Effect of Adaptable Green Manuring Plants on Soil Fertility and Sorghum Yield

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Abstract

A study was conducted in 2008-2010 at Habru District, North Wollo Zone. Its objective was to evaluate the effect of green manuring plants (Tephrosia vogelii, Tithonia diversifolia and Leucenea palida) as intercrop and green manure integrated with N and P on soil fertility and sorghum yield. The results showed that intercropping Tephrosia v. and Leucenea p. with sorghum didn't have significant ($p > 0.05$) impact on sorghum yields. Whereas, intercropping Tithonia d. with sorghum showed significant ($p \leq 0.05$) negative effect on sorghum yields probably due to its vigorous growth and higher biomass which leads to significant nutrient and moisture competition against the test crop. Tephrosia v. and Tithonia d. green manures alone gave significantly ($p \leq 0.05$) higher sorghum grain yield than the control and gave similar grain yield with full recommended N and P and their combination with 100% and 50% of the recommended N and P. Whereas, Leucenea p. didn't have significant effect on grain yield than the control due to its poor growth. Tephrosia v. and Tithonia d. alone gave 104.7% and 85.4% grain yield advantage over the control respectively. The soil analysis result also showed that Tephrosia v., Tithonia d. and Leucenea p. improved soil OC by 9.5%, 8.1% and 2.9% over the control respectively. At the end of the experiment, 8.1% and 7.3% residual deposition of soil OC was recorded in the plots under Tephrosia v. and Tithonia d. respectively. Thus, it is possible to conclude that Tephrosia v. and Tithonia d. alone can give comparable sorghum grain yield with full recommended N and P. However, due to its potential to be a weed, Tithonia d. should be used as a green manure only by biomass transfer. Further investigation on the cost benefit analysis of using green manures alone and their interaction with chemical fertilizer is required.

Key words: intercropping, green manure, biomass transfer, chemical fertilizer

INTRODUCTION

Ethiopia faced a wide set of soil fertility issues that require approaches that go beyond the application of chemical fertilizers; the only practice applied at scale to date. Core constraints include topsoil erosion; some sources list Ethiopia among the most severely erosion-affected countries in the world (FAO, 1998), soil acidification with acidity-affected soils covering over 40 percent of the country, significant depletion of soil organic matter due to widespread use of biomass as fuel; the use of dung as fuel instead of fertilizer is percent (Zenebe, 2007), depletion of macro and micro-nutrients, deterioration of soil physical properties and soil salinity. Hence, integrated soil fertility restoration and soil and water conservation practices should be

and eventually improve the productivity of soils.

Low soil fertility is among the major factors limiting crop production and productivity in Eastern Amhara. This is common in many tropical cropping systems where fertilizer use is low and little or no agricultural residues are returned to the soil for maintaining soil fertility. Besides, long aged continuous cultivation with nutrient-depleting crops and complete removal of crop residues from farmlands and absence of crop rotation result in irreversible nutrient mining by plant uptake (Kidane and Getachew, 1994; Heluf, 2005). As a consequence of these and the prevailing very intense rate of surface soil erosion in the Ethiopian highlands, declining soil fertility is a fundamental impediment to agricultural development and the major reason for the slow growth rate in food production and food insecurity both at household and national levels.

Most soils in the semi-arid areas of northeastern Ethiopia, where the present study area lies, are heavily depleted of plant nutrients and are characterized by low total N, available phosphorus (P) and organic carbon (OC) contents leading to substantial decline in crop productivity (Hailu, 1988; Asnakew, 1994). Hence, to increase crop productivity, the depleted soil plant nutrients should be replenished with chemical and organic fertilizers. Use of chemical fertilizers has been proved to significantly increase productivity of crops in Eastern Amhara (Yared et al., 2003).

However, use of chemical fertilizers to a degraded land and to a soil with a substantially depleted content of organic matter could not give the expected yield return due to the vulnerability of the added chemical fertilizers to losses through erosion and leaching leading to significantly low nutrient recovery efficiency of chemical fertilizers. Thus, as it was suggested by Palm et al. (1997), as cited by W. Bayu et al (2005), an integrated nutrient management program in which both organic and inorganic fertilizers are used is an ideal strategy not only to boost crop productivity but also to restore the physical, biological and chemical soil fertility sustainably.

