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Intercropping Sorghum and Soybean Efficiency Using Contour Ridges Technology in Southern Mali

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Abstract

Kani and Noumpinesso are two neighboring villages in which soil degradation is mainly caused by runoff and erosion. Contour ridges tillage (CRT) was identified as a runoff and erosion controlling technology while improving soil moisture and nutrient availability for crops. CRT technology associated with sorghum and soybean based intercropping system was assessed during 2017 and 2018 cropping season in an experiment under split plot design.

Intercropping systems highly increased sorghum and soybean growth and yields. Sorghum grain yield, biomass yield, height and diameter were increased by 62, 51, 22 and 19%, respectively by intercropping. Soybean grain yield, biomass yield, height and diameter increased by 47, 30, 25 and 25%, respectively. Intercropping sorghum with soybean had an advantage with a Land Equivalent Ratio (LER) of 1.54 and 1.44 in 2017 and 2018 respectively. The technology of CRT added 40, 39, 25 and 21% on sorghum grain yield, straw yield, height and diameter respectively. The same parameters with soybean were greater by 52, 48, 38 and 35%, respectively. The application of CRT was economically profitable with a Value to Cost Ratio (VCR) of 3.3 and 3.0 in sorghum production and 12.8 and 9.2 in soybean production during 2017 and 2018 respectively.

Keywords: sorghum, soybean, contour ridges tillage, intercropping, yields, Land Equivalent Ratio, Value to Cost Ratio

Introduction

Agriculture remains the largest source of employment in Mali and like several countries of the dryland areas, needs to be improved to meet the needs of the growing population. A major contribution to this improvement will be the management of limited and/or inappropriate distribution of precipitation (Masila et al., 2015). In Kani and Noumpinesso (Koutiala district), rainfall insufficiency and inappropriate distribution due to climate variability are the main causes of soil degradation and farmer's crop yield reduction. Most of the rainfall is lost by heavy and rapid runoff leading to erosion in agricultural fields. Julio and Carlos (1999) observed that in Mali, agricultural soils are characterized by low land productivity associated with poor rainfall, low soil fertility, and traditional crop management practices. Efforts have been directed at assessing the impact of contour ridges tillage technology and legumes crops in order to address these problems. Contour Ridges Tillage (CRT) technology is adopted as an agricultural practice for soil and water conservation and is able to increase soil moisture, fertility and crop productivity. It is a holistic landscape approach to manage water and capture rainfall on a watershed scale. The technology was developed locally by the Rural Economic Institute (IER) of Mali and CIRAD (Gigou et al., 2006; Traoré et al., 2017; Dembele et al., 2021). Traore and Birhanu (2019) reported that CRT retains rainfall, increased deep drainage, and improves water and nutrients availability for crops. Traoré et al. (2002) indicated the expected advantages of CRT on soils and it included: i) erosion reduction; ii) increase of growth and yields of trees and crops; iii) soil moisture increase, and iv) gain from forage and building material obtained from grasses that stabilize main ridges. Omer and Elamin (1996) in Kordafan, also reported that CRT improved soil properties, soil moisture storage and sorghum yield.

Sorghum (*Sorghum bicolor*) is produced in Mali for both human and animal's nutrition. In fact, sorghum grain is used to cook main meals in the households while biomass and bran are consumed by animals. Sorghum is the best economic crop in Mali after cotton, rice, and maize. The high economic advantage of crops depends to their exportation, consummation and higher productivity (Sanders et al., 2015). Sorghum is a vital economic crop, providing the main source of income and nutrition in farming households, contributes to food security, and reduces food importation (FAO, 2018). At Kani and Noumpinesso, sorghum is typically considered as the main source of food after maize.

