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Response of Rice to Sulfur and Zinc Applications Under Fallowed and Continuously Cropped Soils in Northern Ghana

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Authors' contributions

This work was carried out in collaboration among all authors. Authors VB, IKD and JXK designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author WD managed the analyses of the study. Authors JNO and EN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The influence of zinc and sulfur on growth and yield of rice was studied for two soils; fallowed and continuously cropped. It was a 2 x 4 x 4 factorial experiment laid out in a randomized complete block design with three replicates, using lixisols of northern Ghana. Sulfur was applied as Sodium Sulfate (Na_2SO_4) at 0, 10, 20, 30 kg S/ha, two days after transplanting. Whilst zinc was applied as Zinc oxide (ZnO) at 0, 4, 8, 12 kg Zn/ha before transplanting. All soils received same rates of NPK (90-60-30 Kg/ha). An initial physico-chemical analysis conducted on the soils revealed that, both were sandy loam in texture and low in zinc but moderately high in sulfur. The fallowed soil was high in all other measured soil nutrients except nitrogen when compared to the cropped soil. The experimental results showed that, rice growth (tiller number, plant height), grain yield parameters (panicle count, percentage filled grains, grain yield) and straw yields are maximized by at least inclusion of sole Zn at 8 kg Zn/ha for both soils, with optimum yield recorded under the combined

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application of 12 kg Zn/ha and 30 kg S/ha for both land use types. Treatments that received 12 kg Zn/ha and 30 kg S/ha had more than twice (50% increase) the yield obtained for treatments that received sole NPK. Yield in both soils responded significantly to additional amounts of sulfur and zinc, indicating that even in a fallowed soil, zinc and sulfur may be inadequate for crop growth, hence their inclusion is needed for better improvement of the rice crop. The fallowed soil recorded the highest grain yield than the continuously cropped soil. The findings revealed the need to consider sulfur and zinc inclusion in NPK fertilizer formulation for maximization of rice production in soils of northern Ghana.

Keywords: sulfur; zinc; rice; fallowed and continuously cropped soil.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is known to be the staple food of the developing world. The crop occupies about 11% of the total arable area [1,2] and is also second to wheat in terms of harvested area. With regards to human nutrition, rice has become the major source of food for about two thirds of the world's population [3] and is known to be the fastest growing food source in Africa [4]. In Ghana, increased consumption and demand have led to consequent importation to about 200% of local production in order to compensate for shortfalls and satisfy the rice hunger of Ghanaians [5].

The vision in most rice consuming African countries is to increase productivity and curb the continual importation of rice at high costs. As a result, many efforts and interventions have been introduced in order to achieve this goal. Some of these efforts include practicing intensive agriculture, sole application of NPK fertilizers, and monocropping of rice plants at specific places that are known to be productive fields for rice growth.

However, the efforts have proven futile as yields continue to decline in their implementation while the environment keep deteriorating [6]. For example, it has been reported by John et al. [7] that exhaustive agriculture, which involves use of high yielding varieties of rice and other crops, leads to substantial removal of plant nutrients from the soil. To avoid soil nutrient depletion, NPK fertilizers have been extensively promoted and used in rice cultivation. This has helped to improve rice yields. However, White and Zadoski [8] and John et al. [7] have disproved the extensive use of NPK fertilizers over time. They argue that continual application of NPK promotes nutrient imbalances and leads to the depletion of inherent micronutrients in the soil. The authors noted that a plant cannot grow and perform well if all the required nutrients are not available in their right proportions. Vanlauwe [9] also stressed on sulfur deficiency in soils which have become prevalent in many African nations, due to the practice of intensive agriculture using NPK fertilizers. As a result, Rhadhika et al. [10] concluded that the use of sole NPK fertilizer for rice production is no longer practical. They argued that this practice tend to deplete inherent secondary and micro nutrients. Wei et al. [11] also reported that a soil which has been allowed to fallow for a period of time is richer in Zn (zinc) than a continuously cropped soil. This is because in a continuously cropped soil, inherent micronutrients are utilized, conveyed and harvested from soil to plants. Somani [12] showed a higher incidence of micronutrient deficiency in crops due to continuous cropping, resulting in loss of fertile topsoil and loss of nutrients through leaching.

