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Productivity of Cotton as Affected by Tillage Practices, Fertilizer Rates and Intercropping Systems in the Guinea Savannah Agroecology, Ghana

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Authors' contributions

This work was carried out in collaboration with all authors. Author PG designed the study and wrote the first draft of the manuscript. Author JXK wrote the protocols and performed the statistical analysis. Authors BKB and DAO managed the literature searchers. All authors read and approved the final manuscript.

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ABSTRACT

Extensive areas of bare, compacted, and nutrient-poor soils hinder crop production in the Guinea Savannah Agro-ecological zone of Ghana. Resolving this challenge can be effected by developing sustainable land management strategies that can adequately improve soil nutrient status and enhance crop yield. Field studies were conducted to evaluate the productivity of cotton as affected by tillage practices, fertilizer rates and intercropping systems in the Guinea Savanna agroecology of Ghana, during the 2016 and 2017 cropping seasons. Treatments consisted of 2 tillage practices

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(ploughing and direct seeding [sole cotton]), 2 fertilizer application rates (54-30-30 kg/ha NPK and 0-0-0 kg/ha NPK) and 3 intercropping systems (sole cotton, cowpea intercrop and soybean intercrop) which were laid in split-split plot design with three replications. The tillage practices, fertilizer rates and the intercropping systems were respectively allocated as the main plot, sub-plot and sub-sub plot treatment respectively. Unlike the three-way interaction effect which did not significantly influence variation in growth, yield and yield components of cotton, the two-way interaction and the single factors were however influential. The combined impact of the NPK fertilizer application rate at 54-30-30 kg/ha and ploughing resulted in higher seed yield of cotton. Comparatively, seed yield of cotton was 35.78% higher when 54-30-30 kg/ha fertilizer rate (1.29 t/ha) was applied compared with 0-0-0 kg/ha fertilizer rate (0.61 t/ha). It is however recommended that resource-poor farmers in the Guinea Savannah agro-ecological zone of Ghana adopt to the use of 54-30-30 kg/ha fertilizer rate and ploughing for cotton seed yield maximization.

Keywords: Cotton; yield fertilizer rates; tillage; intercropping; guinea Savanna; Ghana.

1. INTRODUCTION

Crop production enhancement and increase in global food security relies on sustainable farming practices which improve and conserve the soil, nutrients and water resources. Most importantly, resource-poor farmers in sub-Saharan Africa are concurrently faced with crop yield decline due to inappropriate soil management practices [1,2]. This problem still persists because most farmers in this agro-ecological zone apply varied fertilizer rates and resort continuously to monoculture system of farming year after year. Similarly, basic tools such hoes and cutlasses still remains the most widely used tools in land preparation activities which do not provide a good tilth of the soil. However, tillage practices [3], intercropping systems [4] and fertilizer rates [5] have widely been established as imperative and sustainable management strategies for improved crop yield. As indicated, tillage is crucial for breaking hard-pan soil layers for enhanced root penetration and proliferation [6,7]. Appropriate tillage practices have been demonstrated to ameliorate soil structure and water retention capacity, and thereby ensure soil protection against erosion [8,9]. Intercropping has also been demonstrated as a profound cropping technique for managing variety of crops in a limited land area while ensuring disease, insect and weed suppression [10,11]. Intercropping system utilizes heat and light resources which regulate the nitrogen cycle of the soil for crop yield maximization [12]. According to Grant et al. [13], intensification and diversification of cropping systems influences soil physical, chemical, and biological characteristics and can thus be explored to improve soil health and productivity. Fertilizer benefit expands as food security enhancer and agent of climate change mitigation [14]. Principally, fertilizer application has been investigated to improve soil health with possible translation of increasing yield [15].

Cotton (*Gossypium hirsutum* L.) is an industrial revolutionary crop in Africa with enormous economic benefits [16]. Their production serves as a dominant cash crop for most farmers in sub-Saharan Africa. Smallholder farmers in SSA, especially those in areas with limited opportunities of growing food crops rely on its production as a livelihood source [17]. According to [16] and [18], cotton production forms part of the few non-traditional export crops which earns Ghana a veritable source of foreign exchange (between US$ 150.86 million to US$164.96 million annually) and gross domestic product for economic growth and rural development. The crop is often grown under rain-fed condition with minimal use of purchased inputs [19], serving as incentives to producers. Cotton cultivation in Ghana is predominantly practiced in the Guinea Savannah agro-ecological zone and remains the sixth most cultivated crop after maize, sorghum, millet, rice, and groundnut [20]. However, its production in Ghana is far below the significant level on the global scale [16] as result of farmers not providing necessary conditions for the growth and yield of the crop. Hence, the thrust of this study was to investigate the effects of management systems (tillage practices, fertilizer rates, and intercropping systems) on the productivity of cotton in the Guinea Savanna agroecology of Ghana, where soil fertility remains a serious challenge to crop production.