Soybean (*Glycine max* (L.) Merr.) is a leguminous crop that fixes nitrogen in the soil. In fact, leguminous crops like soybean, cowpea and groundnut help to maintain/ improve soil fertility by accumulating nitrogen from 80 to 350 kg ha^{-1} (Mobasser et al., 2014). Legumes fix nitrogen from the atmosphere biologically in the soil (Thorup, 1994), and this nitrogen can be efficiently utilized by the intercropped cereal in competition (Fan, 2006). I Intercropping cereal and legume is an agronomic method to involve production of two or more crops on the same field (Katyayan, 2005). Intercropping systems added 15-20% to food production every year in the world (Lithourgidis et al., 2011). Consequently, intercropping gives ecological, biological and socioeconomic advantages than sole cropping (Solomon et al., 2014). Encouraging farmers to use their natural resource base in a sustainable manner with integrated soil fertility, crop rotation and/or intercropping and minimum/ conservation tillage methods is necessary (Harold, 2015). Such studies are necessary to provide the requisite baseline information for introducing a leguminous crop and CRT in the farming system of small holder farmers. It is in this context that this study was carried out.

The objective of this study was to determine the effect of CRT on growth and yields of sorghum and soybean based intercropping system and also, its economic profitability.

2. Materials and Methods

2.1. Site Description

The study was carried out at Kani and Noumpinesso in Koutiala district, southern-Mali (Figure 1). Kani is distant of 45 km from Koutiala. It is located at latitude 12°14′43.23″ North and longitude 5°10′57.94″ West at an elevation of 384 m. Kani is part of a Sudanese zone. Kani is characterized by a long dry season from November to March and a rainy season from May to October. Most of the rain is received in August and causes erosion in the watershed through Noumpinesso.

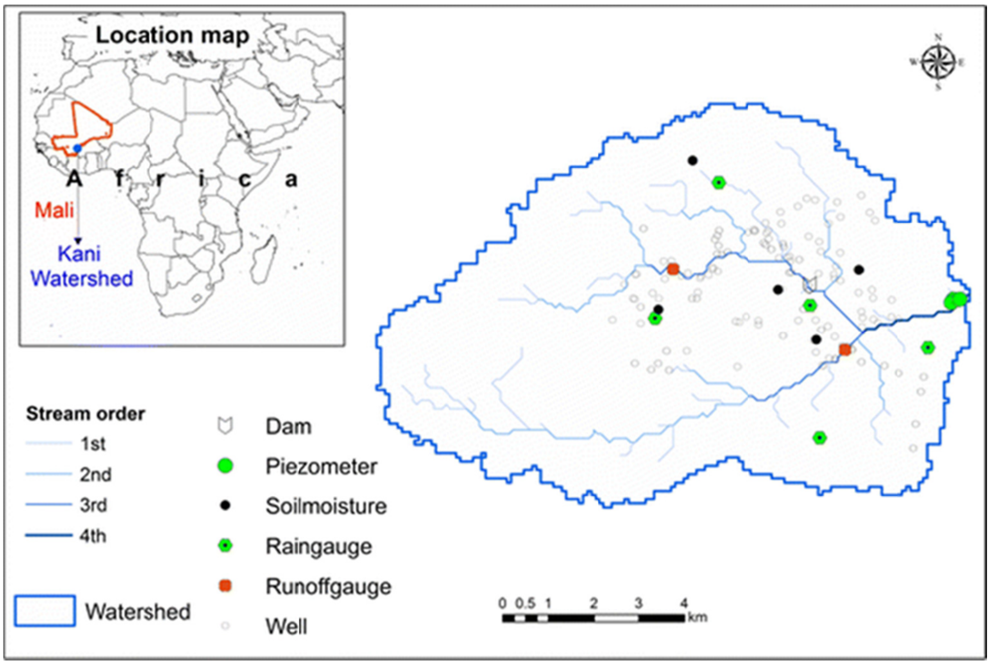

Figure 1. Kani watershed in southern Mali (Koutiala Region) (Birhanu et al., 2018)

Agriculture and livestock are the main activities in Kani and Noumpinesso. Women of this community adopt soybean. They used this crop as condiment, well known in local language as "Soumbala" and deliciously used in soups. Sorghum grain constitutes 20% of human food and its straw serves as fodder.

