

Research Article

Amendment of Tephrosia Improved Fallows with Inorganic Fertilizers Improves Soil Chemical Properties, N Uptake, and Maize Yield in Malawi

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Abstract

Maize production in Malawi is limited mainly by low soil N and P. Improved fallows of N-fixing legumes such as *Tephrosia* and *Sesbania* offer options for improving soil fertility particularly N supply. The interactions of *Tephrosia* fallows and inorganic fertilizers on soil properties, N uptake, and maize yields were evaluated at Chitedze Research Station in Malawi. The results indicated that the level of organic matter and pH increased in all the treatments except for the control. Total N remained almost unchanged while available P decreased in all plots amended with *T. vogelii* but increased in *T. candida* plots where inorganic P was applied. Exchangeable K increased in all the plots irrespective of the type of amendment. The interaction of N and P fertilizers with *T. vogelii* fallows significantly increased the grain yield. The treatment that received 45 kg N ha⁻¹ and 20 kg P ha⁻¹ produced significantly higher grain yields (6.8 t ha⁻¹) than all the other treatments except where 68 kg N ha⁻¹ and 30 kg P ha⁻¹ were applied which gave 6.5 t ha⁻¹ of maize grain. *T. candida* fallows alone or in combination with N and P

fertilizers did not significantly affect grain yield. However, *T. candida* fallows alone can raise maize grain yield by 300% over the no-input control. Based on these results we conclude that high quality residues such as *T. candida* and *T. vogelii* can be used as sources of nutrients to improve crop yields and soil fertility in N-limited soils. However, inorganic P fertilizer is needed due to the low soil available P levels.

1. Introduction

Land degradation and depletion of soil nutrients are widespread in sub-Saharan Africa (SSA) and especially in Malawi. In small-scale farming systems, continuous cropping of cereals without rotation with legumes and inappropriate soil conservation practices have depleted soil fertility [1]. Recent analyses [2] show that N limitation is widespread in Africa. This is specially so due to depletion as a result of soil erosion. According to Stoorvogel et al. [3] and Smaling [4] the annual net nutrient depletion exceeds 30 kg N of arable land in Malawi. The inability of most farmers to practice fallowing due to land shortage and reduced inorganic fertilizer use due to high prices of inorganic fertilizer are some of the major causes of decline in crop productivity in Malawi [5] and sub-Saharan Africa at large.

Many options have been explored to address land degradation and declining soil fertility in Malawi [6–8]. Because organic sources such as animal and plant manure are often in short supply, governments and development agencies tend to promote mineral fertilizers as the solution to low soil fertility [8]. For example, there has been increased emphasis on inorganic fertilizers especially through the Farm Input Subsidy Programme in Malawi [7]. Although inorganic fertilizers provide readily available nutrients, their continuous application may lead to soil and environmental degradation (e.g., acidification, pollution of water bodies, and eutrophication). In addition, inorganic fertilizers may not be sustainable among the resource-poor farmers due to their soaring prices on the global market [5]. For resource-poor farmers investing in fertilizer can also be risky during a drought year; for instance, farmers might not produce enough to cover the costs [8].

Integrating N-fixing perennials with food crops could restore soil health and increase staple yields [8, 9] as they can be self-sufficient in N when planted in degraded land (Djumaeva et al.) [10]. However, the main challenge is in finding species that will grow under the harsh conditions common in degraded soils, where colonization of the area by native vegetation through natural succession processes may be extremely limited. Tephrosia species have been shown to be suitable for rehabilitation of degraded land and acidic soils and increasing soil organic matter (Gichuru; Huancheng and Jueiming) [9, 11–13]. In addition, they are useful

sources of firewood and botanical insecticides [14]. But in Malawi, not many studies have been conducted on *Tephrosia* species to determine the role they play in improving soil fertility and crop yields.

