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Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A review

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Abstract. *Tithonia diversifolia*, a shrub in the family Asteraceae, is widely distributed along farm boundaries in the humid and subhumid tropics of Africa. Green biomass of tithonia has been recognized as an effective source of nutrients for lowland rice (*Oryza sativa*) in Asia and more recently for maize (*Zea mays*) and vegetables in eastern and southern Africa. This paper reviews the potential of tithonia green biomass for soil fertility improvement based on recent research in western Kenya. Green leaf biomass of tithonia is high in nutrients, averaging about 3.5% N, 0.37% P and 4.1% K on a dry matter basis. Boundary hedges of sole tithonia can produce about 1 kg biomass (tender stems + leaves) m^{-1} yr^{-1} on a dry weight basis. Tithonia biomass decomposes rapidly after application to soil, and incorporated biomass can be an effective source of N, P and K for crops. In some cases, maize yields were even higher with incorporation of tithonia biomass than with commercial mineral fertilizer at equivalent rates of N, P and K. In addition to providing nutrients, tithonia incorporated at 5 t dry matter ha^{-1} can reduce P sorption and increase soil microbial biomass. Because of high labor requirements for cutting and carrying the biomass to fields, the use of tithonia biomass as a nutrient source is more profitable with high-value crops such as vegetables than with relatively low-valued maize. The transfer of tithonia biomass to fields constitutes the redistribution of nutrients within the landscape rather than a net input of nutrients. External inputs of nutrients would eventually be required to sustain production of tithonia when biomass is continually cut and transferred to agricultural land.

Introduction

The highlands of eastern Africa are generally densely populated and have a favorable climate for crop production. High population pressure has long ago led to replacement of traditional systems of shifting cultivation with shorter duration, unsustainable fallow systems and continuous cultivation. The use of commercial fertilizers on staple food crops of maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) has generally been restricted to only a few farms endowed with resources, such as cattle and land (Shepherd and Soule, 1998), and with high off-farm income (Niang et al., 1998). The majority of the smallholder farmers, on the other hand, have lacked the financial resources to purchase sufficient fertilizers to replace soil nutrients exported with harvested crop products. As a result, soil fertility has declined, and yields of staple food crops are typically low (Sanchez et al., 1997).

Organic resources are often proposed as alternatives to commercial mineral fertilizers. Traditional organic materials such as crop residues and animal manure, however, cannot by themselves reverse soil fertility decline because they are usually not available in sufficient quantities on most farms, they are low in nutrients, and their processing and application are labor demanding (Palm et al., 1997). In addition, some organic materials have competitive uses, such as fodder for livestock.

Unused, nontraditional organic resources grow on or near smallholder farms. Some have relatively high nutrient concentrations, but little is known about their potential as a nutrient sources to improve soil fertility and crop yields. One such organic resource is the green biomass of tithonia (*Tithonia diversifolia* (Hemsley) A. Gray).

Tithonia, commonly known as Mexican sunflower, is a shrub belonging to the family Asteraceae. Tithonia originated from Mexico, and it is now widely distributed throughout the humid and subhumid tropics in Central and South America, Asia and Africa (Sonke, 1997), and it is common in indigenous fallow systems in Southeast Asia (M. Cairns, personal communication). Tithonia was probably introduced into Africa as an ornamental. It has been reported in Kenya (Niang et al., 1996), Malawi (Ganunga et al., 1998), Nigeria (Ayeni et al., 1997), Rwanda (Drechsel and Reck, 1998) and Zimbabwe (Jiri and Waddington, 1998). In addition, it is also known to occur in Cameroon, Uganda and Zambia.

The reported uses of tithonia include fodder (Anette, 1996; Roothaert and Patterson, 1997; Roothaert et al., 1997), poultry feed (Odunsi et al., 1996), fuelwood (Ng’inja et al., 1998), compost (Drechsel and Reck, 1998; Ng’inja et al., 1998), land demarcation (Ng’inja et al., 1998), soil erosion control (Ng’inja et al., 1998), building materials and shelter for poultry (Otuma et al., 1998). In addition, extracts from tithonia plant parts reportedly protect crops from termites (Adoyo et al., 1997) and contain chemicals that inhibit plant growth (Baruah et al., 1994; Tongma et al., 1997) and control insects (Carino and Rejestes, 1982; Dutta et al., 1993). Extracts of tithonia also have medicinal value for treatment of hepatitis (Lin et al., 1993; Kuo and Chen, 1997) and control of amoebic dysentery (Tona et al., 1998). Among the various uses of tithonia, its medicinal value is one that farmers in western Kenya frequently report.

The green biomass of tithonia was previously recognized to be high in nutrients and effective as a nutrient source for lowland rice (Nagarajah and Nizar, 1982). Studies in the highlands of western Kenya identified green biomass of tithonia as an effective source of nutrients for maize (Gachengo, 1996; Niang et al., 1996). Recent work in Malawi (Ganunga et al., 1998) and Zimbabwe (Jiri and Waddington, 1998) have similarly reported tithonia biomass to be an effective nutrient source for maize.

Research in western Kenya on tithonia biomass as a nutrient source for crops has stimulated tremendous interest. However, much of the recent findings on tithonia in Kenya have not yet been published. In an attempt to provide up-to-date information, Buresh and Niang (1997) briefly highlighted experiences with tithonia in western Kenya. The objective of our paper is to complement Buresh and Niang (1997) by (i) providing a more comprehensive review of findings on the use of tithonia biomass for improvement of soil fertility and crop yields and (ii) identifying knowledge gaps and priorities for future research. Our review is restricted to the transfer of tithonia biomass (i.e., cut and carry) to crop fields for improvement of soil fertility, and it does not include the use of tithonia in either indigenous or planted fallow systems. Indigenous fallows not planted by farmers are found in some less populated areas of western Kenya.

