Recent Advances in the Use of *Tithonia diversifolia* Green Manure for Soil Fertility Management in Africa: A Review

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**ABSTRACT**

Tithonia biomass transfer was presented as a technology that would replenish infertile soils, enhance food security and eradicate poverty in Africa in the 1990s. Since then, a huge volume of research has been conducted and the agronomic effectiveness of tithonia unequivocally demonstrated. Its reported effects on soil properties have however been inconsistent. This has made it difficult to develop a predictive understanding of the effects of tithonia on soil properties. Socio-economically, tithonia failed to live up to the hype on its ability to increase the farmers' incomes. Adoption rates have been dismal mainly because of high labor costs associated with its use. Two decades later, poverty and food insecurity are still widespread in Africa despite the enormous research and extension efforts that were devoted to popularizing the technology.

**Key words:** Adoption, Socioeconomics, Soil, Tithonia research.

In the 1990’s, soil fertility depletion was identified as the fundamental root cause of declining food production in Africa. It was postulated that irrespective of how effectively other constraints were remedied, food production would continue spiraling downward unless soil infertility was conclusively addressed (Sanchez and Leakey, 1997). At that time, fertilizer prices had escalated because of reduced government subsidies. The situation was exacerbated by lack of credit and delays in delivery of fertilizer due to poor transport and marketing infrastructure (Place et al., 2003) resulting in low fertilizer use. This renewed interest in the use of what were considered to be cheap locally available nutrient sources to replenish soil fertility (Kwesiga and Coe 1994). A variety of none traditional organic resources such as *Lantana camara*, *Calliandra calothyrsus*, *Leucaena leucocephala* and *Tithonia diversifolia* (tithonia), were subsequently tested in western Kenya and tithonia identified as the most promising (Gachengo, 1996). Tithonia leaves have a high concentration of N, P and K (Jama et al., 2000) and it was therefore touted as the panacea of the soil fertility problems and hence poverty in Africa.

Tithonia is an annual weed that originated from Mexico and is now found along major roads, paths and on abandoned farmlands in many parts Africa (Agbede et al., 2013). The abundance and adaptation of tithonia to various environments coupled with its rapid growth rate and very high vegetative matter turnover makes it ideal for soil rejuvenation (Olabode et al. 2007). It has been used as mulch, biomass transfer and improved fallows in soil fertility management. The biomass transfer system which involves growing tithonia along boundaries and contours of farms or collection of the same from off-farm niches such as roadsides and applying the leaves and tender stems on the fields mostly during planting (Place et al., 2002) has however received the most research attention.

Initial studies on tithonia biomass for soil fertility manage-
Recent Advances in the Use of *Tithonia diversifolia* Green Manure for Soil Fertility Management in Africa: A Review

and the soil porosity. It has, therefore, often been determined in several tithonia studies. Results are however inconsistent. Some show no effect while others report significant reductions in bd due to tithonia use. For example, in Kenya, bd was not significantly affected by application of tithonia at 1.8 t ha\(^{-1}\) (Waswa et al., 2004) while in southwestern Nigeria, tithonia mulches reduced bd compared to unmulched plots (Agbede et al., 2014) but this reduction was only significant at higher (>10 t ha\(^{-1}\)) and not lower (<7.5 t ha\(^{-1}\)) rates of application. Kolawole et al. (2014) similarly reported a reduction by about 3% on soils treated with 20 t ha\(^{-1}\) of tithonia compared with the untreated soils but at lower rates (<15 t ha\(^{-1}\)), there was no significant reduction. Hafifah et al. (2016), however, observed reduction in bd at a rate of 8.15 t ha\(^{-1}\), a rate that would be considered low by Kolawole et al. (2014) (Table 1). The reduction in soil bd was attributed to increased soil organic matter (SOM) due to decomposition of tithonia by soil microorganisms (Adesodun et al., 2015). It is likely that at lower rates, insufficient SOM was generated to effect a reduction in bulk density.