In traditional agriculture, arable land could be left fallow for some years to allow soil to acquire self-rejuvenation, but increased population pressure leads to little fallow periods, which are not sufficient to restore the soil nutrient pools and soil organic matter levels sufficient to support economic crop yields. In Ethiopia, 95% of the farmers are classified as small-scale who cannot afford high input investments (CSA, 2010). There is, therefore, a need to examine crop production systems that could promote sustainable crop production in Ethiopia. The organic system favours the use of renewable resources and emphasizes the use of techniques that integrate natural processes such as nutrient cycling, biological nitrogen fixation and soil regeneration.

This research, therefore, provides a case study of how the leguminous green manures (*Tephrosia vogelii* and *Leucenea palida*) and a non-legume (*Tithonia diversifolia*) species alone or in combination with chemical fertilizers (N and P) can sustainably increase the yields of sorghum and improve soil organic matter base the in Eastern Amhara region.

2. Materials and Methods

2.1 Experimental Site Description

The study was conducted on the main research station of Sirinka Agricultural Research Center (SARC) in the 2008-2010 main cropping seasons. The study site, Sirinka, is located about 508 km away from Addis Ababa the capital city of Ethiopia in the north east direction, at an altitude of 1850 masl and at 11^0 y ^{0}y y longitude. The average annual rainfall of the study area was 945 mm and the mean maximum and minimum temperatures were 26 and 13^{o}C, respectively. The rainfall distribution across months and main crop growing seasons (July-December) during the three experimental years was depicted below in Figure 1.

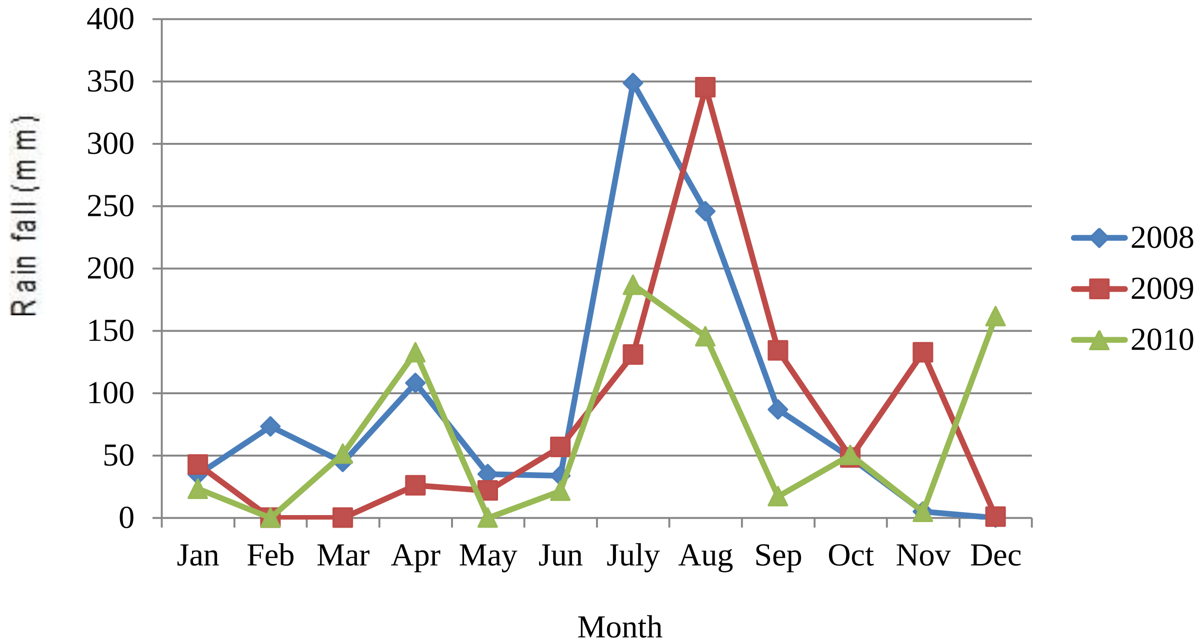

Fig 1. Rainfall distribution across months in the three experimental seasons

The soils of the study site are characterized as a clay to clay loam texture with black to brown color, conducive pH condition for most crop growth, low organic carbon, low total nitrogen and medium available phosphorus (Table 1). The dominant soil type in the study area, based on the FAO/UNESCO System (FAO-UNESCO, 1994), is Eutric Vertisol.

