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Original Article

Role of *Calliandra Calothyrsus* Alley Cropping for Soil Fertility and Maize Production at Bako, Western Oromia

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Agroforestry, Alley Cropping, Calliandra Calothyrsus, Maize Yield, Soil Analysis.

ABSTRACT

Alley cropping is a production system that combines the elements of agriculture with that of trees/shrubs, and offers many potential benefits for Africa's small-scale farmers. The objectives of this study were to test the impact of alley cropping of *Calliandra calothyrsus* when integrated with inorganic fertilizers within maize production and to evaluate the effect of *Calliandra calothyrsus* alley cropping on soil fertility. The study was conducted at Bako Agricultural Research Center for four consecutive years from 2016 to 2019. A total of 6 treatments were used by RCBD arrangement with 3 replications. Grain yield and yield component parameters of maize BH-661 were collected and analyzed. Composite soil samples from 0-15cm depth before sowing and after harvesting each year were collected and analyzed. The maize grain yield results showed a slight variation across the year, which might be due to the effects of *Calliandra calothyrsus* alley cropping which can directly contribute to improving soil fertility. LA and LAI had significant effects on the sole maize treatment with recommended fertilizer where the mean of trend showed the highest grain yield in quintals per hectare. According to the results of soil samples analysis the soil pH in the study site belonged to strongly acidic whereas, after the implementation of the experiment the availability of OC and OM slightly increased, across the treatments. The results of exchangeable bases (Ca and Mg) also showed some variations among the treatments throughout the implementation period. Finally, we recommend that, *Calliandra calothyrsus* alley cropping with maize production can be considered as part of conservation agriculture so that mono-cropping will be substituted with diversified and multipurpose farming systems.

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INTRODUCTION

Farming systems in most African countries are under serious threat due to the ever-increasing population growth and environmental degradation. These difficulties have highlighted the need to take an overall view of land husbandry which is not limited solely to production but also includes the need to conserve natural resources on which production is based [1]. Agroforestry is one of such farming systems that combine production with conservation of natural resources. It is about integrating multipurpose trees, like *Calliandra calothyrsus*, in existing land use patterns so as to improve soil fertility and make food production sustainable from both environmental and economic standpoints. Soil fertility depletion is considered as the major threat to crop production, and food security in Ethiopia. Low soil fertility is the greatest factor in the increased productivity of maize in Western Ethiopia. However, decreasing productivity can be alleviated by the use, among others, of inorganic nitrogen fertilizer [2] as well as alley cropping (integrating multipurpose trees).

Alley cropping is a production system that combines the elements of agriculture with that of forestry and offers many potential benefits for Africa's small-scale farmers. The trees in the alley cropping system act as pumps, moving nutrients down from the lower soil horizons, while at the same time adding organic materials to the soil through litter fall. In addition, the woody perennials used in this system are usually nitrogen-fixing species and thus providing another important boost to soil fertility, and hence it can be undertaken with no, or little, use of costly inputs such as chemical fertilizers. Moreover, our farmers are small and they are not in a position to use these artificial inputs or can use them only in small quantities [3] and [4]. *Calliandra calothyrsus* belongs to Fabaceae (Mimosoideae) family and a small tree or a large shrub that usually grows 4 to 6 m tall but might reach 12 m under favorable conditions [5]. *Calliandra calothyrsus* is a leguminous shrub or small tree species that biologically fixes free atmospheric nitrogen and hence provides nitrogenous fertilizer for companion food crops such as maize. It is a promising agroforestry species because of its biological fixation of atmospheric nitrogen, good coppicing ability, rapid growth, dense foliage and deep root system, and hence particularly suitable for erosion control and rejuvenating degraded soils [6].

