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Maize-Legumes Rotation Effects on Growth and Yield of Maize in a Semi-Arid Agro-Ecology in Northern Ghana

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Authors' contributions

This work was carried out in collaboration among all authors. Author RALK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PVVP, ALA and JKB managed the analyses of the study. Authors PAA, NND and GYM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Low soil fertility is the most significant agricultural production constraint also mentioned by resource-poor Farmers participating in the Annual Review and Planning Sessions organized under the auspices of the Research, Extension and Farmer Linkage Committees across Ghana. It is in an attempt to find a very cost effective but yet cheaper and most sustainable solution that this work was undertaken. A six-year field trials were conducted at the Manga Agricultural Research Station near Bawku in the Upper East Region in northern Ghana to determine the most suitable grain legume rotation partners for maize relative to continuous cultivation of maize (*Zea mays* L.) after maize, which is often practiced by cereal farmers under inherently poor soils conditions. The grain legumes evaluated were cowpea [*Vigna unguiculata* (L.) Walp.], soybean [*Glycine max* (L.) Merr.], groundnuts (*Arachis hypogaea*), pigeon pea [*Cajanus cajan* (L.) Millsp.], mucuna (*Mucuna pruriens* (L.) DC and green gram (*Vigna radiate* (L.) Wilczek. The trial was established in a randomized

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complete block with four replications. Growth, development, grain yield and its components and some derived variables were computed. Mean grain yield of maize in the first year, preceding rotation was 2055 Mt ha^{-1}. All the grain legumes recorded significantly greater grain yields as compared to the farmers' practice of continuous cultivation of maize. This is consistent with the very low Carbon and Nitrogen ratios recorded under the grain legumes as compared to the continuous maize treatment. Maize after pigeon pea, groundnuts and cowpea recorded consistently superior grain yields as compared to the other grain legumes and farmers' practice. Mean grain yield increment recorded for one of the first cycle of rotation was as high as 62% over continuous cropping of maize. Similarly, mean grain yield increment of maize after pigeon pea, groundnut and cowpea over continuous maize was 42.5, 41.5 and 31.5% respectively, over the farmer practice. It was concluded that continuous crop rotation of grain legumes with maize resulted in higher maize grain yields as reflected in the superior economic returns on a sustainable basis than the current farmers' practice of continuous cropping of maize after over the years. This obviously has important implications on food security at the farmer household level not only in northern Ghana but equally so in other countries with similar, agro-ecology zones in the African and Asian Continents.

Keywords: Maize; rotation; grain legumes; grain yield.

1. INTRODUCTION

Maize (*Zea mays* L.) has become an important food crop in the Upper East Region of Ghana, in recent times as evidenced by the acreages of land areas devoted to its cultivation out stripping the traditional staple crops of millet (*Pennisetum glaucum* (L.) R. Br.) and sorghum [*Sorghum bicolor* (L.) as it were, before the mid-2000. Therefore application of external sources of fertiliser either organic or inorganic or both is imperative if increased and stable maize grain production and productivity in the region is to be promoted.

Although farmers use various improved maize varieties with high yield potential, grain yield has been observed to be very low, rarely exceeding 1.0 Mt ha^{-1} in farmers' fields [1]. Increasing population has placed too much pressure on the limited land resources thereby, leading to continuous cropping particularly, of cereals after cereals [2]. Continuous cultivation without adequate replenishment of the natural resource base leads to nutrient depletion (Saïdou et al., 2003). Consequently, average maize yields per unit of land have fallen because maize production has expanded into drought-prone areas, semi-arid areas and partly due to declining soil fertility (Gilbert et al. 1993). Longer cultivation further depletes the soil organic matter content and fertility (Wu et al., 2003). Loss of soil organic matter (OM), and nutrients, low water infiltration and water holding capacity of soils are among the factors that have resulted in poor soil productivity [3]. Acquaye (1986) observed that soil fertility is closely associated with OM content of the soil, which was determined to be 1–2% (0–15 cm depth) in savannah soils.

Among the various management practices for increasing the productivity of crops, fertilizer application normally gives the highest returns (Chowdhury & Chetty, 1979). For maize production, National Agricultural Research Programme (NARP/CSIR) (1998) recommended the application of: nitrogen (N) [100 kg N ha^{-1}], phosphorus (P) [60 kg P_2O_5 ha^{-1}] and potassium (K) [40 kg K_2 O ha^{-1}]. Earlier attempts by the Ministry of Food and Agriculture, Global 2000 and other non-governmental organizations, to promote maize production by supporting farmers with highly subsidized fertilizers appreciably increased maize yield from 0.6 t ha^{-1} under peasant farmers' practice to about 1.2M t ha^{-1} using 200 kg ha^{-1} of NPK [4]. However, fertilizer use in Ghana remains low because most farmers cannot afford it and, therefore, do not use it or use less than the recommended rates. Other approaches to remedy nutrient deficiency and declining soil productivity may be to explore organic sources of fertilizers (Gyamfi et al., 2001). With the rise in the cost of mineral fertilizer and the concerns over sustainability of current cropping systems, green manures have attracted new research interest (Hikwa and Mukurumbira, 1995). However, green manure production requires land that could often be used for food and cash crops (Giller et al., 1997). On the other hand, a number of farmers cultivate food legumes, e.g. cowpea, bambara groundnut (*Vigna subterranean* (L.) Verdc and groundnut in rotation with upland crops and these have beneficial effects on soil fertility. Asibuo and Osei-Bonsu (1999), in studies conducted at Ejura in the forest-savanna transition zone of Ghana, observed that mean maize grain yields after mucuna, canavalia (*Canavalia sericea*) and soybean, without fertilizer N, were 2.3, 1.6 and 1.0 Mt ha^{-1}, respectively. Crop rotation is well known for its improvement effects on crop yield and reduction of financial risk [5]. Consequently, it has been recommended as a measure for financially sustainable crop production [6]. The yield increases often recorded in maize following grain legumes have been attributed to fixed-N and 'other rotation' effects, but these effects have rarely been separated [7]. The present study aims at determining the best grain legume rotation partner for increased and stable maize production in the Savanna agro-ecologies of northern Ghana. This would encourage farmers on the Savanna agro-ecologies to grow grain legumes in rotation with maize.

2. MATERIALS AND METHODS

2.1 The Experimental Area

Field experiments were conducted at the Manga Agricultural Research Station near Bawku, in the Upper East Region (11º01' N, 00º16' W, 249 m above sea level) from 2012 to 2018. The experimental area has a mono-modal rainfall pattern, starting in June and ending in early October. The field was a flat land and the soil is Plinthic Lixisol (FAO-UNESCO, 1988) classification and developed from granite. The soil is deep to moderate deep and well drained.