Basins and plateaus mainly constitute the landscape of Kani and Noumpinesso. Soils of the region are classified mostly as Alfisols according to Soil Taxonomy (Soil Survey Staff, 1999), with many Paleustalfs and frequent Plinthustalfs. The Ustalf classification indicates that soils are indeed, highly weathered and highly leached. The classification of Plinthustalfs is of special concern because it indicates that soils contain a plinthite layer of soft Fe and Al oxides that will harden irreversibly into lateritic stone if exposed. Landscapes of the region have many surfaces resulting from exposed plinthite that have hardened into stone. Such occurrences emphasize the critical need to control and prevent erosion exposure of such surfaces; else additional land will be irreversibly lost. The Alfisol soil order indicates that soils are constrained by both small amounts of nutrients and a low capacity to retain nutrients due to chemical constituents. Crop productivity is further diminished due to low quantities of organic carbon and exhausted state of the soil fertility. While there are debates as to what are the most limiting factors, nutrients or water (Kablan, 2008) seemed to be of prime importance.

In this area, rainfall varied from 800 to 1100 mm by year. Figure 2 showsthat annual rainfall was 1072 mm in 2017 and 1005 mm in 2018. The monthly maximum rainfall of 285 mm was observed in July in 2017 and 382 mm in August in 2018.

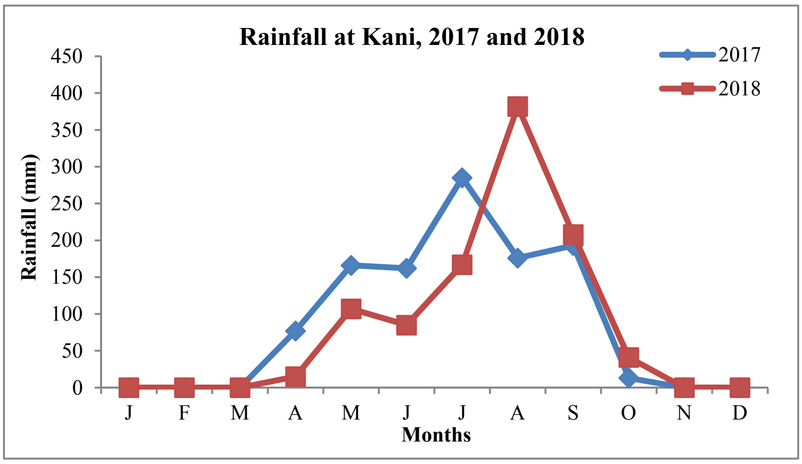

Figure 2. Rainfall situation at Kani (2017, 2018)

2.2 Field Implementation of Contour Ridges Technology

A topographic level and a graduated ruler were used to trace a contour line. Stakes were placed at each 10 m to determine contour line. Diagnosis with farmer (field owner) allowed technicians to identify water circulation routes, erosion problems and flooding that occurred in the field. For each farmer, fields under CRT varied from 1-3 ha. The first contour line started 25 m away from the upstream limit of field. Three (3) or four (4) round trips of an oxen plow was done to make an earth bund or permanent ridge of 1 m wide called "ado". Distance between ado was fifty (50) meters. Rows of seedlings or ridges were parallels of ado for better function of the CRT technology. Spontaneous grasses and/or shrub were usually allowed to grow on ado.

2.3 Implementation of Trials

2.3.1 Experimental Design

Intercropping trials (sorghum-soybean) were conducted on 8 fields (replications), with CRT and no contour ridges technology (NCRT) or farmer's practices plots in 2017 and 2018. All field operations were done at the same period and manner in CRT plots as in NCRT plots.

The trial was a factorial combination of two tillage practices (CRT and NCRT) and three cropping systems (Sorghum Sole crop, Sorghum intercropped with soybean, Soybean sole crop).