Table 1. Physical and chemical properties of the surface soils (0-20 cm) at the study site

Property	Value/Result
pH (H_2O)	6.98
OC (%)	1.35
Total N (%)	0.07
Available P. (mg kg^{-1})	11.77
CEC ($cmol_C$ kg^{-1})	56.44
Texture	Clay to Clay loam
Exchangeable K ($cmol_C$ kg^{-1})	1.27
Exchangeable Ca ($cmol_C$ kg^{-1})	36.85
Exchangeable Mg ($cmol_C$ kg^{-1})	12.61

2.2 Experimental Design and Procedures

The study was conducted in two phases; Intercropping phase and Green manuring (Biomass transfer) phase.

I. The Intercropping Phase

The intercropping phase of the study was comprised of four treatments; three green manures species (*Tephrosia vogelii*, *Leucenea palida* and *Tithonia diversifolia*) intercropped with sorghum and the control (Sorghum without green manure intercrop). The treatments were laid in a randomized complete block design with three replications.

The green manures were planted in the middle of the sorghum plant rows, two weeks after planting sorghum. Uniform rates of the full recommended N/P chemical fertilizers (69/46 N P_2O_5) were applied to all experimental plots. The N fertilizer was applied in a split, half at planting and the remaining half at tillering, while DAP was applied all at planting. The variety of sorghum used for the study was Teshale; it was planted in a row with the spacing of 75 cm between rows and 15 cm between plants.

II. The Green Manuring (Biomass transfer) Phase

In the second phase of the study, the green manures, which had been intercropped with sorghum in the intercropping phase of the study, were chopped at their flowering stage and incorporated in to the soil in the respective plots. After incorporation, but before sowing the subsequent test crop-sorghum, the plots were divided in to three subplots. The subplots were assigned to three levels of N/P fertilizers (0, 50% and 100% of the recommended N/P). The design of the green manuring phase of this study was a split plot design with three replications. The P-fertilizer was applied all at planting while the N-fertilizer was applied in a split (half at planting and the remaining half at knee height).

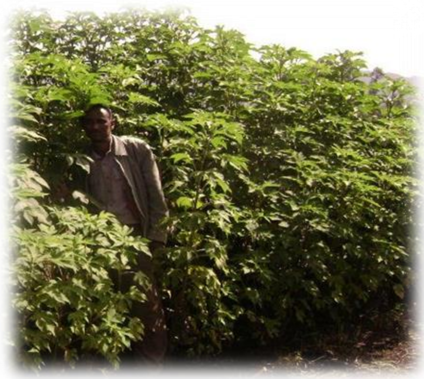

Fig 2. *Tithonia diversifolia*

Fig. 4. Chopping the green manures before incorporation

Fig 3. *Tephrosia vogelii*

2.3. Soil Sampling and Analysis

Soil samples at a depth of 0-20 cm were collected from each plot before planting in the intercropping phase and before and after incorporation of the green manure but before sowing of the test crop during the second phase of the study.

The collected soil samples were analyzed for texture, pH, organic matter (OM), total nitrogen (TN) available P, Ca, Mg and CEC. Soil pH was measured potentiometrically using a digital pH meter in a 1:2.5 soil water suspension (Van Reeuwijk, 1992). Organic carbon (OC) was determined by wet digestion method, and following the assumptions that OM is composed of 58% carbon, the conversion factor, 1.724 was used to convert the OC

in to OM (Walkley and Black, 1934). Determination of total N of the soil was carried out through Kjeldahl digestion, distillation and titration procedures of the wet digestion method (Black, 1965). Available P
1952).

