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Enhancing Indigenous Cropping Systems under Climate Change: A Case Study of Maize (*Zea mays* L.) and Groundnut (*Arachis hypogea*) in Northern Ghana

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Abstract

Due to the continuous cropping of maize and groundnuts on the same land in northern Ghana for livelihood, production yields have declined significantly below potential levels. The purpose of this study was to evaluate the ecological limitations affecting maize and groundnut productivity in northern Ghana and also to analyze the socioeconomic constraints impacting the livelihoods of smallholder farmers. Five cropping systems (*viz.* sole continuous maize (SCM), sole continuous groundnut (SCG), maize-groundnut intercrop (MGI), groundnut/maize rotation (GMR) and maize/groundnut rotation (MGR)), each with or without fertilizer were established under RCBD at Nyankpala during the 2021 and 2022 cropping seasons. For the fertilized rotation treatments, the maize crop received 60-N, 40-P_2O_5, and 40-K_2O, kg/ha, while the groundnut crop received 20-N, 40-P_2O_5, and 40-K_2O, kg/ha using NPK 11, 22, 21, kg/ha with trace elements S, Zn and B. The cropping systems were characterised on grain yields, yield related parameters, resource use and economic returns on investments. The results showed that intercrop and rotation treatments gave better yields. Their land equivalent ratios (LER) were 1.2 and 1.09 respectively, in the two seasons. Maize grain yield under the rotation increased from 2.5 to 3.8 t/ha while groundnut pod yield increased from 0.6 to 0.9 t/ha. The system with highest economic returns was recorded for the rotation systems either with or without fertilizer application. To improve livelihoods and productivity, smallholder farmers in northern Ghana should adopt intercrop and rotation systems, incorporate fertilizer application, and consider soil fertility management practices. Policy support and extension services can facilitate the adoption of these sustainable agricultural practices.

Keywords: cropping systems, fertilizer, intercropping, land equivalent ratio, rotation

1. Introduction

Despite increasing national food security globally, households' food insecurity continues to be a challenge, with an estimated 821 million people currently experiencing both food insecurity and malnutrition (Abegaz, 2018; Gashu et al., 2019; Xie et al., 2019). In northern Ghana where agriculture is the major livelihood source, food insecurity remains a challenge. However, several factors pose significant risk to farms, leading to yield reduction when they are not correctly monitored and well managed. These factors can be grouped into three categories which are technological, biological and environmental. In northern Ghana, the biological factors on food insecurity are primarily related to low crop yields (Mabhaudhi et al., 2018) as a result of low and decreasing fertility of the soil (Ukeje, 2010; Rippke et al., 2016; Badu-Apraku & Fakorede, 2017), and high incidence of pest and diseases (Mpandeli et al., 2018; O'Leary et al., 2018; Nhamo et al., 2019; Sserunkuuma et al., 2001; Doss et al., 2001). The technological factors include low adoption of improved varieties and improved agronomic practices, low use of yield-enhancing inputs like fertilizers and agrochemicals, lack of access to credit, and insufficient credit facilities are all contributing factors to northern Ghana's declining maize productivity (Asante et al., 2014; Bempomaa & Acquah, 2014; Addai & Owusu, 2014). The environmental factors affecting food security are related to the growing climate variability that makes it more difficult to increase crop yield and provide food security in rural areas (Ellis-Jones et al., 2012).

Improvements in crop yields are prerequisite for increased food and nutrition security (New Partnership for Africa's Development, NEPAD, 2014). There is a general agreement that rural agricultural systems need to become more resource-efficient for optimized yields and productivity (Isaacs et al., 2016; Matthews & McCartney, 2018). The use of improved technologies, such as high yielding improved crop varieties, improved nutrient management practices, food preservation and post-harvest processing, advanced irrigation systems and intercropping systems have been shown to enhance the efficiency of agricultural systems (Mabhaudhi et al., 2019a). Similarly, cereal-legume cropping systems offer opportunities for improved resource use efficiency and can sustainably enhance crop productivity. A cereal crop (*e.g.*, maize) grown after a legume crop (*e.g.*, groundnut) benefits from the legume's biological nitrogen fixation. Many scholars have recommended diversifying crop systems by expanding the number of planted species in the same or surrounding locations as a solution to many modern agricultural challenges. Crop diversification decreases the risk of nutrient depletion by allowing the growth of numerous plants with various nutritional requirements. As a result, there is less cost for synthetic fertilizers. Since different crops require different amounts of nutrients, crop rotation enables the uptake of different nutrients from year to year, depending on the crop. Indeed, the common purpose of intercropping is to increase production on a given piece of land by utilizing resources that would otherwise go unused by a single crop. The benefits of intercropping include increased yield (Wang et al., 2022); improved nitrogen cycling, increased soil organic matter (Yu et al., 2015), and the prevention of insect infestations, weeds, and diseases (Zhang et al., 2019). Even though intercropping has proven beneficial for overall yield, the performance of each crop in an intercrop system is affected by the interactions or competition for resources including water, nutrients and light (Martin-Guay et al., 2018).

In this study, we proposed that it is advantageous to intercrop maize (*Zea mays* L.) and groundnut (*Arachis hypoogea*), as the groundnut smaller canopy provides little competition for light to the cereal crop (Saxena et al., 2018). Groundnuts are among the legumes that possess nitrogen-fixing ability, capturing atmospheric nitrogen and converting it into a readily available form for plant use. Smallholder farmers in northern Ghana, especially women, use maize-groundnut intercropping at regular basis due to limited agricultural lands. An agronomic survey of 240 farm households in East Gonja, Nanumba North, Nanumba South, and Kpandai districts found that around 60-70% of women farmers practised maize-groundnut intercropping (MoFA) (2022). Planting density, insufficient soil nutrients, inadequate and fertilizer misapplication, absence of improved seed, and diseases and pests all influenced maize and groundnut mean yields, which were 1.7 and 1.2 tons per hectare, respectively. Prior research has focused on improving intercropping system performance by simultaneous planting of groundnut and cereal with adjustment to row spacing and plant population (Kombiok et al., 2004).

Despite the importance of maize-groundnut cropping systems, there is limited research on their effects on crop yields, resource use efficiency, and fertilizer application in northern Ghana. This study therefore, sought to: evaluate (i) the effects of maize-groundnut cropping systems on crop yields and productivity, (ii) the efficiency of maize- groundnut cropping systems on resource use, and (iii) the contribution of fertilizer application to yields of maize-groundnut cropping systems.

2. Materials and Methods

2.1 Study Site

The study was carried out in the 2021 and 2022 cropping seasons at the Savanna Agricultural Research Institute's (SARI) on-station research field in Nyankpala, Ghana. Nyankpala is situated within the savannah agro-ecological zone, roughly 16 km west of Tamale, the capital city of the Northern Region (SARI, 2020). According to Owusu and Waylen (2013), the region has a warm, semi-arid tropical climate with 800-1,200 mm of annual rainfall, mostly in the months of May and June. There is a 15-20% variation in rainfall, which has a detrimental effect on agricultural output (Kpongor, 2016). From 26 °C in December and January to 39 °C in March, the temperature varies (Ghana Meteorological Agency, 2020). During the rainy season, the mean ambient temperature is 32 °C, and the relative humidity varies from 100% during the wet season to 10% during the harmattan period (Dickinson, 2017). These weather patterns are typical of the savannah region of West Africa (Chimere et al., 2022).