Amongst the required essential nutrients, sulfur and zinc are known to play beneficial roles in increasing the productivity of rice [13]. Reduction in yield of rice is often blamed on zinc and sulfur deficiency. Sulfur insufficiency primarily arises in waterlogged conditions or in low land rice cultivation [14,15,16]. Even though the potential of sulfur and zinc on rice growth and yield have been explored in sub-Saharan countries, the research area has received little attention for soils of northern Ghana from where more than half of the nation's rice is produced. This research was undertaken, therefore, to determine the influence of sole sulfur as a secondary nutrient and sole zinc as a micronutrient, as well as the interaction of sulfur and zinc on the growth and yield of rice on a fallowed land and continuously used land in northern Ghana.

2. MATERIALS AND METHODS

2.1 Experimental Site

The trial was conducted from July to November during the 2019 cropping season at Nyankpala in the Northern Region of Ghana. Geographically, the experimental site is located 16 kilometers west of Tamale on a latitude of 09° 25" and longitude 01° 00" and an altitude of 183 meters above sea level. The location has a flat land surface. This area experiences a unimodal rainfall pattern of about 1000 mm annually [17]. Usually from April to October within the year. The average annual temperature distribution of the area is a minimum of 23.4˚C and a maximum of 34.5˚C. While relative humidity ranges from about 46% for minimum and maximum of 76.8%. The vegetation of the study area is characterized by annual grasses, shrubs, and trees.

2.2 Determination of Soil Physico-Chemical Properties

Soil samples were taken before planting for the experiment. The nutrient composition of the soil was determined at the CSIR-SARI Soil laboratory at Nyankpala. Soil Bulk density was done by the procedure as outlined Fox and Hanify [18], Particle size analysis was done by the hydrometer method as outlined by Day 1965 [19]. Soil pH, total organic carbon, total nitrogen, Available P, Exchangeable cations, sulfur and zinc were determined by following procedures of Lierop and Mackenzie [20], Apel et al. [21], the Kjeldahl method which has been used by other researchers including Bremner [22] Watanabe and Olsen [23] and Gillman [24], Tabatabai [25] and Brown and Eddings [26] respectively.

2.3 Experimental Design and Treatments

The experiment was a 2×4×4 factorial experiment laid out in a randomized complete block design with three replications (Table 1). The experiment involved three factors with different levels. Soil use, being one factor at two levels that is fallowed soil and continuously cropped soil. Sulfate fertilizer rate as another factor at four levels: that is sulfur at 0, 10, 20 and 30 kg/ha. Zinc fertilizer rate was the third factor at four levels: that is zinc at 0, 4, 8 and 12 kg/ha.

Source of sulfur was sodium sulfate (Na_2SO_4) from a research center in Japan. Source of zinc zinc oxide (ZnO). Calculated quantities of both zinc and sulfur in the form of sodium sulfate for the fallowed and continuously cropped fields were weighed using an electronic sensitive scale (Table 1. Weighed quantities of zinc oxide were directly applied to the soil before planting. While that of sulfur was applied to plants two days after transplanting.

2.4 Collection of Plant Data and Data Analysis

Plant data collected included, tiller number, panicle count, plant height, and panicle length, filled and non-filled grain number per panicle, 1000 seed weight, grain yield, and straw yield. The data collected were subjected to analyses of variance (ANOVA) using the Genstat edition 12.1 statistical package. Means separation was done using the least significant difference at a probability of 5%.

3. RESULTS AND DISCUSSION

3.1 Description of the Experimental Soils

Initial soil analysis showed that both the cropped and fallowed soils were sandy loam in texture (Table 2). Both soils were typically very low in zinc, but adequate in sulfur. However, the fallowed soil was slightly high in all other soil nutrients but lower in nitrogen compared to the cropped soil.