Opportunities also exist for the integrated use of organic inputs from N-fixing perennials with inorganic fertilizers [9]. Management systems that rely on organic inputs as plant nutrient sources have different dynamics of nutrient availability from those involving the use of inorganic fertilizers. For sustainable crop production, integrated use of inorganic and organic fertilizer has proved to be highly beneficial [15]. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P, and K fertilizers for a few years, without any micronutrient or organic fertilizer. However, the effect of integrated use of inorganic fertilizer and organic inputs from *Tephrosia* species on soil fertility and crop yields has not been studied in Malawi. Therefore, the objective of this study was to evaluate the combined effect of *Tephrosia* improved fallows and inorganic N and P fertilizers on soil chemical properties, N uptake, and maize yield in Malawi.

2. Materials and Methods

2.1. Site Description

The experiment was conducted on station at Chitedze Agricultural Research Station (located at 13°85'S and 33°38' E) in Lilongwe District, Malawi. The station is located 16 km west of the Capital City, Lilongwe, on the Lilongwe-Mchinji Road to Zambia. It lies at an altitude of 1146 m above the sea level. Chitedze has a mean annual temperature of 20°C (maximum temperature of more than 24°C in November and lowest 16°C in July). Malawi has one long growing season in a year (October to April). The station receives a mean annual rainfall of 892 mm with 85% falling between November and March [16]. During the reported period, the area received a total annual rainfall of about 869 mm. The soils in this area are classified as ferruginous Latosols (Alfisols) and are medium-textured sandy clay loam. Alfisols have a clay-enriched subsoil and relatively high native fertility. They are suitable for food and fiber production. They are widely used both in agriculture and forestry and are generally easier to keep fertile than other humid-climate soils. The study area is characterized by maize mixed cropping. The soils for the study area has sandy, loam texture, are strongly acidic (pH 4.6), moderate soil organic matter (OM) of 2.39%, and have low N (0.12%) and available P content (14.3 µg/g). Soil analyses also indicated moderate K content (0.35 cmol kg⁻¹) in the soils. The initial physical and chemical properties of the soils for the study sites during the reported period are presented in Table 1.

tab1

Table 1: Initial physicochemical soil properties at the study area (0–20 cm depth).

2.2. Experimental Design and Treatments

Tephrosia vogelii and *T. candida* tree fallows were established 4 km apart within Chitedze Research Station in 2009 by direct seeding as pure seed stands at a spacing of 0.75 m × 0.75 m. This experiment was superimposed with application of different rates of inorganic fertilizers. The *Tephrosia* stands were clear-cut and incorporated into the soil during land preparation. Then the land was subdivided into 6 m × 6 m plots (net plot = 5 m × 3 m) to superimpose the inorganic fertilizer rates. The experiment was a factorial combinations with 3 different levels of N (0, 45, and 68 kg of recommended 90 kg N ha⁻¹) and P (0, 20, and 30 kg of recommended 40 kg P ha⁻¹), respectively, plus a no-input control. The N and P fertilizer rates correspond to 0, 50%, and 75% of the national N and P fertilizer recommendations, respectively. The experiment thus consisted of 9 treatments and an added control as indicated in Table 2. These treatments were laid out in a randomised complete block design (RCBD) with three replicates. The no-input control treatment included where neither *Tephrosia* improved fallows nor inorganic fertilizers were applied. The *Tephrosia* standing biomass input to the soil from the fallows was estimated at 3.5 t ha⁻¹ in all the treatments except for the no-input control. This is excluding litter and root biomass remaining in the soil. The control plot was laid out close (5 meters) to *T. candida* plots, which was separated by a 4 m path. Urea and Triple Superphosphate (TSP) fertilizers were used as a source of N and P, respectively. Maize hybrid (Pan 53) was used as a test crop in this study. Maize was planted on December 19th, 2011, two weeks after biomass incorporation. TSP was applied at planting while Urea was split-applied: 50% applied two weeks after planting and 50% at four weeks after planting.

tab2

Table 2: Treatments for each of the *Tephrosia* fallow experiment.

