Short Communication

Effects of *Leucaena* [*Leucaena leucocephala* (Lam.) de Wit] Leaf Biomass and NP Fertilizer Application on Soil Fertility, *Striga* [*Striga hermonthica* (*Del.*) Benth] Management and Sorghum [*Sorghum bicolor* (L.) Moench] Growth and Yield in Pawe District, Northwestern Ethiopia

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Abstract: Sorghum production in Pawe District is often constrained by low soil fertility resulting from continuous cropping with minimum or no input which in turn encourages *Striga* infestation. Field experiment was conducted during the 2010 cropping season to investigate the effects of *Leucaena* leaf biomass incorporation and NP fertilizer application on sorghum growth and *Striga* control. Two levels of *Leucaena* leaf biomass (2.5 and 5 t ha^{-1}) were applied with 50% recommended dose of urea (RDU) with or without 50% recommended dose of diammonium phosphate (DAP). The experiment included a standard treatment of 100% recommended dose of fertilizer (RDF i.e. 100 kg urea + 100 kg DAP) and farmers' practice of growing sorghum without any input as a control. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU gave significantly higher soil organic carbon (OC), cation exchange capacity (CEC), total N and leaf N content whereas significantly higher available P and plant tissue P content were recorded in the 5 t ha^{-1} *Leucaena* + 50% RDF-treated plots, respectively, over the control plots. Grain yield and aboveground biomass of sorghum were increased by 133 and 123%, and 368 and 385% in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots, respectively, over the control plots. The number of *Striga* plants at 65 days after sowing (DAS) of sorghum was also reduced by 82.33% and 96.33% in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots, respectively, over the control plots. Aboveground biomass of *Striga* at 95 DAS decreased by 41.6 and 39.32% in the 5 t ha^{-1} *Leucaena* + 50% RDF and 100% RDF treated plots, respectively, over the control plots. Plots treated with 2.5 t ha^{-1} *Leucaen*a + 50% RDF recorded comparable grain yield (2.160 t ha^{-1}) and even slightly greater sorghum above ground biomass (23.23 t ha^{-1}) than the 100% RDF-treated plots which recorded 2.22 t ha^{-1} of grain yield and 22.66 t ha^{-1} of aboveground biomass, respectively . It is, therefore, concluded that 5 t ha^{-1} *Leucaena* + 50% RDU can be used to improve sorghum productivity and manage *Striga* in the study area. Further research should be conducted across different locations for at least two seasons to substantiate this conclusion considering the cost benefit analysis of the practice.

Keywords: Aboveground Biomass; Grain Yield; Leuceana Leaf Biomass; Striga Infestation

1. Introduction

In Ethiopia**,** sorghum is one of the most widely grown staple cereal crops on which the lives of millions of poor Ethiopians depend. It is one of the leading traditional food crops ranking third in the country following *teff* and maize and second to *teff* for its *injera* (national pancake or bread) making quality (Tewdros *et al*., 2005).

Despite its importance in the livelihood of Ethiopians, sorghum production is constrained by different biotic and abiotic factors. The major sorghum production constraints include low soil fertility, weeds particularly *Striga*, insect mainly stalk borer (*Busseola fusca* and *Chilo partellus*) and birds. The increased land use pressure associated with rapid population growth and continuous cropping with minimum or no inputs is resulting in declining soil fertility. The decline in soil fertility and erratic rainfall favor increased *Striga* [*Striga hermonthica* (Del.) Benth] infestation. *Striga* species are semi-parasitic plants that parasitize the root systems of their hosts; and all *Striga* species except *Striga angustifolia* [Don.] Saldanha are dependent on a host to establish themselves, which makes them obligate parasites (Van Mourik, 2007). *Striga hermonthica* (Del.) Benth is a green erect herb with bright pink flowers and a height of around 30-40 cm at flowering (Van Mourik, 2007). It is thought to have co-evolved with wild relatives of sorghum during domestication in the Sudano-Ethiopian region of Africa (Mohamed *et al*., 1998). It has colonized over 86,000 hectare (h) of Ethiopian cropland resulting in maize yield losses of 76,395 tons (t) per year that is valued at almost $15.8 million per year (Woomer and Savala, 2008).

The presence of this parasitic weed has been assumed by farmers as an indicator of reduced soil fertility conditions (Avav *et al.,* 2009). *Striga* is the second most important sorghum production constraint resulting in yield loss of 560,000 metric tons per year (Wortmann *et al.,* 2006). Therefore, it is becoming a major concern

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threatening sorghum production in many parts of the country.

Growing of preferred cereals, such as maize and sorghum, without the application of chemical fertilizer is often being abandoned because of severe *Striga* infestation. It is widely accepted that applying nitrogen (N) in a form of fertilizer reduces crop losses attributed to *Striga* (Kim *et al.*, 1997). However, in Ethiopia in general and the study area in particular, few farmers have the resource to afford the present escalating price of fertilizer. Applying farmyard manure is also difficult, if not possible, for most resource-poor farmers who own only few or no farm animals. Leguminous trees' leaf biomass is capable of releasing considerable amounts of N that can sustain crop growth and yield (Makumba *et al.,* 2007). The use of N rich tree pruning as a substitute to inorganic fertilizers has proven to be a viable alternative source of soil fertility replenishment in low input smallholder subsistence farming systems where N deficient soils are the major limitation to crop production (Makumba *et al.,* 2007). Esilaba *et al.* (2000) at Sirinka, Ethiopia found that the combined application of manure and N at 40 kg N ha^{-1} and 30 t ha^{-1} for sorghum and 80 kg N ha^{-1} and 30 t ha^{-1} manure for maize increased crop yields during the second season. Moreover, and the combined application of 40 kg N ha^{-1} and 30 t ha^{-1} manure significantly reduced *Striga* emergence on maize. But, resource-poor subsistence farmers in Ethiopia cannot afford applying this much chemical fertilizer and farmyard manure. On the other hand, as indicated by Sharma and Behera, (2010) fast-growing leguminous trees and shrubs such as *Leucaena* are grown in non-agricultural lands or in alley cropping systems for multiple uses including nutrient cycling from the pruned biomass i.e. biomass transfer.