Western Kenya has proven to be an excellent location to quantify the ability of tithonia biomass to improve soil fertility because crop production in western Kenya can be constrained by soil N, P and K deficiencies (Lijzenga, 1998). Measurements of maize response to N, P and K fertilization in smallholder fields indicated that 75% of the 33 study sites had ≤ 4 mg bicarbonate – EDTA extractable P kg^{-1} soil and responded to P fertilization. Once P deficiency was overcome through fertilizer inputs, N limited maize growth in nearly all cases. After P and N deficiencies were overcome, K limited maize growth in about 25% of the study sites (Lijzenga, 1998). Hartemink et al. (1996) and Nziguheba et al. (1998) report properties of soils at two research sites in western Kenya.

The biomass of tithonia used for soil fertility improvement generally includes both green tender stems and leaves but not the woody stem. Biomass production and nutrient concentrations of tithonia, however, are sometimes determined for only green leaves without the green stems, and much of the literature on tithonia does not clearly indicate whether green tender stems were included in reported measurements of biomass production and nutrient concentrations. In order to avoid confusion, in our review ‘green biomass’ refers to green tender stems plus green leaves and ‘leaf biomass’ refers to green leaves. All weights of biomass are reported on a dry weight basis.

Propagation and biomass production

Tithonia typically occurs within hedges or as clusters of pure stands, although in some less-populated areas of western Kenya (e.g., parts of Busia District) it exists as sole stands over extensive areas. The most common locations for hedges with tithonia in western Kenya are around crop fields, along narrow paths and around homesteads (Ng’inja et al., 1998). The tithonia in hedges is usually mixed with other species, consequently its biomass is generally lower in hedges than in pure stands (Lauriks et al., 1999). Landholders in western Kenya tend to cut tithonia in hedges once or twice a year for various reasons such as to reduce competition with crops in adjacent fields, to provide good appearance of the farm and to obtain fuelwood (Palm et al., 1996). Tithonia hedges rapidly grow back after cutting and withstand repeated cuttings.

Tithonia propagates from seeds. Seeds frequently germinate naturally under the tithonia canopy, and the seedlings can be dug up and transplanted elsewhere. When established from seeds in the field, germination can be poor if the seeds are sown deep or covered with clayey soil. Covering the seeds with a thin layer of sandy soil and grass mulch can enhance germination (King'ara, 1998).

Tithonia is more easily propagated from stem cuttings than from seeds (King'ara, 1998). Stem cuttings of 20- to 40-cm length establish readily, regardless of the angle at which they are inserted into the soil. Cuttings buried horizontally in the soil will sprout, but they are less effective than cuttings inserted either upright or at an angle into soil. The cuttings should be planted into moist soil immediately after collection and not allowed to sun dry. Termites can damage stem cuttings, particularly during dry periods. Under such conditions, it might be necessary to establish tithonia with seedlings rather than cuttings.

The biomass production of tithonia is influenced by establishment methods, frequency of cutting, stand density and site conditions. The reported values for tithonia biomass production in western Kenya are generally higher for planted pure stands than for existing hedges. Comparison of production values among studies, however, is confounded by differences in the plant part measured (total above-ground biomass, green tender stems + green leaves or leaves only), the time period since last cutting, water content (dry or fresh weight basis) and units of expression (surface area or linear length of hedge).

King'ara (1998) reported production of green biomass (green tender stems + green leaves) of 2.0 to 3.9 t dry matter ha^{-1} for eight-month-old pure stands of tithonia established from 40-cm-long cuttings by either upright or angled placement in soil at 10 cm by 10 cm spacing. Green biomass was higher for stands established from woody than from soft stem cuttings – 4.2 compared to 2.6 t dry matter ha^{-1} per cutting averaged for three cuttings times (Table 1).

In other cases, better establishment and biomass production have been observed with soft than woody stem cuttings (O. Kyunguti, ICRAF, personal communication). Field observations suggest that while woody cuttings can be superior to soft cuttings (Table 1), woody cuttings are more prone than soft cuttings to damage by termites. Soft cuttings might then be superior to woody cuttings when termite activity is high (King'ara, 1998).

The biomass production of tithonia can be influenced by soil fertility. For example, tithonia established from stem cuttings produced more biomass on soil fertilized with 50 kg P ha^{-1} than on severely P-deficient soil receiving no P application (Table 2). Phosphorus fertilization increased stem biomass (green + woody material) more than leaf + litter biomass.

A survey of farms in Vihiga and Siaya Districts in western Kenya revealed mean tithonia biomass in hedges of 0.75 kg m^{-2} on a dry weight basis, of which 0.08 kg m^{-2} was leaves and 0.67 kg m^{-2} was woody plus green tender

Table 1. Influence of type of stem planting material of tithonia on its production of green biomass (green stems and leaves) on a dry weight basis at three harvest times after planting in western Kenya.

Type of stem planting material	Green biomass production (t dry matter ha^{-1})			
	First cutting (8 months)	Second cutting (13 months)	Third cutting (18 months)	Total
Soft	2.2	3.4	2.3	7.9
Woody	3.4	4.7	4.5	12.6
SED	0.84	1.21	0.77	1.82

Values are the average for upright and angled placement of 40-cm-long stem cuttings into soil.
SED = Standard error of the difference in means; number of replicates = 3.
Source: King'ara (1998).

Table 2. The effect of fertilization on biomass production on a dry weight basis and nutrient content of sole stand of tithonia eight months after establishment from cuttings in western Kenya.

Treatment	Biomass (t dry matter ha^{-1})		Nutrients in leaf + litter ($kg\ ha^{-1}$)			Nutrients in stem ($kg\ ha^{-1}$)		
	Leaf + litter	Stem	N	P	K	N	P	K
No added P	1.0	7.4	32	3.2	33	55	4.6	80
50 kg P ha^{-1}	1.2	9.3	40	4.2	39	70	6.7	112
SED	0.05	0.95	2.1	0.19	3.0	15.6	1.31	16.0

Stem = green + woody stem material
SED = Standard error of the difference in means; number of replicates = 4.
Source: Bashir Jama et al., unpublished data.

stems (Ng'inja et al., 1998). Regrowth of tithonia nine months after cutting was 0.8 kg dry matter m^{-2} of which 0.11 kg m^{-2} was leaf biomass. Assuming that green tender stems plus leaves represent 25% of the total aboveground biomass as observed by King'ara (1998), then the tithonia biomass available after nine months for transfer to fields would be about 0.2 kg dry matter m^{-2} (2 t ha^{-1}). In a more recent survey in western Kenya, the biomass of green tender stems plus leaves of tithonia averaged 0.4 kg dry matter m^{-2} in hedges dominated by tithonia and not cut within the past year (Bashir Jama, ICRAF, unpublished data). The survey of Ng'inja et al. (1998) was conducted near the end of a prolonged dry period, which might account for the lower biomass than found in the more recent survey.