2.2 Soil Physical and Chemical Properties

Composite soil samples for determination of the initial physical and chemical properties were collected prior to planting in 2012 and after 2 cycles of the crop rotation in 2015 at 0–15 cm depth. The samples were air-dried, crushed and sieved through a 2 mm sieve chemical analysis carried out at the Soil Chemistry Laboratory of the Council for Scientific and Industrial Research (CSIR)-Savanna Agricultural Research Institute (SARI) for chemical analysis. The sieved (< 2 mm mesh) air-dried samples were analysed for pH in water using soil to water ratio of 1:2.5 (IITA, 1979). Total N was determined by micro-kjeldahl distillation and titration method (Bremner and Keeney, 1965). Available P was determined by Bray 1 extraction solution procedure (Bray and Kurtz, 1945). Exchangeable bases (Ca, Mg, and K) content in the soil were determined in 1.0 M ammonium acetate extract (Thomas, 1982) and organic carbon by modified Walkley and Black procedure as described by Nelson and Sommers (1982). The mean physical and chemical properties of the surface soil taken from 0-15cm before sowing are presented in (Table 1). The soils of the experimental site are mainly sandy, and also acidic, with high levels of potassium. However, all the other plant growth requirements are below average for increased maize production (Table 1).

2.3 Field Trial Procedures

Since this is a rotation trial it would only be in the second year when the maize crop would follow the previous grain legume crop that inferences could be drawn as to, which grain legume is the best rotation partner for maize in this semi-arid agro-ecology. The entire plot was therefore divided into two equal halves, one was sowed to maize and the other half to a grain legume in the first year after, which the maize followed the legume in every other year. The experimental treatments were: Maize cropping after each of cowpeas, groundnuts, soybeans, pigeon peas, and mucuna cultivation as well as the farmers practice of maize after maize as control plot. Plot size for each treatment was 4.5 m x 5m. The improved maize variety CSIR-Omankwa was sown 3 to 4 seeds per hill on bullock ridges at 0.75m wide, and at 0.40 m between hills and later thinned to 2 plants per hill at exactly 2 weeks after sowing (WAS).

2.4 Cropped Field Management

After thinning basal inorganic fertilisers were applied by hill placement method at 2 weeks after sowing at the rate of 60 kg/ha N as urea, 60 kg P_2O_5/ha as triple super phosphate (TSP) and 60 kg K_2O/ha as Muriate of Potash (MOP). All treatments were top-dressing was with sulphate of ammonia at a rate of 40 kg N/ha for all treatments at 2 weeks after the first fertiliser application as recommended for maize cultivation in Ghana. Two manual weeding at 2 and 6 weeks after planting and ridges were re-shaped to control any remnant weeds and also control root lodging at mid-season. Data on insect pests and diseases were also collected during the course of the season.

2.5 Harvesting and Plant Sample Analysis

Maize was harvested after physiological maturity and yield and its components were determined for statistical analysis. Samples of crop residues from the various treatments were taken and analysed for soil Carbon (C total nitrogen (N) and Phosphorus (P) while carbon: nitrogen (C:N) ratio was also calculated.

Maize was harvested after physiological maturity and yield and its components were determined for statistical analysis. All crop data were subjected to analysis of variance (ANOVA) and where there were significant differences among treatments, means were separated using the LSD test at the $P = 0.05$ level.

2.6 Economic Analysis

Economic analyses were carried out to compare the profitability of different maize and legume rotation treatments. Benefit-cost ratios and net returns of the rotation treatments were used to assess the profitability of the different treatments. The cost of all recommended variable inputs used in the study were considered. Crop prices and all input prices were surveyed in the study area using seasonal averages that prevailed in the study area during the cropping seasons and compared with local market prices published in Agriculture Facts and Figures of MoFA [8].

Net returns and benefit cost ratios were determined annually for rotation treatments as the difference between gross revenue and total variable costs for net returns and the ratio of gross revenue to total variable cost for benefit cost ratios, both of which were determined using crop enterprise budget technique [9]. The value of maize grain per treatment was taken at harvesting periods and therefore there was no cost borne for storage. Variable costs were the actual input prices paid by farmers each year, which included inputs costs (seeds, fertilizers and labour), field operation costs (tillage, harrowing, sowing, harvesting and bagging). Farm revenues were computed per hectare by multiplying the grain yield of each crop by its local average market price.

Net returns per hectare and benefit-cost ratios were therefore calculated by;

$$B/C = TB/TVC$$

Where

B/C- Benefit Cost Ratio
TB - Total Benefit
TVC-Total Variable Cost

All other things being equal, farmers should be willing to adopt any rotation technique if the B/C ratio of that technique is greater than the minimum acceptable B/C ratio of 1.5 (B/C>1.5). Any technique with a B/C ratio greater than 1.5 (B/C >1.5) is economically viable.

Samples of crop residues from the various treatments were taken and analysed for soil C total N and Phosphorus (P) while carbon nitrogen (C:N) ratio was also calculated.

2.7 Rainfall Distribution of the Area

The accumulated rainfall within the experimental period from 1st July to 31st October was collected at Manga Weather Station. The seasonal pattern of rainfall distribution for the long-term (1993-2015) and the two year (2016-2017) experimental periods is presented in Fig. 1.

The pattern of rainfall distribution for the long-term and the two years did not vary significantly. However, in April 2016, was a dry month. The highest rainfall is usually recorded in August, with July and September also recording higher amounts of rainfall.