Therefore, in response to the sorghum production challenges highlighted above, there is a need to identify soil management systems which can maintain adequate level of soil fertility, increase crop yield and most importantly reduce the *Striga* seed bank in the soil. Hence, the specific objectives of this study were to: (1) investigate the effect of *Leucaena* leaf biomass and inorganic fertilizer application on soil fertility, and (2) investigate the effect of *Leucaena* leaf biomass and fertilizer application on sorghum growth and yield and *Striga* management.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at farmer's crop field near Pawe Agricultural Research Center, northwestern part of Ethiopia during the 2010 cropping season. Pawe Agricultural Research Center is located in Metekel Zone of Benishangul Gumuz National Regional State, at about 580 km north-west of Addis Ababa at 11^{o} 12' N latitude and and 36^{o} 25' E longitude.

The agroecological zone of the study area is characterized by hot humid condition with annual rainfall ranging from 1500 to 1800 mm, the average annual rainfall being 1659 mm concentrated in one season, i.e. from May to October (sometimes extending to November). The mean annual maximum temperature is 32 ^{o}C and monthly values range between 27 and 37 ^{o}C. The mean annual minimum temperature is 16 ^{o}C, and monthly values range between 12 and 19 ^{o}C. The meteorological data for the 2010 cropping season of the study area is given in Table 1.

The soils of the study area are broadly categorized as Vertisols (black clay soils) accounting for 40 to 45% of the area; Nitosols (red or redish-brown laterite soils) accounts for 25 to 30% and Luvisols (intermediate soils of blakish-brown color) accounts for 25 to 30% of the the area (Abayneh, 2003). The pH of the soil at the study area ranges from 5.5 to 6.9 (Abayneh, 2003) (Table 2). The major crops grown in the area include maize, sorghum, finger millet, rice, groundnut and sesame.

Table 1. Monthly rain fall and temperature data of the study area (Pawe District) for the 2010 cropping season (May to December).

		Temperature (^{0}C)	
Month	Rainfall (mm)	Mean minimum.	Mean maximum
May	68.7	21.0	39.2
June	270.3	18.9	30.52
July	440.1	18.5	28.35
August	438.1	18.6	28.1
September	242.4	18.1	28.47
October	185.9	18.3	31.7
November	6.4	15.0	32.23
December	0.0	10.8	33.0
Total	1651.9	-	-
Mean	206.50	17.40	31.45

Table 2. Some soil characteristics of the experimental field in Pawe District before treatment application.

Soil characteristics	Values for each block			
	Block 1	Block 2	Block 3	Mean
Sand (%)	26.04	25.08	13.60	21.57
Silt (%)	22.35	29.44	17.85	23.21
Clay (%)	51.60	45.48	68.55	55.21
Textural class	Clay	Clay	Clay	Clay
pH	6.20	6.57	6.12	6.30
Soil organic carbon (OC) (%)	2.17	1.85	1.86	1.96
Total N (%)	0.175	0.181	0.185	0.18
Cation exchange capacity (CEC) (cmolkg^{-1})	40.00	39.00	45.00	41.33
Available P (mg kg^{-1})	22.00	15.00	16.00	17.67
Exchangeable K (cmolkg^{-1})	1.81	1.56	1.65	1.67
Exchangeable Ca (cmolkg^{-1})	22.00	24.00	22.00	22.67
Exchangeable Mg (cmolkg^{-1})	12.00	9.00	10.00	10.33

2.2. Experimental Design and Procedures

The field experiment was conducted during the 2010 cropping season (from May to December). Six treatments were laid out in a randomized complete block design (RCBD) with three replications. The treatments included: (1) 100% RDF: 100% recomonded dose of fertilizer (100 kg urea with 100 kg of DAP); (2) 2.5 t ha^{-1} + 50% RDF: 2.5 tons of *Leucaena* leaf biomass per hectare with 50% recomonded dose of fertilizer (50 kg of urea and 50 kg of DAP); (3) 2.5 t ha^{-1} + 50% RDU 2.5 tons of *Leucaena* leaf biomass per hectare with 50 % recommended dose of urea ; (4) 5 t ha^{-1} + 50% RDF: 5 tons of *Leucaena* leaf biomass per hectare with 50% recomonded dose of fertilizer (50 kg urea with 50 kg of DAP); and (5) 5 t ha^{-1} *Leucaena* + 50% RDU: 5 tons of *Leucaena* leaf biomass per hectare with 50% recomonded dose of urea, and (6) Control: farmers' practice i.e. production of sorghum without fertilizer and *Leucaena* leaf biomass application.

Fresh leaves of *Leucaen*a were collected from locally grown trees (trees around homesteads) and transferred to the experimental plots. The applied fresh *Leucaena* leaf biomass had 4.5% N, 1.04% phosphorus, 0.95% potassium, 1.91% calcium, 0.52% magnesium and C: N ratio of 16.45. The leaf biomass was applied in splits i.e. one half one month before planting the crop and the remaining half does at planting as suggested by Kurdali and Al-Shamma'a (2010), and it was incorporated in to the soil using hand hoe. The leaf biomass was evenly applied so to avoid biasness.

