity (pcc) of the plant part biomass, which is closely related to the level of basic cations and reflects the capacity of organic material to increase soil pH and Al detoxification (Bell, Bessho, 1993) was measured by titrating the organic material suspension (water:biomass weight ratio = 10:1) from its natural pH value down to pH 4.0, using 0.1 M HCl solution (Wong *et al.*, 1998).

To compare the above and below ground biomass production and nutrient accumulation in various treatments, the analysis of variance (ANOVA) following the Statistical Analysis System (SAS Institute, 1982) and Gomez and Gomez (1984) was used. Treatment means were compared, using the least significant difference (LSD) at the 0.05 level of significance.

3. RESULTS

3.1. Fallow growth performance

Generally the three fallows had poor growth performance (very dark green or yellowish stunted plants) in highly nutrient depleted plots. In relatively less depleted plots, the growth was better, but *T. diversifolia* leaves turned yellowish at flowering stage. This would not be confused with the phenological yellowish colour that appears after the flowering stage for many species. At two months after transplanting, few nodules were found on the roots of *T. vogelii* up to 80-cm soil depth.

The average stem height was 138 cm for *T. vogelii* and 120 cm for *T. diversifolia* at six months after planting compared to 55 cm for natural fallow (**Figure 2**). *Tephrosia* plants were not affected by the low amount of rainfall received from December 1996 to March, 1997 while the natural fallow and *Tithonia*'s leaves were wilting. Most of the shrubs had produced flowers at 165th day after transplanting. The maximum height attained by the maize and natural fallow was 113 and 55 cm respectively.

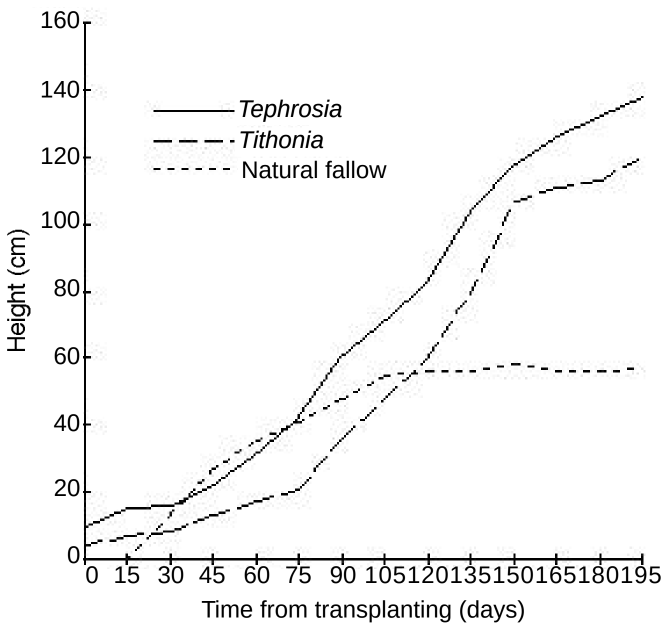

Figure 2. Average height of the three fallows during the growth period — *Hauteur moyenne des trois jachères durant la période de croissance*.

During the first month, *T. vogelii* and natural fallow had the highest percentage ground cover, but *T. diversifolia* showed better performance than *T. vogelii* at later dates (**Figure 3**).

The amount of total biomass (root, litter and above ground biomass) was the highest for the two shrubs, followed by the natural fallow and then the maize. (**Table 2**). The amount of *T. vogelii* litterfall in six months was significantly less than that produced by *T. diversifolia*.

The roots of *T. diversifolia* were healthy and their number was greater (about 9 roots per dm^2 in the top 30 cm of soil and at a distance of 8 cm from the base of the stem) than that of *T. vogelii*, which was about 6 roots per dm^2 in the same soil layer. The lateral roots for *T. vogelii* and *T. diversifolia* grew fast and were about 110 cm long at 75 days after planting. At this time, the taproot of *T. vogelii* attained 140 cm and that of *T. diversifolia* 120-cm depth. The taproot system of *T. vogelii* had reached a maximum length of 225 cm at six months after planting. At the same time, the deep roots in natural fallow had reached 80-cm depth. A reduction in nodule number on *T. vogelii* roots was observed from the 60 day-old seedlings to the harvesting period. At this period, most small roots in the two shrubs and natural fallows were concentrated in the topsoil (0–15 cm) and their amount decreased with soil depth (**Table 3**).