**Soil temperature and moisture**

The effect of tithonia on soil temperature and moisture has been found to depend on its rate of application. Tithonia reduced soil temperature when applied at a rate of 20 t ha\(^{-1}\) but not at rates lower than 15 t ha\(^{-1}\) (Kolawole et al., 2014). Similar results were reported by Agbede et al. (2013). Reduction in temperature was often accompanied by increased moisture retention due to reduced evaporation. In southwest Nigeria, application of 7.5 t ha\(^{-1}\) tithonia significantly increased soil moisture content and reduced temperature irrespective of the tillage method (Agbede and Ogunde, 2015). Other studies have likewise reported increased moisture holding capacity especially at high rates of application (Atayese and Liasu, 2001; Agbede et al., 2014; Hafifah et al., 2016) (Table 1). This again is likely due to an increase in SOM which is colloidal and also buffers the soil against rapid changes in temperature.

**Soil Structure**

Soil structure influences multiple dimensions of soil such as infiltration, drainage and water holding capacity. Tithonia increased structural stability of highly erodible loamy sand compared to inorganic fertilizers but was less effective than poultry manure and composts (Adesodun et al., 2015). Hafifah et al. (2016) reported a similar improvement in soil structure by tithonia and cow manure (Table 1). An improvement in aggregate stability of Inceptisols, due to tithonia application, was attributed to an increase in SOM which acted as a cementing factor for soil particles (Guong, et al., 2010). In addition, the mulch stabilized the soil structure against raindrop impact and thereby prevented erosion, compaction and crusting of the soil (Agbede et al., 2014).

**Effect of tithonia on selected soil chemical properties**

**Soil pH, exchangeable acidity and aluminum**

In acidic soils, which are widespread in Africa, aluminum toxicity constrains crop production. The effects of tithonia on soil pH, exchangeable acidity and aluminum have therefore been extensively studied but results are contradictory. Soil pH has been reported to vary depending on rates of tithonia applied, soil type and time of sampling the soil after tithonia application. An increase in pH due to application of tithonia in both pot and field experiments have been reported by several authors. In an incubation study, Opala et al. (2012a) found that soil pH increased at 4 weeks after application of 33 t ha\(^{-1}\) of tithonia but the pH declined by the 9th week. Similar results were reported by Cong and Merckx (2005) with application of 88 t ha\(^{-1}\). These rates are however extremely high and cannot be applied under normal farming conditions. Some of the field studies that have demonstrated an increase in pH with tithonia application are those of Ikerra et al. (2006) at rates of 2.5 to 7.5 t ha\(^{-1}\) in Tanzania, Shokalu et al. (2010) at 20 t ha\(^{-1}\) and Awopegba et al. (2017) at 5 t ha\(^{-1}\) in Nigeria. In addition to microbial decomposition that releases base cations, the rise in soil pH when undecomposed plant residues such as tithonia are applied to soils has been attributed to decarboxylation of organic anions which results in the consumption of protons (Tang et al., 1999).

In other studies, the pH of tithonia amended soils was not significantly changed (Chukwuka and Omotayo 2009; Waswa et al., 2014) but this reduction was only significant at higher (>10 t ha\(^{-1}\)) and not lower (<7.5 t ha\(^{-1}\)) rates of application. Agbede et al. (2014) (Table 1). This again is likely due to an increase in SOM which is colloidal and also buffers the soil against rapid changes in temperature.