Table 1. Some physical and chemical properties of the surface (0-15 cm) soil at the experimental site at the Manga Agricultural Research Station, 2012

Soil physical and chemical properties	Experimental site at Manga
Sand (%)	80.4
Silt (%)	14
Clay (%)	5.6
Soil texture	Loamy sand
Soil pH (H_20)	4.22
Organic carbon (%)	0.47
Total nitrogen (%)	0.06
Available P (mg kg^{-1})	20.25
Exchangeable cations cmol (+) kg^{-1})	
Ca	0.08
Mg	0.04
K	27.30
CEC [cmol (+) kg^{-1}]	4.55

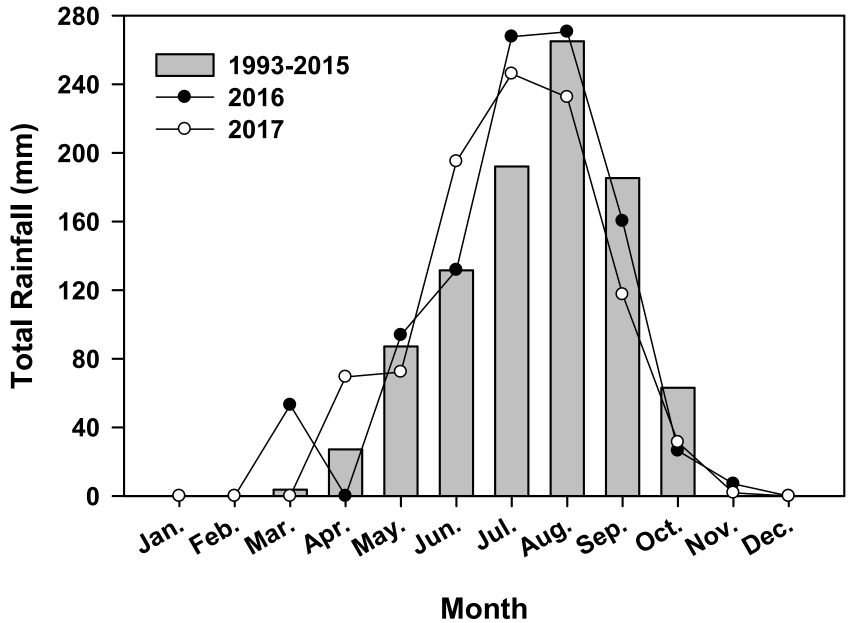

Fig. 1. Patterns of total monthly rainfall for the long-term (1993-2015; bars), 2016 (line; filled circles) and 2017 (line; unfilled circles) at the Manga Agricultural Research Station

3. RESULTS

3.1 Plant Samples Elemental Compositions

Green gram recorded the highest percentage Carbon, which was significantly (P<0.05) greater than those for mucuna, pigeon pea, soybean, and maize but statistically similar to those for cowpea and groundnut (Table 2). Soybean recorded the least total C. The highest total N was recorded for green gram and the lowest for maize. All the grain legumes recorded significantly (P<0.05) greater total N values than maize. The highest total P was recorded by soybean followed by groundnut residues, which were significantly (P<0.01) higher as compared to the rest of the treatments. The lowest C and N ratio was recorded by pigeon pea followed closely by green gram whilst, the highest was recorded by maize residue The differences observed for C and N ratios were highly significant (P<0.01), with that for maize being significantly higher than the statistically similar figures for all the legumes (Table 2).

Table 2. Carbon, N, C, N ratio and total P content of crop residues of preceding crops in a semi–arid agro-ecology in northern Ghana in 2017

Grain legume	Carbon	Total N	C/N ratio	Total P
	%	%	Ratio	mg/kg
Cowpea	51.09	3.67	16.71	440.7
Greengram	56.42	3.95	14.62	482.0
Groundnut	52.78	3.52	18,07	1205
Mucuna	43.58	3.51	18.41	424.0
Pigeon pea	42.12	3.66	13.23	790.3
Soybean	37.34	3.19	17.25	1412
Maize	43.29	1.17	41.95	641.3
LSD (05)	11.97	1.63	11.18	373.5
P value	0.05	0.05	0.01	0.01

Days to maize crop tasseling

The average number of days from sowing to tasseling days to 50% tassel for maize cv. CSIR-Omankwa, across the preceding crops for 2013 to 2017 are presented in Table 3. Days to 50% tassel ranged between 47.0 days and 50.3 days across the preceding crops in the 2013 season. Maize after groundnuts took the least number of days to tassel while the highest number of days to tassel was recorded in maize after mucuna and maize after maize. Days to 50% tassel for maize after each of cowpea, groundnuts, and pigeon pea were less than the trial mean of 48.8 days, those of maize after each of soybean and green gram were equal to the trial mean and those for maize after each of maize and mucuna were higher than the trial mean. In 2013, preceding crop did not influence the number of days to tasseling differentially ($P<0.062$).

In 2014, average days to 50% tassel across the various preceding crops ranged between 45.8 days and 49.3 days. The least days to 50% tassel was recorded for groundnut while the highest DTT was for cowpea. Days to 50% tassel for maize after each of groundnut and mucuna were lower than the trial mean, while those for the rest of the preceding crops were higher than the trial mean of 47.8 days. Just like for 2013, preceding crops did not influence days to 50% tassel differentially ($P<0.336$).

The average days to 50% tassel recorded across the preceding crops ranged from 46.3 days (pigeon pea) to 51.5 days (maize) in 2015. Preceding crops with average days to 50% tassel higher than the trial mean of 48.5 days were cowpea, green gram, and maize whilst average days to 50% tassel figures for groundnut, mucuna, pigeon pea, and soybean were lower than the trial mean. However, the effects of preceding crops on average days to 50% tassel were not significantly different ($P<0.210$).

In 2016, the average days to 50% tassel ranged between 47.0 days (recorded for groundnut) and 50.3 days (recorded for maize) across the different preceding crops. Four of the preceding crops (cowpea, groundnut, mucuna and pigeon pea recorded average days to 50% tassel values lower than the trial mean of 48.3 days, soybean recorded the same value as the trial mean, while green gram and maize recorded average days to 50% tassel values higher than the trial mean. Generally, maize attained 50% tasseled earlier in 2017 as compared to the other years. Days to 50% tassel in 2017 ranged from 44.8 to 48.5 (Table 3). Maize after groundnut was the first to attain 50% tassel whilst, maize preceding maize took the longest time to attain 50% tassel. Maize after maize took a significantly ($P<0.004$) longer time to attain 50% tassel as compared to their counterparts that preceded the grain legumes. Maize preceding groundnut has consistently, attained 50% tassel than maize after the other legumes in all years except for 2015.

Ear placement height (ear height) ranged from 29.8 cm to 46.5 cm across the various preceding crops in 2013. Maize and groundnuts as preceding crops produced the lowest and highest placed ears respectively. Different preceding crops influenced ear height differentially ($P<0.009$). Ear height for maize after groundnuts (the highest placed) was significantly higher than all others except for maize after pigeon pea. Among the legumes as preceding crops, only groundnuts and pigeon pea produced significantly greater ear heights than maize after maize (Table 4).