2.2 Experimental Design

The experimental design was based on a randomized complete block design (RCBD) with maize and groundnut cropping systems (continuous monocropping, rotation, and intercropping) as the main factors with or without crop specific recommended fertilizer application. For all systems that required fertilizer application, the crop recommended rates of 60 kg N ha^{-1}, 40 kg P_2O_5, ha^{-1}, 40 kg K_2O, ha^{-1} and 20 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1}, 40 kg K_2O ha^{-1} were used for maize and groundnut, respectively. A total of 10 treatments were established (Table 1), with each treatment replicated three times. For all cropping systems and crops, treatments were established on experimental plots measuring 10 m by 5 m, with a between plots spacing of 1 m, and a spacing of 1.5 m maintained between experimental blocks. Prior to establishing the trial, initial soil samples were taken to analyse the fertility status of the field.

Table 1. Treatment layout during the 2021 and 2022 cropping seasons

Treatment	**Description**	**NPK rate** (kg/ha)	**2021**		**2022**	
			Maize	**G'nut**	**Maize**	**G'nut**
T1	Sole continuous maize (SCM)	0	No	-	No	-
T2	Sole continuous groundnut (SCG)	0	-	No	-	No
T3	Maize-groundnut intercrop (MGI)	0	No	No	No	No
T4	Groundnut-maize rotation (GMR)	0	-	No	No	-
T5	Maize-groundnut rotation (MGR)	0	No	-	-	No
T6	SCM	60-40-40	Yes	-	Yes	-
T7	SCG	20-40-40	-	Yes	-	Yes
T8	MGI	60-40-40/20-40-40	Yes	Yes	Yes	Yes
T9	GMR	20-40-40/60-40-40	-	Yes	Yes	-
T10	MGR	60-40-40/20-40-40	Yes	-	-	Yes

2.3 Cropping Systems of Maize and Groundnut

The maize and groundnut varieties used for the establishment of the experiment were Sanzal Sima (drought tolerant maize) and SARInut2 (Early maturing groundnut variety). For all cropping systems, maize and groundnut were sown at a spacing of 0.75 m (inter-row) and 0.40 m and 0.20 m (intra-row), respectively with six rows for sole cropping and three rows each for intercropping. Two seeds of maize were sown per planting hill, while groundnut was one seed per hill. The plant densities (plants ha^{-1}) were 16,667 and 66,667 for intercropped and sole cropped maize respectively, and 33,333 and 66,667 for intercropped and sole groundnut, respectively (Oikeh et al., 2008).

To attain the targeted nutrient application rates, basal and top-dressing fertilizers were applied at the rates indicated in the Table 2 below.

Table 2. Treatment level basal and top-dress nutrient application rates

Treatment	**Treatment description**	**NPK rate** (kg/ha)	**Basal nutrient applications kg ha $^{-1}$**						**Top dress** (kg N/ha)
			N	**P_2O_5**	**K_2O**	**S**	**Zn**	**B**	
T1	SCM	0	0	0	0	0	0	0	0
T2	SCG	0	0	0	0	0	0	0	0
T3	MGI	0	0	0	0	0	0	0	0
T4	GMR	0	0	0	0	0	0	0	0
T5	MGR	0	0	0	0	0	0	0	0
T6	SCM	60:40:40	20	40	40	9	1.3	0.9	40
T7	SCG	20:40:40	20	40	40	9	1.3	0.9	0
T8	MGI	60:40:40	20	40	40	9	1.3	0.9	40
T9	GMR	20:40:40	20	40	40	9	1.3	0.9	0
T10	MGR	60:40:40	20	40	40	9	1.3	0.9	40

For treatments where, basal fertilizer application was required, equal amounts of basal fertilizer were applied in each planting hill prior to sowing of seeds, and gently covered with soil. Dollop cups were calibrated and used to ensure exact amount of fertilizer per planting hill. Top dressing was done at 6 weeks after planting (WAP) after weeding. Top dressing rates were based on the specific quantities required for each experimental plot as presented in Table 2. Urea was used for the topdressing by dibbling small holes close to the base of each planting hill, applied and buried. For the intercropping systems, top-dressing of N was applied only to the maize crop. For the groundnut-maize rotation the succeeding maize crop was top-dressed with N at a rate of 40 kg/ha.

2.4 Determination of Resource Utilization

$$\text{Volumetric Water Content (VWC)} = \theta v \times 100 \quad (1)$$

Volumetric water is the proportion of water volume to soil volume. The soil's VWC was measured using Campbell Hydro sense II. Campbell Hydro sense II is a small, handheld tool that makes measuring soil moisture simple. In each plot, a 20-cm rugged probe was inserted into the ground at five locations and the average of the readings determined.

2.5 Light Interception (PAR) and LAI

Photosynthetically active radiation (PAR) was measured using a canopy analyzer (AccuPAR model LP-80 PAR/LAI ceptometer). The section of the spectrum that plants utilise for photosynthesis is the 400-700 nanometer (nm) waveband of energy. The amount of light falling on the crop plant is automatically recorded by this device, and it translates these data into the plant canopy's leaf area index (LAI). To provide simultaneous above and below canopy PAR readings, an external PAR sensor is included with the AccPAR. Measurements were taken throughout the rows using the ceptometer's one-meter bar, which was placed below the plants at four different locations on each plot. Whereas the bar below the plant canopy monitors energy that is not caught by the plants, the external PAR sensor reads radiation that is coming directly at the sensor. The PAR that the plants then absorb is the difference between the two readings.

2.6 Determination of Chlorophyll Content

The Soil plant analysis development (SPAD) 502 plus chlorophyll meter which instantly measures the chlorophyll content of plant was used to determine the chlorophyll content of both maize and groundnut growing plants. The SPAD values of four leaves from the top, the middle and lower parts of five plants were randomly chosen from each plot and the mean calculated to determine the chlorophyll content. Chlorophyll is the green pigment that allows plants to photosynthesize. This process uses sunlight to convert carbon dioxide and water into the building blocks of plants. The SPAD value of all the leaves of the five randomly selected plants determined was then related to the chlorophyll content of the plant.

2.7 Land Equivalent Ratio (LER)

The competition function known as LER was determined to assess the effects of crop competition and compare intercrop performance to that of the sole crop. For making wise decisions, it provides an accurate assessment of the biological effectiveness of the intercropping scenario. In order to calculate the LER of the maize impacted by the groundnut intercropping systems, Mead and Willey (1980) defined the intercrop grain yield as a ratio of the solitary maize grain production. Intercropping is less productive than sole cropping if LER is less than 1, equally productive as sole cropping if equal to 1 and more productive than sole cropping if more than 1.

Thus,

$$LER = La + Lb = Ya/Sa + Yb/Sb \quad (2)$$

Where,

La and *Lb* are the partial *LER* of crop species a and b; *Ya* and *Yb* are the individual crop yields in the intercrops; *Sa* and *Sb* are their sole crop yields.