**Table 1:** Effect of *T. diversifolia* green manure, cow manure and NPK on soil physical properties.

| Treatments                        | Bulk Density (g/cm\(^3\)) | Total Porosity (%) | Aggregate Stability (%) | WHC (%) |
|-----------------------------------|---------------------------|--------------------|-------------------------|---------|
| Control                           | 1.27c                     | 45.38a             | 69.12b                  | 37.85a  |
| *T. diversifolia* (8.15 t ha\(^{-1}\)) | 0.94a                     | 52.40cb            | 74.21d                  | 39.80e  |
| Cow manure (25.85 t ha\(^{-1}\))  | 1.06b                     | 52.88d             | 69.68c                  | 39.58d  |
| NPK (1.35 t ha\(^{-1}\))         | 1.28c                     | 45.31a             | 60.00a                  | 38.16b  |
| *T. diversifolia* + Cow manure    | 1.04b                     | 50.82bc            | 78.80f                  | 38.70c  |
| *T. diversifolia* + NPK           | 1.00ab                    | 51.88cd            | 75.35e                  | 41.25f  |
| Cow manure + NPK                  | 1.05b                     | 49.91b             | 84.10g                  | 42.13g  |
| *T. diversifolia* + Cow manure + NPK | 1.04b                  | 51.00bc            | 85.40h                  | 41.25f  |
| LSD 5%                            | 0.06                      | 1.71               | 0.09                    | 0.24    |

Variables followed by similar letters in the same column indicate not significant in LSD 5% test. 
Source: Hafifah et al. (2016).
Jorge-Mustonen et al., 2013). This was attributed to the short-term nature of the studies, low rates of tithonia used and nitrification with release of H+ ions. However, Mucheru-Muna et al. (2014) observed a decline in soil pH in most of the tithonia treatments in Kenya after 13 cropping seasons. The pH decline is likely due to nitrification and release of H+ as tithonia decomposes (Cong and Merckx, 2005).

An increase in soil pH was associated with decrease in exchangeable acidity and aluminum with tithonia application (Mukuralinda et al., 2011) because Al is precipitated at high pH as Al(OH)₃. Thus, tithonia applied at rates of 2.5, 5.0 and 7.5 t ha⁻¹ significantly reduced exchangeable Al in field and incubation studies (Cong and Merckx, 2005; Opala et al., 2012a). In northern Zambia, Malama (2001) reported a decrease in exchangeable acidity and aluminum with application of 4.5 t ha⁻¹ tithonia. However, in some cases, there was a reduction in exchangeable acidity and aluminum even when tithonia failed to increase pH because of tithonia’s ability to chelate aluminum (Opala et al., 2012a).

### Available phosphorus and phosphorus sorption

The ability of tithonia to reduce P sorption and increase its availability in soils attracted much interest because the preliminary studies were conducted in western Kenya where P deficiencies and high P sorption capacities are widespread. Tithonia reduced P sorption especially when applied at high rates (> 5 t ha⁻¹) (Nziguheba et al., 2002a; Ikerra et al., 2006; Opala et al., 2010) but failed to do so in others at low rates (< 2 t ha⁻¹) (Opala et al., 2007). The reduction in P sorption was attributed to a variety of mechanisms. These include; production of organic acids produced during the decomposition of tithonia which chelate with Al and Fe in the soil solution, thus preventing precipitation of the phosphate; the organic anions produced during the decomposition of tithonia may compete with P for the same adsorption sites and thereby increase P-availability in the soil and increase in pH which increases the negative charge on the soil thus repulsing the negatively charged orthophosphate ions (Iyamuremye and Dick, 1996; Nziguheba et al., 1998; Guppy et al., 2005). Available soil P also increased because it was released when tithonia mineralized (Partey, et al., 2010). In some studies, tithonia was as effective as inorganic phosphate fertilizer in increasing P availability (Opala et al., 2007). Tithonia however has a low P content and therefore it cannot be used as a P source for crops on a field scale. For example, in a study by Opala (2010), the amount of tithonia applied to supply 60 kg P ha⁻¹ was 20 t. This amount of tithonia, would in addition supply about 600 kg N ha⁻¹, which is far in excess of the 70 kg N ha⁻¹ that is recommended for maize in western Kenya. Focus thus shifted to using tithonia as an N source and supplementing it with inorganic P sources such as triple superphosphate and phosphate rock (PR).

With an aim of promoting the use of cheap locally available resources, the ability of tithonia to increase solubility of PR was investigated. It was initially hypothesized that during decomposition, tithonia produces organic acids that solubilize PR and therefore increase P availability (Jama and van Straaten, 2006). Later doubts were cast as to whether this was plausible because tithonia had been reported to increase soil pH in some studies and also had high calcium content which is negatively correlated with PR dissolution. Savini et al. (2006) confirmed that combining PRs with tithonia indeed depressed the dissolution of PRs and hence P availability.