The trial was in Split plot design with eight replications in which tillage practices represented the main plots and cropping systems the subplots. The dimensions of the subplots were 10 × 5 m. The main plots were separated by 1m A local variety of sorghum (*Sorghum bicolor* L. Moench) called "negnebling" (90-100 days) and improved variety of soybean (*Glycine max* L. Merr.) named G115 (110 days) were used. The same trial was conducted on eight different farms corresponding to two sites in which four replications in each site (Kani and Noumpinesso).

2.3.2 Fertilization

Organic manure at 2.5 t ha^{-1} + 50 kg of Cereal complex (17-17-17) + 25 kg ha^{-1} of Urea were applied to sorghum. In soybean, organic manure at 2.5 t ha^{-1} + 50 kg of DAP were used.

2.3.3 Maintenance of Trials

Crop weeding was done at 15 and 30 days after planting. Earthing up was carried out 40 days after planting. Final weeding was done 15 days after the earthing up operation. Growth, development and yields characteristics such as height, diameter, grain yield and straw yield were determined from the center lines in subplots.

2.4 Land Equivalent Ratio (LER)

The performance of intercropping is generally evaluated by:

• Grain yield, biomass yield

• Quality (protein content, etc.)

• LER

Land Equivalent Ratio (LER) assesses the performance of an intercropping system during crops development cycle. It compares the yields of crop intercropped to the yields of sole crop. LER is the area of monospecific cultures required to achieve the same yield as in combination. It is calculated as follows:

If LER = 1, there is no difference between the two culture modes;

If LER < 1, there is a loss of yield in intercropping;

If LER > 1, there is a productive advantage in intercropping system (PerfCom, 2012).

$$LER = \frac{\text{Yield of intercropped cereal}}{\text{Yield of sorghum sole crop}} + \frac{\text{Yield of intercropped soybean}}{\text{Yield of soybean sole crop}} \quad (1)$$

2.5 Determination of Value to Cost Ratio (VCR)

Unsubsidized input costs and crop peak prices were used to calculate the VCR as a first indicator of acceptability of investment, using the formula of Nziguheba et al. (1998):

$$VCR = \frac{Y - Yc}{X} \quad (2)$$

Where, Y is the value of the crop in intervention plots, Yc is the value of the crop harvested in control plots, and X is the cost of inputs (seeds and fertilizers).

2.6 Monitoring of Soil Moisture

A time domain reflectometry (TDR) probe was used for soil moisture measurements at an interval of 10 days during the rainy season. Measurements were made in CR and NCR plots at 1 m depth displaying directly in volumetric moisture (V%). For the principle, access tubes were set up into soil in CRT plots and NCRT plots fields. The Profile Probe (PR2) was inserted in the tubes for data collecting. Hand Held (HH2) moisture meter connected to PR2 Profile Probe by cable show and store data. The manufacturer is Delta-T Devices.

2.7 Statistical Analysis

Data was subjected to analysis of variance using GENSTAT version 12 (GenStat Release 12.1 (PC/Windows Vista) Copyright (2009), VSN International Ltd) and significant means were separated with least significant difference (Lsd) at 5% and correlation analysis. Some data was analyzed using the EXCEL software for intermediate and graphical calculations

3. Results and Discussion

3.1 Impact of Intercropping System on Sorghum Growth, Yields and Advantage Productivity

During the two years of the study, intercropping system highly p (< 0.001) increased sorghum growth and yields. In fact, sorghum grain and straw yields were increased by 62 and 51%, respectively (Table 1). Sorghum height and diameter were increased by 22 and 19% respectively (Table 2). A general assumption of intercropping cereals with leguminous crops is that, leguminous with the specific Rhizobium may have most of nitrogen to supply through fixation of atmospheric nitrogen. Rhizobium leaves to the soil available nitrogen for the companion cereal (Saberi, 2018). There is evidence that leguminous plants can benefit the intercropped cereals in the same season through N excretion and nodule decomposition (Bonetti, 1991). These results corroborated those of Saberi (2018) who indicated that, sorghum associated to soybean also increased dry forage of sorghum by 24.01% in Gorgan and 26.12% in Aliabaad at Iran the mean comparison. He reported that LER in intercropping sorghum and soybean was better than sole cropping of sorghum. Intercropping sorghum to soybean showed a productive advantage of LER of 1.54 and 1.44 at the first and second year, respectively (Table 1). The explanation behind was that LER greater than one means there is a productive advantage in intercropping system (PerfCom, 2012). Our results were related to those of Sagar et al. (2021), who reported that sorghum intercropped with soybean showed a LER of 1.4 in Nigeria.