The total LER was the addition of the partial LERs of the two component crops.

2.8 Crop Yields Data

Both grain and pod yields of the component crops (maize and groundnuts) were determined from a net plot of 5 m × 4 m (20 m^2) from four middle rows ICRISAT (2019). The yield per plot was then multiplied by 10,000 m^2/ha and divided by the plot's area (m^2/plot) in order to convert yield from a plot to a hectare basis. To avoid biased yield estimation, the following measurements were made prior to that: plant count, number of ears or pods, number of grains per ear or pod, and grain moisture percentage. All measurements were converted to kilograms per hectare.

2.9 Statistical Analysis

Data collected from the on-station experiment was subjected to statistical analysis package (Statistix, 2015). The RCBD analysis of variance approach was used to see if there were any treatment differences. All treatments were compared using 0.05 alpha level. Microsoft Excel Program was used for data input before transferring for analysis.

2.10 Economic Analysis of Treatments

The economic benefits associated with the different cropping systems established were assessed using partial budgeting as outlined in Kombiok (2004). All variable input costs were taken into account, as well as the seasonal average operational costs that apply to all treatments during the cropping season in the research area. The amount farmers paid for clearing land, planting, buying supplies like seed, hiring labor to weed, harvest, and transport farm products to their homes were all considered variable costs. Next, the difference between the gross income and the total cost of production for each treatment was computed to determine its worth, or net return per hectare. The mean of the annual net returns over the study period was used to compute average net returns. There were no levies on capital expenses like land, capital interest, farm equipment depreciation, or other overhead. After dividing the net benefit by the operating cost, the benefit ratio of each treatment was determined.

Thus,

$$\text{Net benefit} = \text{Gross returns} - \text{Total variable cost of production} \tag{3}$$

$$\text{Benefit cost} = \text{Net benefit/Total variable cost} \tag{4}$$

3. Results

3.1 Soil, Grain Yield, Pod Yield and LER of Maize and Groundnut

Based on the findings of the soil test, the soil is acidic, has extremely low levels of organic carbon and nitrogen, low levels of phosphorus, and medium levels of potassium. This suggests that the soil will require amendments, such as organic matter and fertilizers, to restore its fertility and structure (Table 3).

Table 3. Initial soil sample result of the experimental site

Community	**Depth** (cm)	**pH (H_2O)** (1:2.5)	**O.C.** (%)	**N** (%)	**P** (mg/kg)	**K** (mg/kg)	**ECEC** ($cmol^+$/kg)
Nyankpala	0-20	4.11	0.195	0.012	5.86	48	7.631

Generally, the most important factors affecting crop yield are water availability, soil fertility, sunlight and management practices (Kombiok, 2004). The result of grain yield of maize treatments with the application of fertilizer recorded significant higher ($P < 0.05$) yield (Table 4) compared to treatments without fertilizer in both years and this may be attributed to the external nutrient supplied since all other factors were similar. Maize grain yield in the rotational treatments of year two was also significantly higher among the treatments in both years (Table 4). The results showed a common assumption that a groundnut crop improves N availability and enhances yield in a subsequent year. The effect on the yield is therefore, influenced mostly by moisture, nutrient and sunlight. However, year two recorded general yield increment as compared to year one although statistically similar, and this may be related to the early onset and even distribution of rains in year two (Figure 1).

Table 4. Effects of cropping systems on grain/pod yield and LER of maize and groundnut

Treatment	**2021**			**2022**		
	Grain/pod yield (kg ha^{-1})			**Grain/pod yield** (kg ha^{-1})		
	Maize	**Groundnut**	**LER**	**Maize**	**Groundnut**	**LER**
T1 SCM-NF	1179.30	-	-	1585.60	-	-
T2 SCG-NF	-	769.23		-	922.00	-
T3 MGI-NF	443.00	324.07	0.8	878.90	380.00	0.95
T4 GMR-NF	-	686.11	-	1696.6	-	-
T5 MGR-NF	1142.20	-	-	-	1012.30	-
T6 SCM-F	2171.90	-	-	2987.90	-	-
T7 SCG-F	-	660.74	-	.	755.70	-
T8 MGI-F	1450.40	348.52	1.2	1934.6	332.50	1.09
T9 GMR-F/MG	-	596.30	-	3839.30	-	-
T10 MGR-F/GM	2453.30	-	-	-	909.30	-
Grand mean	1473.30	562.23		2153.7	722.31	
LSD (0.05)	1022.40	223.23		1925.90	163.14	
P.VALUE	0.013	0.01		0.001	0.000	
CV	38.14	21.82		47.49	12.42	

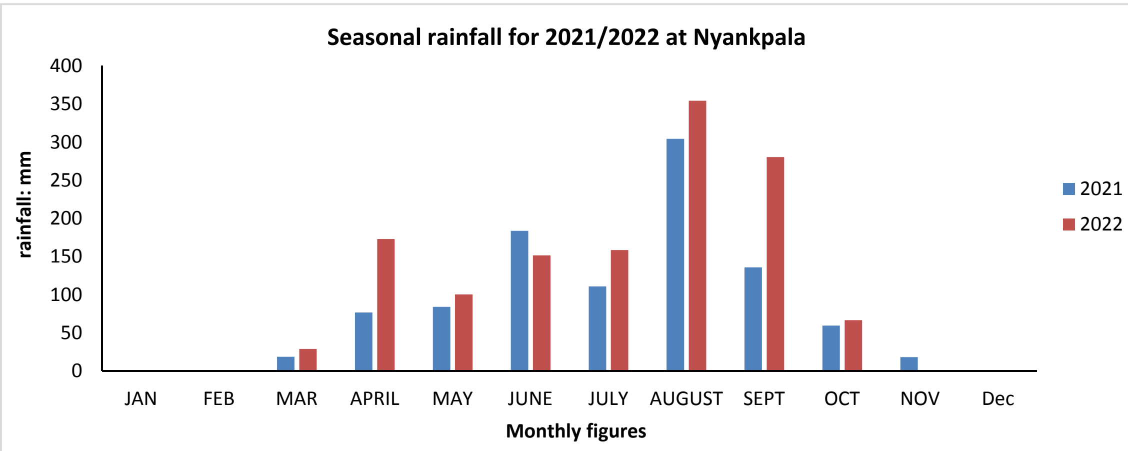

Figure 1. Monthly rainfall at Nyankpala during experimental period

Source: SARI meteorological station.

In terms of groundnut pod yield, there was no significant yield increase (Table 4) among treatment applied with fertilizer and treatments without fertilizer applied in its corresponding sole and intercrop treatments ($P > 0.05$). Though there was an increase in pod yield of groundnut in year two, this was not significantly different from sole or intercrop. Intercropping significantly reduced the yields of individual crops. Similar findings were reported by Kombiok (2004), and Drisah (2006), who indicated a notable decrease of individual grain yields of maize and groundnut intercropped. These are obvious since the plants stand are less.