### Soil organic matter

Soil organic matter is central to the sustainability of soil fertility on smallholder farms in Africa and therefore the influence of tithonia on SOM is of great interest. Increases in organic C, which is a measure of SOM, have been reported by several workers (Waswa et al., 2007; Olubukola et al., 2010). Others have however observed a decline (Mucheru-Muna et al., 2014) or no significant effect (Opala et al., 2010) on SOM when tithonia was applied to soil. There was no clear effect of rate of tithonia application on SOM. Most of the studies that showed an increase in SOM used high rates (> 5 t ha⁻¹). The ability of an organic material to provide nutrients for crops and its ability to simultaneously increase the SOM are generally negatively correlated. High quality organic materials, e.g. tithonia, which are good for short-term soil fertility, because tithonia decomposes quickly, may therefore not necessarily maintain or build SOM (Delve and Ramisch, 2006) unless applied at unrealistically high rates.

### Nutrient composition of tithonia

The reported nutrient content of tithonia is highly variable. High nutrients contents of 3.5 - 4.0% N, 0.35 - 0.38% P, 3.5 - 4.1% K, 0.59% Ca and 0.27% Mg have been reported (Jama et al., 2000). The high nutrient content in tithonia is credited to its ability to scavenge for nutrients in the soil due its proteoid root system. However, other studies such as Mucheru-Muna et al. (2007) reported much lower levels of N and P and suggest that there are other agroforestry species that have similar or higher levels of the major nutrients than tithonia (Table 2). Tithonia, just like other organic materials also contains substantial amounts of micronutrients (Reis et al., 2018) and is hence regarded as a complete fertilizer.

| Treatment          | N (%) | P (%) | Ca (%) | Mg (%) | K (%) | Ash (%) |
|--------------------|-------|-------|--------|--------|-------|---------|
| Cattle manure      | 1.4d  | 0.2a  | 1.0c   | 0.4b   | 1.8b  | 46.1a   |
| Tithonia           | 3.0c  | 0.2a  | 2.2a   | 0.6a   | 2.9a  | 13.2b   |
| Calliandra         | 3.3b  | 0.2a  | 0.9d   | 0.4b   | 1.1c  | 5.8 d   |
| Leucacena          | 3.8a  | 0.2a  | 1.4b   | 0.4b   | 1.8b  | 8.7c    |

Means with same letter in each column, are not statistically different at p< 0.05. Source: (Mucheru-Muna et al., 2007).
Recent Advances in the Use of *Tithonia diversifolia* Green Manure for Soil Fertility Management in Africa: A Review

| Table 3: Effect of tithonia when applied alone or combined with MPR or TSP on maize yields. |
|-----------------------------------------------|
| Treatments | 2001 | 2002 |
| Control (-P) | 1.34f | 0.87e |
| Tithonia 2.5 t ha\(^{-1}\) (T2) | 2.10bcede | 1.5 d |
| Tithonia 5 t ha\(^{-1}\) (T5) | 2.33abc | 1.69cd |
| Tithonia 7.5 t ha\(^{-1}\) (T7) | 2.29abacd | 2.06bcd |
| MPR (P 80) | 1.87e | 2.21abc |
| TSP (P 80) | 2.50a | 1.81cd |
| MPR (P 40) + T2 | 2.36ab | 2.30abc |
| MPR (P 40) + T5 | 2.34abc | 2.31abc |
| MPR (P 40) + T7 | 2.36ab | 2.7a |
| TSP (P 40) + T2 | 2.07cde | 2.50a |
| TSP (P 40) + T5 | 2.29abcd | 2.7 a |
| TSP (P 40) + T7 | 2.48a | 2.84a |
| CV (%) | 7.62 | 15.69 |

Means followed by the same letter in the same column are not significantly different *P* < 0.05 according to DMRT; MGY= Maize grain yield. MPR= Minjingu phosphate rock, TSP= Triple superphosphate. Source: Ikerra et al. (2006).