There were no significant differences in the amount of small root biomass between *T. vogelii*, *T. diversifolia* and natural fallow and no significant interaction between species and soil depth. The small root biomass of maize (Mekonnen *et al.*, 1997) was the lowest. The total small root biomass obtained from the 0–45 cm depth in the three fallows was lower than

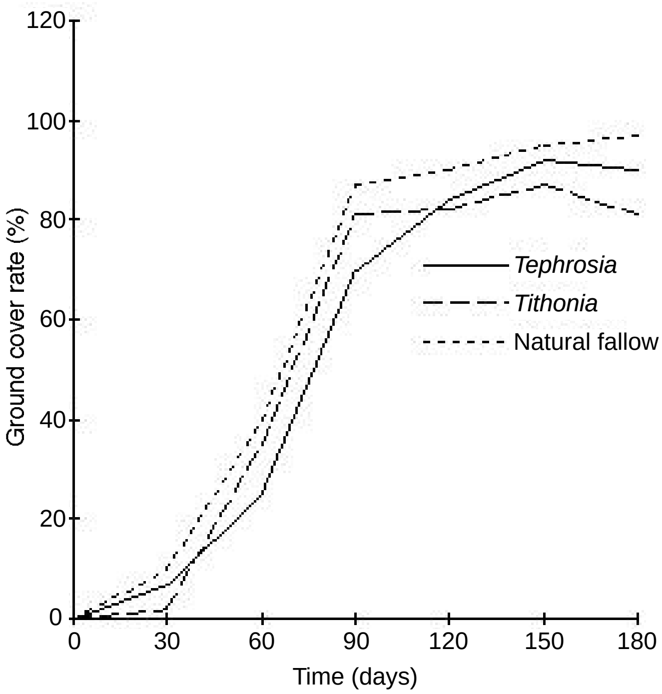

Figure 3. Ground cover percentage in the three fallows — *Degré de couverture moyen dans les trois jachères*.

Table 3. Average small root biomass at various soil depths in the three fallows — *Biomasse moyenne des petites racines en kg/ha à différentes profondeurs de sol dans les trois jachères.*

Soil depth (cm)	**Small root biomass** (kg/ha)				
	T. vogelii	***T. diversifolia***	**Natural fallow**	**Mean/ depth**	**Maize***
0–15	523	902	777	734	193
15–30	359	448	526	444	69
30–45	132	236	97	150	29
Mean/ species	336	528	466		97

$LSD_{0.05}$ for depth means: 133
$LSD_{0.05}$ for species means: 250

* Data from a poor maize crop grown in the same area (Mekonnen *et al.*, 1997), not used in the statistical analysis.

Table 2. Biomass (dry matter) produced by the various fallows during the six-month growth period — *Biomasse (en matière sèche) produite par les différentes jachères en six mois.*

Fallows	**Litter** (t/ha)	**Above ground biomass** (t/ha)	**Root and stolon biomass in 0–45 cm horizons** (t/ha)	**Primary taproots** (t/ha)	**Total biomass** (t/ha)	**(Leaves + twigs): stem ratio**
T. vogelii	1.0	5.3	1.0	2.2	9.5	1:2
T. diversifolia	3.2	4.4	1.6	2.6	11.8	1:3.3
Maize	nd*	2.2**	nd	nd	3.1***	nd
Natural fallow	nd	2.3	1.5	nd	3.8	nd
$LSD_{0.05}$	0.6	1.1	0.3	nd	2.2	nd

* nd: not determined; ** maize stover alone; *** maize stover and cobs together.

the above ground biomass. The ratio of small root biomass to above ground biomass quantity for *Tephrosia*, *Tithonia* and natural fallow was 1:6, 1:5 and 1:1.5, respectively. The percentage of fine roots obtained from the small root biomass was 27–36% for *Tephrosia*, 29–44% for *Tithonia* and 5–18% for the natural fallow.

3.2. Nutrient accumulation in the fallow biomass

The shrub biomass had high concentrations of N, K, and Ca but low P and Mg (**Table 4**). *T. vogelii* leaves and roots had more N, P and K concentrations than other plant parts of the same species. For *T. diversifolia*, the N, P, K and Ca levels were higher in leaves than in other components (stems and roots). *Tithonia* leaves contained more P, K and Ca than *Tephrosia* leaves. Materials from plots where shrub biomass have been removed showed a trend of low nutrient concentration compared to that obtained from the improved fallow plots.