Each experimental plot was 4 m x 4 m (16 m^2) in size and there was 1 m space between plots. There was a 2 m disatnce between blocks. A land race sorghum variety locally known as "Nech Bove" was used as test crop. The variety was selected due to its sensitiveness to *Striga* infestation, and is widely grown in the district due to its high grain yielding potential relative to other varieties. The crop was planted on 15th June, 2010 spaced 0.75 m apart with 0.25 m spacing between plants within each row. There were five rows of sorghum per plot. Data on sorghum leaf nutrient content, growth parameters, grain yield and aboveground biomass, striga counts and above ground biomass were taken from the middle three rows or the net plot area of 2.5 m x 2.5 m (6.25 m^2). All weedy species except *Striga* were removed regularly once a week so as to avoid the effect of other weeds on sorghum growth.

2.3. Soil Sampling and Analysis

The soil and plant tissue analyses were conducted at Water Works Design and Supervision Enterprise in Addis Ababa, Ethiopia. Soil samples were taken from the upper (0-30 cm) soil depth at five spots spots in an X design in each block using auger prior to the application of *Leucaena* leaf biomas mulch to get a composite sample that could represent the block. More over, soil samples were taken using the same method as indicated above from each treatment plot in the block after the crop was harvested and mixed to make composite samples for each treatment. The samples were then air-dried at room temperature, crushed and sieved through a 2 mm mesh for analysis.

Soil texture was determined by Bouyocous hydrometer method (Ryan *et al.*, 2001) and soil pH by pH meter in a 1:2.5 soil suspension (W/V). Soil OC (%) was determined using a Walkley-Black Method as described in (Nelson and Sommers, 1982) and sodium acetate for extraction and CEC was determined using flame photometer as described by van Reeuwijk (2002). Total N was determined using Kjeldhal method as stated in Baker and Thompson (1992) and available phosphorus was determined using Olsen method as described by Ryan *et al.* (2001). The amount of available K was determined using flame photometer; whereas exchangeable bases (Ca and Mg) in the NH_4OAc extract were determined using atomic absorption spectrophotometer as stated by van Reeuwijk (2002).

2.4 Leaf Tissue Sampling and Analysis

Leucaena leaf sub-samples were collected for nutrient content determination before the leaf biomass was soil-incorporated. Sorghum leaf tissue samples were collected at random from the second top leaf of the plant at heading stage as recommended by Jones *et al.* (1991) and Reuter and Robinson (1986). The leaf tissue samples were washed with distilled water to remove any adhering particles and dried in oven at 65 ^oC for 48 hours. The samples were then finely ground and made ready for analysis using wet ashing with concentrated H_2SO_4 and H_2O_2 for N while dry ashing was used for P, K, Ca and Mg using hydrochloric acid as stated by Nathan and Sun (2006).

The leaf N content was determined using Kjeldahl method as stated in Baker and Thompson (1992), P content was determined using colorimetry as stated by Moore (1992), K was determined using flame photometer; while atomic absorption spectrophotometry was used for the determination of Ca and Mg as stated by Nathan and Sun (2006).

2.5 Sorghum Growth Parameters

The parameters measured as sorghum growth components included: plant height (m), stalk diameter (cm) and number of effective tillers. All measurements on the above mentioned parameters were made on the same five randomly selected plants from the net plot area of each treatment. Grain was harvested from all plants in the net plot of 2.5 * 2.5 (6.25 m^2). The collected air-dried heads were threshed, cleaned and weighed for grain weight analysis. The aboveground biomass (t ha^{-1}) was estimated based on air-dried sub-sample plant biomass in each net plot. The percenatage (%) relative yield and aboveground biomass increament (%) over the control (check) ware then determined.

2.6 Parameters for *Striga*

Number of *Striga* shoots that emerged per net plot was recorded at 65 DAS (vegetative stage) and 95 DAS (heading stages) of sorghum. The first *Striga* count was taken at 65 DAS of sorghum where the maximum number of *Striga* emergence could be observed at 60-70 DAS (Kim, 1994). The secound count was made at 95 DAS of sorghum to see the trend of *Striga* infesstation. Similarly, the above-ground biomass of *Striga* was determined from the same net plot area. The *Striga* shoots collected from the net plot area at 95 DAS were sun dried in the field for four days until constant weight was attained and the dry weight was converted to hectare basis.

2.7 Data Analysis

To reduce variation in the results of effective number of sorghum tillers and *Striga* count; and make data analysis valid, the data were transformed using square root transformation ($\sqrt{x+0.5}$).

All data collected were subjected to analysis of variance (ANOVA) to assess treatment effects (Gomez and Gomez, 1984) and the significant differences between means were determined by LSD at 5% probability level using SAS version 9.

3. Results and Discussion

3.1. Soil Fertility Status of the Experimental Plots after Sorghum Harvest

Soil organic carbon (%), total N (%), CEC (cmol kg^{-1}), and exchangeable Mg (cmol kg^{-1}) showed increments in the plots treated with 5 t ha^{-1} *Leucaena* leaf biomass either with 50% RDF or with 50% RDU as compared to the control (Table 3). Significantly higher OC (2.87 and 2.75%), CEC (52.85 and 51.29 cmol kg^{-1}) and total N (0.214 and 0.209%) were recorded in the plots treated with 5 t ha^{-1} + 50% RDF and 5 t ha^{-1} + 50% RDU, respectively. Relative to the control plots, the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots increased OC by 52.66 and 46.28% and total N by 50%, respectively.

