Evaluation and demonstration of leguminous shrubs hedgerows intercropping with maize crop

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ABSTRACT

Smallholder farmers influenced from the challenges of production constraints to afford farm family with surplus food. To improve this problem the present study was designed to evaluate legume shrubs hedgerow intercropping with maize. In the present study, the growth performance of *Sesbania sesban* and *Cajanus cajan* was evaluated to determine their potential in hedgerow intercropping. The result revealed that *Sesbania sesban* performs better than *Cajanus cajan* in terms of biomass provision in the successive pruning, mean height, branching, diameter at breast height and root collar diameter. Biomass produced from *Sesbania sesban* was significantly higher than *Cajanus cajan*, this plays great role in soil nutrient improvement and maize yield also increased. There was an increasing trend in soil properties in terms of organic C, total N, in legume treatments especially in *Sesbania sesban* hedgerow to the initial and control soils. Maize grain yield higher under *Sesbania sesban* hedgerow plot than *Cajanus cajan*, maize with fertilizer and control. This should be intensively demonstrated to sustain the agricultural production as an organic farming through integration of easily adapting, less competing with the companion crop, deep rooted and fast growing legume tree/shrub species. Further research is important in areas of determining decomposing rate of different parts, pruned biomass and potential species should be identified.

Keywords: Biomass incorporation, *Cajanus cajan*, Legume shrubs, *Sesbania sesban*.

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Introduction

In many parts of the tropics and predominantly in tropical Africa, nitrogen (N) is the most limiting nutrient to crop production. Supply of balanced nutrients to the soil is essential to get desired crop yield. N is essential for the growth of plants and when its supply is inadequate, young plant will fail to establish while established plant will become declining (Richards *et al.*, 1993; Assefa *et al.*, 2013). Costs of inorganic fertilizers limit their use in adequate quantities by most smallholder farmers. This has led to increased interest in development of integrated soil fertility management systems that incorporate woody species into crop production systems where leafy biomass provides N to the annual crop (Kang *et al.*, 1990). Low soil fertility is the major cause for low agricultural productivity, food insecurity, low income and poverty in Ethiopia (Abebe *et al.*, 2006). Much of the decline in soil quality is linked to human population growth and organic matter loss due to intensive cultivation. Loss of soil quality is explained through increased bulk density, reduced inorganic matter content and availability of soil nutrients. Obviously, substantial increase of yield will result in correcting soil nutrient deficiencies using different experimentally supported methods. Maintenance of soil quality is considered essential for ensuring sustainable land use; and land resource management must aim at soil conservation (Parysow *et al.*, 2001).

In tropical Africa, nitrogen is the most limiting nutrient to crop production; high costs of inorganic fertilizers limit their use in sufficient quantities by most smallholder farmers. This has led to increased interest in development of integrated soil fertility management systems that incorporate woody species into crop production systems where leafy biomass provide N to the annual crop. Trees and shrubs are used in

hedgerow intercropping cropland or parkland systems, improved fallows and shaded perennial-crop systems. Large amounts of N and moderate amounts of P have been observed in standing biomass, but much variation occurs in the recycling of these nutrients. However, leguminous trees species have shown some potential for soil fertility improvement through biomass transfer, short term fallows, nitrogen fixation, re-activation of the 'N bulge' and phosphorus scavenging (Hartemink *et al.*, 2000). Agroforestry practices are based on the idea that trees increase nutrient cycling, improve soil fertility, and support the growth of crops (Nair *et al.*, 1999). Agroforestry can be a viable option to alleviate degradation and loss of soil fertility from the agricultural fields. Agroforestry, especially alley cropping, can help more efficiently to manage agriculture production system (Jordan, 2004). Trees continuously contribute to soil organic matter through shedding of leaves and roots. High decomposition and mineralization rates under woody species as compared to the open field are due to improved soil conditions under a tree canopy. In this respect, the relatively high organic matter content under a tree canopy is a key factor (Young, 1999). Tree pruning are used as mulch to suppress weeds, green manure, firewood as well as browse. Leguminous trees fixed nitrogen biologically to companion crops (USDA, 2012).