Calliandra calothyrsus is used for fodder, apiculture, fuel wood, fiber, erosion control, shade or shelter, nitrogen-fixing, soil improver, ornamental, boundary or barrier or support, intercropping [5, 7], reduce fallow periods and improve soil fertility [7]. In agricultural systems, it is used to reduce weed growth, conserve soil moisture, and improve soil structure and fertility [7]. Proven information regarding the integration of tree species and inorganic fertilizer with maize varieties (BH-661) is not practiced at Bako and surrounding farmers. Therefore, selecting the integration of tree species with an appropriate rate of inorganic fertilizer that may be high yield maize variety (BH-661), increasing in nutrient concentration associated with soil and maize yield

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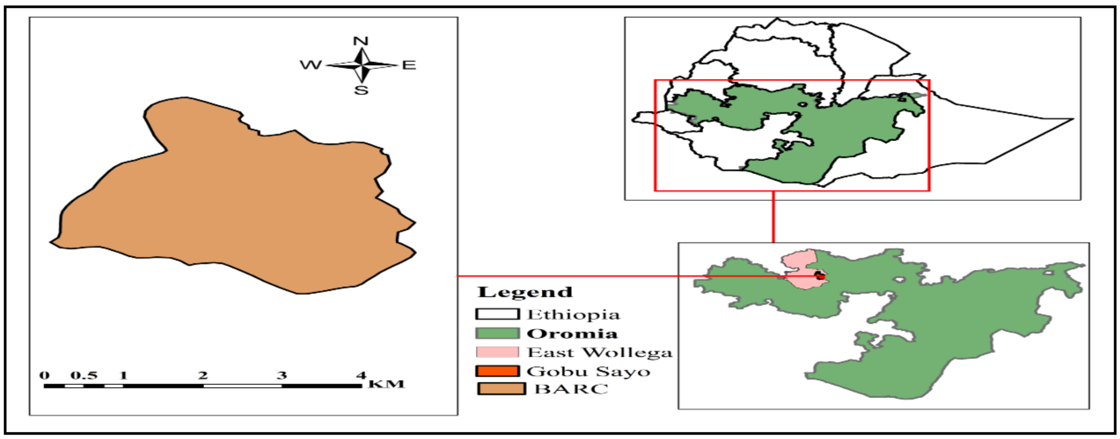
for successful establishment and management of alley cropping multipurpose tree species at this area. For example, *Calliandra calothyrsus* alley cropping with maize production should be considered and more demonstrated as part of conservation agriculture so that mono-cropping will be substituted with diversified and multipurpose farming system, specifically in maize belt areas of Bako and similar sites with the objectives of test the impact of *Calliandra calothyrsus* alley cropping integrated with inorganic fertilizers in maize production and evaluate the effect of *Calliandra calothyrsus* alley cropping on soil fertility.

MATERIALS AND METHODS

Description of the study site

The study was conducted at Bako Agriculture Research center on-station for five consecutive years from 2016/17 to 2020 and it's located in between 37°1'00" E to 37°3'40" E and 9° 4'20"N to 9°7'20" N as indicated in Figure 1.

Fig. 1: Map of the study site.



Source: ETH Administrative Boundary Map

Composite soil samples before sowing and after harvesting were collected and analyzed. A total of 6 treatments were used by RCBD arrangement with 3 replications. Here are treatment combinations of the experiment: T1=Sole maize without fertilizer, T2=Sole maize with recommended fertilizer (NPS), T3= *Calliandra calothyrsus* alley cropping only, T4= *Calliandra calothyrsus* alley cropping + 75% of recommended fertilizer (NPS), T5= *Calliandra calothyrsus* alley cropping + 50% of recommended fertilizer (NPS) and T6= *Calliandra calothyrsus* alley cropping + 25% of recommended fertilizer (NPS).

Experimental Designs

Plot area 11.25*12=135m^2 which means width of a plot = 11.25 m (i.e., 15 rows x 0.75 m b/n rows) from 15 total rows 3 consecutive rows maize starting and one rows *Calliandra calothyrsus* alley cropping (A plot contain 12 rows maize and 3 rows *Calliandra calothyrsus)* and Length of a plot 12 m, Spacing between blocks = 2 m**,** Spacing between plots = 1.5 m, Spacing between Maize= 75 cm*30 cm, Spacing between *Calliandra calothyrsus* trees 0.5 m (Intra row spacing of trees 0.5m). A plot contains 12 rows of maize and 3 rows *Calliandra calothyrsus***.** Maize and multipurpose trees were established concurrently on the same plot. Seedlings of multipurpose trees were raised at a nursery and then transplanted to a field plot. The field between maize rows was maintained during the main rainy season (maintaining the desired maize population). One suitable maize variety (BH-661) was selected for the trials. After establishment, multipurpose trees/shrubs were thinned to an appropriate population density. Multipurpose trees/shrubs were managed through repeated cutting back to the ground level to protect interference with the crop.