Table 1. Sorghum yields and profitability of intercropping sorghum-soybean at Kani and Noumpinesso, 2017 and 2018

Sorghum's grain and straw yields (kg ha^{-1})				
	Grain yield		Straw yield	
	2017	2018	2017	2018
Cropping systems				
Intercropping sorghum	1314	1926	5173	5103
Sole sorghum	771	1248	3727	3137
Mean	1042	1587	4450	4120
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	131.3	180.188	532.1	516.61
CV%	18.4	16.5	17.4	18.3
Soil and water conservation				
CRT	1241	1809	5125	4838
No CRT	843	1366	3775	3402
Mean	1042	1587	4450	4120
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	131.3	180.188	532.1	516.61
CV%	18.4	16.5	17.4	18.3
LER	1.52	1.44		

Note. L.S.D.: least Significant differences; F.pr: F probability; CV: coefficient of variation.

Table 2. Sorghum growth and development at Kani and Noumpinesso, 2017 and 2018

Sorghum's height and diameter				
	Height (m)		Diameter (mm)	
	2017	2018	2017	2018
Farming systems				
Intercropping sorghum	3.01	2.98	16.78	18.58
Sole sorghum	2.54	2.39	13.81	15.87
Mean	2.77	2.69	15.29	17.22
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	0.2016	0.1266	0.811	0.687
CV%	10.6	6.9	7.7	5.8
Soil and water conservation				
CRT	3.1	2.97	16.81	18.81
No CRT	2.44	2.4	13.78	15.63
Mean	2.77	2.69	15.29	17.22
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	0.2016	0.1266	0.811	0.687
CV%	10.6	6.9	7.7	5.8

Note. L.S.D.: least Significant differences; F.pr: F probability; CV: coefficient of variation.

3.2 Impact of Intercropping System on Soybean Growth and Yields

Intercropping system highly p (< 0.001) improved soybean grain and straw yields by 47 and 30% respectively (Table 3). Also, the system increased soybean height and diameter by 25% (Table 4). After climate parameters (rainfall, temperature), soil quality and nutrients deficiency; insect pests and diseases infestation are the major obstacles for soybean productivity. Intercropping system reduce crops attack by pests and diseases As reported by Aini et al. (2005) who mentioned that multiple cropping operates as physical barriers, therefore limiting the evolution of insect pests and fungal pathogens between adjacent ridges. Advantages of intercropping were also reported by Sagar et al. (2021) who revealed that crops productivity output appears more in intercropping system than in sole crop because intercropping can provide higher yields, better efficient use of resources, reduce crop damage by pests and diseases and give a high income to farmers .

Table 3. Soybean yields at Kani and Noumpinesso, 2017 and 2018

	Soybean's grain and straw yields (kg ha^{-1})			
	Grain yield		Straw yield	
	2017	2018	2017	2018
Farming systems				
Intercropping soybean	1920	1611	2747	2653
Sole soybean	1231	1170	2009	2156
Mean	1575	1390	2378	2404
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	215.4	133.077	249.6	267.508
CV%	19.9	13.9	15.3	16.2
Soil and water conservation				
CRT	1931	1645	2878	2823
No CRT	1220	1136	1878	1985
Mean	1575	1390	2378	2404
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	215.4	133.077	249.6	267.508
CV%	19.9	13.9	15.3	16.2

Note. L.S.D.: least Significant differences; F.pr: F probability; CV: coefficient of variation.