Table 3. Days to tasseling of maize cv. CSIR-Omankwa as influenced by different preceding crops in a rotation at the Manga Agricultural Research Station from 2013 to 2017

Preceding crop	2013	2014	2015	2016	2017
Cowpea	48.0	49.3	48.8	48.0	45.8
Greengram	48.8	48.3	49.3	48.8	47.0
Groundnut	47.0	45.8	48.0	47.0	44.8
Maize	50.3	48.5	51.5	50.3	48.5
Mucuna	50.3	46.3	47.8	48.0	46.5
Pigeon pea	48.3	48.3	46.3	48.0	45.8
Soybean	48.8	48.0	48.3	48.3	46.5
Grand mean	48.8	47.8	48.5	48.3	46.3
P value	0.062	0.336	0.210	0.165	0.004
$LSD_{(0.05)}$	2.2	3.4	3.8	2.2	1.79
C.V. (%)	3.1	4.8	5.3	3.1	2.60

Ear placement height

Table 4. Ear placement height (cm) for maize cvCSIR-Omankwa as influenced by different preceding crops in a rotation at the Manga Agricultural Research Station from 2013 to 2017

Preceding crop	2013	2014	2015	2016	2017
Cowpea	37.0	52.5	51.2	57.8	59.1
Greengram	33.2	50.5	50.3	57.1	60.8
Groundnut	46.5	56.3	45.3	68.8	62.1
Maize	29.8	51.7	40.6	53.1	58.9
Mucuna	34.5	52.2	55.3	64.5	69.8
Pigeon pea	42.2	54.1	61.7	59.5	67.4
Soybean	35.5	52.2	50.5	60.1	58.7
Grand mean	37.0	52.8	50.7	60.1	60.9
P value	0.009	0.755	0.094	0.103	0.588
$LSD_{(0.05)}$	8.3	7.5	13.6	10.6	10.34
C.V. (%)	15.1	9.6	18.1	11.8	11.40

Treatment effects on plant height

Maize ears were placed from 50.5 cm to 56.3 cm across the various preceding crops in 2014. Groundnuts and green gram recorded the highest and lowest ear heights respectively. Groundnuts and pigeon pea were the only preceding crops with ear heights greater than the trial mean of 52.8 cm. In 2015, maize after maize had the lowliest placed ears (40.6 cm) while maize after pigeon pea produced plants with the most highly placed (61.7 cm) ears. Only three of the preceding crops (cowpea, mucuna and pigeon pea) resulted in ears placed higher than the trial mean. Like for 2014, differences among the effects of preceding crops on ear height of maize were not significant (P<0.094) (Table 4). Mean ear heights, across the various preceding crops, ranged from 53.1 cm to 68.8 cm in 2016. Maize and groundnuts, as preceding crops, resulted in the lowest and highest placed ears respectively.

In 2017 maize ear placement ranged from 58.7 to 69.8, with maize after greengram having the lowest whilst, maize after mucuna recorded the highest placement (Table 4). Mean ear placement in 2017 was higher than the rest of the years. Maize preceding maize had the lowest ear placement whilst maize preceding mucuna had the highest ear placement.

Plant height ranged from 86.5 cm (after maize) to 110.5 cm (after groundnut) in 2013. The differences observed in the effects of preceding crops on plant height were significant (P<0.034). Compared to maize as a preceding crop, groundnut and pigeon pea were the only legumes that produced significantly (P<0.034) taller plants. Among legumes as preceding crops, the shortest plants were recorded for soybean, and these were significantly shorter than those for groundnut but similar to all the others (Table 5). In 2014, plant heights ranged from 164.5 cm to 170.3 cm recorded for plots previously cropped to soybean and groundnut respectively. However, the differences observed in plant among the different preceding crops were not significant (P<0.933). Plant heights were between 159.9 cm and 188.1 cm for maize and pigeon pea respectively as preceding crops in 2015. Just like for 2014, differences in plant height observed among the various preceding crops were not significant (P<0.068). In 2016, the preceding crop that produced the shortest plants was maize while that, which produced the tallest plants was groundnut. Generally, maize plants in 2017 were taller than those obtained for the rest of the other years with the exception of 2015. The mean plant height that ranged from 164.4 cm to 177.5 cm, across the preceding crops, were not significantly different (Table 5).

In 2017 there were no significant differences in maize height. Plant height ranged between 167.5 cm to 176.8 cm. Maize preceding pigeon pea produced the tallest and maize after mucuna the shortest plants (Table 5).

Table 6 presents the average SPAD readings recorded on the flag leaf across the preceding crops for 2013 to 2016. In 2013, average SPAD readings ranged from 22.4 (pigeon pea) to 28.6 (soybean) across the preceding crops. Groundnut, mucuna, and pigeon pea recorded lower SPAD readings than the trial mean of 25.5 while the rest of the preceding crops recorded higher SPAD readings than that. There were no significant differences (P=0.490) in SPAD readings among the treatments. For 2014, average SPAD readings, across the preceding crops, ranged from 37.8 for cowpea to 41.3 for maize and mucuna. Soybean, maize, and mucuna recorded higher SPAD readings than the trial mean (39.5), green gram recorded same SPAD reading as the trial mean, while cowpea, groundnut, and pigeon pea recorded lower SPAD readings than the trial mean. Treatments did not influenced SPAD readings differentially (P<0.593) in 2014. Average SPAD readings in 2015 were from 22.8 (maize) to 35.5 (cowpea). Green gram and maize recorded lower average SPAD readings than the trial mean of 31.1 while the rest of the preceding crops recorded SPAD readings higher than the trial mean. Effects of preceding crops on SPAD readings did not differ significantly (P<0.088) in 2015. In 2016, the average SPAD readings for the various preceding crops ranged from 36.9 (for maize) to 46.8 (for cowpea). The trial mean for SPAD readings was 42.6, with four preceding crops (cowpea, groundnut, pigeon pea, and soybean) recording higher SPAD readings and three preceding crops (maize, mucuna, and green gram) recording lower SPAD readings than the trial mean. Treatment effects on SPAD readings were not significantly different (P=0.066). SPAD readings in 2017 were greater than those recorded for the other years. However, SPAD readings were not significantly (P<0.05) affected by treatment. SPAD readings ranged from 42.0 to 45.6. Maize after maize recorded the highest SPAD reading whilst, maize preceding pigeon pea recorded the lowest (Table 6).

In 2013, the average number of plants harvested ranged between 32,667/ha and 34,500/ha in response to the various preceding crops. Cowpea was the preceding crop with the lowest number of plants harvested while mucuna and pigeon pea were the preceding crops with the highest number of plants harvested. All the preceding crops, except maize and cowpea, resulted in higher numbers of plants harvested than the trial mean (33,762 plants/ha). However, the different preceding crops did not influence the number of plants harvested differentially (P<0.159; Table 7).