3.2 Effect of Zinc and Sulfur on Growth Parameters of Rice in Northern Ghana

The effect of zinc and sulfur on the growth parameters of (Table3).

3.2.1 Tiller number at 8WATP

There was no three-way interaction effect on tiller number at 8 weeks after transplanting (WATP), but there was a significant *(p=.04)* two-way interaction effect of sulfur application rate by land use type on tiller number at 8WATP (Table 3). Tiller numbers were highest at zero (0 kg/ha) rate of sulfur on the fallowed soil and lowest at 0 kg/ha rate of S on the cropped soil (Fig. 1). As a result, additional amount or increment of sulfur rate in the soil did not have a significant effect on the tiller number on the fallowed land. However, the application of 10 kg/ S ha on continuously cropped land gave the highest tiller number with no further significant increases in tiller number with increased sulfur application rate.

3.2.2 Tiller number at 12WATP

There was no three-way interaction effect and two way interaction effect of land use type, sulfur rate and zinc rate on tiller number at 12WATP, but rather sulfur as a sole factor had significant effect on tiller number at 12WATP (Table 3).

The maximum tiller number was recorded at 30 kg S/ha (Fig. 2). The second highest tiller number was recorded in the 20 kg S/ha. While the lowest tiller number was recorded in 10 kg S/ha and the control plot with no sulfur application.

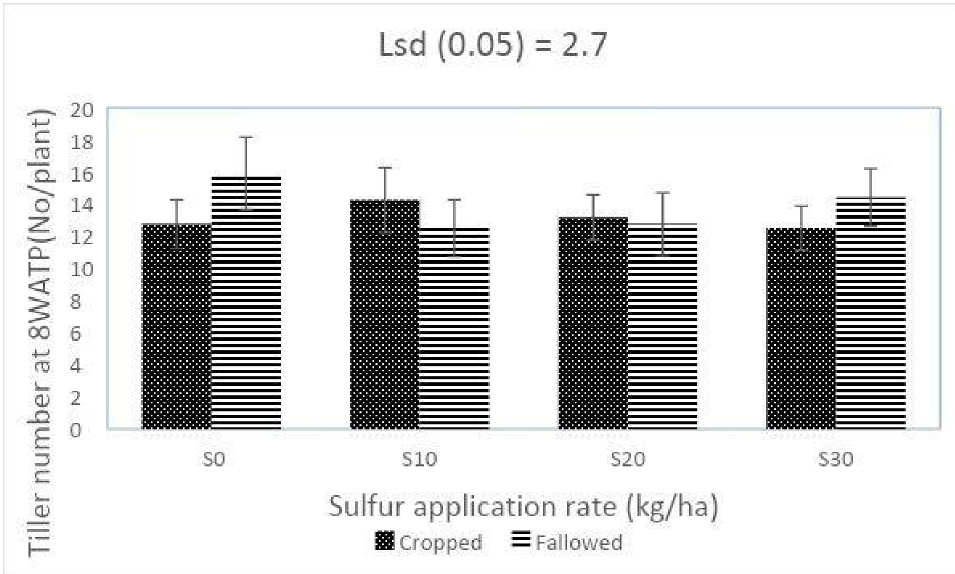

Fig. 1. Interaction effect of land use type (fallowed and cropped) by sulfur application on tiller number of AGRA rice at 8WATP. Bars represent standard error of means (SEM). S0-control, S10-sulfur at 10 kg/ha, S20-Sulfur at 20 kg/ha, S30-sulfur at 30 kg/ha