Table 4. Soybean growth and development at Kani and Noumpinesso, 2017 and 2018

	Soybean's height and diameter			
	Height (m)		Diameter (mm)	
	2017	2018	2017	2018
Farming systems				
Intercropping soybean	0.66	0.85	7.41	11.93
Sole soybean	0.51	0.71	5.65	9.97
Mean	0.58	0.78	6.53	10.95
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	0.03774	0.03715	0.636	0.589
CV%	9.4	6.9	14.2	7.8
Soil and water conservation				
CRT	0.69	0.89	7.55	12.49
No CRT	0.48	0.67	5.51	9.41
Mean	0.58	0.78	6.53	10.95
F.pr (0.05)	<.001	<.001	<.001	<.001
L.S.D.	0.03774	0.03715	0.636	0.589
CV%	9.4	6.9	14.2	7.8

Note. L.S.D.: least Significant differences; F.pr: F probability; CV: coefficient of variation.

3.3 Impact of CRT on Sorghum and Soybean Growth, Yields and Economic Profitability

Contour ridges technology increased grain and straw yield of sorghum and soybean by (62 and 51%) and (47 and 30%), respectively during 2017 and 2018 year of the experiment (Tables 1 and 3). Use of CR method is part of the best technology in reducing erosion and in maintaining moisture and nutrients availability for crop. This technology improves soil humidity in the field, and improves nutrient availability for crop. For sustaining soil productivity, CRT is indicated as a better soil and water conservation method compare to farmer’s practices (Traore & Birhanu, 2020). Then this technology was applied, it increased soil water and nutrient content resulting to increase crop yields. With CRT, yields were increased by 50% for millet, sorghum, and maize (Gigou et al., 2006). Dembele (2014) reported that the effects of CRT significantly increased millet and sorghum yields by 12 and 62%, respectively at Sikidolo in Mali. At the same area of research (Kani and Noumpinesso) sorghum, millet, maize and cotton yields were increased by 70, 63, 87 and 72% respectively (Dembele et al., 2021). The improvement observed in grain yield is attributable to moisture and nutrients conservation capacity of CRT. Soil moisture conservation is vital for smallholder cropping systems as reported by several authors (Irshad et al., 2007; Birhanu et al., 2020; Traore et al., 2017, Dembele et al., 2021). Moisture stored in soil profile by CRT method, supplied water to crop at the end of rainy season when plants are flowering and filling their grains, leading to yield increase. Our finding is in agreement with those of Li et al. (2008) and Khlifi (2010), who reported that CRT increased soil nutrient and available soil moisture for crop root uptake and improved crop growth and yields than NCRT.

In the domain of economy, application of CRT gave a Value to Cost Ratio (VCR) of 3.3 and 3.0 in sorghum production and 12.8 and 9.2 in soybean production in 2017 and 2018 respectively (Table 5). VCR greater than 2 means the treatment is economically profitable (Nziguheba et al., 2010). In fact, CRT reduces runoff and soil erosion, saves more water for crops, increases crops yield and farmer’s economic profitability. Our results corroborate those of Dembele et al. (2021) who indicated that CRT was economically profitable on sorghum, millet, maize and cotton production with a VCR greater than 2. High VCR of soybean production is due to the high cost of soybean in market. Sorghum cost 125 f CFA against 300 f CFA for Soybean. Fertilizers were applicate with micro-dosing system to reduce the amount of fertilizers used and also increase farmer’s income. High income for farmers in soybean production is also due to the no application of urea to soybean.