Table 5. Plant height (cm) of maize cv. CSIR-Omankwa in response to different preceding crops in a rotation at Manga from 2013 to 2017

Preceding crop	2013	2014	2015	2016	2017
Cowpea	98.0	165.7	175.8	165.4	175.0
Greengram	95.8	169.6	167.0	164.7	169.2
Groundnut	110.5	170.3	170.6	177.5	173.9
Maize	86.5	167.2	159.9	164.4	167.8
Mucuna	98.2	166.7	174.2	175.3	167.5
Pigeon pea	103.2	169.4	188.1	169.4	176.8
Soybean	90.8	164.5	175.3	171.1	169.9
Grand mean	97.6	167.7	173.0	169.7	172.0
P value	0.034	0.933	0.068	0.275	0.547
LSD $_{(0.05)}$	13.6	12.0	16.6	13.3	12.0
C.V. (%)	9.4	4.8	6.5	5.3	4.70

SPAD readings on the flagleaf

Table 6. Effects of preceding crop on SPAD readings from the flag-leaf of maize cv. CSIR-Omankwa at Manga in 2013 to 2017

Preceding crop	2013	2014	2015	2016	2017
Cowpea	28.5	37.8	35.6	46.8	45.4
Greengram	25.8	39.5	28.8	38.1	43.4
Groundnut	23.1	38.1	34.5	45.1	42.1
Maize	26.6	41.3	22.8	36.9	45.6
Mucuna	23.6	41.3	31.7	41.9	43.6
Pigeon pea	22.4	39.0	32.7	44.8	42.0
Soybean	28.6	39.7	31.5	44.4	40.9
Grand mean	25.5	39.5	31.1	42.6	43.03
P value	0.490	0.593	0.088	0.066	0.521
LSD $_{(0.05)}$	7.8	4.6	8.5	7.2	5.57
C.V. (%)	20.6	7.9	18.4	11.3	8.70

Number of plants harvested

The average number of plants harvested from plots with the various preceding crops ranged between 30,833/ha (for cowpea) and 34,000/ha (for pigeon pea) in the 2014 season. Plots previously planted to cowpea, maize, and soybean produced fewer harvestable plants than the trial mean while plots previously planted to the remaining crops produced more harvestable plants than the trial mean. Just like for 2013, there were no significant differences (P=0.353) among the different preceding crops regarding their effects on the number of plants harvested (Table 7).

In 2015, between 25,333 and 30,667 plants were harvested per hectare for the various preceding crops, with green gram recording the lowest and cowpea recording the highest. With the exception of maize and green gram all the other preceding crops resulted in higher average numbers of plants harvested than the trial mean. The differences observed among the effects of the various preceding crops, on the numbers of plants harvested, was significant (0.046). As preceding crops, all the legumes, except green gram, produced significantly higher average numbers of plants harvested than maize. On the other hand, green gram with the lowest average number of plants harvested, had significantly fewer plants harvested than cowpea and mucuna only (Table 7).

In the 2016 trial, the highest average number of plants harvested (31,667/ha) was recorded for cowpea as a preceding crop while the lowest (29,167/ha) was recorded for soybean as a preceding crop. Four of the legumes (cowpea, green gram, groundnut, and mucuna) recorded higher average number of plants harvested than the trial mean while maize and the other two legumes (pigeon pea and soybean) recorded lower average number of plants harvested than the trial mean. There were no significant differences (P=0.17) among the preceding crops regarding their effects on the average number of plants harvested per hectare (Table 7).

Table 8 presents the average number of cobs harvested per hectare (cobs harvested) for the various preceding crops from 2013 to 2016. Cobs harvested in 2013 were between 46,000 and 59,333 across the various preceding crops. The lowest and highest cobs harvested were recorded for maize and cowpea respectively. All the legumes had more cobs than maize, but only maize and green gram produced fewer cobs than the trial mean. However, the average number of cobs harvested did not differ significantly with preceding crop.

In 2014, average number of cobs harvested was lowest for maize after cowpea (47,167 cobs/ha), while maize after mucuna recorded the highest average number of cobs harvested (57,167 cobs/ha). Averages for number of cobs harvested plots with cowpea, groundnut, and soybean were lower than the trial mean while those for the rest of the crops were higher than the trial mean. There were no significant differences (P=0.059) between preceding crops regarding the average number of cobs harvested.

In 2015, maize as a preceding crop produced the lowest average number of cobs (23,333 cobs/ha) while cowpea, with 38,667 cobs/ha produced the highest. All the legumes produced more cobs than maize. Apart from maize and mucuna (with fewer cobs than the trial mean), all plots for the

Table 7. Number of plants harvested for maize cv. CSIR-Omankwa in response to different preceding grain legume crops in a rotation at Manga from 2013 to 2017

	2013	2014	2015	2016	20017
Cowpea	32,667.0	30,833.0	30,667.0	31,667.0	57,500
Greengram	33,833.0	32,833.0	26,500.0	32,000.0	52,833
Groundnut	33,833.0	33,333.0	30,000.0	30,833.0	55,333
Maize	32,833.0	32,167.0	25,333.0	29,667.0	53,000
Mucuna	34,500.0	33,833.0	30,500.0	31,000.0	54,167
Pigeon pea	34,500.0	34,000.0	29,167.0	29,833.0	56,167
Soybean	34,167.0	32,333.0	29,667.0	29,167.0	59,000
Grand mean	33,762.0	32,762.0	28,833.0	30595.0	55,500
P value	0.159	0.353	0.046	0.17	0.05
LSD (0.05)	1656.5	2992.0	3745.4	2406.6	4463
C.V. (%)	3.3	6.1	8.7	5.3	5.40

Number of cobs harvested

other preceding crops produced more cobs than the trial mean in 2015. The differences in treatment effects on the average number of cobs harvested were however, not significant (P=0.099).

In 2016, the lowest average number of cobs harvested was 43,333 cobs/ha (maize after maize) whilst the highest average number of cobs was 54,500 cobs/ha recorded from maize after cowpea. All the plots previously planted to legumes produced more cobs than that previously planted to maize. Three of the leguminous preceding crops (cowpea, green gram, and pigeon pea) produced more number of cobs than the trial mean of 49,524 cobs/ha while the remaining three legumes (mucuna, groundnut, and soybean) and maize recorded fewer cobs than the trial mean. The effects of the various preceding crops on average number of cobs were significantly different (P=0.051). Although the six legumes did not differ significantly in their effects on average number of cobs, only cowpea and green gram recorded significantly more cobs than maize while the remaining four legumes did not differ significantly from maize in their effects on average number of cobs harvested. Generally, mean number of cobs at harvest in 2017 were greater than the rest of the years. Number of cobs at harvest was significantly (P<0.05) influenced by treatment (Table 8).Maize preceding soybeans produced the highest number of cobs whilst, those obtained when maize preceded greengram was the least. The number of cobs produced by maize after soybeans were significantly (P<0.05) greater than those obtained when maize preceded maize, greengram and mucuna (Table 8). Similarly, maize after cowpea produced superior number of cobs compared to those obtained when maize preceded maize and greegram.