Crops' light interception and light use efficiency (LUE), which depend on canopy characteristics like leaf distribution and photosynthetic capacity, directly affect the accumulation of dry matter and the generation of yield. Results of sun light interception by the treatments presented in (Figures 6 and 7) showed that there was an increase in light interception from 4 WAP to 8 WAP. However, there were significant differences among treatments at the various stages of growth 4 WAP, 6 WAP and 8 WAP with the intercropped treatment (Figures 8 and 9) recorded higher light interception ($P < 0.05$).

In terms of groundnut pod yield, there was no significant yield increase ($P > 0.05$) among treatment applied with fertilizer and treatments without fertilizer application in its corresponding sole and intercrop treatments. Treatments with applied fertilizer in both years gave higher LER of 1.2 and 1.09, respectively (Table 4) and intercrop treatment without fertilizer in both years recorded LER of 0.8 and 0.95 respectively, which means both the treatments are more productive since their LER are above 1.

3.2 Soil Plant Analysis Development (SPAD) Value of Maize Affected by Maize-Groundnut Cropping Systems

3.2.1 SPAD Value of Maize and Groundnut

The SPAD values of fertilized treatments of both maize and groundnut were significantly higher as compared to non-fertilized treatments in both years ($P < 0.05$). SPAD values of both crops decrease as their ages increase (Figures 2, 3, 4 and 5). At week 10, groundnut was within the senescence period so SPAD reading was not taken.