Response of crops to tithonia biomass

Initial studies on tithonia’s ability to increase yields focused on maize, which is the staple food in most of sub-Saharan Africa. Tithonia was shown to be as effective as or better than inorganic fertilizers in Kenya (Kometu et al., 2004; Opala et al., 2015), Zambia (Malama, 2001), Cameroon (Kaho et al., 2011) and Malawi (Ganunga et al., 2005). Table 3 shows typical results from Tanzania (Ikerra et al., 2006). Responses depended on the site and season. Later it was recommended that tithonia be tried on high value crops to increase financial returns and other crops were therefore studied. Tithonia induced higher yields of soybean and common beans than fertilizers in DR Congo (Emery et al., 2013) and Nigeria (Jorge-Mustonen et al., 2013) respectively. Tithonia also increased yields of vegetables such as Celosia in Nigeria (Babajide et al., 2012), rape in Zimbabwe (Chikuvire et al., 2013) and Kales in Kenya (Mwangi and Mathenge 2014). Yields of tomatoes increased by 130% with application of tithonia compared to the control with no nutrient inputs in Cameroon (Ngosong et al., 2015).

In Nigeria, the yield of okra was significantly higher in soil under tithonia fallow than under spear grass (Agbede et al., 2014). Tithonia also improved carrot yield and quality in Kenya (Jeptoo et al., 2013) and Nigeria (Agbede et al., 2017). The sweetness of watermelon was also enhanced under high levels of tithonia application (Aguyoh et al., 2004). Cassava (Kolawole et al., 2014) and yam (Agbede et al., 2014) yields in southwest Nigeria, sesame (Babajide et al., 2012) and pepper (Atta, 2011) have also been tested and found to positively respond to tithonia application.

The studies reviewed herein unequivocally demonstrated the agronomic effectiveness of tithonia. The better performance of tithonia compared to inorganic fertilizers was more pronounced in acid soils with high aluminum content compared to soils low in aluminum (Opala et al., 2012b). This was attributed to tithonia’s ability to chelate Al and hence reduce aluminum toxicity (Opala et al., 2010). Tithonia’s effectiveness was also related to its ability to reduce P sorption and increase P availability, provide a wide range of macro and micronutrients, improve soil structure and moisture conservation compared to inorganic fertilizers (Ikerra et al., 2006; Nziguheba et al., 2002; Adesodun et al., 2015).

Economics of tithonia use

The good agronomic performance of tithonia precipitated its rushed presentation to farmers although it had not been evaluated economically. Later, several studies combined agronomic evaluation with economic analysis. Nziguheba et al. (2002b) found greater financial returns when tithonia was applied alone than when fertilizers were used, or with tithonia integrated with fertilizers on maize in western Kenya. Conversely, others (Micheni et al., 2002; Mucheru-Muna et al., 2007) reported higher benefits when tithonia was integrated with fertilizers than when applied alone on maize in Central Kenya. The benefit-cost ratios (BCRs) for tithonia in the Mucheru-Muna et al. (2007) study were higher than the critical value of 2 (Table 4) which is the minimum required for adoption of a technology by farmers. There were however other treatments e.g. leucaena, calliandra and cattle manure in the same study which had higher BCRs and hence a better potential for adoption than tithonia. Micheni et al. (2002) ranked tithonia, when applied alone, above cattle manure in profitability but both were lower than inorganic fertilizers.

High labour costs and tithonia’s unavailability in sufficient quantities when needed were however a major constraint in the utilization of tithonia biomass. Opala et al. (2010) observed that labor costs of tithonia accounted for 100% of the total costs in maize production in western Kenya when tithonia was applied alone and ranged from 69 to 87% of the total added costs when it was combined with inorganic fertilizers.

