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Effect of Adaptable Green Manure Plants on Sorghum Yields and Soil Fertility in Eastern Amhara Region of Ethiopia

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Abstract
A study was conducted in Eastern Amhara Region of Ethiopia to evaluate effects of intercropping sorghum with Tephrosia vogelii, Tithonia diversifolia and Leucenea palida on sorghum yield and soil fertility. The results showed that intercropping Tephrosia v. and Leucenea p. with sorghum didn't have significant ($p > 0.05$) negative effect on sorghum yields. However, sorghum-Tithonia d. intercropping significantly ($p \leq 0.05$) harmed sorghum yields. The results of sorghum yields in the subsequent two experimental years, after ploughing under the above ground biomass of the green manures, revealed that plots which received Tephrosia v. and Tithonia d without inorganic fertilizers gave significantly ($p \leq 0.05$) similar yields with application of 100% of the recommended NP fertilizers. However, due to its poor growth and lowest biomass, Leucenea p. didn't effect a significant yield difference over the control. At the end of the experiment, 8.1 and 7.3% residual deposition of soil organic carbon was recorded on the plots under Tephrosia v. and Tithonia d., respectively. Thus, it is possible to recommend sorghum-Tephrosia v. intercropping and green manuring. While, due to its weed effect, Tithonia d. is not recommended for intercropping; it is rather recommended to transfer its biomass through cut and carry system.
Key words: intercropping, green manure, biomass transfer, inorganic fertilizer

1. INTRODUCTION

Ethiopia faces 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 estimated to reduce Ethiopia's agricultural GDP by 7 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 implemented to improve soil's resistance to erosion, ameliorate soil acidity and alkalinity 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 (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.

As reported by Yared et al. (2003), use of chemical fertilizers has been proved to significantly increase productivity of crops in Eastern Amhara. 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) 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. As stated by Central Statistical Agency (CSA) of Ethiopia (CSA, 2010), 95% of the farmers in the country are classified as small-scale, who cannot afford high input investments. There is, therefore, a need to examine crop production systems that could promote sustainable crop production in Ethiopia. The organic system favors 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 integrated use of green manures derived from legumes (Tephrosia vogelii and Leucenea palida) and a non-legume (Tithonia diversifolia) species and chemical fertilizers can sustain the yields of sorghum and improve soil organic matter in Eastern Amhara Region of Ethiopia.

2. MATERIALS AND METHODS

2.1 Experimental Site Description

The study was conducted in Eastern Amhara Region of Ethiopia on a research station at 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 meters above sea level and at $11^{0}45'00''$N latitude and $39^{0}36'36''$E 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 soils of the study site are characterized as a clay to clay loam texture with black to brown color, pH condition conducive 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 is Eutric Vertisol (FAO UNESCO, 1994).

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 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) treatment. 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 knee height, while DAP was applied all at planting. The variety of sorghum used for the study was an early maturing improved variety, 'Teshale'. It was planted by drilling in a row with the spacing of 75 cm between rows and 15 cm between plants.

II. The Green Manuring 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).

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 according the procedures described by Sahilemedihin and Taye (2000).

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 DISCUSSION

3.1 Effects of intercropping the green manures on yields of sorghum

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

The grain yield obtained from the Tephrosia v. and Leucenea p. intercropped with sorghum might be due to the nitrogen fixing ability of both green manuring plant species and the subsequent 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 1).

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 1). 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 1, 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 1). This might be attributed to the vigorous growth of Tithonia d. which led to significant competition for nutrient and moisture against sorghum. While, the highest biomass weights of sorghum were measured from the control and Leucenea p. intercropped with sorghum (Table 1). The growth performance and the biomass return of Leucenea p. 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 1. Effects of intercropping green manures on sorghum grain yield and biomass weight

Treatment*	2008		2009		Combined over years	
	Grain yield	Biomass weight	Grain yield	Biomass weight	Grain yield	Biomass weight
	(kg ha^{-1})					
Control	3535.2a	22217	3321.6	12431.5	3428.4a	17324.4ab
Tephrosia v.	3135.0a	21366	3239.2	11500.7	3187.1ab	16433.4b
Leucenea p.	3405.9a	23766	2717.7	12893.2	3061.8bc	18329.7a
Tithonia d.	2408.8b	20281	3033.1	11945.6	2783.4c	16113.5b
GM	3186.0	21907.8	3077.9	12192.8	3129.6	17050.3
CV (%)	6.6	7.03	9.4	4.7	8.7	6.3
LSD	468.6	ns	ns	ns	349.4	1338.3

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

3.2 Effect of green manuring with and without NP fertilizers on sorghum yields

3.2.1 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 2, 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 NP followed by 100% of the recommended NP alone, Tithonia d. combined with 50% of the recommended NP, 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 NP gave the highest grain yield (2470 kg ha^{-1}) followed, by Tephrosia v. + 100 % recommended NP, Tephrosia v. alone and 100% recommended NP (Table 2). 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 (Figure 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 v. and Tithonia d. and reported that Tephrosia v. performed better than Tithonia d. in a low rainfall during the growing season. 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.