The biomass produced by *T. diversifolia* fallow in six months period accumulated more nutrients than the natural vegetation fallow biomass and maize stover + cobs (**Table 5**). This high amount of nutrients accumulated was also observed with *T. vogelii* fallow for N and Ca. For all the three fallows, the most important plant part that contributed to the biomass and nutrient quantity was the above ground material. This was due to the high biomass production and to some extent to the high nutrient content in leaves including soft twigs.

The proton consumption capacity (pcc) of *Tithonia* leaves was high, about 50 $cmol_c$/kg of biomass while

Table 4. Average nutrient concentrations in the various plant parts at the cutting of six-month-old fallows — *Teneur moyenne en éléments nutritifs de la biomasse à la récolte des jachères de six mois*.

Type of biomass	Nutrients (g/ha)				
	N	P	K	Ca	Mg
T. vogelii					
Tephrosia mixture*	19.0 c**	0.6 c	12.3 g	9.0 c	2.2 cde
Tephrosia leaves	30.5 a	1.2 b	15.7 f	13.0 bc	4.7 ab
Tephrosia litter	14.9 d	0.5 c	10.6 g	15.6 ab	2.2 cde
Tephrosia stems	10.0 e	0.8 bc	7.8 h	14.8 ab	2.8 cd
Tephrosia roots	24.3 b	1.4 ab	20.5 e	3.3 f	2.0 cde
Tephrosia stumps	6.4 f	0.3 c	1.8 j	4.0 ef	0.5 e
T. diversifolia					
Tithonia mixture	22.3 b	0.9 bc	37.1 b	11.5 bcd	3.6 abc
Tithonia leaves	30.0 a	1.8 a	46.0 a	19.1 a	3.7 ab
Tithonia litter	14.3 d	0.5 c	28.8 c	7.9 def	5.5 a
Tithonia stems	16.6 cd	0.6 c	16.8 f	4.8 cde	3.5 b
Tithonia roots	11.1 e	0.6 c	24.5 d	0.4 efg	1.8 de
Tithonia stumps	8.4 ef	0.5 c	5.7 i	1.4 efg	0.8 e
$LSD_{0.05}$	3.0	0.5	1.8	4.9	2.0
CV	11%	29%	6%	26%	30%
Natural fallow (NF)					
NF leaves	15.4a	0.8a	17.0 a	4.3	2.5
NF roots + rhizomes	12.6a	0.5a	8.5 b	0.1	0.9
$LSD_{0.05}$	9.2 ns	0.4 ns	3.5	-	-
CV	19%	20%	8%	-	-
Maize					
Maize stover	10.8 a	0.6 b	10.3 c	3.7	3.3 a
Maize grains	13.7 a	1.1 a	18.4 a	tr	0.5 b
Cores	7.7 b	0.5 b	13.0 b	tr	0.5 b
$LSD_{0.05}$	3.0	0.4	1.3	-	1.0
CV	12%	20%	4%	-	32%

* Mixture means above ground biomass including stems, soft twigs and leaves together; ** values with the same letters in column are not significantly different at $p < 0.05$.

Table 5. Nutrient accumulation during the six-month fallow period — *Mobilisation d'éléments nutritifs par la biomasse d'une jachère de 6 mois*.

Treatments	**Total biomass** (t/ha)*	**Nutrients** (kg/ha) N	P	K	Ca	Mg
T. vogelii	9.5	154	5.7	100	75	17
T. diversifolia	11.8	191	8.1	271	70	32
Natural fallow	3.8	54	2.6	52	10	7
Maize stover + cobs	3.1	34	2.1	37	8	8
$LSD_{0.05}$	2.2	43	1.9	52	14	6
CV (%)	16	18	19	23	16	17

*Total biomass = above ground, litter and root biomass.

that of natural fallow, maize stover and all *Tephrosia* material was medium, about 20 $cmol_c$/kg (**Figure 4**). The pcc of *Tithonia* roots and stems was about 14 $cmol_c$/kg. The couch grass rhizomes had the lowest pcc (5 $cmol_c$/kg).

4. DISCUSSION

The amount of above ground biomass produced by *T. vogelii* and *T. diversifolia* during the six-month fallow was lower than that reported by Amadalo *et al.* (1995) who obtained 10 t and 13 t/ha of above ground biomass from *T. vogelii* and *T. diversifolia* respectively on more fertile soils in the same area after a six-month fallow period. The low biomass produced may have been due to low soil fertility (**Table 1**) and inadequate rainfall (**Figure 1**). According to Fungameza (1991) and Drechsel *et al.* (1996), the amount of biomass produced by *T. vogelii* is influenced by the fertility status of the soil and the amount of rainfall. Sanchez *et al.* (1997) stated that a soil with some fertility is necessary for the growth of organic material, be it green manure or plant biomass for transfer.