2. MATERIALS AND METHODS

2.1 Study Area

This study was conducted during the 2015 and 2016 cropping seasons at the experimental field of Integrated Water and Agricultural Development (IWAD), Yagaba in the Mamprugu Moaduri District of northern Ghana. The study area is located within longitude 0°35'W and 1°45'W and latitude 9°55'N and 10°35'N in the Guinea Savanna vegetational zone of Ghana. The vegetation of the site is Savanna grassland characterised by shrubs and few scattered tress such as *Parkia biglobosa* (shea trees) and *Azadirachta indica* (neem trees). The land was previously cropped with maize and allowed of fallow for a period of two years before the commencement of this current study. The area experiences a tropical continental climate of warm and semi-arid conditions with monomodal rainfall ranging between 900 and 1100 mm which occur between May and October annually. The dry season period however lasts long than the rainy season which makes the area very vulnerable and susceptible to bush fires [21]. Temperatures ranging between 25 and 30ºC are averagely recorded on monthly basis [22] whereas the soil is characterized as sandy-loam with moderate drainage system free from concretions.

2.2 Soil Sampling

Initial and post-harvest soil samples were collected at a depth of 0-20 cm with auger. Soil samples collected were bulked together as a composite sample for analysis. The collected samples were air-dried under room temperature, ground and sieved through 2.0 mm mesh to give a fine earth fraction for the determination of the chemical properties. Soil pH was measured as soil to water ratio of 1:1.25 with a pH meter [23]. The total nitrogen (TN) content of the fine earth fraction was determined under Kjeldahl digestion method described by [24]. Soil organic carbon (OC) content was determined using the wet combustion method described by [25] whereas available phosphorus and exchangeable potassium were measured using the spectrophotometer and the flame emission photometry following the methodologies of [26] and [27] respectively.

2.3 Land Preparation and Agronomic Management

In view of the two-year antecedent period of fallow, the field was heavily infested with both annual and perennial weeds. This incidence warranted the use of glyphosate ($C_3H_8NO_5P$), a non-selective herbicide at 1.4 kilogram per hectare active ingredient (kg a.i/ha) for weed control. Some sections of the experimental field were ploughed mechanically with tractor whilst other portions were seeded directly. The field was lined and pegged into experimental units with direct seeded plots preceding the ploughed plots. Individual plot size of 5 x 5 m was used. Germination test for cotton seeds was conducted to ascertain their viability level (found to be above 80%) before planting. Seeds of cotton, genotype (Stomp 279) was obtained from the Integrated Water and Agriculture Development, Yagaba, Ghana, and were planted at 5 seeds per hill with a recommended spacing of 80 x 40 cm. Seedlings were thinned to two per stand at seven (7) days after emergence. Similarly, three seeds of locally inoculated cowpea (Songotra) and soybean (Jenguma) genotypes procured from the Savannah Agriculture Research Institute, Tamale, Ghana were drilled manually as intercrops at two (2) weeks after the emergence of the component crop. The intercrops were planted at a spacing of 80 cm x 10 cm and thinned to two seedlings per hill a week after their emergence. Post-emerged weeds were controlled with atrazine ($C_8H_{14}ClN_5$) (a.i. WP 80 g/l/ha) at 3 and 6 weeks after planting (WAP). NPK and sulphate of ammonia were applied as basal and top dressing fertilizers respectively at 3 and 6 weeks after planting using the band placement method.

2.4 Treatments and Experimental Design

The study was a 2 x 2 x 3 factorial experiment laid in a split-split plot design with three replications. Treatments consisted of three factors which were tillage practice (ploughing and direct seeding), fertilizer rate (54-30-30 kg/ha NPK [recommended rate] and 0-0-0 kg/ha NPK [zero rate]) and intercropping system (sole-cotton [no intercrop], cowpea intercrop and soybean intercrop). The tillage practices, fertilizer rates and the intercropping systems were respectively allocated as the main plot, sub-plot and sub-sub plot treatment respectively. The tillage practice was assigned as the main plot factor whereas the fertilizer rate and the intercropping system were assigned as sub-plot and sub-sub plot factors respectively. Blocking was done to ensure higher precision among factors under evaluation.

2.5 Data Collection

Soil chemical properties and plant productivity parameters were collected for analysis during the study. Soil reaction (pH), total nitrogen (TN), available phosphorus (P), exchangeable potassium (K), and organic carbon (OC) content were evaluated as initial and post-harvest soil chemical properties. Productivity parameters gathered on cotton included plant height, boll number, boll weight, and seed yield. Nodulation count and effectiveness were gathered as parameters on the cowpea and soybean intercropping systems. A total of six (6) plants sampled and tagged on each experimental plot were considered for data collection. The whole production system was subjected to economic analysis to ascertain their benefit/cost ratio.