Hossain *et al.* (2007) also found highest OC (%) and total N (%) in the 5 t ha^{-1} *Leucaena* leaf green manure treated plots 105 days after incorporation as compared to green manure from *Erythrina orientalis, Acacia auriculiformis, Dalbergia sissoo* and the control (no green manure) plot. The results of this study also support the conclusion made by Kang *et al.* (1985) that large amounts of N could be obtained from *Leucaena* pruning. This was due to the high N content of the applied *Leucaena* leaf biomass.

CEC, that is the ability of the soil to adsorb (hold) cations, and which is an indication of the soils potential fertility, was significantly ($P < 0.05$) higher in plots treated with 2.5 t ha^{-1} *Leucaena* + 50% RDF, 5 t ha^{-1} *Leucaena* + 50% RDF or 5 t ha^{-1} *Leucaena* + 50% RDU than both the 100% RDF-treated and the control plots. Significantly higher ($P < 0.05$) exchangeable Mg (17.05 cmol kg^{-1}) was recorded in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots. But, there was no significant difference in available K (mg K Kg^{-1}) and exchangeable Ca (cmol kg^{-1}) among treatment means.

There was very high variation in available P among treatments. Available P (30.86 mg P Kg^{-1}) recorded in the 5 t ha^{-1} *Leucaena* + 50% RDF-treated plots was considerably greater by 901.95% than the available P (3.08 mg P Kg^{-1}) recorded in the the control plot. The result of the present study was in line with Larbi *et al.* (1993) who reported that available P tended to increase with increasing proportion of prunning applied as mulch. However, the current finding contracdts with the finding reported by Atta-Krah (1990) and Haggar (1994) who indicated that lower soil P was recorded in plots treated with *Leucaena* leaf mulch than the conventional cropping system. This may be due to the released P was fixed by clay colloids.

3.2. Sorghum Leaf Nutrient Content

The highest leaf N content (3.35%) was recorded in 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots and the lowest (2.44%) was in the control plots (Table 4). There was an increment by 37.29% in leaf N content in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots over the control plots. The results of the present study were in agreement with the findings reported by Cox and Unruh (2000). According to Cox and Unruh (2000), leaf N content recorded in the plots treated with 100% RDF, 2.5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU falls in the sufficient range (2.5-4.0) at flowering (heading stage) of sorghum, whereas leaf N content at this growth stage in the control plots was in the deficient range (2.4%).

The highest (1.55%) leaf P content was recorded in the plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF, while the lowest leaf P content (0.76%) was recorded in the control plots. This shows that plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF increased leaf P content by 103.95% over the control plots. Despite the significant difference ($P < 0.05$) among treatments in leaf P content at flowering of sorghum, the values recorded in all treatments were in the high range (> 0.5%) (Cox and Unruh, 2000).

Table 3. Soil fertility status of experimental plots as influenced by *Leucaena* leaf biomass and fertilizer application in Pawe in 2010.

Treatment	OC (%)	CEC($cmolkg^{-1}$)	Total N (%)	A.P (mg P Kg^{-1})	A.K (mg K Kg^{-1})	Ex.Ca ($cmolkg^{-1}$)	Ex.Mg ($cmolkg^{-1}$)
1) 100%RDF	2.06^{bc}	43.26^{bc}	0.16^{bc}	21.77^{ba}	259.5^{a}	18.89^{a}	10.04^{bc}
2) 2.5 t ha^{-1} + 50% RDF	2.64^{ba}	50.59^{a}	0.18^{ba}	14.56^{ba}	253^{a}	19.91^{a}	13.67^{ba}
3) 2.5 t ha^{-1} + 50% RDU	2.56^{ba}	47.37^{ba}	0.18^{ba}	$5.17b^{a}$	110.8^{a}	20.51^{a}	14.02^{ba}
4) 5 t ha^{-1}+ 50% RDF	2.75^{a}	52.85^{a}	0.214^{a}	30.86^{a}	253.6^{a}	21.28^{a}	15.53^{a}
5) 5 t ha^{-1}+ 50% RDU	2.87^{a}	51.29^{a}	0.219^{a}	18.80^{ba}	125.1^{a}	21.73^{a}	17.05^{a}
6) Control	1.88^{c}	38.67^{c}	0.140^{c}	3.08^{b}	97.8^{a}	19.56^{a}	8.39^{c}
CV(%)	13.31	11.83	7.36	13.23	15.65	9.48	18.48
LSD (0.05)	0.59	6.34	0.04	26.13	NS	NS	NS

Values along column followed by the same letter (s) are not significantly different (P < 0.05); OC = Soil organic carbon; A.P = Available P; A.K= Available K; Ex.Ca = Exchangeable; Ca; Ex. Mg = Exchangeable Mg,

Table 4. Leaf nutrient content (%) of sorghum at 95 DAS (heading stage) as influenced by *Leucaena* leaf biomass and fertilizer application in Pawe in 2010.