Table 5. Economic profitability of CR technology on sorghum and soybean production

		VCR	
		2017	2018
Sorghum	CRT	3.0	3.3
Soybean	CRT	12.8	9.2

4. Correlation of Sorghum and Soybean Production With CRT and Intercropping Application

Positive correlation was found with sorghum grain yield and soil moisture using CRT technology (Figure 3). Similar correlation was also observed with sorghum straw soil moisture (Figure 4). Contour ridges technology was adopted in Mali, particularly at Sikidolo, Fansirkoro, Flola, Mpessoba, Kani, Noumpinesso etc. by increasing crop yields (Doumbia et al., 2009; Traoré & Birhanu, 2019; Birhanu et al., 2020; Dembele et al., 2021). This technology improves soil quality by increasing soil moisture and nutrients in which crop profit from. Our results corroborates which of Traoré and Birhanu (2019), when they reported that CRT significantly improved soil moisture and increased crops production at Flola and Mpessoba in Mali. This technology stops runoff on soil surface, and consequently increases the availability of moisture and nutrients for crop. With some periods of drought noticed in two seasons of research, sorghum benefit the moisture in CRT plots to increased his development and yields

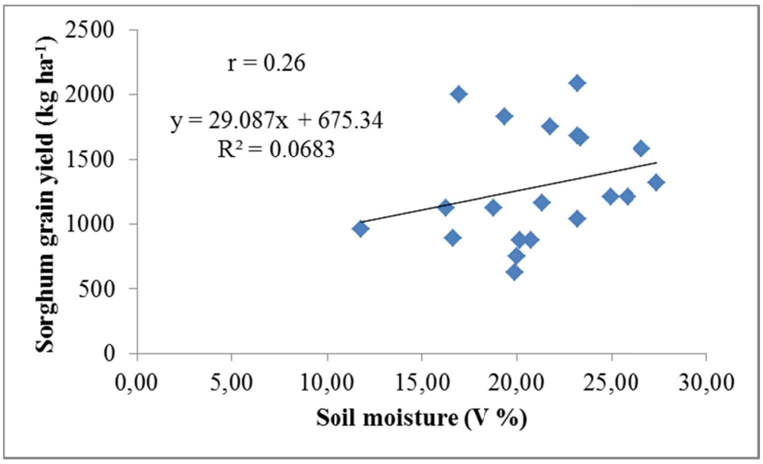

Figure 3. Correlation of sorghum grain yield and soil moisture using CRT technology

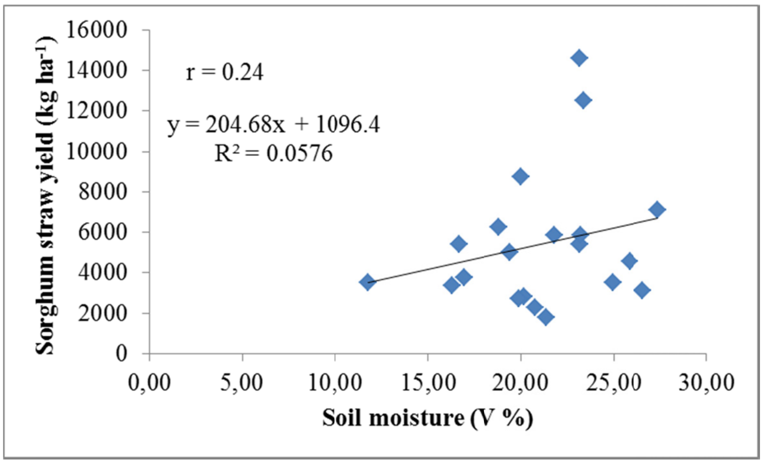

Figure 4. Correlation of sorghum straw yield and soil moisture using CRT technology

5. Conclusion

Intercropping system highly p (< 0.001) increased sorghum and soybean growth and yields. In fact, sorghum grain yield, straw yield, height and diameter were increased by 62, 51, 22 and 19% respectively. Intercropping sorghum and soybean had a positive productive advantage showing a mean LER of 1.49 across the two years. Contour ridges technology improved sorghum grain and straw yield by 40 and 39% respectively. Moreover, the use of CR technology was economically profitable with a VCR of 3.3 and 3.0 in sorghum production and 12.8 and 9.2 in soybean production.

Therefore the technology can be proposed to national extension services and NGOs for upscaling.

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