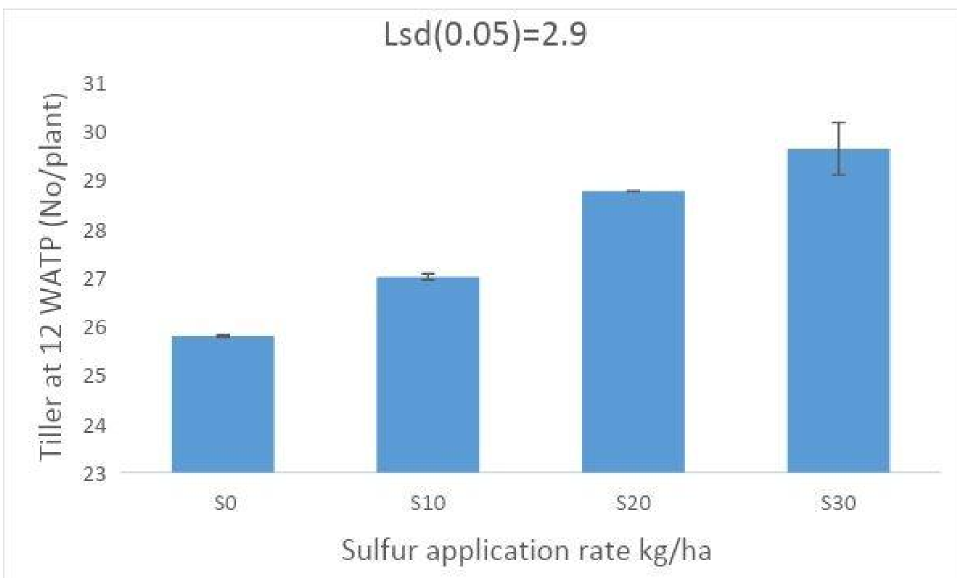

Fig. 2. Effect of sulfur application rate on tiller number of AGRA rice at 12WATP. Bars represent (SEM). S0-control, S10-sulfur at 10 kg/ha, S20-Sulfur at 20 kg/ha, S30-sulfur at 30 kg/ha

Table 1. Factorial combination of rate of zinc and sulfur under fallow and continuously cropped fields used to study growth and yield of AGRA rice in Northern Ghana in the year 2020

Treatment code	Fallowed (Kg/ha) land	Cropped land (kg/ha)	Description (kg/ha)
T1T2	Zn0S0 Zn0S10	Zn0S0 Zn0S10	Control
T3	Zn0S20	Zn0S20	Zinc at 0+sulfur at 10Zinc at 0+sulfur at 20
T4T5T6T7T8	Zn0S30Zn4S0 Zn4S10	Zn0S30Zn4S0 Zn4S10	Zinc at 0+sulfur at 30Zinc at 4+sulfur at 0 Zinc at
T9	Zn4S20Zn4S30	Zn4S20Zn4S30	4+sulfur at 10Zinc at 4+sulfur at 20Zinc at 4+sulfur at 30
	Zn8S0	Zn8S0	Zinc at 8+sulfur at 0
T10T11T12T13T14	Zn8S10 Zn8S20 Zn8S30	Zn8S10 Zn8S20 Zn8S30	Zinc at 8+sulfur at 10 Zinc at 8+sulfur at 20 Zinc at
T15	Zn12S0 Zn12S10Zn12S20	Zn12S0 Zn12S10Zn12S20	8+sulfur at 30 Zinc at 12+sulfur at 0 Zinc at 12+sulfur at
T16	Zn12S30	Zn12S30	10Zinc at 12+sulfur at 20
			Zinc at 12+sulfur at 30

Table 2. Initial soil analysis at a depth of 0-20 cm for the fallowed and continuously cropped soil

Soil parameter	Cropped	Fallowed	Level at which nutrient is deficient
Bulk density (kg/m3)	1500	1700	
pH	5.92	6.87	
Organic carbon (%)	1.84	2.23	
Available nitrogen (%)	0.153	0.117	
Available phosphorous (mg/kg)	12.16	19.37	
Exchangeable cations			
Potassium	119.76	154.92	
Calcium	2.1	4.8	
Magnesium	0.9	1.6	
Micronutrient level			
Sulfur (mg/kg)	65.9	67	5 - 20.0
Zinc (mg/kg)	0.3	0.82	0.6 – 0.83
Particle size distribution (%)			
Sand	61.72	55.72	
Silt	24.36	36.36	
Clay	13.92	7.92	
Texture	Sandy loam	Sandy loam	