Alley cropping is a new step because the trees are used primarily for soil improvement. Alley cropping is one of an important agroforestry practice in which high organic biomass produced from the pruning's of hedgerow species and build soil organic matter constituted with beneficial soil nutrients. In alley cropping, food or fodder crops are grown between hedgerows species. In this system, arable crops are grown in between the hedges of woody species, preferably legumes, that are regularly cut back to minimize the competition between tree and crop for light, water and nutrients (Tossah *el al.*, 1998). By combining deep rooting trees with shallow rooting crops, alley cropping systems use resources more efficiently than mono-cropping systems. While alley cropping has been widely promoted in the tropics as an option for subsistence farmers (Nair *et al.*, 1999).

In Ethiopia, agricultural production system is intensively monoculture, either in large scale or in small-scale farmlands. The productivity declines from time to time due to soil fertility loss and insufficient supply of plant nutrients. The tradition of agricultural production in small-scale farm faces a series of challenges, specifically the mineral fertilizer application due to its cost and affordability problem. To address this problem, agroforestry practices may play an important role

for a sustainable agricultural production and soil fertility improvement; due to its ecological ad economic feasibility. This study intended to evaluate the potential legume shrubs on maize yield and soil fertility improvement in alley cropping through hedgerows of legume shrub species.

Objectives

- To evaluate shrubs biomass under hedgerow management and to what extent its biomass maintain maize yield on local soils
- To evaluate the effects of shrubs on soil improvement and crop yield variations.

Expected output

The better contributing legume shrub for soil fertility improvement and maize yield enhancement on agricultural lands under alley cropping was identified. The main aim of this study was to identify the important legume shrub's contribution on soil nutrient addition on agricultural land, as well as transferred biomass benefit on maize yield increment.

Materials and Methods

Study area description

The experiment was carried out from March 2017 to August 2019 at Kayisa kebele farmers training center (FTC) in Debub Ari district of South Omo Zone. The study site has a bi-modal rainfall pattern with shorter rainy season from March-May, which is important for crop production and longest rainy season from August- November. It is located between 36°41' E and 05°50' N. Biophysically, the area characterized as altitudinal ranges from 1435–2400 m above sea level, total annual rainfall is 1304.4 ± 250.7 mm. The annual mean minimum and maximum temperatures are 16.3 ±0.9°C and 27.7 ± 1.4°C from Jinka station and the major soil texture of the area is sandy loam, with the percentage of 12, 10 and 78 for clay, silt and sand, respectively. The communities practicing mixed type of production system that means crop production and animal raring termed as agro pastoralists.

Experimental design and treatments

Completely randomized block design (RCBD) with three replications was used to conduct the experiment. The experiment was done on FTC at Kayisa Kebele in Debub Ari district. The treatments assigned for experimentation were maize grown between alley widths of Cajanus cajan (T1), maize grown between alley widths Sesbania sesban (T2), maize grown with inorganic fertilizer (T3) and maize grown without any addition of inorganic fertilizer or organic amendments (T4). Double rows of legume

Int. J. Agril. Res. Innov. Tech. 11(1): 60-68, June 2021

61

shrubs were established on prepared agricultural land. The plot size required for this study was 10 m x 10 m, constructed to carry out the experimentation. Seeds of legume shrub species were directly sown on early prepared trail field with plant spacing of 50 cm x 50 cm within and between shrubs row. The spacing between rows of maize and shrub was 75 cm, and 75 cm x 30 cm for maize within and between rows, respectively. Crop cultivation was done after 15 to 30 days of biomass transferring and incorporation.

Growth performance

Measurements of the growth parameters were done after full establishment and shrubs attain enough growth status to generate required data. Plant height, root collar diameter, diameter at breast height and branch number was determined on 10 randomly selected plants of each shrub species. In the present study, S. sesban and C. cajan species performance under alley cropping system attain promising growth. All desirable tending, periodical pruning and biomass transferring activities were done throughout the experimentation period. Pruning and biomass transferring has been undertaken prior to crop planting; it was attained to incorporate the pruned biomass and facilitation of the decomposition process.

Collected data

Growth parameters

All necessary management activities were done throughout the experimentation period. Activities like thinning, weeding, pruning, biomass transferring and incorporation, plowing and sowing annual crop/maize/ and fencing were done. For legume shrubs growth parameters like height, root collar diameter (above ground 10 cm), DBH (diameter at breast height 1.3 m), branch number, leafy biomass (including leaf and green branches) incorporated into soil and wood production data were collected during the experimentation period. On the other hand, maize crop data collection has carried out from the planting time to the harvesting stage. Collected data were time of planting, germination, plant height, number of ears, ear length total biomass, TSW and grain yield.