Table 4: Net benefit, benefit-cost ratio (BCR) and return to labor from 2000 to 2003 in Chuka, Meru South District, Kenya.

| Treatment | Net benefit | BCR | Return to labor |
|-----------|-------------|-----|----------------|
| Cattle manure | 645b | 5.0bc | 5.0bc |
| Cattle manure+30 kg N ha\(^{-1}\) | 616b | 3.5c | 6.8bc |
| Tithonia | 784a | 4.0bc | 4.0d |
| Calliandra | 653b | 5.8ab | 5.9cd |
| Leucaena | 780a | 7.0a | 7.0bc |
| Tithonia+30 kg N ha\(^{-1}\) | 787a | 3.5c | 6.3cd |
| Calliandra+30 kg N ha\(^{-1}\) | 747a | 4.4bc | 9.0b |
| Leucaena+30 kg N ha\(^{-1}\) | 572b | 4.3bc | 6.9bc |
| 60 kg N ha\(^{-1}\) | 666b | 3. c | 12.5a |
| Control | 272c | 5.2abc | 5.2cd |

Means with same letter in each column are not statistically different at *p* < 0.05. Source: Mucheru-Muna et al. (2007).
Among the earliest studies on adoption of tithonia technology was that by Makokha et al. (1999) who reported that only 52% of the farmers were using it in western Kenya. It was assumed that since these were initial years of the technology, the numbers would rise with time. However, this was not to be. For example, none of the farmers chose to test tithonia in western Kenya after focus group discussions but they experimented and rejected the technology claimed they did not notice any improvement in crop yields after using tithonia. This was however attributed to the fact that some farmers applied very small quantities of tithonia such as 1 t ha\(^{-1}\) instead of the recommended rate of 5 t ha\(^{-1}\) which in essence led to no noticeable effect on crop yield (Makokha et al. 1999).

**Adoption of tithonia for soil fertility management**

Among the earliest studies on adoption of tithonia technology was that by Makokha et al. (1999) who reported that only 52% of the farmers were using it in western Kenya. It was assumed that since these were initial years of the technology, the numbers would rise with time. However, this was not to be. For example, none of the farmers chose to test tithonia in western Kenya after focus group discussions but they instead chose farmyard manure integrated with fertilizers (Odendo et al., 2004). In an earlier study in the same region, Odendo et al. (2004) reported that except for those hosting the experiments, most farmers were unable to conceptualize how the tithonia biomass technology worked. In a similar study, Place et al. (2005) observed inside ICRAFS pilot villages, there was a rapid surge of users between 1997 and 1999, where the user rates reached about one quarter of households. There was then a significant decline in use in 2000. The explanation given for these trends was that considerable technical support along with the bandwagon effect may have led to early high rates of testing. This was followed by discontinuity by those who did not receive sufficient benefits or were unable to manage the technology due to ICRAF and partners reduced backstopping efforts. Interestingly, Kiptot (2008) found that most farmers who experimented and rejected the technology claimed they did not notice any improvement in crop yields after using tithonia. This was however attributed to the fact that some farmers applied very small quantities of tithonia such as 1 t ha\(^{-1}\) instead of the recommended rate of 5 t ha\(^{-1}\) which in essence led to no noticeable effect on crop yield (Makokha et al. 1999).

**Conclusion**

Two decades after tithonia was presented as a technology that would enhance food security and eradicate poverty in Africa, the situation has not changed despite enormous research and extension efforts to popularize the technology. A lot of useful biophysical information has been obtained from the research and its agronomic effectiveness repeatedly demonstrated. It is clear however that most of the perceived benefits associated with tithonia were in fact related to its being an organic material and therefore it was not unique as hyped by its earlier advocates. In several instances, some of the other organic materials and even fertilizers had better effects on soil properties, yields and economic returns than tithonia but these findings were often not given prominence. Instead tithonia was hastily presented to farmers before a thorough socioeconomic evaluation. The outcome was spectacular failure to adopt it by farmers because of high labor costs and negative financial benefits. Future research should therefore focus on integrated use of all available sources of nutrients on the farm in an environmentally and socioeconomically sustainable manner while involving farmers at all stages to ensure that only acceptable technologies are upscaled.

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