2.6 Statistical Analysis

Data on plants were processed with Microsoft Excel 2010 and subjected to analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS version 20.0). Treatment means were separated using least significant difference (LSD) approach at 5% significant level.

3. RESULTS

3.1 Basal and Post-harvest Soil Chemical Properties

Pre-cropping and post-harvest soils samples which were analyzed for their chemical properties were moderately and strongly acidic going by the pH values. Soil samples evaluated were also low in total nitrogen and organic carbon content despite their moderateness in available phosphorus and exchangeable potassium (Table 1).

3.2 Vegetative Growth, Yield and Yield Components of Cotton

Height of cotton was not significantly (*P*=.51) influenced by the combined effect of tillage practice, fertilizer rate and intercropping system. Similarly, the combined effect of tillage practice and fertilizer rate (*P*=.27), tillage practice and intercropping system (*P*=.35), and fertilizer rate and intercropping system (*P*=.18) did not also influence height of cotton significantly. Besides, individual factors of tillage practice (*P*=.10) and intercropping system (*P*=.71) did not influence plant height significantly. Notwithstanding, height of cotton plants were significantly taller with fertilizer treatment (*P*=.02). Cotton plants were taller for ploughed plots supplied with 54-30-30 kg/ha NPK fertilizer rate in the absence of an intercrop. Cotton plants increased in height with time, while cotton-cowpea intercrop recorded the shortest height. The height increment of cotton was lowest at 12 to 16 weeks after planting (WAP) contrary to the earlier successive trend of height increase (Fig. 1).

Variation in boll number was not significant (*P*=.49) as shown by the three-way interaction effect. The combined effect of tillage practice and fertilizer rate (*P*=.25), fertilizer rate and intercropping system (*P*=.59), and tillage practice with intercropping system (*P*=.68) did not equally produce significant variation in boll number. However, the sole factors of fertilizer rate (*P*=.01) and tillage practice (*P*=.01) had varied effects on boll number. Among the sole treatments, greater variation in boll number was achieved under ploughing, soybean intercrop and fertilizer application rate at 54-30-30 kg/ha. In terms of fertilizer rate, boll number was 37% higher with plants supplied with 54-30-30 kg/ha fertilizer rate (37) than the untreated fertilizer control rate (0-0-0 kg/ha). In general, the control treatments (direct seeding, 0-0-0 kg/ha fertilizer rate and the absence of intercrop) least influenced boll number determination. A mean boll number of 27 were produced per plant (Fig. 2a and 2b).

Differences in boll weight were not significant (*P*=.39) for the three-way interaction of tillage practice, fertilizer rate and intercropping system. Similarly, significant differences were not achieved among the two-way interaction effects encompassing tillage practice and fertilizer rate (*P*=.16), tillage practice and intercropping system (*P*=.18) as well as fertilizer rate and intercropping system (*P*=.49). On the contrary, fertilizer application as a single treatment factor significantly (*P*=.01) improved boll weight of cotton. Heavier boll weights of cotton were recorded on ploughed plots integrated with

Table 1. Effect of tillage practice, fertilizer rate and intercropping system on soil chemical properties during the 2015 and 2016 cropping seasons

Sampling type	(1:1.25 H_2O)	(%)	(%)	(mg/kg)	(mg/kg)
	pH	OC	N	P	K
Basal	5.64	0.07	0.09	11.24	10.87
Post-harvest	5.38	0.05	0.07	10.94	10.49

soybean and provided with 54-30-30 kg/ha fertilizer rate. Boll weight was 12% higher under 54-30-30 kg/ha NPK fertilizer rate (4.77 g) compared with the 0-0-0 kg/ha NPK fertilizer (3.73 g) rate. Although soybean intercrop supported heavier boll weight of cotton, it was statistically similar compared to cowpea-cotton intercrop (Fig. 3).