Exchangeable Ca and Mg were extracted with 1M buffered ammonium acetate extractant and were measured using atomic absorption spectrophotometer (Chapman, 1965). Similarly, CEC was determined by 1M buffered ammonium acetate extraction method and distillation of the ammonium saturated soil in a Kjeldahl distillation apparatus while receiving the distillate in boric acid and then titrating with sulfuric acid (Chapman, 1965).

2.4 Crop Data Collection

Plant height was measured at maturity, from five random plant samples of the harvestable rows, from the ground level to the tip. Straw yield was obtained as the difference of the total above ground plant biomass and grain yield, and adjusted for the moisture content. Whereas, 1000 seed weight was measured by weighing 1000 seeds from the harvest. Grain yield was measured by taking the weight of the grains threshed from the central harvestable rows of each plot and converted to kilograms per hectare after adjusting the grain moisture content to 12.5%. Biomass was measured by weighing the total above ground plant biomass within the harvestable rows.

3. Results and Discussions

3.1. Effects of Green Manures on Sorghum Yields

3.1.1. Effects of intercropping green manuring plants on the grain yield and biomass weight of sorghum

The first experimental year data analysis results as shown in Table 2 revealed that there was statistically significant ($P \leq 0.05$) difference in the grain yield of sorghum due to the effect of intercropping green manures with sorghum. However, there was no significant ($p > 0.05$) effect of intercropping green manures on the biomass weight of sorghum (Table 2). The highest grain yield (3540 kg ha^{-1}), which was statistically similar ($P > 0.05$) with the grain yields obtained from the *Tephrosia v*. and *Leuceneap*. intercropped with sorghum the lowest grain yield was obtained from the control. This was accounted for there was no moisture and nutrient competition in the control treatment as compared to the green manure intercropped treatments.

The grain yield obtained from the *Tephrosia v*. and *Leuceneap*. intercropped with sorghum might be due to the nitrogen fixing ability of both green manuring plant species and the subsequent probability of supply of N to the test crop-sorghum. The lowest grain yield which was significantly different from the other treatments was obtained from the Tithonia d.-sorghum intercropped treatment (Table 2). While, in the second experimental year, intercropping green manures with sorghum did not have significant effect on the grain yield and biomass weight of sorghum (Table 2). This might be accounted for the lower rainfall in the second experimental year which resulted in slower growth and lower biomass yields of the green manures. As a result, the green manures did not have a significant impact on the nutrient and moisture uptake by sorghum.

The combined analysis over the two experimental years as shown in Table 2, however, revealed that the mean effect of intercropping green manures on the grain yield and biomass weight of sorghum were statistically significant ($p \leq 0.05$). The control (non-intercropped) treatment was the highest yielder though it was statistically similar with the grain yield obtained from the Tephrosia v. intercropped with sorghum. The grain yield obtained from *Tithonia d*. intercropped with sorghum (2780 kg ha^{-1}), was by 18.8% lower than that obtained from the control plot and by 12.7% than *Tephrosia v*. intercropped with sorghum (Table 2). This might be attributed to the vigorous growth of *Tithonia d*. which leads to high competition for nutrient and moisture against sorghum. While, the highest biomass weights of sorghum were measured from the control and *Leuceneap*. intercropped with sorghum (Table 2). The growth performance and the biomass return of *Leuceneap*. was by far lower than the other green manure species which made it the least in putting pressure on the moisture and nutrient uptake of sorghum.