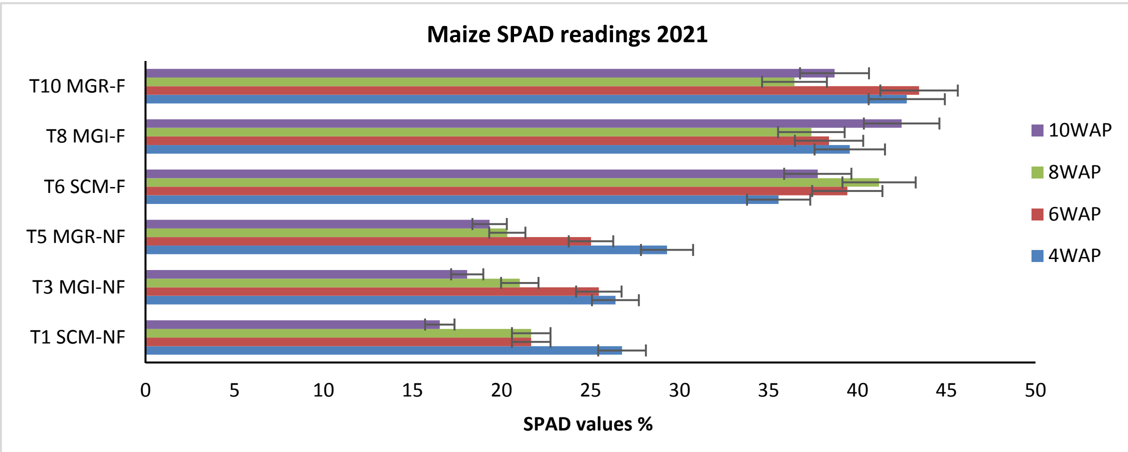

Figure 2. Maize SPAD values, 2021

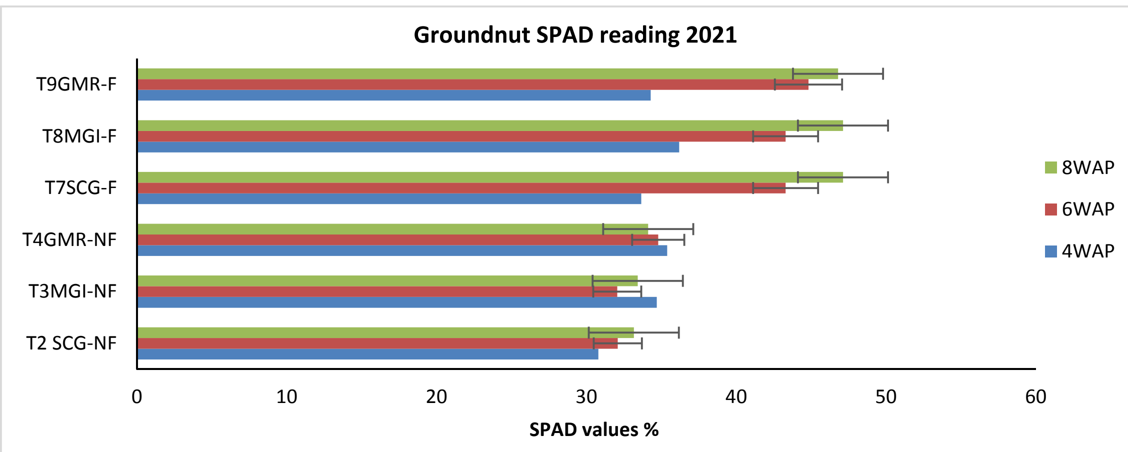

Figure 3. Groundnut SPAD values, 2021

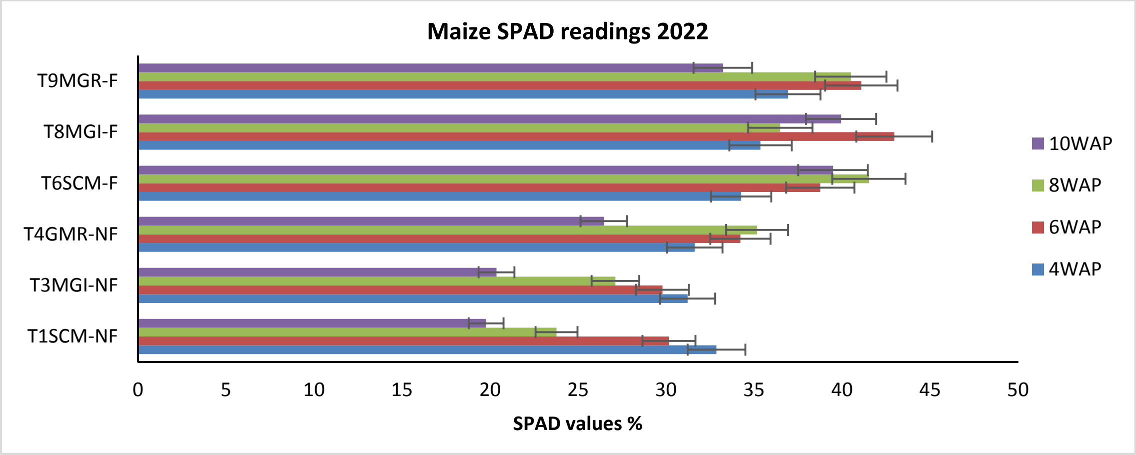

Figure 4. Maize SPAD values, 2022

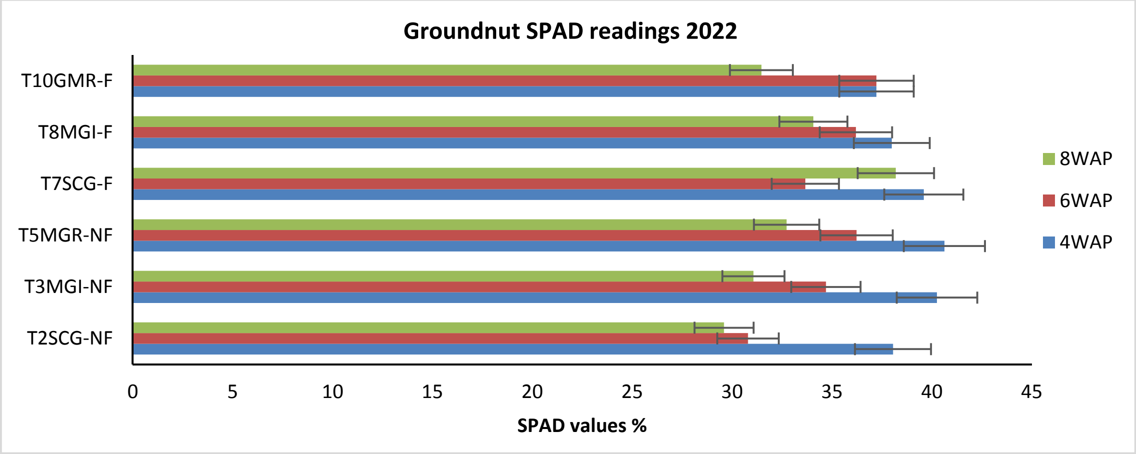

Figure 5. Groundnut SPAD values, 2022

3.2.2 Photosynthetic Active Radiation (PAR) Affected by Cropping Systems

A rise in light interception was observed from 4 WAP to 8 WAP, as demonstrated by (Figures 6 and 7). However, there were significant differences among treatments at the various stages of growth 4WAP, 6 WAP and 8 WAP with the fertilized intercropped treatment (T7, T8 and T9) recorded higher light interception ($P < 0.05$).

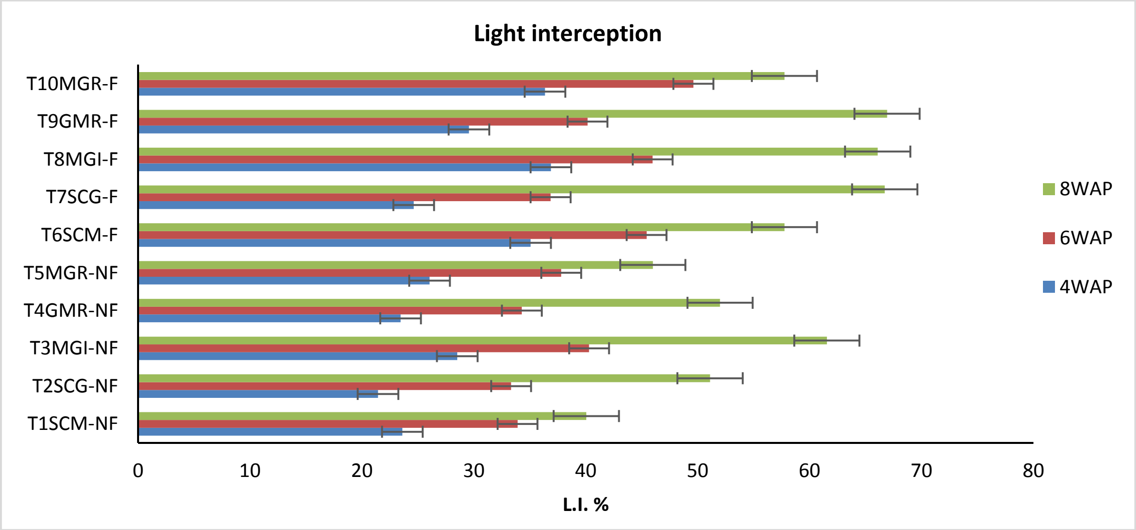

Figure 6. Light interception 2021

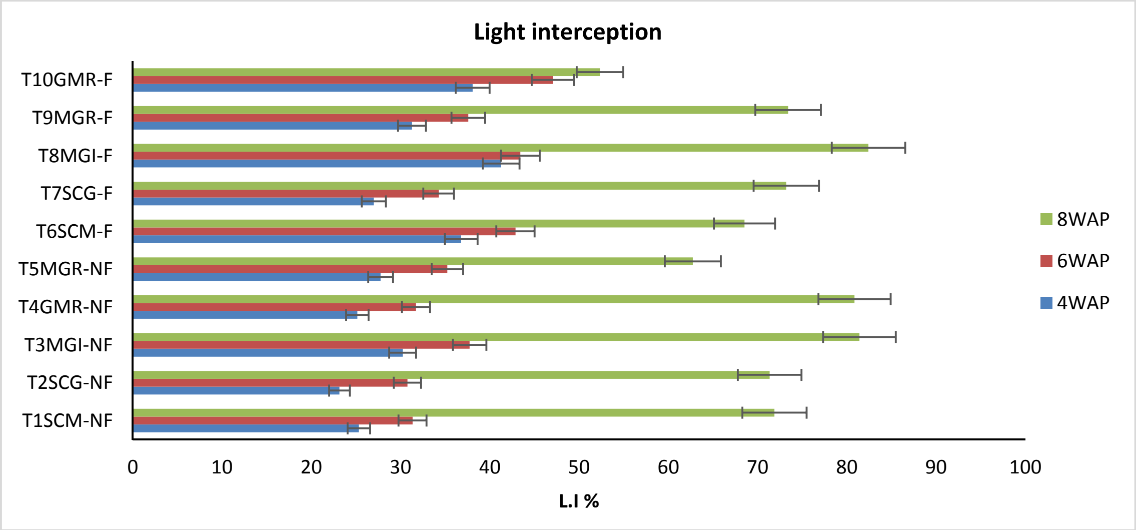

Figure 7. Light interception 2022

3.2.3 Leaf Area Index (LAI) of Maize Groundnut Affected by Cropping Systems

Intercropped systems significantly recorded higher LAI as compared to sole cropping systems ($P < 0.05$). LAI increased at development stages (WAP) and decreased as the plant completed its growth cycle (Figures 8 and 9).