2.3. Soil Sampling and Analysis

Two samplings were made before biomass incorporation and after harvesting maize. Composite soils were collected across the two experimental sites (*T. vogelii* site and *T. candida* site) at a depth of 0–20 cm within the fields before planting to characterize the soils of the study site. The soils were analyzed for soil texture, soil pH, total N, available P, K, Ca, and Mg, and Organic C (OC). Soil samples were analyzed at Chitedze Agricultural Research Station using the standard laboratory procedures used by the station [17]. Soil pH was measured using a soil to water ratio (1 : 2.5). The exchangeable bases were extracted with 1 M Ammonium Acetate (NH₄OAc) at pH

7. In the extract, K was determined using a Flame Photometer. Ca and Mg were determined on Atomic Absorption Spectrophotometer (AAS). Organic carbon was determined following the Wet Digestion method as described by Walkley and Black [18] whereas Kjeldahl procedure was used for determination of total N as described by Jackson [19]. The soil texture was determined by the hydrometer method. Available P was determined using Mehlich 3 method.

2.4. Plant Sampling and Analysis

Fresh leaves and twigs (foliar samples) of *Tephrosia* were randomly collected from 10 trees from the two study sites at maturity stage and mixed, and a composite sample was taken for each site. The collected samples were dried at 70°C for 48 hours to a constant weight and the dried tissues were grounded and sieved through 0.5 mm size and transported to Chitedze Research Station for analyses. The samples were analyzed for N, P, K, Ca, Mg, and C. The N content of the plant tissues were determined by Kjeldahl procedure whereas P content was determined calorimetrically according to Murphy and Rilley [20] and the K content of the plant tissue was determined by the Flame Photometer while Ca and Mg were determined by AAS. Organic C was determined using Dichromate-Oxidation Method.

2.5. Maize Yield Measurements

Nutrient uptake was assessed in the plant dry matter (DM) at 25 days after planting (DAP), 60 DAP, and at harvest (at harvest in grain and stover). Total dry matter yield and grain and Stover yields were estimated per hectare at grain moisture content (MC) of 12.5%.

2.6. Statistical Analysis

Data collected on soil and yields were subjected to analyses of variance (ANOVA) in order to evaluate the effects of the treatments on soil chemical properties and maize yield. ANOVA was conducted using the GENSTAT statistical package 14th edition. Due to the nature of the experiment, Dunnett's method of preplanned mean comparison was used instead of comparing all treatments with each other. Planned comparisons provide a better alternative to post-hoc tests and increased statistical power because of the focus on a limited number of comparisons related to a clear hypothesis about the effect size [9]. In this study, all other treatments means were compared to the no input "control."

3. Results

3.1. Characterization of Organic Materials Used in the Study

The average nutrient concentrations in the various parts of *Tephrosia* standing biomass are presented in Table 3. The N content in *Tephrosia* biomass ranged from 2.2 to 5.2%. *T. candida* leaves had the highest N content (5.2%) and twigs had the lowest (2.2%). The N content of residues was in the order *T. candida* leaves > *T. vogelii* leaves > *T. vogelii* leaf + twig mixtures > *T. candida* mixtures > *T. vogelii* twigs > *T. candida* twigs. The highest P content was recorded in *T. vogelii* leaves (0.6%) with the lowest in *T. candida* twigs and *T. vogelii* leaf + twig (0.2%).

tab3

Table 3: Nutrient concentration of *Tephrosia* biomass used in the fallow experiment.

Based on the amount of *Tephrosia* standing biomass (leaf and twigs mixtures) incorporated into the soil, the estimated N, P, and K input for each site are summarized in Table 4. This is in addition to the nutrients supplied by the litter fall (which could not be estimated) and applied inorganic fertilizers.

tab4

Table 4: The amount of *Tephrosia* standing biomass incorporated into the soil and the corresponding N, P, and K inputs.