Tabel 2. Effects of intercropping green manures on sorghum grain yield and biomass weight (kg ha^{-1})

	2008		2009		Combined over years	
Treatment*	**Grain yield**	**Biomass weight**	**Grain yield**	**Biomass weight**	**Grain yield**	**Biomass weight**
Control	y y		yy	y	y	y
Tephrosia v.	y y	y	y y		y	yy
Leuceneap.	y	y		y	y	y
Tithonia d.			y yy		y	y
GM	y		y		y	y
CV		y				y
LSD		y		y	y	yy y

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different; ns-non significant (p > 0.05)*

3.1.2. Effects of incorporating green manuring plants with different rates of N and P on sorghum yield and biomass weight

3.1.2.1 Grain yield of sorghum

The statistical result showed that there was a highly significant ($P \leq 0.01$) difference in the grain yield and biomass weight of sorghum due to the interaction effects of the green manure species and chemical fertilizers. As it is depicted in Table 3, in the first experimental year, the highest grain yield (4580 kg ha^{-1}) was obtained from the combined application of *Tithonia d*. with 100% the recommended N and P followed by 100% of the recommended N and P alone, *Tithonia d*. combined with 50% of the recommended N and P, *Tithonia d*. and *Tephrosia v*. alone.

The vigorous growth and relatively higher biomass obtained from *Tithonia d*. enabled it to be the higher nutrient supplier, up on decomposition, to sorghum. Moreover, different studies showed that *Tithonia d*. had high concentrations of N, K, Ca and low concentrations of P and Mg and could supply significant amount of the mentioned nutrients to the subsequent crop up on decomposition and mineralization (Rutunga et al., 1999; Olabode et al., 2007). The green manuring plants, *Tithonia d*. and *Tephrosia v*. alone increased the grain yield of sorghum by 66.0% and 44.3%, respectively over the control. Whereas, in the second year, *Tephrosia v*. + 50% recommended N and P gave the highest grain yield (2470 kg ha^{-1}) followed, by *Tephrosia v*. + 100 % recommended N and P, *Tephrosia v*. alone and

100% recommended N and P (Table 3). Due to low amount of rainfall (Fig 1) that caused moisture deficit in the late growth stages of the test crop, lower grain yield was measured from the entire experiment in the second year as compared to the first year.

Unlike *Tithonia d*., *Tephrosia v*. was not affected much by the moisture deficit during the second year (Fig.1). Hence, the plots under *Tephrosia v*. gave significantly higher grain yield than those under the other green manuring plants. Nevertheless, *Tephrosia v*. and *Tithonia d*. green manures alone increased sorghum grain yield by 209.8% and 64.0%, respectively over the control during the second year. This result is supported by Rutunga et al. (1999) who conducted a study on biomass production and nutrient accumulation by *Tephrosia vogelii* and *Tithonia diversifolia* and reported that *Tephrosia v*. performed better than *Tithonia diversifolia* in a low rainfall during the growing season.

Table 3. Effects of combined use of green manures and chemical fertilizers on the grain yield (kg ha^{-1}) of sorghum in the 2009 and 2010 experimental seasons

Green Manure*	**2009**			**2010**		
	0% N/P	**50% N/P**	**100% N/P**	**0% N/P**	**50% N/P**	**100% N/P**
Control	2493.7d	3497.2abcd	4570.2a	756.2e	1670.0cd	2022.9abc
Tephrosia v.	3598.8abcd	2943.3cd	3108.6bcd	2342.6ab	2465.7a	2378.1ab
Leuceneap.	2884.5cd	4078.6abc	3023.9bcd	773.7e	1188.2de	1898.9bc
Tithonia d.	4140.4ab	4251.0ab	4579.4a	1240.4de	1539.0cd	1978.7abc
GM		3574.0			1679.6	
CV (%)		11.3			15.5	
SEM		402.9			260.6	

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

On the contrary, according to a research report from Fungameza (1991) and Drechsel *et al*. (1996), the amount of biomass produced by *Tephrosia v*. was influenced by the fertility status of the soil and the amount of rainfall. According to a study report by Rutunga *et al*. (1999), the above ground biomass of both *Tephrosia v*. and *Tithonia d*. could accumulate higher amounts of N, K, Ca and Mg than the natural fallow and maize. The same authors also justified that *Tithonia d*. had higher concentration of the aforementioned nutrients than *Tephrosia v*. However, as *Tephrosia v.* is a leguminous plant, if there is adequate soil moisture and relatively fertile soil conducive for microbial growth, it has got a special merit of fixing atmospheric N apart from taking up soil N.