The average weights of dried cobs, as influenced by preceding crop from 2013 to 2016, are presented in Table 9. In 2013, average weights of dried cobs ranged between 1,467 kg/ha (for maize) and 2800 kg/ha (for cowpea) across the array of preceding crops. Maize and soybean had lower cob weights than the trial mean while the plots for the rest of the preceding crops produced higher average cob weights than the trial mean. Differential effects on cob weight were observed for the preceding crops, with all the legumes producing significantly (P=0.015) heavier cobs than maize.

In 2014, average weight of dried cobs for the array of preceding crops ranged between 3,583 Mt ha^{-1} (for cowpea) and 6,050 Mt ha^{-1} for pigeon pea. The plots with maize, soybean, and cowpea as preceding crops produced lower average cob weights than the trial mean while the plots with the rest of the preceding crops produced higher average cob weights than the trial mean. Significant differences (P<0.008) were observed for the effects of the different preceding crops on average weight of dried cobs. Average weight of dried cobs from the plots planted previously to pigeon pea were the highest in 2014 and was significantly higher than those for cowpea, soybean and maize, but similar to those for groundnuts, green gram, and mucuna. On the other hand, groundnut, green gram, and mucuna also produced heavier dried cobs than maize but not cowpea and soybean.

In 2015, average weights of dried cobs ranged between 900 kg per ha and 2,633 kg per ha across the various preceding crops. Maize and

Table 8. Number of cobs harvested for maize cv. CSIR-Omankwa in response to different preceding grain legume crops in a rotation at Manga from 2013 to 2017

	2013	2014	2015	2016	2017
Cowpea	59,333	47,167	38,667	54,500	57,500
Green gram	50,833	54,833	38,000	54,000	52,833
Groundnut	56,000	53,667	37,667	47,500	55,333
Maize	46,000	54,000	23,333	43,333	53,000
Mucuna	54,500	57,167	34,833	48,000	54,176
Pigeon pea	56,500	56,667	37,833	50,167	56,167
Soybean	54,500	53,333	37,000	49,167	59,500
Grand mean	53,952	53,833	35,333	49,524	55,500
P value	0.107	0.059	0.099	0.051	0.05
LSD (0.05)	8,951	6,140	11,044	7,087	4463
C.V. (%)	11.2	7.7	21.0	9.6	5.40

Weight of dried cobs

pigeon pea were the preceding crops with lowest and highest weights for dried cobs respectively. Four of the preceding crops (pigeon pea, cowpea, groundnut and mucuna) resulted in average cob weights greater than the trial mean while three of the preceding crops (maize, green gram, and soybean) resulted in lower average dried cob weights than the trial mean. Preceding crops were observed to have differential effects on average weight of dried cobs (P<0.001). Pigeon pea, as the preceding crop with the highest dried cob weight in 2014, had significantly higher weight of dried cobs than soybean, green gram, and maize but similar weight of dried cobs to mucuna, groundnut and cowpea. On the other hand, all the maize after legume plots, except maize after green gram, had significantly heavier dried cobs than maize after maize.

Maize after groundnut produced the highest weight for dried cobs of 3,542 Mt ha^{-1} while maize after maize produced the lowest weight for dried cobs of 2,425 Mt ha^{-1} in 2016. Average weights of dried cobs for maize after each of green gram, pigeon pea, and maize were lower than the trial mean while those for maize after each of cowpea, groundnut. Mucuna and soybean were higher than the trial mean. Treatment effects on average weights of dried cobs were observed to differ significantly (P<0.016). The effects of treatments involving legumes on average weight of dried cobs did not differ significantly. However, treatments involving groundnut, cowpea, mucuna and soybean had significantly heavier dried cobs than that maize while, the treatments involving green gram and pigeon pea did not differ statistically from that for maize.

3.2 Grain Yield Response to Preceding Crop

Grain yield in 2013 ranged between 1,040 Mt ha ha^{-1} and 2,137 Mt ha^{-1} across the different types of preceding crop. These lower and upper range figures were recorded for maize and groundnuts respectively. Mean grain yield for any the maize after legume (hereafter legume) plots was higher than the trial mean whiles that for the maize after maize (hereafter maize) plot was lower than the trial mean. Legumes produced similar but statistically higher grain yields than maize (Table 10).

Mean grain yield, ranging between 2,479 Mt ha^{-1} and 3,625 Mt ha^{-1} across the various preceding crops, were recorded in 2014, with cowpea and pigeon pea as preceding crops recording the lowest and highest grain yield respectively. Two legumes (cowpea and soybean) and the maize plots recorded lower grain yield than the trial mean, while those of the remaining four (all legumes) were higher. Differences in treatment effects on grain yield were significant (P<0.014). Grain yield for pigeon pea (the highest) was significantly higher than cowpea, soybean, and maize but similar to green gram, mucuna and groundnut (Table 10).

In 2015, maize produced the lowest grain yield while pigeon pea produced the highest, with 720 Mt ha^{-1} and 2,107 Mt ha^{-1} respectively. Mean grain yield figures for cowpea, groundnut, mucuna and pigeon pea exceeded the trial mean, while those for green gram, soybean, and maize were below the trial mean. The Differences among effects of preceding crop on

Table 9. Weight (kg) of dried cobs of maize cv. CSIR-Omankwa in response to different preceding grain legume crops in a rotation at Manga from 2013 to 2017

Treatment	2013	2014	2015	2016	2017
Cowpea	2800	3583	2204	3500	5558
Green gram	2417	4983	1454	2967	3967
Groundnut	2833	5183	2046	3542	5283
Maize	1467	4550	900	2425	3517
Mucuna	2250	5250	2050	3367	4058
Pigeon pea	2717	6050	2633	2975	4758
Soybean	2383	4442	1717	3458	4467
Grand mean	2410	4863	1858	3176	4515
P value	0.015	0.008	0.001	0.016	0.001
LSD (0.05)	734.5	1111.1	650.7	640.7	707
C.V. (%)	20.5	15.4	23.6	13.6	10.5