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Collected Data

Growth performance parameters of maize such as days to emergence, days to flowering, days to maturity, plant height, dry matter yield, maize grain yield and yield components were collected. Topsoil samples at a depth of 0-15 cm) were collected before planting and after harvesting. During each cropping season assess the impact of treatments on soil physical and chemical properties particularly organic matter, total nitrogen, available P, Ca, Mg, and pH before and after each implementation year to check the change in soil properties.

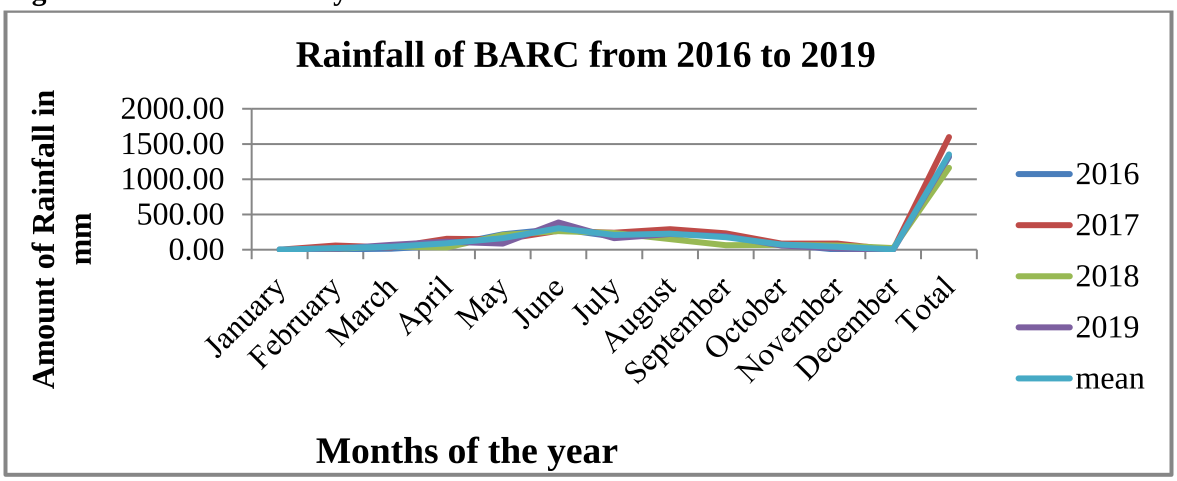
Method of data analysis

Data were analyzed using Statistical Analysis System (SAS) version 9.3 and subjected to ANOVA to determine significant differences among treatments. Means were separated using the Least Significant Difference (LSD) test at a 95% confidence interval. Pearson Correlation analysis was also performed to reveal the relation between different parameters.

Climate data of the study area

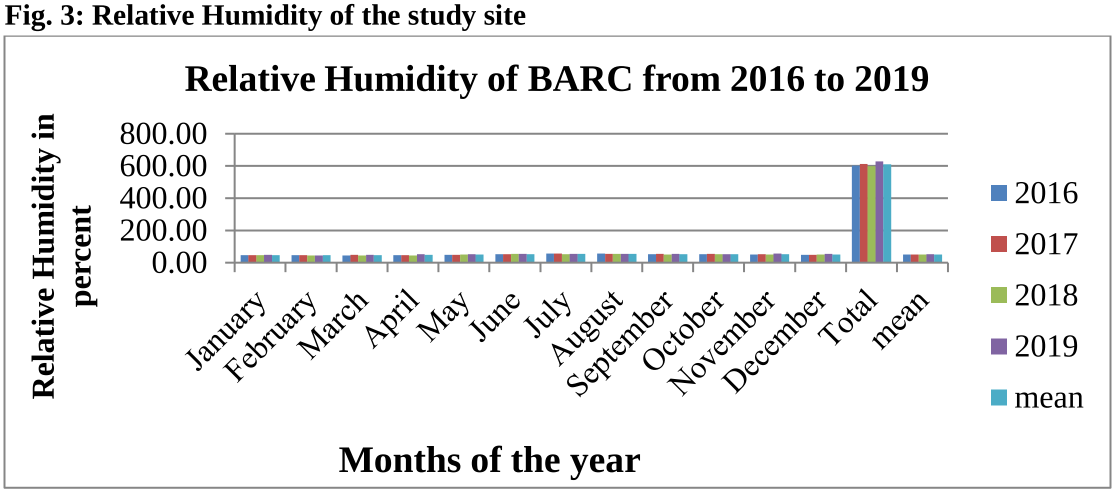
The four-year climatic information of the study site is displayed in the graph below and helps to show the distribution of rainfall, temperature and relative humidity of the site during the implementation periods (Figures 2, 3 and 4).