3.2. Effect of *Tephrosia* Improved Fallows and Inorganic Fertilizers on Soil Properties

Soil pH did not significantly vary with treatments though there was an increase in pH upon application of treatments in both species as compared to the initial pH (Table 5). In *T. vogelii* fallows, the pH increased from 4.9 to 6.4 while, in *T. candida*, it increased from 4.2 to 5.3 constituting a 30.6% and 22.4% increase from the initial conditions, respectively.

tab5

Table 5: Soil chemical properties as affected by *Tephrosia* improved fallows and application of inorganic fertilizers.

In *T. vogelii* fallows, total N, available P, Ca, Mg, OC, and organic matter did not significantly increase with the application of inorganic fertilizers, but exchangeable K significantly ()

increased. In *T. candida* fallows, available P and exchangeable bases (K, Ca, and Mg) did not significantly differ with application of inorganic fertilizers. However, total N, organic C, and organic matter varied with application of inorganic P (). Total N remained unchanged in almost all the plots for *T. vogelii*, but in *T. candida* fallows total N decreased in some of the plots while, for available P, it was vice versa. The exchangeable K for both fallows increased as compared to the initial properties. There was also an increase in Soil Organic Matter (SOM) in some plots for both *T. vogelii* and *T. candida* fallows. The increase in SOM ranged from 1.5% to 32.7%.

3.3. Effect of Tephrosia Improved Fallows and Inorganic Fertilizers on Maize Yield

In the *T. vogelii* plots, treatments significantly influenced grain yield (), stover yield (), and total dry matter yield (), but harvest index did not significantly vary with treatment (Table 6). Grain, stover, and total dry matter yields in all treatments were significantly higher than the control. Plots which received 45 kg N ha⁻¹ and 20 kg P ha⁻¹ produced the highest grain yield (6.8 t ha⁻¹) thus increasing yield on average by 5.7 t ha⁻¹ (518%) over the control or by 1.3 t ha⁻¹ (24%) over fallow plots that received no inorganic fertilizer (NOP0) amendment. The next highest yield (6.5 t ha⁻¹) was recorded in plots that received 68 kg N ha⁻¹ and 30 kg P ha⁻¹, and this achieved 5.4 t ha⁻¹ (491%) over the control (Table 6). Stover yield and total dry matter showed similar variations with treatment as grain yield. The *T. vogelii* fallow without inorganic fertilizer input increased maize yield by 400% over the no-input control (Table 6).

tab6

Table 6: Effect of *T. vogelii* and *T. candida* fallows and inorganic fertilizers on maize grain yield (t/ha), average yield increase (t/ha) over control and NOP0 (unfertilized fallow), stover and dry matter yield (t/ha), and harvest index (%) of species.

In the *T. candida* fallow plots, grain yield, stover yield, total dry matter yield, and harvest index did not significantly increase due to application of N and P fertilizers (Table 6). Comparison of treatments using Dunnett's test indicated that most N and P application rates except for NOP20, NOP30, and N45P30 had significantly higher yields in *T. candida* fallows than the control. The *T. candida* fallow without inorganic fertilizer input increased maize yield by 3.3 t ha⁻¹ over the no input control, and performed even better than some inorganic fertilizer rates. The negative values for the control, NOP20, NOP30, N45P20, and N45P30 in column 5 of Table 6 indicate that these fertilizer amendments had lower yields relative to fallow plots without inorganic fertilizer amendment (NOP0) (Table 6). In both *T. vogelii* and *T. candida* fallows, the harvest index obtained with all treatments was in the acceptable range of 0.4–0.6 for maize.