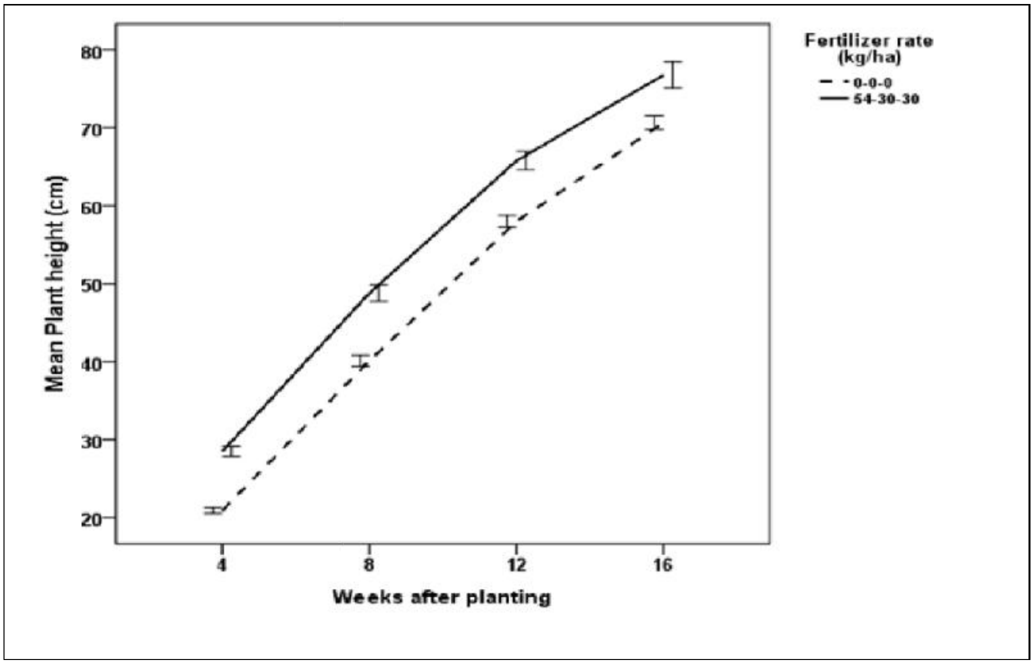

Fig. 1. Effect of fertilizer rate on plant height of cotton during the 2015 and 2016 cropping seasons. Bars represent standard error of mean (SEM)

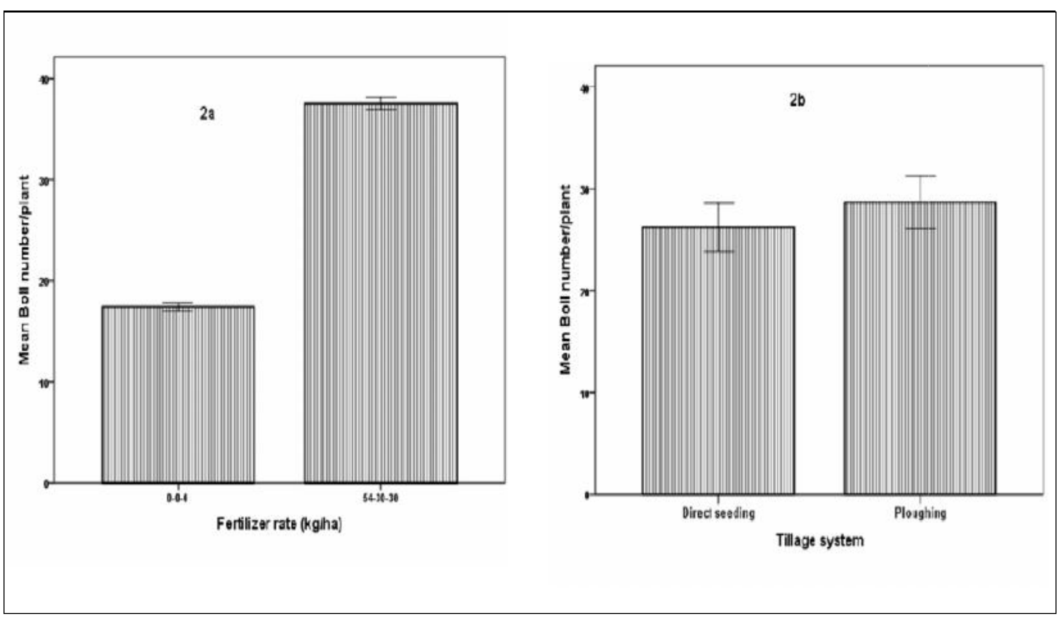

Fig. 2. Effect of fertilizer rate (a) and tillage practice (b) on boll number of cotton during the 2015 and 2016 cropping seasons. Bars represent standard error of mean (SEM)