Fig. 2: Rainfall of the study site.



Source: Bako Agricultural Research Center Meteorological Station, 2022

Fig. 3: Relative Humidity of the study site



Source: Bako Agricultural Research Center Meteorological Station, 2022

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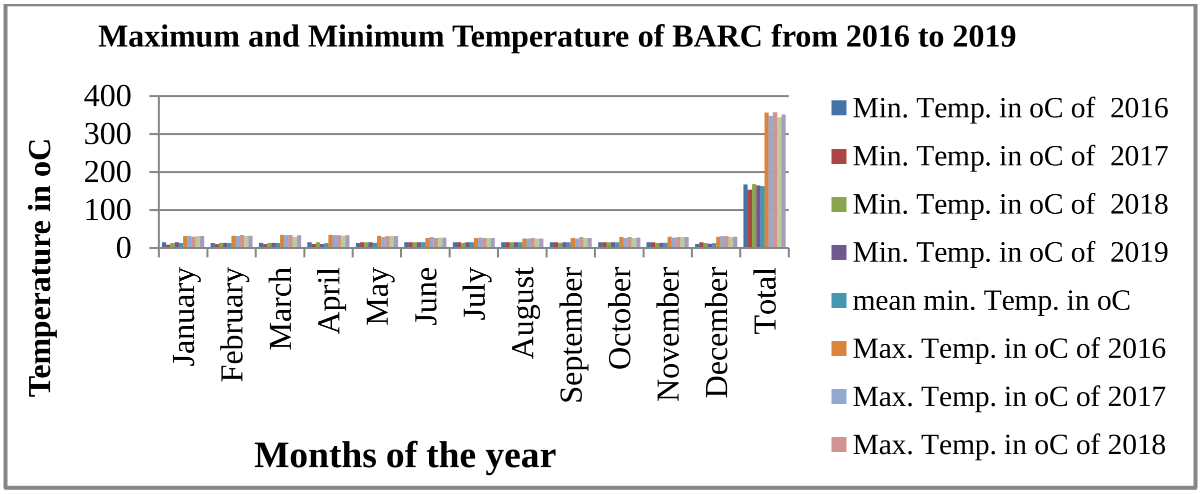
Fig. 4: Minimum and maximum temperature of the study site.



Source: Bako Agricultural Research Center Meteorological Station, 2022

Soil sampling and laboratory analyses

The study was conducted for four consecutive years using *Calliandra calothyrsus* as alley cropping practices which mainly bring a positive impact on maize yield production and soil properties (table 1,2,3,4). Composite soil samples were taken in each experimental field from 0-15cm depths to determine the baseline fertility status of the experimental fields at the beginning of the experiment.. Then the collected soil samples were analyzed at BARC soil laboratory. Soil organic carbon (OC) content was determined by using the Walkley-Black method [8]. Available phosphorous (AP) was determined by the Bary II method [9]. Total N was analyzed using the Kjeldahl method, as described by [10]. Exchangeable bases (Ca, and Mg) were determined after extracting the soil samples by ammonium acetate (1N NH4OAc) at pH 7.0. Exchangeable Ca and Mg in the extract were analyzed using an atomic absorption spectrophotometer. The pH of the soil was measured potentiometrically with a digital pH meter in the supernatant suspension of 1:2.5 soils: water ratio [11].

RESULTS AND DISCUSSION

Grain Yield and Yield Components

Trends of Yield within Treatments

The maize grain yields during the four cropping seasons are displayed in comparison with different treatments (table 1). The results showed a slight variation across the year, the change might be due to the implementation of *Calliandra calothyrsus* as alley cropping. Since the species has legumes, behaviors directly contribute to improving the soil fertility which provides nutrients for the maize crops.