Sorghum under *Tephrosia v*. alone gave the highest and more stable grain yield in both years despite the insignificant difference with some of the treatments as mentioned above. This might be accounted for better and stable biomass yields of *Tephrosia v*. in both years due to its relatively better tolerance to low soil moisture.

The combined analysis result over the two years, as it is depicted in Table 4, indicated that the highest grain yield was obtained from *Tithonia d*. + 100% recommended N and P followed by 100% of the recommended N and P alone, *Tephrosia v*. alone, *Tithonia d*. + 50% recommended N and P, *Tephrosia v*. + 50% recommended N and P and *Tithonia diversifolia* alone. Thus, *Tephrosia v*. and *Tithonia d*. alone could give statistically similar grain yields with 100% recommended N and P and all green manure species + 100% and 50% recommended N and P. In general, *Tephrosia v*. and *Tithonia d*. alone gave a grain yield advantages of 104.7 and 85.4% over the control respectively (Table 4).

Table 4. Effects of the combined use of green manures and chemical fertilizers on the grain yield (kg ha^{-1}) of sorghum pooled over the two experimental years

	Combined over years		
Green Manure*	**0% N/P**	**50% N/P**	**100% N/P**
Control	1451.2c	2400.9b	3041.8ab
Tephrosia v.	2970.7ab	2704.5ab	2743.3ab
Leucenea p.	1829.1c	2633.4b	2461.4b
Tithonia d.	2690.4ab	2895.0ab	3279.1a
GM		2584.4	
CV (%)		17.6	
SEM		455.5	

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

3.1.2.2. Biomass weight of sorghum

In the first year, there was statistically significant ($p \leq 0.05$) interaction effects of the green manures with the chemical fertilizers on the biomass weight of sorghum. As it is shown in Table 5 below, *Tithonia d*. + 50% recommended N and P gave the highest sorghum biomass yield followed by *Tithonia d.* + 100% recommended N and P, 100% recommended N and P, *Tephrosia v.* alone and *Tithonia diversifolia* alone (Table 5).

Table 5. Effects of the combined use of green manures with chemical fertilizers on the biomass weight (kg ha^{-1}) of sorghum in 2009

	2009		
Green Manure*	**0% N/P**	**50% N/P**	**100% N/P**
Control	11778de	13056bcde	14481abc
Tephrosia v.	15111ab	12278cde	12630bcde
Leucenea p.	11148e	14111bcd	11111e
Tithonia d.	14235abcd	16741a	14778abc
GM		13581.84	
CV (%)		9.15	
SEM		1242.57	

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

In the second year, however, there was no significant interaction effect of the green manures with the chemical fertilizers on the biomass weight of sorghum. Nevertheless, the main effects of both the chemical fertilizers and the green manures had significant effects on the sorghum biomass (Table 6). Among the green manures, *Tephrosia v*. alone gave the highest sorghum biomass weight of 9890 kg ha^{-1}, followed by *Tithonia d*. alone. As mentioned above, the low rainfall in the second year contributed to the significantly lower sorghum biomass weight measured from the green manure *Tithonia d*. than *Tephrosia v*. due to its better tolerance to moisture stress. There was no significant difference between 100% recommended N and P and 50% recommended N and P in sorghum grain yield.

Table 6. Effects of the combined use of green manures with chemical fertilizers on the biomass weight (kg ha^{-1}) of Sorghum in 2010

NP levels	**Biomass weight (kg ha^{-1})**
0%	6777.8b
50%	7800.0a
100%	8314.8a
GM	7620.915
CV	12.4
LSD	947.7
Green Manure	
Control	6765.4bc
Tephrosia vogelii	9888.9a
Leuceneapalida	6333.3c
Tithonia diversifolia	7604.9b
GM	7620.915
CV (%)	12.4
LSD	947.7

** Treatments within a column followed by the same letter are not significantly different.*

The pooled analyses over years indicated that there was no significant (P > 0.05) interaction between the green manures and chemical fertilizers on the biomass weight. However, as it was elucidated in Table 7, the main effect of both the green manures and the chemical fertilizers on biomass weight was significant. Among the green manure species, *Tephrosia v*. recorded the highest biomass weight (114.5 qt ha^{-1}) followed by *Tithonia d*. while the lowest biomass weight was obtained from the control and *Leuceneapalida*. There was no significant difference between 50% recommended N and P and 100% recommended N and P in biomass weight though relatively higher biomass weight was recorded by 50% recommended N and P (Table 7).