Drechsel and Reck (1998) reported that biannual pruning of tithonia hedges in Rwanda produced about 8 kg fresh biomass per m of hedge in a year. This corresponds to about 1 kg dry matter m^{-1} yr^{-1}. The production of tithonia green biomass could be lower if tithonia was mixed with other species in the hedges, which is the typical situation in western Kenya (Ng'inja et al., 1998; Lauriks et al., 1999).

Nutrient concentration of tithonia biomass

Green biomass of tithonia, as compared to green biomass of other shrubs and trees, is relatively high in nutrients. Average nutrient concentrations of green leaves of tithonia collected in East Africa were 3.5% N, 0.37% P and 4.1% K on a dry weight basis (Table 3). As shown in Table 3, the variability associated with these nutrient concentrations can be high. The N concentrations are comparable to those found in N_2-fixing leguminous shrubs and trees, whereas the P and K concentrations are higher than those typically found in shrubs and trees. The averages and corresponding range in concentrations reported in Table 3 for tithonia are generally within the ranges of 3.2 to 5.5% N, 0.2 to 0.5% P and 2.3 to 5.5% K reported by Nagarajah and Nizar (1982) for the analysis of 100 samples of tithonia leaves plus tender stems in Sri Lanka.

The concentration of nutrients in tithonia can conceivably be influenced by plant part, age of tithonia, position of the leaf within the plant canopy, soil fertility and provenance. The nutrient concentration tends to be lower in senesced than green leaves. For example, a comparison of senesced and green leaves collected from plants at ten locations in western Kenya revealed a mean N concentration of 1.1% for senesced leaves as compared to 3.2% for green leaves (Bashir Jama, unpublished data). Nutrient concentrations in litterfall and wood are relatively low compared to fresh leaves of tithonia. Nutrient concentrations of only 1.3% N, 0.08% P and 0.5% K, for example, were observed for undercomposed tithonia litter on the soil surface under a tithonia canopy in western Kenya. Stems (woody + green) harvested eight months after establishment of tithonia averaged 0.8% N, 0.07% P and 1.1% K. Although leaves (not including green tender stems) represent only about 15 to 17% of

Table 3. Nutrient conentration of green leaves of tithonia as compared to other shrubs and trees.

Species	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Mean	Range	Mean	Range	Mean	Range
Tithonia diversifolia	3.5	3.1–4.0	0.37	0.24–0.56	4.1	2.7–4.8
Calliandra calothyrsus	3.4	1.1–4.5	0.15	0.04–0.23	1.1	0.6–1.9
Crotalaria grahamiana	3.2	3.0–3.6	0.13	0.13–0.14	1.3	0.9–1.6
Lantana camara	2.8	2.3–4.0	0.25	0.18–0.30	2.1	1.8–2.4
Leucaena leucocephala	3.8	2.8–6.1	0.20	0.12–0.33	1.9	1.3–3.4
Sesbania sesban	3.7	1.4–4.8	0.23	0.11–0.43	1.7	1.1–2.5
Tephrosia vogelii	3.0	2.2–3.6	0.19	0.11–0.27	1.0	0.5–1.3

Source: Gachengo et al., unpublished data.

the total above-ground biomass of tithonia (Table 2), the leaves contain about 35 to 40% of the above-ground plant N and P and about 25 to 30% of the above-ground plant K.

The highest known P concentrations in tithonia were found in the green leaves of plants growing on the Sukula Hills phosphate deposit (0.70% P) and the Busumbu phosphate deposit (0.73% P) in eastern Uganda (Jeremiah Maroko, ICRAF, personal communication). The application of 50 kg P ha^{-1} to a P-deficient soil before establishment of tithonia from stem cuttings, however, had little effect on P concentration in leaves of eight-month-old tithonia in western Kenya. The P application only increased leaf P concentration from 0.34% to 0.36%. The application of P, however, increased total quantities of N and P in leaves (Table 2) as a result of increased biomass production.

Tithonia biomass is also high in nutrients other than N, P and K. Gachengo et al. (1999), for example, found 1.8% Ca and 0.4% Mg in green tithonia biomass. Soils under tithonia hedges tend to be higher in exchangeable Ca and Mg than soils in adjacent cropped land with no recent use of fertilizer and manure (Table 4). Exchangeable K and extractable inorganic P, on the other hand, do not tend to be significantly higher under tithonia hedges. High Ca and Mg in the soil under tithonia hedges could result from scavenging of these nutrients by tithonia from a large soil volume, accumulation of the nutrients in leaves and then cycling of the nutrients through leaf fall to soil under the hedges. Higher soil nutrients under tithonia hedges than in cropped fields can also arise from little historic cutting and removal of tithonia from hedges, whereas removal of crop biomass from fields can result in considerable exports of nutrients. Tithonia hedges might also trap nutrients in soil eroded from adjacent fields.

Table 4. Soil properties under existing mature hedges with tithonia and in adjacent agricultural fields with no recent use of fertilizer and manure in western Kenya.

Sampling location	pH (H_2O)[a]	Exchangeable cations ($cmol_c$ kg^{-1})[a]			Extractable P (mg kg^{-1})[a]
		Ca	Mg	K	
Under hedges	5.9	5.6	2.1	0.3	2.0
Cropped fields	5.6	3.9	1.3	0.2	1.3
SED	0.1	0.4	0.2	0.1	0.3

[a] pH was determined in a 1:2.5 soil/water suspension; exchangeable Ca and Mg were determined by extraction with 1M KCl; and exchangeable K and extractable P were determined by extraction with 0.5 M sodium bicarbonate + 0.01 M ethylenediaminetetraacetic acid (pH 8.5).
SED = Standard error of the difference in means; number of replicates = 9.
Source: Bashir Jama et al., unpublished data.