Sample collection and nutrient analysis

The legume species used have the potential of contributing decomposable biomass soil fertility improvement and capable of providing biomass after frequent pruning. These data were needed to evaluate hedgerow species effect on maize yield and potential of improving soil fertility in turn crop yield enhancement. Soil samples of each plot were collected before establishing hedgerows species and after intercropping or at the end of the experimentation period. The soil samples were randomly collected from 0-20 cm soil depth and bulked into a composite sample used before establishment. The plot based soil sample was taken at the end of the experimentation period to know the effect. The soil samples were air dried, grounded and sieved with 2 mm mesh for chemical analysis. The pH of the soil was measured in 1: 2.5 (soil: water ratio), soil organic carbon by Walkey and Black procedure (Nelson and Sommers, 1996), total nitrogen content of the soil was determined by wet-oxidation (wet digestion) procedure (Kjeldahl, 1883) and available P by using Bray II method (Bray and Kurtz, 1945). Potassium contents of the extract were determined with flame photometer, the available sulfur of soil can be done by the turbidymetric methods and extracted by calcium chloride dehydrate, the concentration of SO_4-S can be read by spectrophotometer in 420 nm wave length. Soil texture was determined by hydrometer method (Day, 1965). On the other hand, leaf sample for each shrub species was collected to evaluate the nutrient composition, pruned of biomass produced in nutrient release after incorporation into the soil and to determine released nutrient with maize crop yield.

Data analysis

Shrubs growth performances parameters, biomass production, leaf nutrient parameters, soil parameters and maize yield and yield component data were computed by using SAS software. The means values of the parameters were compared using the least significant difference (LSD) at 5% level of significance using SAS statistical software (version 9.0) and for data organization Microsoft excel sheet was used.

Results and Discussion

Growth performance of established legume shrubs

The growth parameters presented on Table 1, 2 and 3 shows the performance evaluation in the successive growing period. The experiment conducted on effect of legume shrub species contribution on annual crop production under alley cropping practice, species growth performance evaluation was conducted with respect to different growth parameters during the experimentation period (Table 1, 2 and 3). The mean height, root collar diameter, DBH and number branches of *Sesbania sesban was* significantly higher than that *Cajanus cajan* used in the current study. The amount of leaf biomass (PM) produced from *Sesbania sesban* (11.56 ton ha^{-1}) was significantly higher than *Cajanus cajan* (3.20 ton ha^{-1}) in alley cropping system. This result is in line with finding of Sjögren *et al.*

(2010), who reported that *Sesbania sesban* showed a very high growth potential in 6 and 18 months improved fallows conducted in Kenya. Biomass production in each cutting period resulted with different values, this due to certain factors related with the performance, time of establishment, frequency cutting and period at which pruning carried out. The biomass production is effected with different parameters, such as branch number, root collar diameter, DBH and the type the species used and tolerance to frequency of pruning.

Table 1. Growth performance parameters of the grown leguminous shrub species in hedgerows intercropping.

Legume Species used	Measured parameters			
	H (m)	RCD (cm)	DBH (cm)	BN
Cajanus cajan	1.80[b]	2.34[b]	1.10[b]	91.00[b]
Sesbania sesban	2.70[a]	3.33[a]	2.00[a]	150.00[a]
LSD	0.839	0.910	0.840	51.200
CV (%)	29.20	24.85	42.80	33.00

Source own data, 2017-2019

Means with the same letter are not significantly different within rows; where: H (height), BN (branch number), DBH (diameter at breast height), LSD (least significant difference), CV (coefficient of variation)

Table 2. Biomass transferred at each cutting period on plots of legumes species.

Cutting frequency	Shrub species used	
	Cajanus cajan	*Sesbania sesban*
FRB	30.00 kg	113.30 kg
SRB	23.90 kg	87.00 kg
TRB	42.10 kg	146.50 kg
Average	32.00 kg	115.61 kg

Source own data 2017-2019
Where FRC (first round biomass), SRB (second round biomass), TRB (third round biomass)

Table 3. Biomass production per hedgerow species grown in alley cropping system.