3.4. Effect of Tephrosia Biomass and Inorganic Fertilizers on Maize N Uptake

The results of N concentrations and uptake in aboveground biomass and grain and stover are presented in Figure 1. In the *T. vogelii* fallow plots, N uptake in the grains was significantly improved by application of N alone (). High N accumulation in maize aboveground biomass was observed from 25 to 60 DAP in treatment NOP0 with 0 kg N ha⁻¹ and 0 kg P ha⁻¹ of inorganic fertilizers but fallow biomass accumulated 100.8 kg N ha⁻¹, as compared to no-input control with only 13.1 kg N ha⁻¹ (Figure 1). In addition, there was a sharp increase in tissue N accumulation in all the fertilized maize between 25DAP to harvest. The maximum N accumulation in maize aboveground biomass at harvest averaged 163.2 kg N ha⁻¹ and 131.8 kg N ha⁻¹ for maize which received 45 g N ha⁻¹ and 20 kg P ha⁻¹ and fallow biomass alone, respectively.

fig1

Figure 1: Effect of *T. vogelii* and *T. candida* biomass and inorganic fertilizers on maize N uptake.

In *T. candida* fallows N uptake increased over time. N uptake in the aboveground biomass at 25DAP, 60DAP and at harvest ranged from 8.7 to 14 kg N ha⁻¹, 10.7 to 99.1 kg N ha⁻¹, and 25.8 to 112.4 kg N ha⁻¹, respectively (Figure 1). N uptake at 60DAP and at harvest was the highest in the treatment with 68 kg N ha⁻¹ and 0 kg P ha⁻¹ while the control had the lowest. The N uptake by maize that received *T. candida* fallow biomass alone as N source was about 249% higher than the no-input control which was not significantly different from the treatment which had the highest N uptake.

Maximum N uptake in grain was found in treatment combinations of 45 kg N ha⁻¹ and 20 kg P ha⁻¹ and 68 kg N ha⁻¹ and 30 kg P ha⁻¹ in Tephrosia improved fallows. Similarly, N uptake in maize stover was greater in treatment combinations of 45 kg N ha⁻¹ and 20 kg P ha⁻¹. Maximum grain N concentrations were recorded in treatment combinations of 68 kg N ha⁻¹ and 20 kg P ha⁻¹ followed by fallow biomass alone (NOP0). Similarly, maximum stover N concentration was recorded in treatments where 45 kg N ha⁻¹ and 20 kg P ha⁻¹ and 68 kg N ha⁻¹ and 30 kg P ha⁻¹.

4. Discussion

The N, P, K, and bases estimated in the Tephrosia fallow biomass especially Tephrosia leaf + twig found in this study are within the ranges observed by other researchers (Hagedorn et al.) [21, 22]. On the other hand, the results for N concentration in Tephrosia leaves alone are greater than those found by other studies (2.85–4.0%).

Tephrosia fallows increased in soil organic matter relative to the control. This could be attributed to decomposition of the Tephrosia biomass while that of high N content accumulated in the fallow biomass. The results are in agreement with findings of Nabahungu et al. [23] in Rwanda who reported that use of tithonia green manure and maize residues improved soil fertility, but available P after harvest decreased in all plots except in control when compared to other treatments which clearly indicated that P was immobilized [24]. The results clearly demonstrate the beneficial effects of combined application of organic and inorganic fertilizers.

The present study suggests that, through incorporation of Tephrosia vogelii fallow biomass alone, resource-poor farmers can be able to increase maize grain yield by up to 400% over the no-input control. The results also show that resource-poor farmers can increase grain yield by up to 6–24% with modest amounts of inorganic fertilizers amendments (e.g., N45P20) of Tephrosia fallows. The significant differences in the maize yield between the control and fallow alone or the fallow amended with inorganic fertilizers confirm that high levels of maize production cannot be achieved without additional N and P inputs. Through incorporation of fallow biomass alone (NOP0) it was possible to increase maize yield by 400% in *T. vogelii* and 300% in *T. candida* over the control. This increase in grain yield with fallow was probably due to higher nutrient concentration of *T. vogelii* biomass and the faster decomposition of the fallow biomass as reported earlier. Palm et al. [25] reported that organic materials with N content above 2.5%, lignin contents less than 15%, and polyphenol content of 4% or less should be incorporated directly with annual crops. Similar results of increased maize yields after two years of Sesbania fallows and pigeon pea fallows have been reported [11, 26]. Maroko et al. [27] attributed increase in crop yield after Sesbania fallow to rapid release of plant-available N from litter and leaves resulting in an increased supply of inorganic N at crop planting after fallow period and increased soil N mineralization rates. Other researchers have observed greater maize production through application of high quality organic inputs like tithonia in combination with inorganic fertilizer as compared to sole application of mineral fertilizers (Gachengo) [25, 28, 29].