Table 10. Grain yield (kg) response of maize cv. CSIR-Omankwa to different preceding grain legume crops in a long-term rotation at Manga from 2013 to 2017

Preceding crop	2013	2014	2015	2016	2017	Mean
Cowpea	2093	2479	1763	2800	3033	2434
Green gram	1788	3388	1163	2373	2208	2184
Groundnut	2137	3625	1637	2833	2862	2619
Maize	1040	3121	720	1940	1900	1744
Mucuna	1642	3525	1640	2693	2125	2325
Pigeon pea	2020	4117	2107	2380	2563	2637
Soybean	1792	3046	1373	2767	2358	2267
Grand mean	1787	3329	1486	2541	2436	2316
P value	0.019	0.014	0.001	0.016	0.001	
LSD $_{(0.01)}$	600	795.8	520.5	512.6	335	
C.V. (%)	22.6	16.1	23.6	13.6	9.80	

Table 11. Gross revenue, total variable cost, net returns and benefit cost ratios of rotation effects

Treatment	Budget line	Years					
		2013	2014	2015	2016	2017	Mean
Cowpea	Rev	1,360.45	2,231.10	1,674.85	2,240.00	3,033.00	2107.88
	Cost	650.00	820.00	1,040.00	970.00	1,100.00	916.00
	GM	710.45	1,411.10	634.85	1,270.00	1,933.00	1191.88
	B/C	2.09	2.72	1.61	2.31	2.76	2.30
Green gram	Rev	1,162.20	3,049.20	1,104.85	1,898.40	2,208.00	1884.53
	Cost	650.00	820.00	1,040.00	970.00	1,100.00	916.00
	GM	512.20	2,229.20	64.85	928.40	1,108.00	968.53
	B/C	1.79	3.72	1.06	1.96	2.01	2.11
Groundnut	Rev	1,389.05	3,262.50	1,555.15	2,266.40	2,862.00	2267.02
	Cost	650.00	820.00	1,040.00	970.00	1,100.00	916.00
	GM	739.05	2,442.50	515.15	1,296.40	1,762.00	1351.02
	B/C	2.14	3.98	1.50	2.34	2.60	2.51
Maize	Rev	676.00	2,808.90	684.00	1,552.00	1,900.00	1524.18
	Cost	550.00	700.00	920.00	850.00	950.00	794.00
	GM	126.00	2,108.90	-236.00	702.00	950.00	730.18
	B/C	1.23	4.01	0.74	1.83	2.00	1.96
Mucuna	Rev	1,067.30	3,172.50	1,558.00	2,154.40	2,125.00	2015.44
	Cost	650.00	820.00	1,040.00	970.00	1,100.00	916.00
	GM	417.30	2,352.50	518.00	1,184.40	1,025.00	1099.44
	B/C	1.64	3.87	1.50	2.22	1.93	2.23
Pigeon pea	Rev	1,313.00	3,705.30	2,001.65	1,904.00	2,563.00	2297.39
	Cost	650.00	820.00	1,040.00	970.00	1,100.00	916.00
	GM	663.00	2,885.30	961.65	934.00	1,463.00	1381.39
	B/C	2.02	4.52	1.92	1.96	2.33	2.55
Soybean	Rev	1,164.80	2,741.40	1,304.35	2,213.60	2,358.00	1956.43
	Cost	650.00	820.00	1,040.00	970.00	1,100.00	916.00
	GM	514.80	1,921.40	264.35	1,243.60	1,258.00	1040.43
	B/C	1.792	3.34	1.25	2.28	2.14	2.16

grain yield were significant (P<0.001). Except for green gram, all the legumes produced significantly higher grain yields than maize in 2015. Various similarities and differences were observed for the effects of the different legumes on grain yield (Table 10).

Grain yields ranged between 1,940 Mt ha^{-1} for maize and 2,833 kg per ha for groundnut in 2016. Grain yields for groundnuts, cowpea, soybean and mucuna as preceding crops were higher than the trial mean, while those for green gram, pigeon pea, and maize were lower than the trial mean. The differences in the effects of preceding crops on grain yield were significant (P<0.016). Effects of legumes on grain yield were similar, with those of cowpea, groundnut, mucuna, and soybean only being significantly higher than that for maize while those for green gram and pigeon pea were similar to maize (Table 10).

In 2017 maize grain yields ranged between 1900 to 3033 kg per ha. Grain yields were significantly (P<0.001) influenced by treatment, with maize preceding cowpea resulted in the highest grain yield, whilst, maize after maize produced the lowest (Table 10). Grain yields of maize after cowpea, groundnut and pigeon pea were greater than the trial mean. Maize grain yield after cowpea out-yielded maize preceding the rest of the treatments with the exception of maize following groundnut (Table 10). Over the 6 year period mean increment in grain yield recorded by pigeon pea, groundnut and cowpea over the farmers' current practice of preceding maize with mare are 51.1%, 50.2% and 39.6% respectively.

3.3 Economic Analysis

The results for 2013 shows that cowpea, groundnuts and pigeon pea rotations scored over 2.0 B/C ratios indicating their economic viability. Greengram, Mucuna and soybean were also viable with a B/C ratio of 1.79, 1.64 and 1.79 respectively. However, maize recorded the lowest it B/C ratio of 1.23 which is lower than the minimum acceptable B/C ratio of 1.5 which implies is not economically viable. For 2014 maize recorded the highest B/C ratio of 4.01 followed by groundnut with 3.98. Mucuna and green gram also recorded B/C ratio of 3.87 3.72 respectively. All 2014 rotations were all economically viable. In 2015 with the exception of groundnut, mucuna and pigeon pea all other rotations were not economically viable. All treatments in 2016 were economically viable. However, maize recorded the lowest B/C of 1.83. All treatments in 2017 were also all economically viable. A mean B/C ratio for the five years indicates that all the treatments for the period are all economically viable with maize recording the lowest B/C ratio of 1.96 which implies all the legume rotations were more economically viable than the continues maize cropping as shown in Table 11.