Tithonia biomass as a source of nutrients

Research in the mid 1990s in western Kenya generated awareness of tithonia biomass as a source of nutrients for crops (Gachengo, 1996; Niang et al., 1996). Gachengo (1996) demonstrated increased maize yield following incorporation of fresh tithonia biomass at the equivalent of 5 t dry matter ha^{-1} on a site deficient in N, P and K in western Kenya. Niang et al. (1996) found greater maize yield following incorporation of tithonia biomass than biomass of other common shrubs and trees in western Kenya.

One recognized advantage of tithonia is the ease of handling its biomass due to the absence of thorns, which makes tithonia more attractive to farmers than the thorny *Lantana camara* L. – another common species in hedges. Since 1996, the cutting and carrying of green tithonia biomass from hedges to nearby fields for use as a nutrient source in crop production has been examined in dozens of researcher-managed trials in western Kenya. In addition, the use of tithonia biomass has been tested by hundreds of farmers. On-farm research has demonstrated that soil fertility benefits are greater for green biomass than for dried biomass of tithonia (Otuma et al., 1998). The authors did not provide an explanation for this observation, but Mafongoya and Nair (1997) reported increased polyphenol content and reduced nutrient release following drying of plant biomass.

Green leaf biomass of tithonia decomposes rapidly after incorporation into soil. Gachengo et al. (1999) reported a half-life of about one week for the disappearance of dry matter in the rainy season in western Kenya. The corresponding half-lives for nutrient release were about one week for N and two weeks for P (Gachengo et al., 1999). The N concentration in tithonia leaves (Table 3) is higher than the critical level of 2.0 to 2.5% below which net immobilization of N would be expected (Palm et al., 1997). The P concentration is higher than the critical level of 0.25% for net P mineralization (Blair and Boland, 1978; Palm et al., 1997). Lignin (6.5%) and total extractable polyphenols concentrations (1.6%) in tithonia green biomass (Gachengo et al., 1999) are below levels that significantly reduce decomposition (Palm and Rowland, 1997). The high water content of green biomass might also enhance decomposition. The water content of 60 samples of green stems plus leaves collected from hedges in western Kenya during dry and wet seasons averaged 85% (± 5%) (Bashir Jama, unpublished data).

Source of nitrogen

The high N concentration and rapid decomposition of green tithonia biomass (Gachengo et al., 1999) make it an effective source of N for crops. The decomposition of tithonia leads to a rapid increase in soil inorganic N, as shown in Table 5. Higher soil inorganic N from tithonia than urea at two weeks after planting can be attributed to incorporation of all tithonia biomass at planting, whereas urea was split applied with only one-third (20 kg N ha^{-1}) added at planting.

Table 5. Effect of green tithonia biomass and urea on inorganic N (ammonium + nitrate) in the top 15-cm soil layer and maize grain yield on an acid soil in western Kenya.

Treatment	N rate (kg ha^{-1})	Inorganic N (kg ha^{-1}) at two weeks after planting	Maize grain yield (t ha^{-1})[b]
Control	0	13	3.0
Tithonia	60	33	4.8
Urea	60[a]	23	6.4
SED		4.0	1.0

All treatments received 100 kg P ha^{-1} and 100 kg K ha^{-1}, and P consequently did not limit maize. Inorganic N before planting was comparable in all treatments (25 kg N ha^{-1}).

[a] Split applied, 20 kg N ha^{-1} at planting and 40 kg N ha^{-1} at four weeks after planting.

SED = Standard error of the difference in means; number of replicates = 4.

[b] Yield is adjusted to a grain water content of 15.5%.

Source: Bashir Jama et al., unpublished data.

Quantification of the N contribution of tithonia to crop yield is confounded by the presence of the other nutrients in tithonia. When measuring the N contribution of tithonia, relative to commercial N fertilizer, it is essential to either (i) balance the application rates of all nutrients by adding mineral fertilizers with the N fertilizer to match the amounts of nutrients contained in tithonia or (ii) eliminate all other nutrient constraints by adding – with both the tithonia and N fertilizer – high rates of all potential limiting nutrients as mineral fertilizer. An examination of maize yields under N-limiting conditions, when P and K limitations were eliminated by large application of triple superphosphate and potassium chloride, confirms increased grain yields with application of tithonia.

The fast decomposition of tithonia leaf biomass might suggest a more rapid release of N than uptake of N by crops, leading to a low crop recovery of the N from tithonia. Gachengo et al. (1999), however, did not find this to be the case. They reported 25% recovery of added tithonia-N by the first maize crop and 79% recovery by three consecutive maize crops. These apparent N recoveries are higher than the 20% or less reported for most organic inputs (Giller and Cadisch, 1995). With application of P fertilizer (25 kg P ha^{-1}) to alleviate the P deficiency at the study site, the apparent recovery of tithonia-N increased to 46% by the first maize crop and 103% for three consecutive maize crops (Gachengo et al., 1999).

Source of phosphorus

Phosphorus release from soil incorporated green biomass of tithonia is rapid, and tithonia can supply plant-available P at least as effectively as an equivalent amount of P from soluble fertilizer. Nziguheba et al. (1998) reported that labile inorganic soil P, as determined by extraction with anion exchange resin, was higher at two weeks after incorporation of 15 kg P ha^{-1} as tithonia

(8.1 mg P kg^{-1}) than as triple superphosphate (3.6 mg P kg^{-1}) on an acid soil in western Kenya. The corresponding soil P level in the unfertilized control was 2.5 mg P kg^{-1}.

In another study, green biomass of tithonia (1.8 t dry matter ha^{-1}) was compared on a P-limited soil with mineral fertilizers (urea, triple superphosphate and potassium chloride) at equivalent rates of N (60 kg ha^{-1}), P (6 kg ha^{-1}) and K (60 kg ha^{-1}) for three seasons at two sites. At these application rates, maize was severely limited by P, not limited by K and possibly limited in some cases by N. Under these conditions, maize yield following tithonia application was consistently comparable to and sometimes slightly higher than yield following application of mineral fertilizer (Figure 1).