Table 7. Effects of the combined use of the green manures with N and P on the biomass weight (kg ha^{-1}) of sorghum combined over years

NP levels	**Biomass weight (kg ha^{-1})**
0%	9602.7b
50%	11061.1a
100%	10768.1a
GM	10463.82
CV	10.88
LSD	705.06
Green Manure	
Control	9625.0b
Tephrosia v.	11451.9a
Leucenea p.	9291.7b
Tithonia d.	11428.0a
GM	10463.82
CV (%)	10.88
LSD	814.51

**Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

3.2 Effects the Green Manures on Soil Organic Matter

The soil analyses results after the incorporation of the green manuring plants in 2009 and 2010 indicated that there was a slight increase in the soil organic carbon (OC) due to the addition of the green manures in to the soil (Table 8) compared to the control. However, there was no significant (P > 0.05) difference among the green manuring plants. The combined analysis over years revealed that *Tephrosia v., Tithonia d*. and *Leucenea p*. improved the soil OC (%) by 9.5, 8.1% and 2.9% over the control respectively (Table 9).

While, 8.1% and 7.3% residual deposition of soil OC was obtained from the plots under *Tephrosia v*. *Tithonia d*. respectively, at the end of the experiment (Table 9).

Table 8. Effect of the green manures on soil organic carbon (% SOC) in each experimental year

		Before planting	After harvesting		Before planting	After harvesting
Green Manure	2008	2009 (After incorporation)	2009	2009	2010 (After incorporation)	2010
Control		1.20	1.30		1.45	1.41
Tephrosia v.		1.39	1.38		1.61	1.57
Leucenea p.	1.23	1.29	1.26	1.51	1.53	1.46
Tithonia d.		1.36	1.39		1.60	1.54
GM		1.31	1.33		1.55	1.50
CV (%)		3.6	6.4		12.5	13.4
LSD		0.74ns*	0.17ns		0.36ns	0.36ns

**ns-non significant*

Table 9. Effects of the green manures on soil organic carbon combined over years

Green manure	**Before intercropping**	**Before planting /after incorporation/**	**After harvesting**
Control		1.33	1.35
Tephrosia v.		1.50	1.48
Leucenea p.	1.37	1.41	1.37
Tithonia d.		1.48	1.47
GM		1.43	1.42
CV		10.6	11.7
LSD		0.23ns*	0.19ns

**ns-non significant*

4. Conclusions and Recommendations

Intercropping of *Tephrosia vogelii* and *Leucenea palida* with sorghum did not impose significant negative impact on the growth and yield of sorghum. However, *Tithonia diversifolia*. intercropped with sorghum reduced the growth and yield of sorghum due to its vigorous growth which caused nutrient and moisture competition against sorghum. In addition, *Tephrosia vogelii* and *Tithonia diversifolia* alone as green manure increased sorghum grain yield equally with 100% recommended N and P + green manures and 50%

and 100% of the recommended N and P alone. *Tephrosia vogelii* had better tolerance to low soil moisture than *Tithonia diversifolia*. The soil analyses results also indicated that green manuring plants *Tephrosia vogelii, Tithonia diversifolia* and *Leucenea palida* improved soil organic carbon content over the control.

In general, *Tephrosia vogelii* intercrop and green manure (biomass transfer) gave better sorghum yield equivalent to the use of the full recommended N and P. Due to its potential to be a weed, it is recommended to use *Tithonia diversifolia* as biomass transfer for green manuring whereas *Tephrosia vogelii* is recommended both as an intercrop and as a green manure in areas with similar soil types and agro-climatic conditions. However, the economic profitability of these green manuring plants alone and integrated with N and P should be studied.

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