Table 1: Comparison of Grain Yield (GY) values within treatments from 2016 to 2019

Treatments	GY-2016	GY-2017	GY-2018	GY-2019
1	8.09	9.15	15.83	13.42
2	34.62	39.72	50.51	47.98
3	8.58	12.16	9.61	3.71
4	28.45	36.52	19.99	23.4
5	23.03	33.64	17.23	12.75
6	19.57c	22.68b	13.45bc	13.04c
Grand Mean	**20.39**	**25.65**	**21.10**	**19.05**
LSD (5%)	**4.75**	**8.87**	**6.69**	**6.34**
CV	**12.81**	**19.45**	**17.82**	**18.69**

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Treatment description: T1= Sole maize without fertilizer, T2= Sole maize with recommended fertilizer (121 kg/ha NPS+100 % (87 kg/ha N (urea), T3= Maize with *Calliandra calothyrsus* alley cropping only, T4= Maize with *Calliandra calothyrsus* alley cropping + (Recc.121 kg/ha NPS + 75% (59.5 kg/ha N (Urea)), T5= Maize with *Calliandra calothyrsus* alley cropping + (Recc.121 kg/ha NPS + 50 % (32 kg/ha N (urea)), T6= Maize with *Calliandra calothyrsus* alley cropping + Recc.121 kg/ha NPS + 25% (4.5 kg/ha N (urea))

According to our observation from the above table, yield reduction from the initial revealed which might be due to the erratic rainfall distribution of the site across the years (fig.3). The general yield trend showed relatively higher in treatments 2 and 4 which produced higher yields than other treatments across the years.

Mean of Yield and Yield Components

The leaf area (LA), leaf area index (LAI), dry biomass (DM), harvesting index (HI), thousand seed weight (TSW), normalized difference vegetation index (NDVI) and grain yield (GY) of maize during the four cropping years were presented (table 2). LA and LAI had a significant effect on Sole maize with recommended fertilizer and the grain yield of maize was significantly different on Sole maize with recommended fertilizer (121 kg/ha NPS+100 % (87 kg/ha N (urea).

Table 2: Overall average of grain yield and yield components with treatments from 2016-2019

Treatment	LA (cm^2)	LAI	DBM (kg)	HI	TSW (gm)	NDVI	GY (Q per ha)
1	3549.65	1.60	18.18	0.32	271.37	0.65	11.6225
2	6502.43	2.96	52.93	0.38	347.70	0.75	43.2075
3	3406.50	1.48	16.67	0.27	278.83	0.66	8.515
4	5617.00	2.46	42.59	0.35	329.73	0.75	27.09
5	5703.20	2.50	34.50	0.34	309.33	0.73	21.6625
6	5251.48	2.31	30.19	0.31	296.04	0.72	17.185

Note: LA = Leaf area, LAI = Leaf area index, DBM= Dry biomass, HI = Harvest Index, TSW= Thousand seed weight, NDVI= Normalized difference vegetative index, GY= Grain yield.

LA, LAI, DBM and NDVI ranges between 3406.50-6502.43, 1.48-2.96, 16.67-52.93 and 0.65-0.75, respectively. Yields of maize in the 2019 production year declined due to the presence of high rainfall and the occurrence of logging effects. Due to this effect, overall maize grain yields on average of the study site become decreased. High rainfall variability has an effect on maize yield variability [12, 13].

Analysis of soil properties

The results of the soil properties of the study site are presented in Table 3. According to the results the soil pH in pH (1:2.5 (H_2O) suspension was 5.43. This showed that the study site belongs to the strongly acidic (5.1-5.5) range [14, 15, and 16]. In soils with pH below 5.5, Ca or Mg may be deficient [16].