The ratio of leaves (including soft twigs) to woody material (stems) for *Tephrosia* and *Tithonia* at harvesting was about 1:2 and 1:3.3, respectively. This means that the amount of leaves which are rich in nutrients was high at the harvesting time. Such an observation is in agreement with Nagarajah and Nizar (1982) who have suggested harvesting the green material from the *Tithonia* plant at flowering stage.

The small roots were a significant component of biomass in the three fallows, although at a lower level compared to litterfall and above ground biomass. However, their contribution to the biomass input may be reduced when some small roots/rhizomes such as those of *Tithonia* and *Digitaria*, that shoot when left fresh in the soil, are removed from the soil during the process of weeding. The primary taproots of the shrubs were woody and low in N content (**Table 4**) in that they may not rapidly decay after cutting the fallow. The deep roots of the two shrubs as well as the high amount of small roots in the 0–45 cm depth for the three fallows are likely to improve the recycling of nutrients from the subsoil (Kang, Wilson, 1987). However, the efficiency of recycling process may be

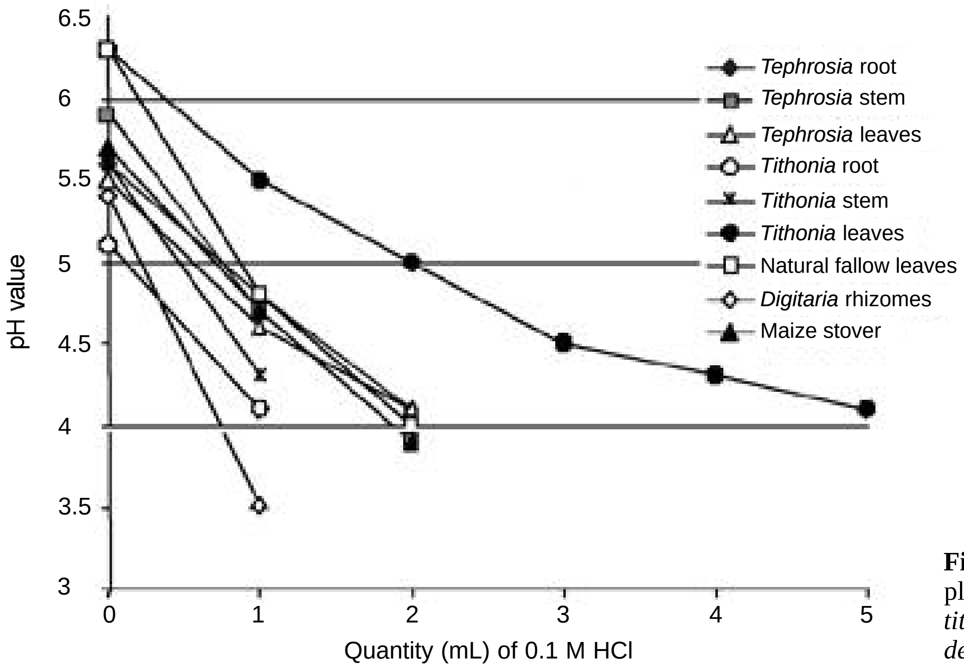

Figure 4. Titration curves of various plant part materials — *Courbes de titration obtenues pour divers types de matériaux végétaux*.

limited where the subsoil is poor as is the case for Maseno soils with low P content. Since the small root length density was not determined, the high percentage of fine root biomass for the shrubs was of a limited use. No firm comparison between the efficiency of the shrubs and that of the natural fallow or maize for soil nutrient uptake could be done.

Legume tissues usually have higher nitrogen content than those of non-fixing shrubs (Sprent, Sprent, 1990). This N is taken up from both soil mineral N and N_2 fixed through symbiotic relationships. *T. vogelii* though a legume was highly infested with nematodes, which might have caused the poor nodulation observed on the roots. Other reasons for this poor nodulation might be the high soil acidity, low level of soil phosphorus and the low nodulating capacity of *T. vogelii*. Giller and Wilson (1991) reported that phosphorus depletion could have a serious negative effect on N_2-fixation by legumes. Furthermore, a good nodulation with naturally occurring rhizobium was observed on *Tephrosia candida* DC. at the same site (observation from Rutunga). More research on *T. vogelii* nodulation is needed since N_2-fixation is one of the important characteristics for agroforestry studies (Nair, 1984) and for nutrient-depleted-soils such as in Maseno, external inputs from outside are needed to improve their fertility status (Sanchez *et al.*, 1997).