Shrub species	Biomass pruned and transferred	
	BM kg ha^{-1}	BM ton ha^{-1}
Cajanus cajan	3200[b]	3.200[b]
Sesbania sesban	11561[a]	11.561[a]
LSD	30.62	3.062
CV (%)	41.51	41.510

Source own data, 2017-2019
Where BM (biomass), LSD (least significant difference), CV (coefficient of variation)

Table 4. Total biomass, leaf and wood biomass produced from hedgerow species.

Shrub species	Wood biomass and total biomass			
	WBM kg ha^{-1}	WBM ton ha^{-1}	LBM ton ha^{-1}	TBM ton ha^{-1}
Cajanus cajan	2750.00	2.75	3.20	6.00
Sesbania sesban	7933.00	7.93	11.56	19.50

Source own data, 2017-2019
Where WBM (wood biomass), LBM (leaf biomass), TBM (total biomass)

Soil fertility improvement in hedgerow species

Hedgerows species restore some ecosystem functions to fields by increasing nutrient cycling and maintaining levels of soil organic matter. The result showed a variation in different soil physicochemical properties under alley cropping practice (Table 5, 6 and 7). Soil parameters were increased, but statistically no significant difference exist except in case of sulfur, it was significantly increased in hedges *Sesbania* as

Int. J. Agril. Res. Innov. Tech. 11(1): 60-68, June 2021

63

compared with the other treatments (Table 6). The soil nutrients contributed by *S. sesban* were OC, TN, P, B and S higher than that of *C. cajan*, none alley cropped plots and before planting (Table 5). Hedgerows species play an important role in soil nutrient improvement through large biomass addition. The result of this study in line with findings of Young (1999) who reported provision of plant available N from decomposing *Sesbania* biomass, increased soil organic matter, improved nutrient, water retention in the soil. Miah *et al.* (1997) observed higher soil pH and organic C in alley cropping system. Kwesiga *et al.* (1999) also reported Short-duration planted fallows using leguminous species replenish soil fertility and to increase subsequent maize yields at Eastern Zambia. Alley cropping helped to maintain soil fertility by increasing nutrient cycling and reducing leaching of nutrients (Chamshama *et al.*, 1998). Evans *et al.* (2001) reported nitrogen accumulation had also been achieved by cutting materials from trees/ shrubs intentionally grown for green leaf manure production. Nutrients released from leaf determined by leaf biomass produced from legume species grown on experimentation site. *S. sesban* provides high leaf biomass compared with Pigeon pea and it plays important role in releasing beneficial nutrients to crop production. Leaf analysis result showed that the amount of nutrient concentration varies from species to species. The legume species improve the soil through biological nitrogen fixation where by

recycled nutrients are deposited through litter or when pruned biomass was transferred. Decomposable biomass/Soil organic matter and organic carbon increased in alley cropping practice at the study site, this in line with the findings of Miller and Donahue (1990) who reported that SOM was major source of nutrients such as nitrogen, and available P and K in unfertilized soils. In addition, organic carbon is positively correlated with available N and K nutrients (Maiti and Ghose, 2005). Addition of green manure from hedgerows also improves soil physical qualities such as bulk density (Alegre and Rao, 1996). The production of green leaf biomass has an ideal contribution in release of important crop available nutrients through its decomposition and modifying the agricultural land either it is by improving physical, biological or chemical properties. Promising leguminous trees/shrubs improve soil fertility as source of nutrient for agricultural crops are being exploited in the alley cropping system (Chu *et al.*, 2004). The biomass produced by *Sesbania* hedgerows has wider importance in the composition of important soil nutrients and increased yield in simultaneously cropping season. Similarly, Bekele (2007) reported in most parts of SSA, farmers use improved fallows as a strategy for improving soil fertility within a shorter time-period. Alley cropping is most effective at maintaining soil fertility on continuously cropped land.

Table 5. Analyzed soil physico-chemical parameters before experimentation.

Soil parameters							Soil texture (%)			
pH	%TN	%OC	P (ppm)	K (ppm)	B (ppm)	SO4-S	Clay	Silt	Sand	Class
5.70	0.11	1.33	15.65	74.12	0.45	10.96				
S. ac	Md	L	Md	Md	Md	Md	12	10	78	Sandy loam

Source own data, 2017-2019
Where, Md (medium), L (low), S.ac (slightly acidic)

The average compositions of clay, silt and sand percentages were 12, 10 and 78, respectively. Thus according to USDA soil

textural classification of the experimental area was classified as sandy loam.