Table 3: Overall average of grain yield and soil parameters with treatments from 2016 to 2019

Composite soil before sowing (2016)	pH	OC (%)	OM (%)	P	TN (%)	Mg	Ca	GY (Q per ha)
	5.43	1.40	2.04	8	0.12	7.3	8.00	--------
Treatment								
1	5.17	1.84	3.17	9.45	0.16	8.00	9.19	11.62
2	5.10	1.91	3.20	10.02	0.16	7.32	10.40	43.21
3	5.29	1.86	3.21	10.30	0.16	12.92	10.93	8.515
4	5.08	1.82	3.13	11.30	0.16	8.33	7.50	27.09

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Composite soil before sowing (2016)	pH	OC (%)	OM (%)	P	TN (%)	Mg	Ca	GY (Q per ha)
	5.43	1.40	2.04	8	0.12	7.3	8.00	--------
5	5.09	1.87	3.21	6.72	0.16	8.06	9.58	21.66
6	5.16	1.93	3.33	10.21	0.17	11.04	8.41	17.19

Note: pH= pH (1:2.5) (H2O), OC= Organic Carbon (%), OM= Organic Matter (%), P= Available Phosphorus (mh/kg) soil, TN= Total Nitrogen (%), K= Exchangeable Potassium ((cmol (+)/kg soil, Mg= Magnesium (meq/100g) soil, Ca= Calcium (meq/100g) soil

Furthermore, the composite soil results for total N (%) and available P (mg/Kg) soil of the study site were 0.12 and 8, respectively as indicated in Table 3. According to the rating range for the composite soil results of the study site the concentrations of total N classified within the range of low rating (0.05-0.12 [17, 18, 19]. A similar trend was obtained for extractable available phosphorus concentration which falls under the low rating range with a value of 8 in the study site (5-10) [18, 19]. Low available soil P content of the study site was a good indicator of the soil P supply for maize production. Whereas, during the implementation period the values of total N and available P showed variation this variation would be due to the combined effect of the applied treatments. For the composite soil analysis, the availability of organic carbon and organic matter concentrations of the study site were found within 1.40 and 2.04 range which were considered in low rating ranges (low OC ratings between 0.5-1.5 and low OM ratings between 0.86-2.59) [19, 20]. Whereas, across the treatment after the implementation of the experiment the availability of OC and OM slightly increased, this might be due to the practice of alley cropping and application of different fertilizer rates. The results of exchangeable bases (Ca and Mg) also showed some variations among the treatments throughout the implementation period.

Regarding the soil pH the highest value was recorded at T3 with 5.29 values, while lower pH revealed under the T4 with 5.08 values (table 3). The main reason for the change observed in pH values of the study site might be due to the sole application of alley cropping using *Calliandra calothyrsus* species that directly modified the level of pH availability of the site.

Correlation of Soil Properties and Grain Yield

The correlation impact of different soil properties against grain yield was displayed across the implementation periods. As presented in Table 4, at the early stage of the experiment the maize grain yield showed a positive correlation with OC, OM and TN, having values of 0.254, 0.249, and 0.1875, respectively. The contributions of using legume species as alley cropping might show the positive interaction of some soil chemical properties with maize grain yield production.

Table 4: Correlation analysis of grain yield and some soil parameters

	GY	pH	OC	OM	P	TN	Mg	Ca
GY	1	-0.0037	0.25369	0.24944	-0.04520	0.18747	-0.02186	-0.04997
pH		1	0.13964	0.14199	0.14337	0.16118	0.05105	0.10570
OC			1	0.99983	-0.50217	0.95564	-0.37608	-0.46704
OM				1	-0.49797	0.95547	-0.38170	-0.46456
P					1	-0.50474	0.07253	0.18381
TN						1	-0.32753	-0.49673
Mg							1	0.33553
Ca								1

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CONCLUSION AND RECOMMENDATION

Alley cropping system is the cultivation of food, forage, or specialty crops between rows of trees. This system is a larger version of intercropping or companion planting conducted over a longer time scale. The current experiment shows us that through alley cropping of *Calliandra calothyrsus* with maize we can diversify our products: food, feed, fuel and fences, and also we can simultaneously sustain productivity and improve soil fertility. This alley cropping trial has tried to observe and identify the shrub/crop intercrops where trends of yield and yield components negatively/positively correlated with soil parameters in average. The experiment could also identify that the fertilizer rate and other agronomic management only will not a matter for successful alley cropping practices, but also identified that alley cropping practices can be challenged with rainfall amount, temperature and relative humidity. Farmers may also use alley cropping to transition from one farming system to another system. The annual crops grown in alley cropping can provide short-term annual income until the trees are mature. The versatile nature of this system allows a producer to react to markets, labor limitations, and changing goals. Like all agroforestry systems, alley cropping must be considered as part of the whole farm operation.

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