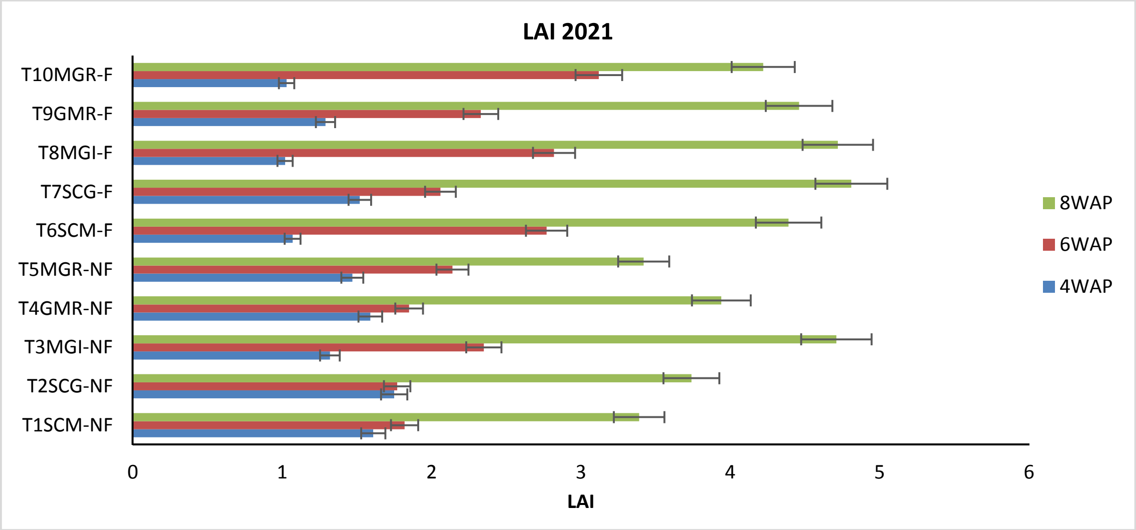

Figure 8. LAI in 2021

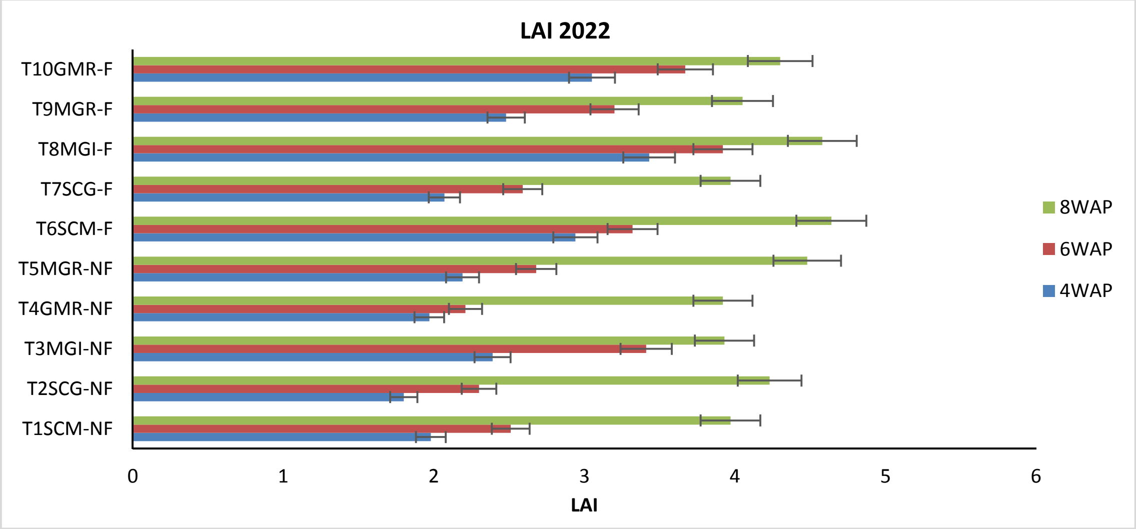

Figure 9. LAI in 2022

3.2.4 Cropping Systems Impact on Soils % Volumetric Water Content (VWC)

Intercropped plots (treatments) had significant higher values of VWC ($P < 0.05$) among the various week intervals than the sole crops of maize and groundnut (Figures 10 and 11). However, treatment with fertilizer applied had significantly higher values among all treatments. Sole crops have more exposed soil, increasing evaporation and water loss, less dense canopies allow more direct sunlight, increasing soil temperature and evaporation. Fertilizers can enhance soil structure, increasing water-holding capacity. Promote healthy root development, enabling better water stimulate plant growth.

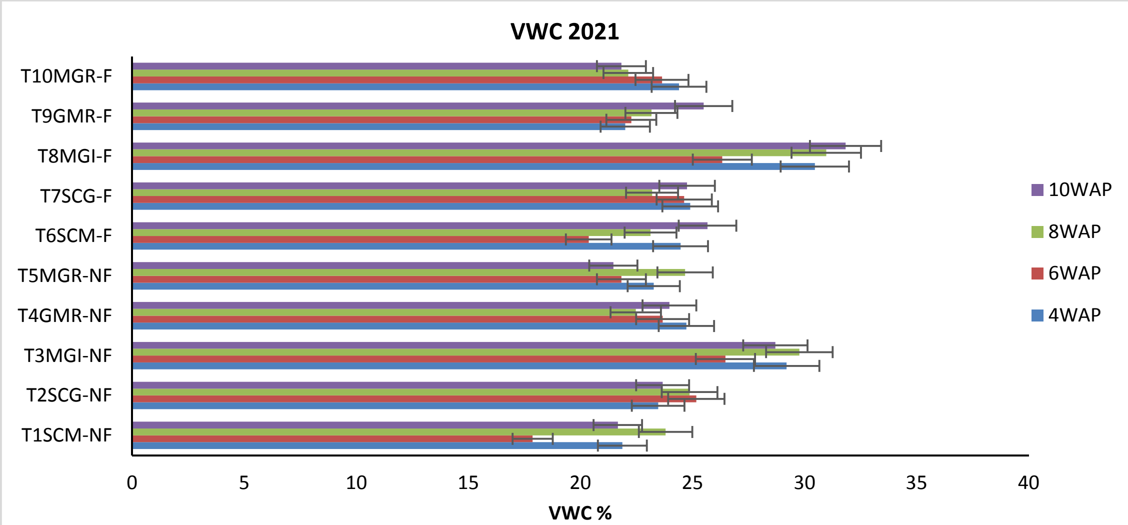

Figure 10. VWC in 2021

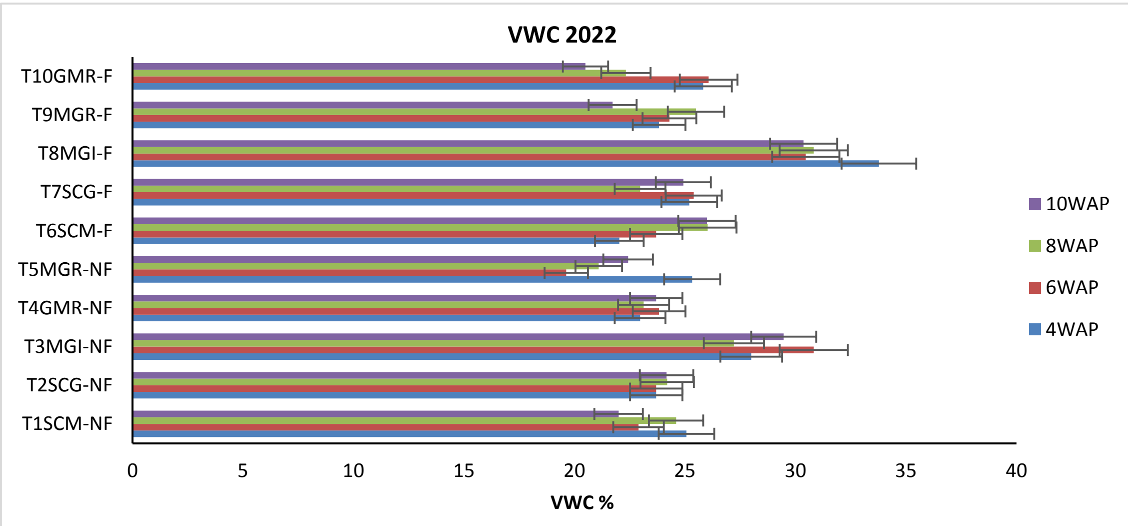

Figure 11. VWC in 2022

4. General Discussion

A thorough understanding of physical and chemical properties of the soil within the site is very important. The analyses indicated that the experimental site is sandy silt in texture and strongly acidic in soil reaction (pH <5.5) with a very low organic carbon content (< 1%) and total nitrogen (< 0.1%). The pH felt short of the optimum for agronomic purposes of crop production and needed some liming to bring the pH upwards. The available P and exchangeable cations (except for K) were smaller than 10 mg/kg and 5 $Cmol^{+}$/kg respectively, and hence the effective cations exchange capacity of the soil (Landon, 1991). All of the figures recorded (except for K) were considered lower limits and below the optimum for crop production without external input.