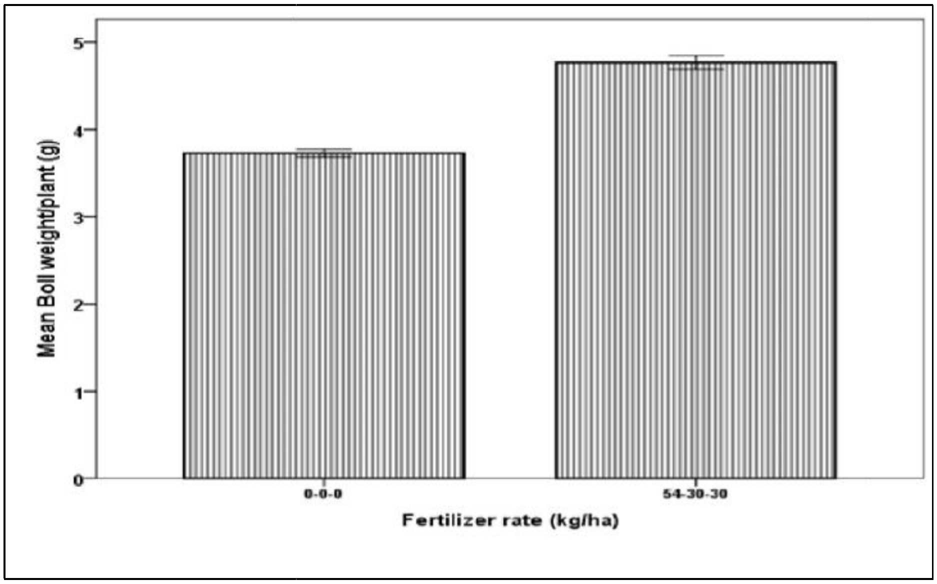

Fig. 3. Effect of fertilizer rate on boll weight of cotton during the 2015 and 2016 cropping seasons. Bars represent standard error of mean (SEM)

Seed yield of cotton did not vary significantly (*P*=.29) under treatments involving tillage, fertilizer rate and intercropping. In contrast, the combined influence of tillage and fertilizer (*P*=.03) for sole cotton affected seed yield of cotton. Ploughing (1.05 t/ha) increased seed yield of cotton by 10.60% compared with the direct seeded treatment (0.85 t/ha). There was also 35.78% increase in seed yield when cotton plants were supplied with 54-30-30 kg/ha rate of fertilizer (1.29 t/ha) compared with no fertilizer application (0-0-0 kg/ha; 0.61 t/ha). Ploughed plots treated with 54-30-30 kg/ha fertilizer rate and soybean-cotton intercrop improved seed yield of cotton (Fig. 4). The combined impact of soybean-cotton intercrop, 54-30-30 kg/ha fertilizer rate and ploughing supported maximum seed yield of cotton.

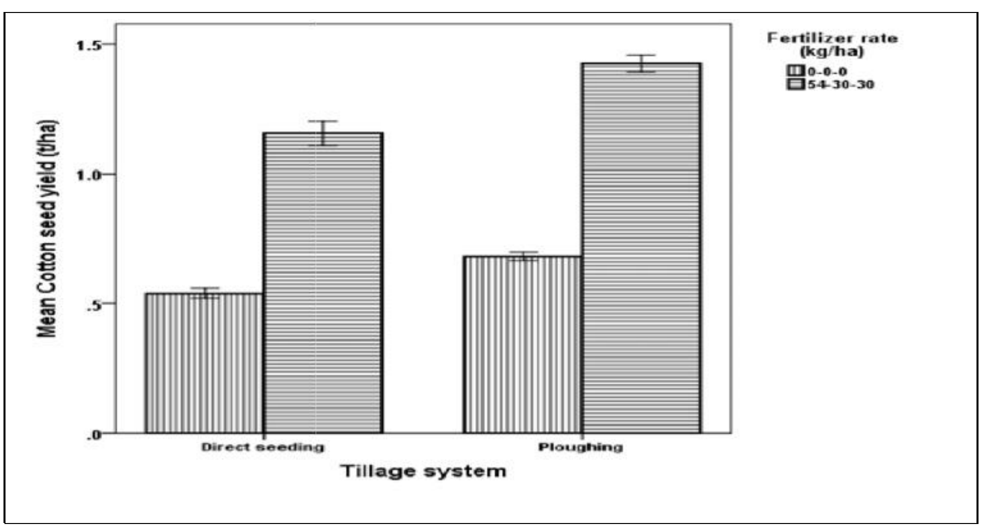

Fig. 4. Effect of fertilizer rate and tillage practice on cotton seed yield during the 2015 and 2016 cropping seasons. Bars represent standard error of mean (SEM)

3.3 Nodule Count and Nodule Effectiveness of Cowpea and Soybean Intercrops

Interaction effect of tillage system and fertilizer rate (*P*=.19) was not significant on cowpea and soybean nodule count. In addition, the tillage system established as sole treatment did not influence nodule count significantly (*P*=.07). However, fertilizer application rate significantly (*P*=.04) influenced nodule count of cowpea and soybean (Fig. 5). Among the individual factors, ploughing and fertilizer rate at 54-30-30 kg/ha resulted in higher nodule count. Comparatively nodule count of soybean-cotton intercrop (99.0) was 1.8% higher than that of cowpea-cotton intercrop (95.50).

Ploughing and fertilizer application rate at 54-30-30 kg/ha enhanced nodule formation in soybean and cowpea. The combined effects of tillage practice and fertilizer significantly (*P*=.01) improved nodule formation in cowpea and soybean under the intercropping systems (Fig. 6). Ploughing and 54-30-30 kg/ha rate of NPK application enhanced nodulation compared with the other treatment combinations. Nodulation (7.36%) was higher for experimental plots that received 54-30-30 kg/ha fertilizer rate (54.18) compared with 0-0-0 kg/ha fertilizer rate (46.82). Similarly, ploughing (84.75) resulted in 4% increase in nodule effectiveness compared with the direct seeding (78.17) treatment.