Another field study in western Kenya (ICRAF, 1998), compared green biomass of tithonia with mineral fertilizers (urea, triple superphosphate and potassium chloride) at three rates of N, P and K (Figure 2). The ratio of added N:P:K was 10:1:10 for the three application rates, which corresponded to tithonia rates of 0.9, 1.8 and 3.6 t dry matter ha^{-1}. Maize yield tended to be higher with tithonia than mineral fertilizer. At the intermediate rate, however, maize yields are unexpectedly low following tithonia application (Figure 2)

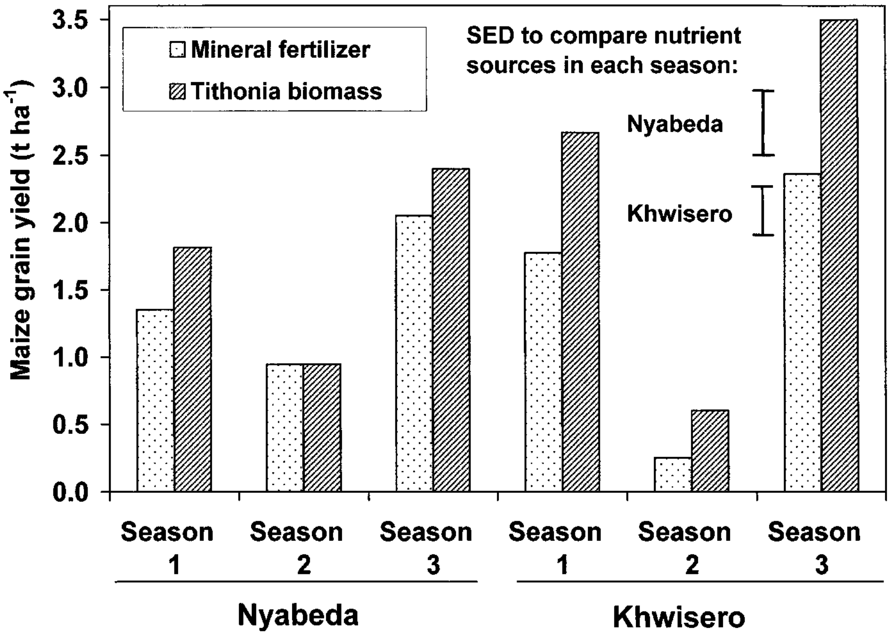

Figure 1. Effect of seasonal application of green biomass of tithonia and mineral fertilizers at equal rates of N (60 kg N ha^{-1}), P (6 kg P ha^{-1}) and K (60 kg K ha^{-1}) on maize grain yield for three seasons at two locations in western Kenya. Grain yields without added P were 0.8, 0.3 and 1.0 t ha^{-1} for the respective seasons at Nyabeda and 1.6, 0,2 and 1.4 t ha^{-1} for the respective seasons at Khwisero. SED = Standard error of the difference in means for nutrient sources; number of replicates at each location = 4. *Source:* Bashir Jama et al., unpublished data.

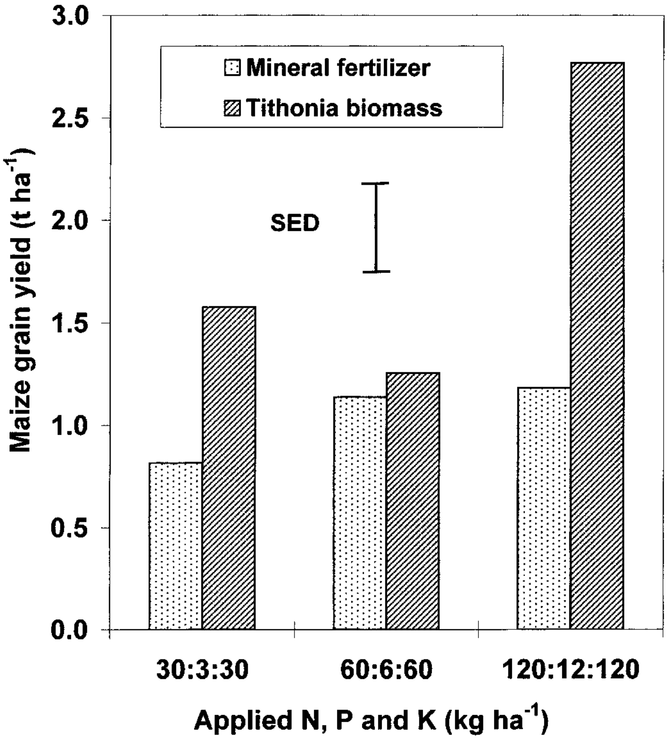

Figure 2. Effect of green biomass of tithonia and mineral fertilizers at equal rates of N, P and K on maize grain yield in the season of nutrient application at a site in western Kenya. Yield was 0.5 t ha^{-1} without added fertilizer and 0.7 t ha^{-1} with added N (100 kg N ha^{-1}) plus K (100 kg K ha^{-1}). SED = Standard error of the difference in means; number of replicates = 4.
Source: ICRAF (1998).

apparently because of a high incidence of striga (*Striga hermonthica* (Del.) Benth.) in several plots treated with tithonia (ICRAF, 1998). Mean grain yield for the three application rates was higher ($P < 0.09$) with tithonia than mineral fertilizer.

At the higher rate of nutrient application in Figure 2, the N and K rates (120 kg ha^{-1}) were sufficiently high to eliminate N and K deficiency, but the P rate (12 kg P ha^{-1}) did not eliminate P deficiency in maize. The higher maize yield with tithonia than mineral fertilizer, in this case when only P was limiting, suggests that P availability might be greater following application of tithonia than soluble P fertilizer (triple superphosphate) as was shown by Nziguheba et al. (1998). Higher maize yield with tithonia than only mineral NPK fertilizer could also result from the addition with tithonia of other nutrients, which are not included in the mineral fertilizer but could potentially influence maize growth after N, P and K deficiencies are eliminated.