The below and above ground biomass of the two shrubs accumulated higher amount of N, K, Ca and Mg than the natural fallow and the maize. The high N content in *T. vogelii* leaves and litter recorded in this study had also been reported by Kwesiga and Coe (1994) and Drechsel *et al.* (1996). For *T. diversifolia*, Nagarajah and Nizar (1982) found that dried leaf and soft stem mixture contained about 20.0 g N/kg, 1.6 g P/kg and 33.2 g K/kg, which is in agreement with the current study. The P concentration in *T. diversifolia* leaves although higher than that in the *Tephrosia* and natural fallow materials, was lower than the value of 2.7-3.8 g/kg recorded by Gachengo (1996). Such a difference may be due to the low P content in soils obtained from study site. The nutrient content of the leaf materials from the two shrubs agrees with the range of 25–40 g N/kg, 1–3 g P/kg, 10–25 g K/kg and 15–20 g Ca/kg reported by Young (1997) for fast growing N_2-fixing trees. Since *Tephrosia* was not well nodulated and *Tithonia* is not a legume, the mechanisms used by the two shrubs to extract more nutrients from the soil than do the natural vegetation and the maize need to be assessed.

The techniques used for establishment of the shrub fallows included the nursery, which may not be affordable to farmers. *Tephrosia* may be successfully established by direct seeding (Niang A., ICRAF: personal communication) and Kendall and van Houten (1997) reported that *Tithonia* is also easily established by cuttings or direct seeding, and this is an appropriate way of doing when these planted fallows are introduced in agricultural practice under farmer's conditions. Once the biomass of fallows is harvested and incorporated into the soil, the subsequent crops could benefit from the nutrients released through decomposition and mineralisation. The 5.3 t/ha of dry *Tephrosia* mixture or 4.6 t/ha of *Tithonia* mixture could provide about 100 kg N/ha and only 3 to 4 kg P/ha. Compared to the current recommended rate of about 25 kg P/ha for maize in Kenya (FURP, 1994), this amount of N would be sufficient, while phosphorus would be insufficient. Palm (1995) and Palm *et al.* (1997) reported that organic inputs are very low suppliers of P because of their low P concentrations. In this case, there is a need for supplementing P from external sources for better crop growth. Another condition for increasing crop performance with the biomass is an appropriate rate of decay, which ensures the release of nutrients just when needed by the crop.

If there was more available land, a twelve month-duration fallow would be more appropriated since it will have more time for roots to recycle nutrients from deeper soil horizons and for increasing organic matter in topsoil through litter and root biomass. However, the woody material may develop (Drechsel *et al.*, 1996) and this is true particularly for *Tephrosia.* Thus, the biomass harvested may be a mixed quality material that decomposes slowly and releases nutrients for relatively a long period.

The high proton consumption capacity of *Tithonia* leaves may be in relation with their high content in K and Ca, and indicates that such a material is more efficient in reducing soil acidity than the other plant parts and other species materials studied when used as green manure. This is in accordance with the findings by Nziguheba *et al.* (1998) that *Tithonia* leaves have a potential to reduce the P fixation capacity of the soil. However, a greenhouse experiment showed that the effect of organic material on soil acidity reduction is temporary, lasting not longer than three months (Hoyt, Turner, 1975).

5. CONCLUSION

T. vogelii and *T. diversifolia* are fast growing shrubs that can accumulate substantial amounts of biomass and nutrients during a six-month fallow. This may be particularly true where the rainfall is adequate and well distributed and where soil fertility is high or improved with fertilizer inputs. The above ground biomass and litterfall from the shrubs have high concentrations of N and K but low phosphorus levels. However, *Tithonia* leaves had higher a Pconcentration than *Tephrosia* and natural fallow leaves. According to the results obtained in this study, a period of six months is appropriate for the production of high quality biomass (green manure) from the two shrubs. Their ability to accumulate high levels of N and K makes them suitable substitutes for the natural fallow. Although they show higher nutrient accumulation rates than the natural fallow they require more labour and some investment for planting material. More research is also needed on how they accumulate the nutrient (symbiosis, soil nutrient mining) and how these nutrients are released through biomass decomposition, hence their availability to crops. Furthermore, alternative sources of P for high crop yield need to be addressed.

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