Table 2. 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% NP	50% NP	100% NP	0% NP	50% NP	100% NP
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
Leucenea p.	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

According to a study report from 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 shown in Table 3, revealed that the highest grain yield was obtained from Tithonia d. + 100% recommended NP followed by 100% of the recommended NP alone, Tephrosia v. alone, Tithonia d. + 50% recommended NP, Tephrosia v. + 50% recommended NP and Tithonia d. alone.

Thus, Tephrosia v. and Tithonia d. alone could give statistically similar grain yields with 100% recommended NP and all green manure species + 100% and 50% recommended NP. In general. Tephrosia v. and Tithonia d. alone gave grain yield advantages of 104.7 and 85.4% over the control, respectively (Table 3).

Table 3. 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

Green Manure*	Combined over years		
	0% NP	50% NP	100% NP
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.

3.2.2 Biomass yield 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 yield of sorghum. As it is shown in Table 4 below, Tithonia d. + 50% recommended NP gave the highest sorghum biomass yield followed by Tithonia d. + 100% recommended NP, 100% recommended NP, Tephrosia v. alone and Tithonia d. alone (Table 4).

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Table 4. Effects of the combined use of green manures with chemical fertilizers on the biomass yield (kg ha^{-1}) of sorghum in 2009

	2009		
Green Manure*	**0% NP**	**50% NP**	**100% NP**
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 yield of sorghum. Nevertheless, the main effects of both the chemical fertilizers and the green manures had significant effects on the sorghum biomass (Table 5).
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 NP and 50% recommended NP in sorghum biomass yield.

Table 5. 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	7620.9
CV (%)	12.4
LSD	947.7
Green Manure	
Control	6765.4bc
Tephrosia v.	9888.9a
Leucenea p.	6333.3c
Tithonia d.	7604.9b
GM	7620.9
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 yield of sorghum. However, as it was elucidated in Table 6, 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 treatment and Leucenea p (Table 6).

Power et al. (1986) also revealed that sowing of sorghum in double row strips with legume as intercrops gave the highest dry matter accumulation and highest uptake of NPK was observed by the intercropped sorghum as compared to sole sorghum. Similarly, Singh and Balyan (2000) indicated that the intercropping systems registered significant increase in total productivity (sorghum equivalent) over sole sorghum.

Table 6. Effects of the combined use of the green manure species with the chemical fertilizers on the biomass weight (kg ha^{-1}) of sorghum combined over the two experimental years

NP levels	Biomass weight (kg ha^{-1})
0%	9602.7b
50%	11061.1a
100%	10768.1a
GM	10463.8
CV (%)	10.9
LSD	705.0
Green Manure	
Control	9625.0b
Tephrosia v.	11451.9a
Leucenea p.	9291.7b
Tithonia d.	11428.0a
GM	10463.8
CV (%)	10.9
LSD	814.5

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

3.3 Effects the Green Manures on Soil Organic Carbon

The soil analyses results after working the above ground biomass of the green manure plants in to the soil in 2009 and 2010 experimental seasons indicated that there was an increase in the soil organic carbon (SOC) due to the addition of the green manures in to the soil compared to the control (Table 7). The combined analysis result over years revealed that Tephrosia v., Tithonia d. and Leucenea p. improved the SOC (%) by 9.5, 8.1% and 2.9% over the control, respectively (Table 8). While, 8.1% and 7.3% residual deposition of SOC was obtained from the plots under Tephrosia v. Tithonia d., respectively at the end of the experiment (Table 8).

Azeez (2009) also reported that achievement of high C gains in organic system occurs due to the use of green manures, fertility conserving crop rotations with intercropping and compost utilization. According to Grubinger (2008), management of green manures under rotations has been also shown to be successful in increasing SOC and enhancing N supply.

Table 7. 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 green manure addition)	**2009**	**2009**	**2010** (After green manure addition)	**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		NS	NS		NS	NS

NS-non significant

Table 8. Effects of the green manures on soil organic carbon combined over years

Green manure	Before green manure addition	After green manure addition	At the end of the experiment
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		NS	NS

NS-non significant

4. CONCLUSION AND RECOMMENDATIONS

Intercropping Tephrosia v. and Leucenea p. with sorghum did not have a significant negative effect on the growth and yield of sorghum. However, Tithonia d.-sorghum intercropping significantly reduced the growth and yield of sorghum due to its vigorous growth which most likely caused nutrient and moisture competition against sorghum. Use of Tephrosia v. and Tithonia d. alone as green manures increased sorghum grain yield equivalently with the use of 100% of the recommended NP fertilizers and the combined use of green manures with half and full of the recommended NP fertilizers. It was also found out that Tephrosia v. had better tolerance to low soil moisture than Tithonia d. The soil analyses results also revealed that by using the green manure plants Tephrosia v., Tithonia d. and Leucenea p., soil organic carbon content can be improved.

In general, Tephrosia v. is recommended to be used as an intercrop with sorghum and as a green manure through which equivalent sorghum yield with that of use of the full recommended NP fertilizers can be harvested. However, due to its potential to be a weed, Tithonia d. is only recommended to transfer its biomass through cut and carry instead of intercropping with sorghum. Because, it had a yield penalty on sorghum in the first season of intercropping with sorghum.

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