Zinc critical deficient level is as determined by Takkar et al.[27] and Shukla et al. [28]. Sulfur critical level is as determined by Buri et al. [29]

3.3 Panicle Count

There was a significant (*p=.04*) three-way interaction effect of sulfur and zinc by land use type on panicle number (Table 3). The combined application of 12 kg Zn/ha and 30 kg S/ha on continuously cropped soil gave higher panicle number of 16. Similar results were obtained with 8 kg Zn/ha by 0 kg S/ha and 0 kg Zn/ha with 10 kg S/ha on the same soil (Fig. 3). Nevertheless, the combined application of 4 kg Zn/ha by 0 kg S/ha and 8 kg Zn/ha by 0 kg S/ha on the fallowed land gave similar panicle number of 16. The least number of panicles was recorded in the control plot for both land use types.

3.4 Panicle Length

There was no three-way interaction effect of treatment factors on panicle length, but rather there was a two way interaction effect of land use type by zinc application rate on panicle length (Table 3). There was also no one way significant effect of sulfur on panicle length. Interaction of land use type with zinc application rate significantly (*p<.001*) affected panicle length at harvest. Application of 4 kg Zn/ha on the fallowed land gave the longest panicle (26.5 cm), followed by application of 8 kg Zn/ha on the continuously cropped land (26 cm) with similar results recorded for treatments that received 12 kg Zn/ha (25.5 cm) on the same soil (Fig. 4). Treatments that received 4 kg Zn/ha on the continuously cropped land recorded the shortest panicle length (24 cm).

3.4.1 Filled grain

There was no three-way interaction effect of treatment factors on filled grain per panicle of AGRA rice. But rather there was a two-way interaction effect of zinc by land use type on filled grain. Sulfur as a sole factor did not also significantly affect filled grain (*p<.001*) (Table 3). For the interaction of land use type with zinc application rate, application of 12 kg Zn/ha on the fallowed land gave the highest number of filled grains (190 grains/panicle) (Fig. 5). Similar results were obtained with the application of zinc at 4 and 8 kg Zn/ha on the same soil (160 grain/panicle). In contrast, application of 8 kg Zn/ha on the cropped land gave the highest number of filled grain (150 grain/panicle) on the cropped land. The least number of filled grain was obtained at no zinc application or the control for both soils (101 grains/panicle) and application of 4 kg Zn/ha on the continuously cropped soil.

3.5 Total Number of Spikelet

There was no three-way interaction effect of treatment factors on total spikelet number per panicle. But rather there was a two-way interaction effect of zinc by land use type on total spikelet number. Sulfur as a sole factor did not also significantly affect total spikelet number (Table 3). Maximum spikelet number was recorded by the application rate of 12 kg Zn/ha for both land use types (Fig. 6). Similar results were achieved by the application rate of 4 and 8 kg Zn/ha for both land use types. The least number of spikelet were recorded by no zinc application in both land use forms.

3.6 Percent Filled Grain

There was three-way interaction effect of treatments on percent filled grains of AGRA rice (*p<.001*) (Table 3). The highest percentage of filled grains was recorded by the application of 12 kg Zn/ha in combination with 30 kg S/ha on both land use types which was 99% filled (Fig. 7). The control plot with zero Zn and S application rate, recorded the least number of percent filled grains (60% filled).

3.6.1 Straw yield

There was no three-way interaction effect of treatment factors on straw yield. But there was two-way interaction effect of zinc and sulfur application rate on straw yield at harvest (*p=.030*) (Table 3). The highest straw weight was recorded by 12 kg Zn/ha and 30 kg S/ha (80 g/pot) (Fig. 8). The combined application of 12 kg Zn /ha and 20 kg S/ha also increased the weight of straw (60 g/pot). However, the least straw weight was recorded by the application of no sulfur and zinc (40 g/pot).