Table 6. Analyzed soil physico-chemical properties under each legume shrub species.

Treatments	Soil parameters						
	pH	%OC	%TN	P (ppm)	K (ppm)	B (ppm)	SO4-S
Cajanus cajan + maize	5.74	1.170	0.101	15.97	79.89	0.58	7.31[B]
Sesbania sesban + maize	5.68	1.400	0.120	23.98	90.78	0.61	19.74[A]
Maize with fertilizer	5.74	1.340	0.117	17.96	103.38	0.33	5.72[BL]
Maize without fertilizer	5.66	1.200	0.101	18.98	97.92	0.58	10.97[AB]
Before planting	5.71	1.091	0.094	15.65	74.12	0.45	10.96[AB]
LSD	NS	NS	0.04	11.64	60.02	0.45	12.30
CV (%)	2.88	15.19	15.29	23.44	25.04	33.25	41.86

Source: Own data, 2017-2019

Int. J. Agril. Res. Innov. Tech. 11(1): 60-68, June 2021

64

Table 7. Correlation between the measured soil parameters.

	pH	OC	TN	P	K	B	SO4-S
pH	1						
OC	0.469	1					
TN	0.466	0.997[*]	1				
P	-0.275	0.240	0.240	1			
K	-0.303	0.230	0.230	0.524[*]	1		
B	-0.209	-0.397	-0.395	-0.017	-0.203	1	
SO4-S	-0.152	0.368	0.364	0.216	-0.100	0.384	1

Source own data, 2017-2019

Table 8. Leaf nutrient analyzed from hedgerow shrub species.

Species(treatments)	Nutrients released			LBM kg ha^{-1}	LBM ton ha^{-1}
	%N	%P	%K		
Cajanus cajan	3.65	0.47	4.18	3200[b]	3.200
Sesbania sesban	4.71	0.59	4.31	11561[a]	11.561

Source own data, 2017-2019

Where: LMB (leaf biomass), ha^{-1} (per hectare), for N 0.3 g of leaf sample used and 0.5 g was used for P and K analysis.

 Table 9. Contribution of green biomass for nutrient release.

Shrub species	LBM ton ha^{-1}	N (from LBM)	P (from LBM)	K (from LBM)
Cajanus cajan	3.20	116.80 kg	15.04 kg	133.76 kg
Sesbania sesban	11.56	544.52 kg	68.21 kg	498.30 kg

Source own data, 2018-2019

Where: LMB (leaf biomass), ha^{-1} (per hectare), for N 0.3 g of leaf sample used and 0.5 g was used for P and K analysis

Relation between organic matter and organic carbon obtained from green biomass

The present study result showed that the amount of organic matter depends on legume shrub species used in hedgerows intercropping practice and biomass produced by these species. Form the shrub species, *S. sesban* provides huge amount of organic matter and nitrogen concentration in comparison with *C. cajan*, these related with organic carbon and C: N ratio at which the mineralization process determined. For instance the variation of C: N value for both species showed (Table 10) that the amount of carbon and nitrogen nutrients constituted in the organic biomass of the species. The C: N value described as 11.22 and 14.32 for *S. sesban* and *C. cajan*, respectively. Mineralization of organic matter depends on this critical parameters at which the process under taken. The result of the present study in line with previous studies of Aerts and de Caluwe (1997), Teklay *et al.* (2007) who reported the concentrations of nitrogen (N), phosphorus (P), and the ratios of C/N are recognized as the main organic biomass quality variables controlling rates of decomposition. Mineralization process occurs faster at lower C: N ratio (high nitrogen) at which the conversion of organic minerals into in organic or mineral form and easily available for crop uptake.

Table 10. Analyzed value for organic matter, organic carbon and C: N ratio for each species.