Source of potassium

Green biomass of tithonia contains as much K as N. Tithonia biomass can effectively supply K and thereby overcome K deficiency and increase crop yield. In an experiment during the long rainy season in western Kenya, maize yield was markedly higher with tithonia biomass than urea applied at equivalent rates of 60 kg N ha^{-1} when averaged for four P fertilizer treatments in which maize was not limited by P (Table 6). Application of 60 kg K ha^{-1} as potassium chloride dramatically increased maize yield in the urea treatment (1.1 to 5.3 t ha^{-1}), thereby confirming that maize was limited by K at the site. The comparable maize yields with urea + 60 kg K ha^{-1} as potassium chloride (5.3 t ha^{-1}) and with tithonia (5.0 t ha^{-1}), which supplied about 60 kg K ha^{-1}, suggests that tithonia biomass was comparable in effectiveness with potassium chloride as a K source (ICRAF, 1998).

Integrated use of tithonia with mineral fertilizers

Green biomass of tithonia is undoubtedly a potential source of N, P and K for crops. The quantities of green biomass available from tithonia growing near to smallholder agricultural fields, however, will typically not be sufficient to supply all the nutrients required to eliminate nutrient deficiencies over large areas of the fields. The integration of tithonia biomass with mineral fertilizers is consequently essential to supply sufficient nutrients. The integration of tithonia and mineral fertilizers would have added advantages, as compared to sole use of mineral fertilizers, if tithonia enhanced the use efficiency of mineral fertilizers or provided non-nutritional benefits to crops.

Assuming mean concentrations of 3.5% N, 0.37% P and 4.1% K, green biomass of tithonia equivalent to 2 to 4 t dry matter ha^{-1} will likely supply sufficient N (70 to 140 kg N ha^{-1}) and K (80 to 165 kg K ha^{-1}) to crops. At

Table 6. Effect of potassium, as potassium chloride, on maize receiving either urea or green tithonia biomass in western Kenya. All values are the average of four phosphorus treatments.

N source	Maize grain yield (t ha^{-1})[a]	
	No K	60 kg K ha^{-1}
Urea	1.1	5.3
Tithonia	5.0	5.8
SED to compare K levels	0.35	
SED to compare N source	0.40	

SED = Standard error of the difference in means; number of replicates = 4.

[a] Yield is adjusted to a grain water content of 15.5%.

Source: ICRAF (1998).

rates below 2 t dry matter ha^{-1}, however, the integration of tithonia biomass with commercial N fertilizer or rotation of N_2-fixing legumes in the crop production areas will likely be required to eliminate N deficiency. Application of tithonia at 5 t dry matter ha^{-1}, which supplies about 18 kg P ha^{-1}, can overcome moderate P deficiency. However, it does not provide sufficient P to overcome severe P deficiency, such as on soils where crops response to well above 18 kg fertilizer P ha^{-1}. Consequently, P fertilizers must be integrated with tithonia to overcome P deficiencies on such soils.

Results in Table 7, for example, indicate low maize yields (1.1 and 1.3 t ha^{-1}) with application of only 6 kg P ha^{-1} as either tithonia or mineral fertilizer. Application of an additional 50 kg P ha^{-1} as soluble P fertilizer (triple superphosphate) dramatically increased yields with both tithonia and mineral fertilizers. Maize yield tended to be higher with tithonia + P fertilizer (4.2 t ha^{-1}) than with solely mineral fertilizers (3.6 t ha^{-1}), suggesting that integration of tithonia and P fertilizer might provide additional benefits than sole use of mineral fertilizers to maize production. These differences in yield, however, were not significant ($P = 0.05$). Significantly greater maize growth with tithonia + P fertilizer than with an equivalent rate of N, P and K as mineral fertilizers was observed in a pot study by Gachengo (1996).

In summary, results from western Kenya reveal that crop yield can be much greater with combined use of tithonia and P fertilizer than with solely NP mineral fertilizer when tithonia overcomes an additional nutrient constraint such as K (Table 6). The yield advantage with tithonia as compared to an equivalent amount of NPK mineral fertilizer can be large (Table 8 – 5 of Palm et al., 1997), but it is often small or inconsistent (Tables 5 and 7; Figures 1 and 2). In all reported studies, the differences in crop yield between tithonia

Table 7. Maize yield following application of equal rates of N, P and K as either green biomass of tithonia or as mineral fertilizers in western Kenya.

Treatment	Nutrient added (kg ha^{-1})			Maize grain yield (t ha^{-1})[a]
	N	P	K	
Control	0	0	0	0.5
Tithonia	60	6	56	1.3
NPK fertilizer	60	6	56	1.1
Tithonia + 50 kg P ha^{-1} as TSP	60	56	56	4.2
NPK fertilizer + 50 kg P ha^{-1} as TSP	60	56	56	3.6
SED				0.42

The rate of tithonia application was 1.8 t dry matter ha^{-1}.
TSP = Triple superphosphate.
SED = Standard error of the difference in means; number of replicates = 4.
[a] Yield is adjusted to a grain water content of 15.5%.
Source: Bashir Jama et al., unpublished data.

Table 8. Effects of 15 kg P ha^{-1} as green tithonia biomass or triple superphosphate (TSP) on increase in microbial biomass P and decrease in sorbed P at 0.2 mg P L^{-1} in solution.

Weeks after application	Increase in microbial P (mg P kg^{-1})			Reduction in sorbed P (mg P kg^{-1})		
	TSP	Tithonia	Tithonia + TSP[a]	TSP	Tithonia	Tithonia + TSP
2	1.8	4.3**	7.8**	19	40**	17
16	0	1.6	3.7**	–4	20*	9

[a] Tithonia and TSP were applied at a 1:1 ratio at a total P rate of 15 kg P ha^{-1}.
* and ** designate significance at $P = 0.05$ and 0.01, respectively. All values are relative to a control with no added TSP or tithonia.
Source: Nziguheba et al. (1998).

and mineral fertilizer are not due to differences in nutrient distribution in soil because the tithonia and mineral fertilizers were incorporated in a similar fashion into soil.