A two-way interaction effect of land use type (fallowed and continuously cropped) by sulfur application rate was also observed (Table 3). Highest straw weight was recorded by 30 kg S/ha on fallowed and cropped soils (70 g/pot) (Fig. 9). Application of 10 kg S/ha and 20 kg S/ha also increased straw weight on the cropped soil as well as the fallowed soil (60 g/pot). The least weight of straw was recorded in no sulfur application on the cropped soil (40 g/pot).

3.6.2 Grain yield

There was no three-way interaction effect of treatments on grain yield, but rather a two-way interaction effect of zinc and sulfur application rate on grain yield (*p=.035*) (Table 3). The combined application of 30 kg S/ha and 12 kg Zn/ha recorded the highest grain yield (60 g/pot) (Fig. 10). Lower increments in grain yield were recorded in other treatment combinations of sulfur and zinc. However, the lowest grain yield of 35 g/pot was recorded by the control (0 kg/ha Zn and 0 kg/ha S). An increase in grain yield of 71% over application of sole NPK was thus realized upon inclusion of Zn and S at rates of 12 kg/ha and 30 kg/ha, respectively, in the fertilization regime.

Table 3. Summary of analysis of variance table indicating three way, two way and one way factorial effect of sulfur and zinc application rates on growth and yield parameters of AGRA rice under fallowed and continuously cropped soils in Northern Ghana during the 2020 cropping season

Units	TA8	TA12	PC	PHAH	FG	TS	PF	PL	TGW	GY	SY
Soil	Ns	Ns	Ns	Ns	**	Ns	Ns	Ns	Ns	*	**
Sulfur	Ns	*	Ns	Ns	Ns	Ns	*	Ns	Ns	Ns	**
Zinc	Ns	Ns	Ns	Ns	**	Ns	*	Ns	Ns	Ns	**
Soil*sulfur	*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	**
Soil*zinc	Ns	Ns	*	Ns	*	*	Ns	**	Ns	Ns	Ns
Sulfur*zinc	Ns	Ns	Ns	Ns	Ns	Ns	**	Ns	Ns	*	*
Soil*sulfur*zinc	Ns	Ns	*	Ns	Ns	Ns	*	Ns	Ns	Ns	Ns
% Cv	23.5	17.5	18	5.2	6	8.4	7.6	5.1	6.5	5.8	2.9
Lsd 5%	2.7	2.9	3.9	8.2	1.8	2.2	1.7	1.8	6.5	2.6	2.7 2.5

** Represent probability level at 5%, ** represent probability level at 1%, Ns represent not significant. TA8 = tiller count at 8 weeks, TA12 = tiller count at 12 weeks, Pc = panicle count, PHAH = plant height at harvest, FG = filled grain, Ts = total spikelets, Pf = percent filled grains, PL= panicle length, TGW = thousand grain weight, GY = grain yield, and SY = straw yield. Units represent the interactions from three-way factorial, followed by two way and the single effects on parameters. Graphs are drawn for the significant levels highlighted. %CV represents the coefficient of variation*