3.4 Benefit/Cost Analysis

Economic analysis on the productivity of cotton indicated that the combined effect of ploughing, 54-30-30 kg/ha fertilizer rate and soybean-cotton intercropping produced the highest benefit/cost ratio (2.4). Their combined influence ensured a profit of GH¢ 2258.00 (Table 2). Intercropping system involving cowpea-cotton combined with ploughing and fertilizer application (54-30-30 kg/ha) recorded the second highest benefit/cost ratio (2.3), indicating a profit margin of GH¢ 2143.00. However, least benefit/cost ratio (1.3) was achieved when cotton was seeded directly without fertilizer and an intercrop.

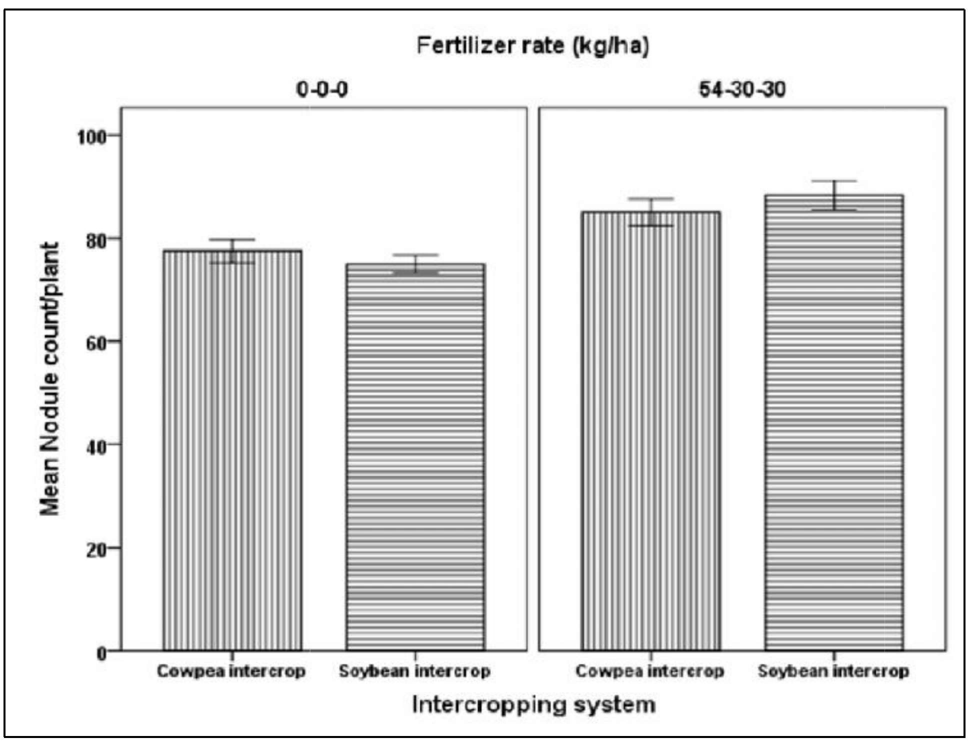

Fig. 5. Nodule count of cowpea and soybean as affected by fertilizer rate during the 2015 and 2016 cropping seasons. Bars represent standard error of mean (SEM)