Processes by which tithonia increase nutrient availability

Nziguheba et al. (1998) reported that incorporation of green tithonia biomass equivalent to 5 t dry matter ha^{-1} to an acid soil in western Kenya increased P in soil microbial biomass and reduced P sorption by soil (Table 8). In this study, the plots were kept free of weeds and not cropped in order to eliminate plant uptake of P as a factor affecting soil P fractions and processes. Increased P in soil microbial biomass at two weeks after tithonia incorporation presumably indicates enhanced biological cycling and turnover of P in labile pools of soil P. Enhanced microbial biomass P following integration of tithonia with triple superphosphate, and not with sole application of triple superphosphate (Table 8), supports the hypothesis that tithonia increases labile pools of soil P. Soil microbial P before maize planting has been shown by Buresh and Tian (1997) to be directly correlated to maize yield on a P-deficient soil in western Kenya.

In an adjacent study with a lower rate of tithonia application (1.8 t dry matter ha^{-1}) and with maize cropping, Mutuo (2000) did not detect increased microbial P following application of tithonia. The difference in findings between Nziguheba et al. (1998) and Mutuo (2000) could be related to differences in rates of tithonia, but it nonetheless highlights the methodological challenges encountered in detecting subtle changes in soil P pools under field conditions with low levels of organic inputs.

The reduction in P sorption following application of tithonia (Table 8) presumably results from production of organic acids during tithonia decomposition, which temporarily bind to the oxides and the hydroxide surfaces of clay particles (Iyamuremye and Dick, 1996). Application of triple superphosphate fertilizer did not reduce P sorption, and the integration of tithonia with triple superphosphate (1:1 ratio) at the same level of total added P (15 kg ha^{-1}) had no effect on P sorption (Table 8).

Non-nutritional effects of tithonia on crop yields

Striga (*S. hermonthica*) – a parasitic weed – is a major pest of maize in western Kenya. An increase in available soil N is known to reduce the damage of striga to crops (Mumera and Below, 1993). Consequently, it has been hypothesized that tithonia biomass, because of its rapid decomposition and release of inorganic N, might also reduce the damage of striga to crops. The results to date in western Kenya, however, have not shown consistent trends for the effects of tithonia biomass on either striga populations in maize fields or the susceptibility of maize to yield loss from striga.

Gacheru et al. (1999) compared tithonia and urea at comparable N rates at three sites receiving potassium chloride to overcome K deficiency. At low levels of striga infestation (< 10 striga plants m^{-2}), maize yields were comparable for tithonia and urea. However, maize yields were greater with tithonia than urea at high levels of striga infestation (> 10 striga plants m^{-2}). These results suggest that tithonia provides a benefit to maize at high levels of striga infestation that is not obtained with a comparable level of N from urea. The results, however, were obtained under conditions of P limitation to maize growth and do not eliminate the possibility that interactive effects of N sources (tithonia versus urea) and striga infestation on maize yield were confounded by P effects on either maize growth or susceptibility of maize to striga.

Research to date from western Kenya has not found a reduction of plant-parasitic nematodes following application of green tithonia biomass. Tithonia biomass, however, does increase the population of saprophytic nematodes, which might lead to increased decomposition and nutrient turnover (Johan Desaeger, ICRAF, personal communication).

Recommendations for tithonia use

Buresh and Niang (1997) cautioned that the transfer of tithonia biomass was not a universally appropriate intervention for soil fertility improvement in western Kenya. They concluded that its potential was greatest on small landholdings with nearby production of tithonia biomass and with ample, low-cost labor for cutting and carrying the biomass. The availability of labor and its cost relative to the value of crops are important considerations because the cutting and carrying of tithonia biomass are labor intensive. The importance of labor is further amplified by the bulkiness of green tithonia biomass due to its high water content and the need to cut and carry it during a period of peak labor demand for land preparation and planting.

Table 9. Economic analysis for application to tithonia biomass to maize and kale (*Brassica oleracea*) under farmer-management conditions in western Kenya.

Crop	Number of farmers	Mean tithonia application rate (t fresh weight ha^{-1})	Labor cost for application (US$ ha^{-1})	Mean increase in net revenue (US$ ha^{-1})
Maize	62	19	257	–153
Kale	23	14	180	708

Source: Adapted from ICRAF (1997).

The use of tithonia biomass is economically more attractive with high- than low-valued crops (Table 9). Tithonia biomass was not profitable for low-valued maize at the rates of application used by farmers in this study. On the other hand, tithonia biomass was very profitable with kale (*Brassica oleracea* cv *acephala*) – a high-valued green vegetable. Application of tithonia biomass to maize, however, can be profitable in western Kenya, particularly at relatively low rates of tithonia application (Jama et al., 1999). Tithonia biomass will likely be more attractive at sites with both N and K deficiencies rather than only N deficiency because tithonia effectively supplies K, which is frequently not present in the fertilizers available in local markets.

Farmers adopting the use of tithonia in western Kenya diversify crops in plots receiving tithonia biomass and grow maize after vegetables receiving tithonia biomass (Niang, unpublished). Maize grown in rotation with vegetables receiving tithonia might benefit from residual effects of the tithonia biomass. Residual benefits are possible at least for high rates of tithonia application. Gachengo et al. (1999), for example, observed increased yield for two subsequent maize crops following a maize crop receiving tithonia biomass at 5 t dry matter ha^{-1} on an N, P and K deficient site. The nutrient(s) and factors responsible for this residual benefit to maize were not ascertained.

Constraints to use of tithonia

Little awareness by farmers

Limited awareness of the potential of tithonia as a nutrient source is evident even in areas such as western Kenya where it has been present for a long time. On-farm surveys in western Kenya indicate that farmers more often use tithonia biomass through composting than direct application to fields (Ng’inja et al., 1998). This suggests the need for more awareness on the merit of directly applying tithonia to soil for soil fertility improvement.

Labor

Considerable labor is required for cutting and transporting biomass to fields, especially if the tithonia is far from the homestead. Even though tithonia biomass is relatively easy to handle because it does not have thorns, the handling can be unpleasant because it is sticky and exudes a pungent smell (Jiri and Waddington, 1998).