The results of the study highlight how important crop rotation, fertilizer use, and meteorological factors are in determining groundnut and maize yields. Notably, the results showed that the application of fertilizer greatly increased the output of maize grains, with rotational treatments producing better yields of maize grains in the second year. On the other hand, the yield of groundnut pods was not significantly affected by the use of fertilizer. Intercropping also resulted in lower yields for each individual crop.

The yield discrepancies were caused by several causes. Water availability was important since yield increases in the second year were probably caused by the early start and even dispersion of the rains. Fertilizer application also improved soil fertility, which had a favorable effect on maize grain yield. Sunlight was considered to remain constant among treatments, even though it was not specifically addressed. Crop rotation and fertilizer application are two management techniques that have a positive impact on yields.

Intercropping produced two results. On the one hand, because of greater plant competition, it decreased agricultural yields per individual. However, the groundnut's capacity to increase nitrogen availability was advantageous for the ensuing maize harvest. These results are consistent with other studies by Kombiok (2004), and Drisah (2006), which found that intercropping reduced individual grain yields in a comparable way.

The ramifications of the study are complex. First and foremost, increasing maize yields requires the application of fertilizer. Crop rotation has the potential to enhance soil fertility and production. Finally, intercropping can raise system productivity even if it doesn't always result in higher yields for individual crops.

In order to enhance crop yields and management strategies, future studies should look into the best times and rates to apply fertilizer. Furthermore, investigating different intercropping strategies to reduce yield losses and evaluating the long-term impacts of crop rotation on soil fertility and health may be beneficial.

In summary, this research offers significant perspectives on enhancing crop yields and management strategies for groundnut and maize farming systems. In order to increase crop productivity and sustainability, farmers and other agricultural professionals can make well-informed decisions by comprehending the intricate relationships between crop rotation, fertilizer application, and weather.

Many research investigations conducted on maize and groundnut combinations demonstrated that, economically, the yields of the component crops offset the losses, even if the component crops often have lower yields when compared to their solitary or pure stands. Even though the grain and pod yields of both groundnut and maize in the intercrop plots decreased similarly, treatments with fertilizer applied in both years produced Land Equivalent Ratios (LER) of 1.2 and 1.09 (Table 5), which amply demonstrated the benefit of intercropping. Intercrop treatment without fertilizer in both years recorded LER of 0.8 and 0.95 respectively, which is a disadvantage to the farmer. A yield advantage (LER > 1), a yield disadvantage (LER < 1), or an intermediate result (LER = 1) are the three possible results for LER for intercropping. Yu et al. (2015) and Martin-Guay et al. (2018) in their research findings showed an average land equivalent ratio (LER) of around 1.22±0.02 and 1.30±0.01 or 1.29±0.02 in intercrops with maize. Although they only included a small number of studies on maize-groundnut intercropping, these earlier studies were global meta-analyses that took a wide range of species combinations into account. According to Francis (1986), the fractions of yields relative to their solitary and LER, an indicator of intercropping productivity, are equivalent. With this result, it means land resource use efficiency was better guaranteed by intercropping maize and groundnut with the application of fertilizer.

Maize and groundnut intercropping has the potential to boost crop yields, lower risk, and improve soil fertility because of interspecific complementarity. Ghosh (2004), also stated that it is possible to increase system production and resource use effectiveness by intercropping cereal and legumes. In this study, we found that intercropping greatly increased land use efficiency. Odhiambo et al. (2011), and Feike et al. (2012) stated that the main reason for farmers practicing intercropping is that it can increase land productivity and profitability. Selecting the right crops for intercropping can make good use of resources, thereby increasing the yield per unit area of farmland. The average LER in this investigation was consistent with meta-analyses based on combinations of multiple species. The broad consensus that intercropping cereals and legumes offers an advantage in land usage is supported by this.

Given interspecific complementarity, intercropping of maize and groundnuts as cereal legume is a good strategy to increase system production and resource use efficiency. The higher percentage of intercepted light and better utilization of the intercepted light in mixed crops can be used to explain their higher productivity when compared to sole groundnuts and maize, respectively which is also reported by (Searle et al., 1981; Li et al., 2001; Ghosh, 2004; Li et al., 2009).

Numerous studies reported that yield advantage in intercropping was mainly due to greater light interception and use efficiency. It has been demonstrated that combining tall and short species, as in maize-groundnut intercropping systems, increases light absorption due to the increased soil cover (Zhang et al., 2020). Furthermore, because C4 species have higher saturation points than C3 species, intercropping of shorter C3 species and taller C4 species might increase the LUE.

Intercropped treatments with fertilizer inclusion recorded higher significantly LAI as compared to sole cropping system treatments (Figures 10 and 11). These results are quite consistent with expectations, given that fertilizer was applied close to maize. This also reported by Alhassan (2000) when he intercropped sorghum with groundnut. After 8 WAP, the LAI values of all treatments decreased, most likely as a result of less dry matter being divided at this point between fruit development and leaf production, which were the main physiological processes requiring the accumulation and storage of dry matter at this stage. Similar findings were reported by Kombiok (2004), and Alhassan (2000), who proposed the onset of senescence.

The result of maize and groundnut chlorophyll content presented in figure. The SPAD value of fertilized treatments of both maize and groundnut were significantly higher as compared to non-fertilized treatments (Figures 4, 5, 6, and 7). SPAD values of both crops decreases as their age increases. According to Dwyer et al., central leaves in maize plants have greater N concentrations prior to anthesis, which thereafter begin to decline up to two weeks after anthesis. However, groundnut SPAD values were higher as compared to maize values in both years and this could be attributed to groundnut ability to capture Nitrogen from the atmosphere.

Volumetric moisture content (VWC) varied significantly between different week intervals according to the findings (Figures 10 and 11). In general, intercropped plots had significantly higher VWC during the various week intervals than the sole crops of maize and groundnut. This can be attributed to the biomass ability to conserve moisture. The outcome is similar to the report of Ajayi (2015). The maize-groundnut intercrop improved soil and water conservation due to the additional surface soil protection it provided, and with appropriate intercrop selection, the competition for water under intercropping may be lessened. It was also clear that the VWC among the intercropped treatments was higher than that of the sole crops, indicating that groundnut in the intercropped treatments was capable of acting as live-mulch to shield the soil from direct sunlight, so slowing down the loss of moisture from the soil. Additionally, it was found that maize absorbed moisture more readily than groundnut. These findings are consistent with those of Crookston and Kent (1976), who found that the rate and amount of water uptake are influenced by the roots' capacity for absorption.