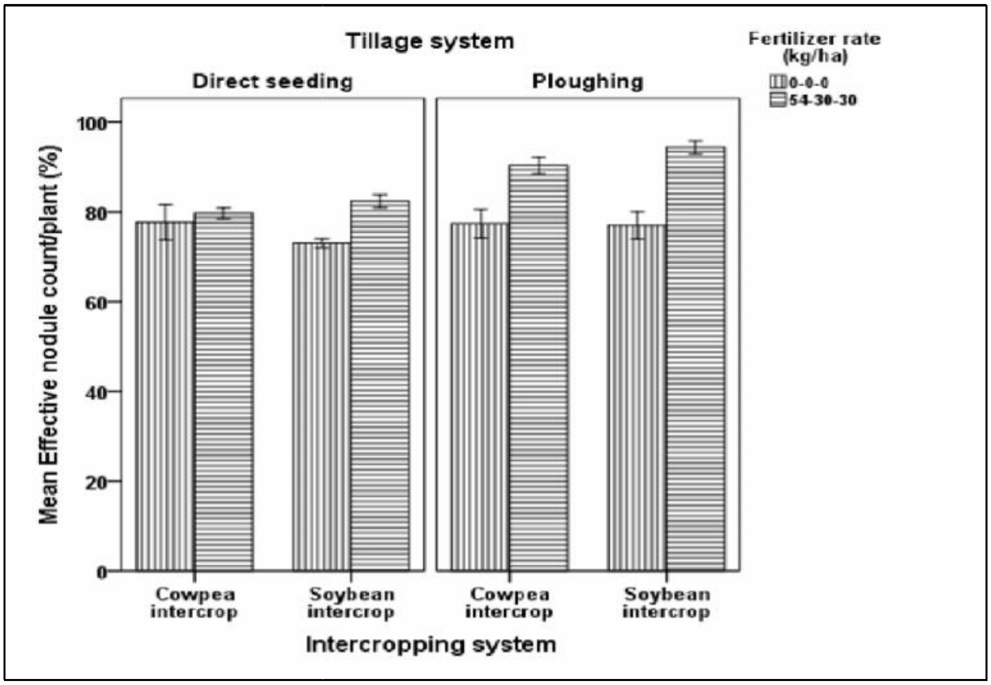

Fig. 6. Nodule effectiveness of cowpea and soybean as affected by fertilizer rate and tillage practice during the 2015 and 2016 cropping seasons. Bars represent standard error of mean (SEM)

Table 2. Benefit/cost analysis on the productivity of cotton as affected by tillage practice, fertilizer rate and intercropping system in the Guinea Savanna Agroecology, Ghana. Data gathered during the 2015 and 2016 cropping seasons. Bars represent standard error of mean (SEM)

Operation input	Expenditure/ha (GH¢)	Income/ha (GH¢)	Profit/ha (GH¢)	Benefit/cost ratio
D_S+F_0+I_0	785	1031	246	1.3
D_S+F_0+I_c	965	1321	356	1.4
D_S+F_0+I_s	975	1352	377	1.4
D_S+F_1+I_0	1145	1895	750	1.7
D_S+F_1+I_c	1335	2385	1050	1.8
D_S+F_1+I_s	1345	2447	1102	1.8
P+F_0+I_0	1110	1744	634	1.6
P+F_0+I_c	1290	2134	844	1.7
P+F_0+I_s	1300	2206	906	1.7
P+F_1+I_0	1470	3093	1623	2.1
P+F_1+I_c	1650	3793	2143	2.3
P+F_1+I_s	1660	3918	2258	2.4

D_S+F_0+I_0 = Direct seeding + 0-0-0 kg/ha fertilizer rate + No intercrop, D_S+F_0+I_c = Direct seeding + 0-0-0 kg/ha fertilizer rate + Cowpea intercrop, D_S+F_0+I_s = Direct seeding + 0-0-0 kg/ha fertilizer rate + Soybean intercrop, D_S+F_1+I_0 = Direct seeding + 54-30-30 kg/ha fertilizer rate + No intercrop, D_S+F_1+I_c = Direct seeding + 54-30-30 kg/ha fertilizer rate + Cowpea intercrop, D_S+F_1+I_s = Direct seeding + 54-30-30 kg/ha fertilizer rate + Soybean intercrop, P+F_0+I_0 = Ploughing + 0-0-0 kg/ha fertilizer rate + No intercrop, P+F_0+I_c = Ploughing + 0-0-0 kg/ha fertilizer rate + Cowpea intercrop, P+F_0+I_s = Ploughing + 0-0-0 kg/ha fertilizer rate + Soybean intercrop, P+F_1+I_0 = Ploughing + 54-30-30 kg/ha fertilizer rate + No intercrop, P+F_1+I_c = Ploughing + 54-30-30 kg/ha fertilizer rate + Cowpea intercrop, P+F_1+I_s = Ploughing + 54-30-30 kg/ha fertilizer rate + Soybean intercrop

4. DISCUSSION

The reduction in post-harvest soil chemical properties in comparison with the baseline soil chemical properties is evident that the cotton and the intercrops (cowpea and soybean) were able to utilize the nutrient elements in the soil to ensure increase in growth and yield. Although cotton is a short term crop, it is known to have high nutrient use-efficiency [28,29], an incidence which might have resulted in the differences in soil chemical properties.