Availability

The wide-scale use of tithonia biomass will likely be constrained by its supply. Land holdings in western Kenya are becoming smaller due to increasing human population and concomitant land fragmentation. Land fragmentation can increase field boundaries and contours for planting tithonia hedges. The farm and homestead boundaries can, however, have competing uses for crops and trees that are considered by farmers to be of higher value than tithonia. This has already occurred in the central highlands of Kenya where niches once occupied by tithonia are now planted to napier grass (*Pennisetum purpureum* Schumach.) for fodder for dairy cattle (Eva Gacheru, personal communication). Assuming a landholding of one hectare surrounded by a tithonia hedge with an annual production of tender twigs and leaves equivalent to 1 kg dry matter m^{-1} length of hedge, the total biomass produced for transfer to cropped area would be 0.4 t dry matter ha^{-1} yr^{-1}. As landholdings decrease in size, the biomass production from perimeter hedges would increase on a surface area basis. For example, hedges surrounding a 0.25 ha landholding would produce 0.2 t dry matter yr^{-1}, which could cover the entire 0.25 ha area at a rate of 0.8 t matter ha^{-1} yr^{-1}. This rate of tithonia biomass application would supply about 28 kg N ha^{-1} yr^{-1} and 3 kg P ha^{-1} yr^{-1}, which would be insufficient to meet the nutrient requirement for crops. Farmers in western Kenya, however, tend to concentrate organic inputs, such as farmyard manure and tithonia biomass, in selected portions of their cropped land area rather than distribute the limited organic resource at a small rate throughout the entire cropped area.

The production of tithonia biomass even in small landholding with internal and external boundaries for tithonia hedges will not be sufficient to meet the nutrient requirements for crop production on all the remaining area of the landholding. The production of tithonia biomass, however, can be sufficient to meet the nutrient requirements for crop production in relatively small plots within the landholding. Tithonia biomass can, therefore, be particularly well suited for high-valued crops that generate income, which can then be used to purchase fertilizers for use with crops. In such a case, tithonia biomass transfer could ‘jump start’ income generation for resource-poor farmers and serve as a ‘stop-gap measure’ until the farmers have sufficient income to purchase fertilizers.

Nutrient mining by tithonia

Tithonia is not a legume, and it does not biologically fix atmospheric N_2. Tithonia obtains its N and other nutrients through effective retrieval of nutrients from the soil. The transfer of tithonia biomass to fields, therefore, constitutes the cycling of nutrients within the farm and landscape rather than a net input of nutrients to the system. The continual transfer of nutrients from tithonia hedges to crop fields might not be sustainable for long periods. The application of fertilizer to tithonia hedges could ensure sustained production of tithonia, but this is unlikely to be an option for resource-poor farmers.

Potential to become a pest
Tithonia is a prolific seeder, which can colonize farmlands. If uncontrolled, it might become a weed in crop fields and thereby increase labor for weeding.

Remaining issues

The trade-off between use of field and homestead boundaries and other uncultivated areas for production of a nutrient source (i.e., tithonia biomass) versus production of fodder or generation of income (e.g., trees for valuable timber and non-timber products) must be considered. The challenge is to compatibly integrate tithonia into production systems with crops, high-valued trees and livestock.

In some cases, the combined use of organic materials with mineral fertilizers can result in greater plant recovery of added nutrients than with sole use of mineral fertilizers (Palm et al., 1997). Research is needed to document the occurrence and understand the processes for enhanced nutrient availability and crop production with integrated use of tithonia and mineral fertilizers as compared to sole use of mineral fertilizers. This research should consider not only the effects of integrated nutrient use on nutrient availability and plant-use efficiency of added nutrients but also consider effects on non-nutritional yield constraints, such as pests and diseases. A predictive understanding of the processes by which tithonia increases crop yield is essential in order to manage and target the use of tithonia biomass for optimal benefits in crop production.

High labor requirements for cutting and transferring tithonia biomass further necessitate the optimal management of relatively small quantities of tithonia. Past research frequently employed relatively high tithonia rates ($\geq$ 5 t dry mater ha^{-1}). Future research should focus on rate that can realistically be achieved with the labor and quantities of tithonia available in smallholder agriculture – for example, rates in the range of 1 to 2 t ha^{-1} yr^{-1} in western Kenya. Information is needed on the minimum rate of tithonia required to increase nutrient availability through such processes as enhanced soil biological activity, reduced P sorption, better synchronization of nutrient supply and increased plant-use efficiency of nutrients from soil and mineral fertilizers. The minimum quantities of tithonia required for non-nutritional benefits, such as reduced detrimental effects of striga, should also be determined.

Optimal management of tithonia, as constrained by labor and supply of green biomass, requires an understanding of the trade-offs in the economics associated with (i) use of tithonia biomass on staple crops versus higher-valued crops and (ii) distribution of biomass at a low rate over an entire field versus concentration of the biomass in only a section of the field. Tithonia biomass, in most researcher-managed trials in western Kenya, was broadcast and incorporated immediately before planting. Farmers in western Kenya are already experimenting with split and spot applications of tithonia biomass. Split application might be an option to shift cutting and carrying of biomass away from peak periods of labor demand, and spot application in the planting hole might be an option to reduce the required quantities of biomass. Application of tithonia biomass on the soil surface as a mulch without incorporation might also be option to reduce labor. Additionally, given the high labor demand for the direct use of tithonia at times of peak labor demand for other operations, composting and the use of tithonia in compost pits merit investigation as a means to spread labor requirements.

The high concentrations of nutrients in tithonia leaves together with the relatively rapid growth of tithonia has raised scientific interest in the mechanisms by which a non-N_2-fixing plant acquires such large quantities of nutrients in relatively infertile soils. Little is known about the rooting, mycorrhizal infection and rhizosphere processes of tithonia. An understanding of the processes of nutrient acquisition would be valuable in assessing the magnitude of variation in nutrient uptake and tissue concentrations among tithonia provenances, identifying other plant species for effective nutrient acquisition on infertile soils and developing management practices to enhance retrieval and cycling of soil nutrients in agroforestry systems. An understanding of nutrient acquisition by tithonia and redistribution of nutrients within the landscape through transfer of tithonia biomass would also help to assess the sustainability of the tithonia biomass production. Long-term studies or farm nutrient budgets may also help determine the sustainability of tithonia-use systems.

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