Treatment	Leaf nutrient content (%)				
	N	P	K	Ca	Mg
1) 100% RDF	2.73^{bc}	1.28^{b}	0.78^{a}	1.80^{a}	0.56^{a}
2) 2.5 t ha^{-1} + 50% RDF	2.81^{bc}	1.22^{bc}	0.75^{a}	1.63^{a}	0.58^{a}
3) 2.5 t ha^{-1} + 50% RDU	2.73^{bc}	1.01^{dc}	0.62^{a}	1.57^{a}	0.47^{a}
4) 5 t ha^{-1} + 50% RDF	3.01^{ab}	1.55^{a}	0.62^{a}	1.45^{a}	0.61^{a}
5) 5 t ha^{-1} + 50% RDU	3.35^{a}	1.25^{bc}	0.85^{a}	1.45^{a}	0.52^{a}
6) Control	2.44^{c}	0.76^{d}	1.21^{a}	1.85^{a}	0.47^{a}
CV(%)	9.35	33.63	23.08	23.12	18.94
LSD (0.05)	0.484	0.26	NS	NS	NS

Note:Values along column followed by the same letter (s) are not significantly different (P < 0.05.

However, no significant difference was recorded between treatments in leaf K, Ca and Mg (%) content of sorghum among treatments. The recorded leaf K content was at the deficient level (< 1.4%) according to Cox and Unruh (2000) in all treatments with slight difference among means whereas sorghum leaf Ca content was in the high range (> 0.6%) in all treatments. Leaf Mg content recorded in the plots treated with 2.5 t ha^{-1} *Leucaena* + 50% RDU and the control plots was in the sufficient range (0.2 to 0.5 %) where as it was in the high range (> 0.5%) in the 100% RDF, 2.5 t ha^{-1} *Leucaena* + 50% RDF, 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots (Cox and Unruh, 2000).

3.3. Growth Parameters of Sorghum

The data on plant height, stalk diameter and number of effective tillers per plant showed significant differences ($P \leq 0.05$) among treatments (Table 5). Plant height and stalk diameter increased with increase in *Leucaena* leaf biomass level. The tallest plant height of 3.58 and 3.54 m were recorded in plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50%

RDU, respectively, as compared to 3.15 m in the 100% RDF-treated plots and 2.10 m in the control plots.

Though the difference was not significant among the treatments except the control, the thickest stalk diameter was recorded in plots treated with 5 t ha^{-1} *Leucaena* + 50% RDU (2.89 cm) and 5 t ha^{-1} *Leucaena* + 50% RDF (2.88 cm). However, there was significant difference ($P < 0.05$) in number of effective tillers per plant among treatments. Plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU produced significantly higher average number of effective tillers of 1.33 and 1.56, respectively, than the control plots (0.71).

Table 5. Plant height, stalk diameter and number of effective tillers as influenced by *Leucaena* leaf biomass and fertilizer application.

Treatment	Height (m)	Stalk diameter (cm)	No. of effective tillers/plant
1) 100% RDF	3.15^{cd}	2.66^{a}	0.88(0.33)^{cd}
2) 2.5 t ha^{-1} + 50% RDF	3.34^{bc}	2.76^{a}	1.16 (0.89)^{b}
3) 2.5 t ha^{-1} + 50% RDU	3.11^{d}	2.70^{a}	0.99(0.56)^{cb}
4) 5 t ha^{-1} + 50% RDF	3.58^{a}	2.88^{a}	1.332(1.333)^{a}
5) 5 t ha^{-1} + 50% RDU	3.54^{ab}	2.89^{a}	1.4(1.56)^{a}
6) Control	2.10^{e}	1.80^{b}	0.71(0)^{d}
CV(%)	6.89	10.05	25.5
LSD (0.05)	0.15	0.25	0.16

Values along column followed by the same letter (s) are not significantly different ($P < 0.05$); Numbers in the parenthesis are original data (data before square root transformatio

Hossain *et al.* (2007) also found tallest rice plant height and the greatest number of effective tillers per hill from plots treated with *Leucaena* leaf green manure compared to plots treated with green manure from *Erythrina orientalis, Acacia auriculiformis, Dalbergia sissoo* and the control (no green manure). Similarly, Latt *et al.* (2009) found significantly higher plant height and tiller number of rice in green manure treatments than those in the urea and no application treatments. The vigorous growth of sorghum in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} + 50% RDU-treated plots which resulted in the tallest plants, thickest stalk diameter and highest average number effective tillers might be attributable to the highest OC and total N content (Hossain *et al.,* 2007; Latt *et al.,* 2009).

3.4. Sorghum Grain Yield and Aboveground Biomass

Grain yield differed significantly ($P < 0.05$) with treatment difference (Table 6). Applications of 5t ha^{-1} *Leucaena* + 50% RDU and 5 t ha^{-1} *Leucaena* + 50% RDF gave significantly higher ($P < 0.05$) grain yield of 2.65 t ha^{-1} and 2.54 t ha^{-1}, respectively, than the control (1.12 t ha^{-1}) and 100% RDF-treated plots (2.22 t ha^{-1}). The pronounced response of sorghum grain yield and aboveground biomass to the application of 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU; and the comparable grain yield and aboveground biomass obtained from plots treated with 2.5 t ha^{-1} *Leucaena* + 50% RDF with the 100% RDF contradicts the investigation of Nyathi and Campbell (1995) who elucidated that *Leucaena* which is reach in N but low in P, resulted in largest yield reduction, assuming that this material resulted in P immobilization.