In response to varied management practices, plant height is considered a major component in vegetative growth assessment. Height of cotton as influenced by the 54-30-03 kg/ha fertilizer rate is a reflection that mineral fertilizers significantly improve crop growth and development, making them an indispensable component in cotton production [30]. Maximum assimilation of fertilizer by cotton has been expressed to influence growth with translated impact on yield improvement [31]. The stimulation of growth as influence by the 54-30-30 kg/ha fertilizer application rate could be due to increase in nitrogen element present which was suitable in meeting the N requirement of the plant. As indicated, higher N application rate in cotton production promotes vigorous and rapid vegetative growth [32,33]. Research has also confirmed the optimization of nitrogen to increase N-use efficiency among intercropping system [29]. Increase in plant height in response to higher levels of nitrogen has been confirmed in the studies of [34] and [35] in maize production. They asserted that phonological characteristics improvement in crops is facilitated by increase in N rate. Besides, least height of cotton among experimental plots which did not receive chemical fertilizer treatment (0-0-0 kg/ha fertilizer rate) could possibly be a reflection of less sufficient utilization of nutrients by the crop [36]. Although plant height is pre-determined genetically [37], yet lack of chemical fertilizer treatment might have affected the growth of cotton. As reported also, cotton contains about 22.7 to 25.0 kg N $bale^{-1}$ [38] of which a deficiency in N may reduce vegetative and reproductive growth coupled with premature senescence [39]. The impact of ploughing to have produced taller plants might be due its profound role in providing catchment area for precipitation and allowing seedling roots to extend further into the soil profile where moisture and available nutrients are deposited [40]. [8] described ploughing to improve the survival and growth of crops by breaking up hardpans and impervious soil layers which encourages root growth area for deeper root development. The absence of intercrop to have influenced plant height might be due the absence of competition for nutrients and water resources which might have compensated for the improved growth of the sole cotton.

Yield and yield components were generally enhanced by ploughing, soybean integration and the application of 54-30-30 kg/ha fertilizer rate. However, soil fertility stress might have resulted in least boll number, boll weight and seed yield prior to the combined impact of the untreated controls. It is known that supplying growing crops with optimal nutrients improve yield significantly. In this study, optimal nutrients were curtailed from the chemical fertilizer and the leguminous intercrops whose combination might have provided a balanced nutrient requirement for the component crop. Similarly, the existing soil nutrient in view of the two-year antecedent period of fallow might have contributed to the improvement of soil nutrient [41]. This result is in line with the assertion made by [42] and [8] who were of the view that optimal quantities of nutrients received from balanced macro and micronutrient doses improves crop yield significantly. Cotton response to nitrogen ascertained from the leguminous intercrops and the chemical fertilizer elements (N, P, and K) might have reflected the early boll fill (data not shown) which consequently resulted in the higher boll number. This result is in agreement with the findings of [43] and [44], who observed that excess nitrogen promotes vegetative growth often at the expense of ensuring reproductive development, especially at bloom or at early boll-fill stage, laying emphasis on the use of NPK and cover crops in their experimental setup. Increase in boll number and heavier boll weight achieved on the use of the leguminous cover crops might be due to late planting of the cover crops as intercrops which might have enabled the cotton to utilise existing environmental resources (light, water and nutrients) sufficiently before the introduction of the cover crops. Greater response to yield and yield components promoted by the intercrops other than the sole cotton plants might be due to the overlap of cotton and cover cropping growth cycles. This effect might have occurred in resonance to higher light capturing by the intercrops as compared to the sole cotton [45]. Cover crops used as intercrops have been delved into as a system which keeps the soil covered and possess higher smothering effect against weeds coupled with pest reduction incidence. The involvement of cover crops in a cropping system actively improves soil tilth, aeration, organic matter and organic carbon content due to their proliferation of root biomass [46]. It is also established that crops that differ in the utilization of environmental resources can complement each other and make better use of combined resources than when they are grown separately [47]. Kebebew et al. [48] reported higher cotton yield among intercrops whereas [49] reported a reduction instead. The combined impact of 54-30-30 kg/ha fertilizer rate, ploughing and soybean intercrops resulted in higher production cost and profit. The above statement is however not justifiable enough to warrant a concrete conclusion if the assertion of [50] is to be considered. They emphasized that the higher the production cost, the higher the profit and vice versa.

5. CONCLUSIONS

Yield improvement of cotton and efficiency in resource utilization in the Guinea Savanna agro-ecological zone of Ghana can best be realized on account of suitable management practices involving tillage, fertilizer recommendation rate and intercropping system. The results of the study indicated that cotton responded differently to the varied treatments (tillage practice, fertilizer rate and intercropping system) evaluated. Seed yield was maximized under ploughed experiment plots compared with directly seeded plots. The NPK (compound fertilizer) application rate at 54-30-30 kg/ha improved cotton growth, yield and yield components. In terms of intercropping system, cotton plants were taller under sole crop treatment due to lack of interspecific competition between the intercrops and cotton plants, whereas boll number, boll weight and seed yield were higher under cowpea and soybean integration. Seed yield performance of cotton was 35.8% higher prior to the influence of the recommended chemical fertilizer (54-30-30 kg/ha) than the untreated fertilizer rate (control: 0-0-0 kg/ha). Although intercrops were not directly provided with chemical fertilizer, nodulation count and effectiveness of soybean-cotton and cowpea-cotton were improved under ploughed experimental plots treated with 54-30-30 kg/ha fertilizer rate. The combined impact of 54-30-30 kg/ha fertilizer rate, ploughing and soybean intercrops resulted in higher production cost and profit for cotton.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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