The low yields obtained from *T. candida* fallows as compared to *T. vogelii* fallows could be attributed to pest infestation. *T. candida* fallow site was affected by pest infestation during the initial maize establishment phase and the maize plants were attacked by white grubs 4 weeks after planting which caused death of maize. The results are similar to Chikowo et al., [30] who

evaluated the residual N effect of two-year legume fallows of *Sesbania sesban*, *Acacia angustissima*, and *Cajanus cajan* on two subsequent cropping systems under minimum and conventional tillage management. They reported that maize growth following the legumes for two subsequent cropping systems was affected due to pest infestation and drought. In addition, these legumes adapted poorly and did not improve N cycling in sandy soils of Zimbabwe. Despite large inputs of litter and continued recycling of N during the cropping phase, legume species that regrow after cutting can result in depressed yields in drought seasons. Sanchez [31] also reported that the main reason for the decline in yield is soil fertility depletion, increased weed infestation, deterioration of soil physical properties, and increased insect and disease attacks.

The high N accumulation in maize aboveground biomass was probably due to the addition of mineral fertilizer and rapid assimilation of nutrients by the maize plants. In addition, the high N accumulated in the maize with fallow biomass alone could be associated with the decomposition of *T. vogelii* and *T. candida* biomass; thus, there was better synchrony of N release to N demand by crop. This implies that improved fallow along with or low dose of NP fertilizers not only conserves soil N but makes nutrient uptake more efficient. Low N accumulation in unfertilized maize (no input control) was probably due to low levels of soil nutrients to influence plant uptake and growth and lack of synchrony of N release to N demand by the crop.

The highest N uptake recorded between 60DAP and at harvest during the reported period was due to high demand of N by the maize crop during this growth period. In this region, maize grows rapidly from 25DAP to harvest (silking-grain filling stage) and this is the phase when maize has the highest demand for N [32, 33]. Increased N uptake in fallow biomass alone or in combination with inorganic fertilizers is an indication of more availability of plant nutrients in these treatments than in the no-input control. This is in agreement with Makumba et al. [34] and Harawa et al. [35] who reported increased N uptake by maize in treatments that had been applied with tree pruning combined with inorganic fertilizers. Kramer et al. [36] also indicated that the inorganic N source applied in combination with organic sources is better utilized than inorganic source of nutrient alone. The N uptake by maize is governed by its concentration in plants and dry matter accumulation. The overall N uptake following the various treatments application showed that combined use of organic and inorganic nutrient sources was better utilized by the maize plant. This might be due to slow and continuous supply of nutrients to maize plant as required by the plants due to influence of chemical fertilizer on organic fertilizer as noted by Palm et al. [25].

5. Conclusion and Recommendations

From the results of this study it is concluded that Tephrosia improved fallows can increase soil fertility and improve maize yield in Malawi. *T. vogelii* has a potential to supply inorganic soil N through fallow biomass as well as improve soil pH and soil organic carbon. The results suggest that integrated use of Tephrosia improved fallow and inorganic fertilizer can raise agricultural productivity in Malawi if, for example, resource-poor farmers could apply low rates of inorganic fertilizers (50% N and 50% P of the recommended fertilizers rates) in combination with Tephrosia fallow, thus, reducing the need for purchasing fertilizer by 50%. However, further research and development efforts are needed to scale up this integration. We also recommend further research to develop site-specific recommendations.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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