4. DISCUSSION

The major production constraint militating against increased and sustainable maize production and productivity in Ghana has been low soil fertility and inappropriate agronomic practices. To address this situation there is the need to embark upon sound and scientific agronomic practices that seek to reverse the current situation where farmers apply very low rates of inorganic fertilizers rarely exceeding 20 kg N ha^{-1} and expect to attain economic yields. It is in this light that this study is very critical. Quite, besides this, there has also been a lacuna, as to which grain legume performs best for maize in drier agro-ecological zones in the face of dwindling soil fertility status against the backdrop of farmers' inability to purchase chemical fertilisers to ameliorate this perennial constraint. The results of the current study has very important implications for the northern farmer who can barely afford important inputs such as payment for seeds and land preparation not to talk about expensive chemical fertilisers and other inputs such as herbicides and insecticides. However, this work has shown that the best predecessor crops for maize in this case are pigeon pea and groundnuts. Peasant farmers do not apply apply fertilizers and pesticides in the cultivation of these as compared to cowpea. Average rainfall received for the experimental period were: 2013 – 862.8 m, 2014 – 699.8 mm 2015 – 871.8 mm, 2016 – 961.8 mm and 2017 – 895.2 mm. However, the highest mean grain yields were achieved in 2014 due to a better distribution of rainfall and not due to the amount of rainfall received. This observation affirms the long held view that the quantity of rainfall has not changed but its distribution has changed, and this has dire consequences on crop production and productivity in the savanna agro-ecological zone. Maize after the grain legumes consistently out-yielded the current farmers' practice of growing maize after maize. Generally, maize after grain legumes attained tasseling and flowering (not shown) earlier than their control counterparts. In an ecology where the rains set in late and terminate early this will enable plants to escape the characteristic terminal droughts experienced in most of the growing seasons.

Maize plants that followed their grain legume counterparts also produced appreciably taller plants, which positioned them to better position to capture and use efficiently photosynthetically active radiation leading to better accumulation of dry matter as reflected in their superior yields. Maize after grain legumes generally, recorded higher plant populations as a result of better establishment from the onset, thereby resulting in greater numbers of cobs at harvest thereby leading to higher weight of dried cobs and grain yields. This could be ascribed to the greater percentage C and N recorded for the crop residues of these grain legumes and also the lower C and N ratio recorded for the legume residues in sharp contrast to the greater values recorded for their maize counterparts. Higher C:N ratios are not desirable as these often immobilizes nitrogen, leading to the activities of anaerobic micro-organisms, with a resultant utilization of soil nitrogen at the expense of crop plants. The higher grain yields reported for pigeon pea could be ascribed to its low nitrogen harvest index, as pigeon pea normally sets seeds very late in the season and even behaves like a perennial. This assertion amplifies, the observations made by Cheruiyot et al. [10].

Under the marginal conditions of the western Highveld, instances occurred where cowpea, groundnut and sunflower (*Hapalium* (Cass) Cass had a suppressive effect on the yield of the following maize, an aspect that needs further investigation as to identify the cause [11]. Maize yields were consequently higher when maize was planted in rotation with cowpea compared to maize mono cropping [12]. Corn yield was more responsive to fertilizer-N after peanut as preceding crop than continuous corn. Fertilizer requirement by corn were also reduced by up to 64 kg N/ha when corn followed peanut [13]. This is in perfect harmony with the results of the current work, as maize yields after grain legumes were consistently, greater than maize preceding maize. Soybean-corn rotation has been recommended as a good cropping practice for soil quality and crop productivity improvement [14]. This observation is in sharp contrast with the findings of our work, whereby soybean was not found to be a good predecessor crop for maize. Yield of cereals following grain legumes are generally larger than those following cereals [15]. Petra et al. (1987) and Bowen et al. (1988) suggested that a major reason for the higher yields of maize after cowpea was an N carry-over effect from the legume. Sanginga et al. [16] reported 1.2 to 2-fold increase in yield of maize growing after soybean compared to maize growing after maize. These gains in maize yields after soybeans were far greater than those reported in the current work.

The carry-over effect may have 2 reasons, 1) addition by the legume to the soil N pool because of symbiotic, N_2 fixation, and 2) less removal of inorganic N by the legume compared to the cereals, a phenomenon, which has been termed the ''N-sparing'' effect (Evans et al., 1991; Keating et al., 1998). Cowpea depleted soil mineral N more than maize in a maize sole cropping and maize/cowpea mixed in northern Ghana (Hardter and Horst, 1991). For example, maize yields have been increased by 32.1% in West Africa by using pigeon pea as a cover crop [17]. Positive rotation effects on crop yields have been reported by many scientists for years [18,7]. This observation ties in pretty well with the findings of the current work, whereby maize after pigeon pea consistently recorded superior maize grain yields. Crop type would affect the C:N ratio of the residue, with typically lower C:N ratio in legumes than the non-legume crops, and thus C:N ratio of the crop residue tended to be negatively correlated with N_2O emissions [19]. The above observation corroborates the significantly lower C:N ratios obtained in this study. Zhao-Hai Zeng et al. [20] recommended that the long-term benefits that legumes-cereals can have on crop yield, improvement of soil properties, and environmental quality, an international emphasis for the sustainable agriculture should be continued to focus on the potential role of introducing legumes into cereal cropping systems in the future agriculture of the whole world. From economic analysis the mean B/C ratio for the five years indicates that all the treatments for the period are all economically viable with maize recording the lowest B/C ratio of 1.96 which implies all the legume rotations were more economically viable as compared to the farmers' current practice of cropping maize after maize. This is therefore convincing enough to persuade farmers to adopt this practice of following maize and in fact other cereals such as sorghum and millet, which are the staple food crops of most of the people in northern Ghana and also in other similar agro-ecologies in Africa and Asia.

5. CONCLUSION AND RECOMMENDATIONS

Results of the current long-term study results have amply and unequivocally demonstrated that maize following a grain legume, especially pigeon pea, groundnut or cowpea has resulted in better crop growth, development and higher grain yields, which are consistent over the period. These yields and yield components of maize were low in their cropping counterpart that did not follow a grain legume, as currently practiced by most farmers in the drier area of semi-arid agro-ecologies. This would mean maize farmers can cut down in the cost of the production of these two superior grain legumes and save their limited resources to be ploughed in when they are to cultivate maize in the preceding year. Generally, maize growth, development and yields after a grain legumes in successive first, second and third cycles of rotation have amply demonstrated superior growth, development, grain and biomass yields as compared to continuous cultivation of maize or short-term rotation of maize after legume.

These findings have huge economic and environmental implications for cereal and more so maize farmers in the semi-arid agro-ecological zones of northern Ghana and elsewhere with similar edaphic and climatic conditions. These results therefore give hope to resource-challenged peasant farmers who should be encouraged to adopt this recommendation for increased and stable maize yields, against the backdrop of erratic rainfalls due to climate change and variability that has characterised the semi-arid regions of northern Ghana and beyond.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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