However, the current finding is in line with the findings reported by Hossain *et al.* (2007). The authors reported that application of tree litter of different species had a significantly positive effect on the yield parameters of rice. They concluded that it is worthy to note that addition of tree litter to inorganic fertilizer produced significantly higher yield than inorganic fertilizers solely. From their experiment grain yield of plots treated with *Leucaena* resulted in yield increment over the control plots (plots treated with recommended dose of inorganic fertilizer) by 39.6%. This indicates that there is a possibility of replacing the expensive commercial fertilizers by the locally produced fertility enhancing green manure sources to improve productivity and gain yields from maize-based cropping systems. Nahar *et al.* (1996) also found higher rice grain yield from *Leucaena* leaf green manure-treated plots than plots applied solely with chemical fertilizer. Furthermore, Sharama and Behera (2010) found near maximum wheat grain yield when equal amounts of N were substituted through use of *Leucaena* and urea.

In a similar trend to the grain yield, aboveground biomass of sorghum also showed high variation among treatments (Table 6). Application of 5 t ha^{-1} *Leucaena* + 50% RDU and 5 t ha^{-1} *Leucaena* + 50% RDF, which yielded 42.81 and 41.45 t ha^{-1}, respectively, also resulted in a 385.3 and 368.94% increment, respectively, over the control plots (Figure 1). Plots treated with 5 t ha^{-1} *Leucaena* + 50% RDU and 5 t ha^{-1} *Leucaena* + 50% RDF produced significantly ($P < 0.05$) higher aboveground biomass even than the 100% RDF-treated plots. Aboveground biomass of sorghum increased by 385.3% in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots followed by a 368.94% increment in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots over the control plots (Figure 1). This could be attributed to the improvement in plant height, stem diameter and number of effective tillers due to the beneficial effect of *Leucaena* leaf biomass addition as also reported by Latt *et al.* (2009). The increment in grain yield and above-ground biomass of sorghum seemed to benefit from *Leucaena* leaf biomass addition that has contributed significantly to the N and P nutrition of the crop.

Table 6. Effect of *Leucaena* leaf biomass and fertilizer application on sorghum grain yield and aboveground biomass.

Treatment	Grain yield (t ha^{-1})	Aboveground biomass (t ha^{-1})
1) 100% RDF	2.22^{b}	22.66^{b}
2) 2.5 t ha^{-1} + 50% RDF	2.16^{b}	23.23^{b}
3) 2.5 t ha^{-1} + 50% RDU	2.01^{c}	17.93^{c}
4) 5 t ha^{-1} + 50% RDF	2.54^{a}	30.95^{a}
5) 5 t ha^{-1} + 50% RDU	2.65^{a}	32.03^{a}
6) Control	1.12^{d}	6.60d
CV (%)	7.26	11.29
LSD (0.05)	1.4	4.03

Values along column followed by the same letter(s) are not significantly different (P < 0.05).

3.5. Number and Aboveground Biomass of Striga

Striga number per plot showed significant differences (P < 0.05) among treatments (Table 7). The number of Striga per plot was highest in the control (9/plot) and lowest in the 2.5 t ha^{-1} *Leucaena* + 50% RDU, 5t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU- treated plots each producing one per plot at 65 DAS (vegetative stage). This agrees with the findings reported by Avav *et al.* (2009) that the highest numbers of Striga stands emerged in plots that had neither mucuna leaf biomass nor fertilizer. The highest number of Striga in the control plots at 65 DAS agrees with the discussion made by Gurney *et al.* (1999) that early infestation by Striga had more negative effect on the host plant than late infestation. Gacheru and Rao (2001) also found lowest Striga infestation when 120 kg N was applied with or without P using fresh foliage of 5 t (dry weight) ha^{-1}.

However, at the later growth stages of sorghum (heading stage) the number of *Striga* significantly (P < 0.05) increased in the 5 t ha^{-1} *Leucaena* +50% RDF and 5 t ha^{-1} *Leucaena* +50% RDU-treated plots even were greater than in the control plots (Table 7). Esilaba *et al.* (2000) also found that addition of fertilizer N increased the mean *Striga* emergence on sorghum. They suggested that the later increase in *Striga* emergence may be related to production of a more extensive sorghum root system which increased the root surface area and thus stimulated emergence of the parasitic weed population. The vigorous growth of sorghum in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots in this study also implies an extensive root growth and increased root surface area of sorghum attributed to improved OC, total N and available P. Despite the highest number in the later growth stages, the growth of *Striga* at these plots was highly suppressed by the shade created by the vigorous growth of sorghum. This agrees with the findings reported by Kureh *et al.* (2003) that N-fertilizer delayed *Striga* emergence, promoted maize growth and shoot dry matter production and reduced *Striga* damage.

Dry weight of *Striga* was also significantly (P < 0.05) influenced by the different treatments. Plots treated with 5 t ha^{-1} *Leucaena* +50% RDF gave the lowest *Striga* dry weight (1.99 t ha^{-1}), followed by plots treated with 100% RDF (2.062 t ha^{-1}) (Table7). Significantly higher (P < 0.05) *Striga* dry weight was recorded in the control plots. The reduction (by 41.72%) in *Striga* infestation level in aboveground biomass was recorded in the plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF, followed by a 38.72 and 37.54% reduction in the plots treated with 100% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots, respectively (Table 7). This indicates that application of *Leucaena* leaf biomass and fertilizer had resulted in the impediment of *Striga* germination during the vegetative growth (early growth) stage of sorghum. This could be attributed to the N released from the applied *Leucaena* leaf biomass and fertilizer during the active growth stage of sorghum which enabled the crop to uptake nutrients for its robust growth. This, in turn, implies that much of the nutrient released from the added *Leucaena* leaf biomass and fertilizer was utilized by the crop in its active (vegetative) growth stage.