Parameters	Shrub species used in hedgerows intercropping	
	Sesbania sesban	*Cajanus cajan*
%OM	90.92	89.90
%OC	52.86	52.27
%N	4.71	3.65
C:N ratio	11.22	14.32
In terms long term production	Used for 10-11 production season	Used for 2-3 production season

Source: own data, 2017- 2019
Where: OM (Organic Matter), OC (Organic Carbon), N (Nitrogen), and C: N (Carbon to Nitrogen ratio)

Int. J. Agril. Res. Innov. Tech. 11(1): 60-68, June 2021

65

Maize crop production under alley cropping

Alley cropping is an important farming practice carried on annual crops with legume hedgerow species, through which soil fertility improved and productivity increased. The grain yield of maize grown in alleys was influenced significantly ($P < 0.05$) by nitrogen levels (Table 9). Maize yield production was maintained in alley cropping practice, affected with different beneficial nutrients contributed by organic biomass of hedgerow species. In the present study, maize grain yields was higher in *Sesbania* hedgerow intercropping than the other plots, significantly different from Pigeon pea plot (Table 10). Maize grain yield obtained from *C. cajan* hedgerow intercropping twice lower than that of *S. sesban* intercropping, this is due to the amount and nutrients released from pruned biomass produced from the hedgerow species. The trend in the order of *S. sesban* + maize > maize + fertilizer > control (maize without IF) > *C. cajan* + maize. The amount and release of nutrients determined by pruned biomass, its decomposition rate, type of hedgerow species, soil type and active soil microorganisms. Total biomass of maize crop grown on plots of *S. sesban* hedgerow had the highest value than the other plots. Grain yield of maize highly correlated with yield components like plant height, seed weight and total biomass, these factors have direct effect on grain yield (Table 11). The present study result in line with the findings of Naya *et al.* (2007), who reported inclusion of appropriate nitrogen fixing tree/shrub legumes in farming systems usually reduces N loss through leaching thereby maximizes yield from croplands. Similarly, Aihou *et al.* (1998) reported 107% more maize yield in alley cropping on the degraded site. Maize yield improvement through alley cropping with different woody species has been reported in many countries (Chamshama *et al.*, 1998; Tossah *et al.*, 1998; Friday and Fownes, 2002).

Table 11. Maize yield and yield component parameters measured in alley cropping practices of hedgerow species.

Treatments	Measured parameters			
	Ph in m	HSW in g	TBM ton ha⁻¹	GY in ton ha⁻¹
Cajanus cajan + maize	2.12	33.81	13.99	2.62[b]
Sesbania sesban + maize	2.47	40.88	28.07	5.97[a]
Maize with fertilizer	2.34	36.50	19.34	4.49[ab]
Maize without fertilizer	2.20	36.14	15.43	3.40[ab]
LSD	NS	NS	NS	1.64
CV (%)	6.10	12.61	28.67	24.65

Source: own data, 2017- 2019
Where: Ph (plant height), HSW (hundred seed weight), TBM (total biomass), GY (grain yield)

Table 12. Pearson correlation results of yield components relation with maize grain yield.

Correlation factors(components}	Grain yield	Significant
Treatment	0.062	0.85 Ns
Plant height	0.960	0.0001*
Hundred seed weight	0.610	0.032*
Total biomass	0.970	0.0001*

Source: own data, 2017- 2019

Conclusion and Recommendation

The results obtained showed that hedgerow intercropping improved the soil nutrients over the pre-planting. Particularly, *S. sesban* hedgerow plays an important role in improvement of soil nutrients; as well, it increased maize grain yield and compatible species under hedgerow intercropping. However, more plant nutrients were gradually built up in hedgerow plots than in the fertilizer and control plots. Therefore, pruned biomass of legume species incorporated into the soil under hedgerow intercropping reduced the rate of soil nutrient depletion and increased productive base of the soil through nutrient released during the decomposition of pruned biomass. From the present study, issues to be considered as future direction are hedgerow intercropping needs special attention towards the demonstration of the practice in appropriate form to stakeholders to sustain their agricultural production, integration of livestock component to improve the economic return of farm households and technical support should be provided through professional experts is important. *S. sesban* has good growth performance, huge leafy green biomass adheres with important soil nutrient

composition in the study area, it is recommended as an important legume shrub to integrate on agricultural land with annual crops under hedgerow intercropping. This should be intensively demonstrated to sustain the agricultural production as an organic farming through integration of easily adapting, less competing with the companion crop, deep rooted and fast growing legume shrub species. Further research is important to determine rate of decomposing of pruned biomass, potential species should be identified having uniform growth performance and ideal to integrate with annual crops.

Conflict of interest

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

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Int. J. Agril. Res. Innov. Tech. 11(1): 60-68, June 2021

67

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Int. J. Agril. Res. Innov. Tech. 11(1): 60-68, June 2021

68