There have been reports of beneficial interactions between maize and legumes (groundnut) in strip intercropping and rotation by (Liu et al., 2018; Liu et al., 2017) including high land use efficiency, improved soil fertility, decreased disease and insect incidence, and assurance of steady output. The increased usage of natural resources, notably light, is an ecological benefit of cereal-groundnut intercropping. Optimizing maize row distance and gap width in maize-groundnut strip intercropping resulted in a significant increase in the photosynthetic active radiation (PAR) at the top of the groundnut canopy as well as the photosynthetic rate and radiation-use efficiency (RUE) of maize leaves close to the ear.

Due to the overall increase in the prices of products and services in Ghana, as well as the rise in agricultural inputs and farm operations, high variable cost of production was generally seen during the research period (Tables 5 and 6). Plots with intercropped maize and groundnuts had greater production costs than single-crop plots. Due to the fixed costs of inputs and land preparation, solitary cropping has a low cost of production. The greatest total net returns were from sole groundnut treatment without fertilizer in year one and maize groundnut rotation treatment in year two. This might be explained by the fact that the two treatments produced a larger yield (Tables 5 and 6). The higher groundnut yield of sole cropping in year one could be attributed to the availability of required nutrients for groundnut production since the land was fallowed two years before it was put into production. The higher yield with higher return recorded with maize in year two with maize groundnut rotation treatment was attributed to the contribution of nutrients of the remains of the groundnut cropped in the previous year. Drisah (2006) and Kombiok (2004) observed similar results when they alternated treatments of cowpea and groundnut with maize.

Table 5. Variable cost and net benefit of maize and groundnut: Season one

Treatment	Maize grain yield (kg ha^{-1})	Groundnut pod yield (kg ha^{-1})	Gross return of maize (GHC) *(100 kg = GHC200.00)	Gross return of groundnut (GHC) **(40 kg/bag = GHC300.00)	Total gross returns (GHC)	Total variable cost of production (GHC)	Net returns (GHC)	Benefit Cost Ratio (BCR)
T1 SCM-NF	1179.30	-	2,358.60	-	2,358.60	1,420.00	938.60	0.66
T2 SCG-NF	-	769.23	-	5,769.23	5,769.23	1,420.00	4,340.23	3.06
T3 MGI-NF	443.00	324.07	886.00	2,430.53	3,316.53	1,460.00	1,856.53	1.27
T4 GMR-NF	-	686.11	-	5,145.83	5,145.83	1,420.00	3,725.83	2.62
T5 MGR-NF	1142.20	-	2284.40	-	2,284.40	1,420.00	864.40	0.61
T6 SCM-F	2171.90	-	4343.80	-	4,343.80	2,550.00	1,793.80	0.70
T7 SCG-F	-	660.74	-	4,955.55	4,955.55	1,970.00	2,985.55	1.52
T8 MGI-F	1450.40	348.52	2900.80	2,613.90	5,514.70	2,220.00	3,294.70	1.48
T9 GMR-F	-	596.30	-	4472.25	4,472.25	1,970.00	2,502.25	1.27
T10 MGR-F	2453.30	-	4906.60	-	4,906.60	2,550.00	2,356.60	0.92

Note. Total Gross return = Gross returns of maize + groundnut;

Total variable cost of production = Land preparation+ inputs + cost of labour for farm operations;

Net returns = Total Gross returns – Total variable cost of production;

Benefit cost ratio = Net returns/Total variable cost of production.

Table 6. Variable cost and net benefit of maize and groundnut: Season Two

Treatment	Maize grain yield (kg ha^{-1})	Groundnut pod yield (kg ha^{-1})	Gross return of maize (GHC) * (100 kg = GHC200.00)	Gross return of groundnut (GHC) ** (40 kg/bag = GHC300.00)	Total gross returns (GHC)	Total variable cost of production (GHC)	Net returns (GHC)	Benefit Cost Ratio (BCR)
T1 SCM-NF	1585.60	-	7,135.20	-	7135.20	1860.00	5275.20	2.84
T2 SCG-NF	-	922	-	9,220.00	9220.00	1850.00	7370.00	3.98
T3 MGI-NF	878.90	380	3,955.05	3,800.00	7755.05	1855.00	5900.05	3.18
T4 MGR-NF	1669.60	-	7,513.20	-	7513.20	1860.00	5653.20	3.04
T5 GMR-NF	-	1012.30	-	10,120.00	10120.00	1850.00	8270.00	4.47
T6 SCM-F	2987.9	-	1,3441.55	-	13441.55	3210.00	10231.55	3.19
T7 SCG-F	-	755.70	-	7,557.00	7557.00	2525.00	5032.00	1.99
T8 MGI-F	1934.60	322.50	8,705.70	3,225.00	11930.70	2868.00	9062.70	3.16
T9 MGR-F	3839.30	-	17,276.85	-	17276.85	3210.00	14066.85	4.38
T10 GMR-F	-	909.30	-	9,093.00	9093.00	2525.00	6568.00.	2.60

Note. Total Gross return = Gross returns of maize + groundnut;

Total variable cost of production = Land preparation+ inputs + cost of labour for farm operations;

Net returns = Total Gross returns – Total variable cost of production;

Benefit cost ratio = Net returns/Total variable cost of production.

The cost-benefit analysis revealed varying levels of economic viability across treatments. Notably, treatments with fertilizer application generally exhibited higher net returns and benefit-cost ratios (BCR) compared to those without fertilizer. These results align with Odhiambo et al.'s (2011) study, which reported higher net returns. However, these results differ from Kombiok's (2004) study, which reported lower net returns and BCR values for maize and groundnut production. This discrepancy may be attributed to variations in production costs, market prices, and climatic conditions.

5. Conclusions

Crop rotation and intercropping with fertilizer application are emphasized in the study as beneficial soil management and conservation approaches. Maize and groundnut intercropping and rotation has the ability to raise productivity and income in vulnerable agricultural systems, retain soil nutrients, improve food security, and provide as a feasible starting point for ecological intensification. It is essential for developing countries to conserve land in addition to assisting smallholder agriculture in meeting their demands for protein and food. The dominant crop species, maize, makes the largest contribution to the high LER of maize/peanut intercropping. Despite the potential competition for water and plant resources from the soil, it still serves as the best management techniques for crop production to a small-scale farmer.

Overall, the study recommends intercropping and crop rotation with 60:40:40 kg/ha of NPK fertilizer application as beneficial soil management and conservation approaches for smallholder farmers, improving productivity, income, and food security while conserving land and soil nutrients.

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Authors Contributions

Mr. HA, Dr. SN and Prof. AMM were responsible for study design and revising. Mr. HA, Dr. AM and Dr. AA were responsible for data collection. Mr. HA drafted the manuscript and Prof. RA, Dr. VKA and Dr. SN revised it. All authors read and approved the final manuscript.

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The data supporting this study's findings are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data Sharing Statement

No additional data are available.