Table 7. Effect of *Leucaena* leaf biomass and fertilizer application on *Striga* infestation in number at 65 and 95 DAS of sorghum and aboveground biomass at 95 DAS.

Treatment	Number of *Striga* per plot (6.25 m²) At 65 DAS (vegetative stage)	At 95 DAS (heading stage)	*Striga* above ground biomass (t ha^{-1})
1) 100% RDF	1.39(1.78)^{b}	6.74(49.67)^{d}	2.06^{bc}
2) 2.5 t ha^{-1} + 50% RDF	1.44(3.44)^{b}	7.32(61.55)^{dc}	2.24^{bc}
3) 2.5 t ha^{-1} + 50% RDU	0.98(0.67)^{b}	7.55(64)^{bdc}	2.40^{b}
4) 5 t ha^{-1} + 50% RDF	0.88(0.33)^{b}	8.99(91.44)^{a}	1.99^{c}
5) 5 t ha^{-1} + 50% RDU	0.88(0.33)^{b}	8.90(90.55)^{ba}	2.13^{bc}
6) Control	3.25(9.22)^{a}	8.12(70.78)^{bac}	3.41a
CV (%)	24.74	17.80	19.06
LSD(0.05)	0.67	1.38	0.34

Values along column followed by the same letter (s) are not significantly different (P < 0.05); Numbers in the parenthesis are original data (data before square root transformation).

4. Conclusions

The findings revealed that application of 5 tons of *Leucaena* leaf biomass either with 50% RDF or with 50% RDU resulted in significantly (P < 0.05) higher % OC, total N content and CEC than both the 100% RDF and control plots. Available P was highest in the 5 t ha^{-1} *Leucaena* + 50% RDF-treated plots, followed by the 100% RDF-treated plots as compared to any other plots. The improvement in these soil fertility parameters resulted in significantly (P < 0.05) taller plant height, higher stalk diameter, maximum average number of effective tillers and, which in turn, ultimately resulted in significantly (P < 0.05) higher grain yield and above ground biomass of sorghum than in the control plots. Similarly, application of *Leucaena* leaf biomass and fertilizer could delay *Striga* germination.

Therefore, we can conclude that application of *Leucaena* leaf biomass at 2.5 t ha^{-1} with 50% RDF and 5 t ha^{-1} either with 50% RDF or with 50% RDU can substitute the 100% RDF to improve sorghum productivity and manage *Striga*.

Hence, it is recommended that (1) application of *Leucaena* leaf biomass with fertilizer should be considered as one option to improve soil fertility, increase sorghum productivity and manage *Striga* in Pawe District; (2) since this study was conducted for a single cropping season, further research should be done for more cropping seasons to substantiate these findings; and (3) further investigation should also be done to determine the long term effect of applying *Leucaena* leaf biomass in terms of soil fertility improvement, crop productivity and soil *Striga* seed bank and *Striga* management considering cost-benefit analysis over the chemical fertilizer in the study area.

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6. References

Abayneh, E. 2003. Soils of Pawe Agricultural Research Centre. National Soil Research Centre. Ethiopian Agricultural Research Organization Technical Paper No. 78.

Atta-Krah, A.N. 1990. Alley farming with Leucaena: effect of short grazed fallows on soil fertility and crop yields. *Experimental Agriculture* 261: 1-10.

Avav, T., Shave, P.A., Magani, E.I. and Ahom, R.I. 2009. Effects of Mucuna biomass and N-fertilizer on *Striga hermonthica* (Del.) Benth. Infestation in maize (*Zea mays* L.). *Journal of Animal and Plant Sciences* 4: 320-328.

Baker, W.H. and Thompson, T.L. 1992. Determination of total nitrogen in plant aamples by Kjeldahl. *In*: Plank, C.O. (ed.). Plant Analysis Reference Procedures for the Southern Region of the United States. Southern Cooperative Series Bulletin 368.

Cox, F.R. and Unruh, L. 2000. Reference sufficiency ranges-field crops. *In*: Campbell, C.R. (ed.). Reference Sufficiency Ranges for Plant Analysis in the Southern Region of the United States. Southern Cooperative Series Bulletin 394.

Esilaba, A.O., Fasil, R., Ransom, J. K., Wondimu, B., Gebremehdin. W. and Beyenesh, Z. 2000. Integrated nutrient management strategies for soil fertility improvement and *Striga* control in northern Ethiopia. *African Crop Science Journal* 8: 403-410.

Gacheru, E. and Rao, M.R. 2001. Managing *Striga* infestation on maize using organic and inorganic nutrient sources in western Kenya. *International Journal of Pest Management* 47: 233-239.

Gomez, K.A. and Gomez A.A. 1984. *Statistical Procedure for Agricultural Research (*2nd edition*)*. An International Rice Research Institute Book. A Wiley-Interscience Publication. John Wiley and Sons, Singapore.

Gurney, A.L., Press, M.C. and Scholes, J.D. 1999. Infection and Density Influence the Response of

Sorghum to the Parasitic Angiosperm *Striga hermonthica*. *New Phytologist* 143: 573-580.

Hagger, J.P. 1994. Trees in alley cropping: competitors or soil improvers? *Outlook on Agriculture* 23: 27-32.

Hossain, K. L., Wadud, M.A. and Santosa, E. 2007. Effect of Tree Litter Application on Lowland Rice Yield in Bangladesh. *Bulletin of Agronomy* 35: 149-153.

Jones, J., Wolf, B. and Mills, H.A. 1991. *Plant analysis handbook*. Micro-Macro Publishing Inc., Athens, GA, USA.

Kang, B.T., Grimme, H. and Lawson, T.L. 1985. Alley cropping sequentially cropping maize and cowpea with leucaena on a sandy soil in Southern Nigeria. *Plant and Soil* 85: 267-277.

Kim, S.K. 1994. Genetics of maize tolerance of *Striga hermonthica*. *Crop Science* 34: 900-907.

Kim, S.K., Adetimirin, V.O. and Akitunde, A.Y. 1997. Nitrogen effects on *Striga hermonthica* infestation, grain yield, and agronomic traits of tolerant and susceptible maize hydrids. *Crop Science* 37: 711–716.

Kurdali, F. and Al-Shamma'A, M. 2010. Growth and nitrogen uptake in sorghum plants manured with *Leucaena leucocephala* leaves as affected by nitrogen rate and time of application. *Communications in Soil Science and Plant Analysis* 41: 308-319.

Kureh, I., Chikoye, D., Schulz, S., Emechebe, A.M., Hussaini, A.M., Kormawa, P., Schuliz, S., Ellis-Jones, J., Frank, L. and Odunze, A.C. 2003. Reduction of *Striga hermonthica* parasitism on maize using host-plant resistance, N-fertilization and rotation with legume trap crops. *African Crop Science Conference Proceedings* 6: 167-171.

Larbi, A., Jabbar, M.A.M, Atta-Krah, A.N. and Cobbina, J. 1993. Effect of taking a fodder crop on maize grain yield and soil chemical propwrties in leucaena and gliricidia alley farming systems in Western Nigeria. *Experimental Agriculture* 29: 317-321.

Latt, Y.K., Myint, A.K., Yamakawa, T. and Ogata, K. 2009. The Effects of Green Manure (*Sesbania rostrata*) on the Growth and Yield of Rice. *Journal of Faculty of Agriculture of Kyushu University* 54: 313–319.

Makumba, W., Akinnifesi, F.K., Janssen, B. and Oenema, O. 2007. Optimization of nitrogen released and immobilization from soil-applied prunings of *Sesbania sesban* and maize stover. *Scientific Research and Essay* 2: 400-407.

Mohamed, A.H., Gebisa, E., Butler, L.G. and Housley, T.L. 1998. Moisture content and dormancy in *Striga asiatica* seeds. *Weed Research* 38: 257-265.

Moore, K.P. 1992. Determination of phosphorus in plant tissue by colorimetry. *In*: Plank, C.O. (ed.). Plant Analysis Reference Procedures for the Southern Region of the United States. Southern Cooperative Series Bulletin 368.

Nahar, K., Haider, J. and Karim, A.J.M.S. 1996. Effect of organic and inorganic nitrogen sources on rice performance and soil properties. *Bangladesh Journal of Botany* 25: 73-78.

Nathan, M.V. and Sun, Y. 2006. Methods for Plant Analysis. A Guide for Conducting Plant Analysis in Missouri. University of Missouri Soil and Plant Testing Laboratory, Division of Plant Sciences, University of Missouri-Columbia.

Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. pp 570-571. *In*: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Madison.

Nyathi, P. and Campbell, B.M. 1995. Interaction effect of tree leaf litter, manure and inorganic fertilizer on the performance of maize in Zimbabwe. *African Crop Science Journal* 3: 451-456.

Reuter, D.J. and Robinson, J.B. 1986 (eds.) Plant analysis: An interpretation manual, 2nd ed. CSIRO Publ., Australia. (http://www.publish.csiro.au/pid/437.htm (Accessed on 15 June, 2010).

Ryan, J., Estefan, G. and Rashid, A. 2001. Soil and Plant Analysis Laboratory Manual. 2nd Edition. Jointly published by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the National Agricultural Research Center (NARC). Available from ICARDA, Aleppo, Syria.

Sharma, A.R. and Behera, U.K. 2010. Green leaf manuring with prunings of *Leucaena leucocephala* for nitrogen economy and improved productivity of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. *Nutrient Cycling Agroecosystem* 86: 39–52.

Tewodros, M., Girma, A. and Abdel-Rahman M.A.T. 2005. Effect of Reduced Tillage and Crop Residue Ground Cover on Yield and Water Use Efficiency of Sorghum (*Sorghum bicolor* (L.) Moench) Under Semi-Arid Conditions of Ethiopia. *World Journal of Agricultural Sciences* 1: 152-160.

Van Mourik, T.A. 2007. *Striga hermonthica* seed bank dynamics: process quantification and modeling. PhD dissertations. Wageningen University, Wageningen, Netherlands. (http://edepot.wur.nl/121907). (Accessed on 20 August, 2010).

Van Reeuwijk, L.P. (ed.) 2002. Procedures for Soil Analysis.Technical Paper 9. (http://www.isric.org/ISRIC/webdocs/ docs/ tp9blanco.pdf) (Accessed on 15 November, 2010).

Woomer, P.L. and Savala, C.E.N. 2008. *Striga* Technology Extension Project (STEP): Long Rains 2008 Report. Forum for Organic Resource Management and Agricultural Technology. Nairobi, Kenya.

Wortmann, C.S., Martha, M., Mburu, C., Letayo, E., Girma, A., Kaizzi, C., Chisi, M., Mativavarira, M., Xerinda, S. and Ndacyayisenga, T. 2006. Atlas of Sorghum Production in Eastern and Southern

Africa. The Board of Regents of the University of Nebraska, US. http:www.intsormil.org/smscientificpubs/Sorghum (Accessed on 21 March 2011).