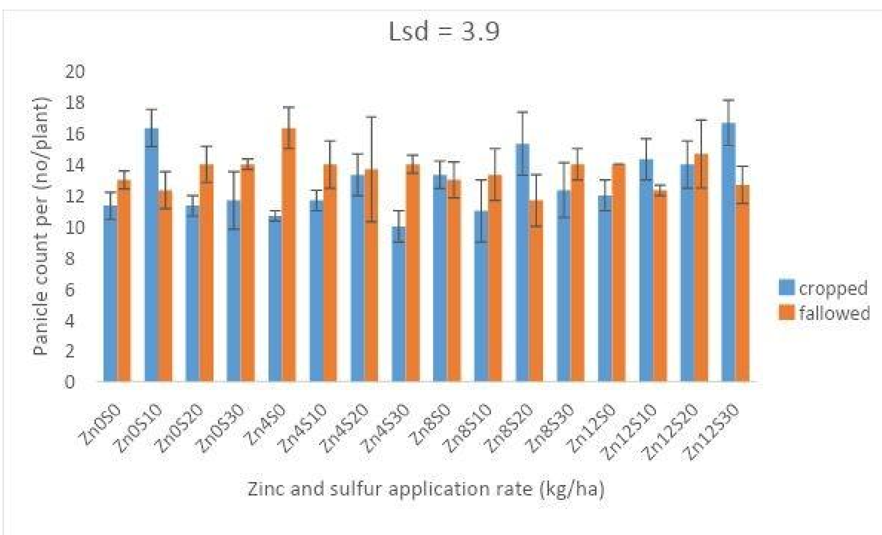

Fig. 3. Interaction effect of zinc application rate, sulfur application rate and land-use type (continuously cropped and fallowed soils) on panicle count of AGRA rice cultivated in Northern Ghana during the 2019 cropping season. Bars represent (SEM)

Zn0S0- control plot, Zn0S10- Zinc at 0 in combination with sulfur at 10 kg/ha, Zn4S0-Zinc at 4 kg/ha with sulfur at 0 kg/ha, Zn8S0- Zinc at 8 kg/ha with sulfur at 0 kg/ha, Zn12S30- Zinc at 12 kg/ha with sulfur at 30 kg/ha

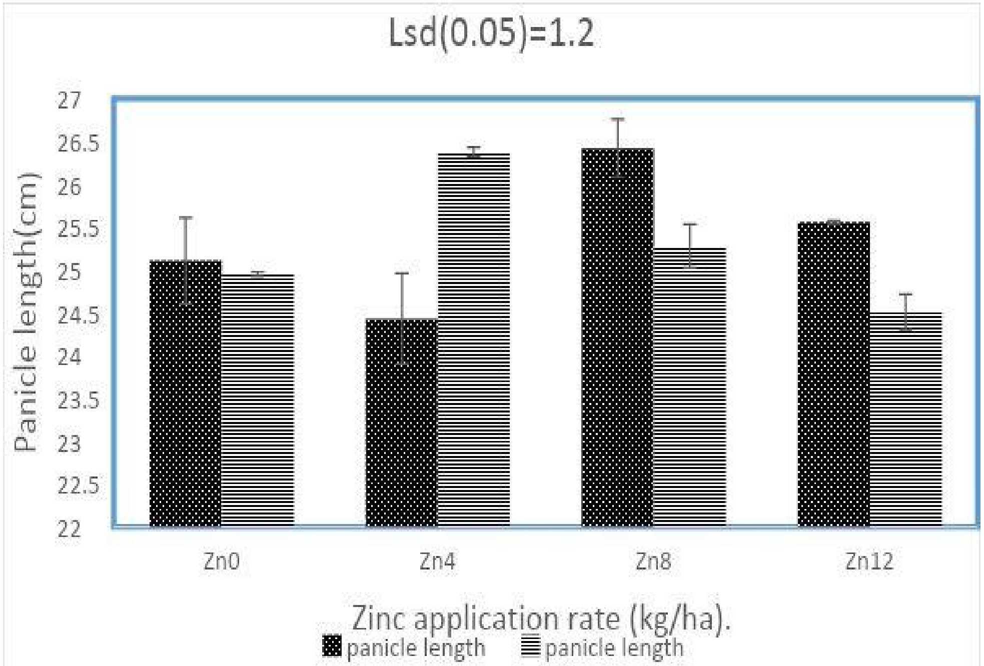

Fig. 4. Interaction effect of zinc application rate and land usetype (fallowed and continuously cropped soil) on panicle length of AGRA rice in northern Ghana during the 2019 cropping season. Bars represent (SEM). Zn0- control, Zn4-zinc at 4 kg/ha, Zn8-zinc at 8 kg/ha, Zn12-zinc at 12 kg/ha

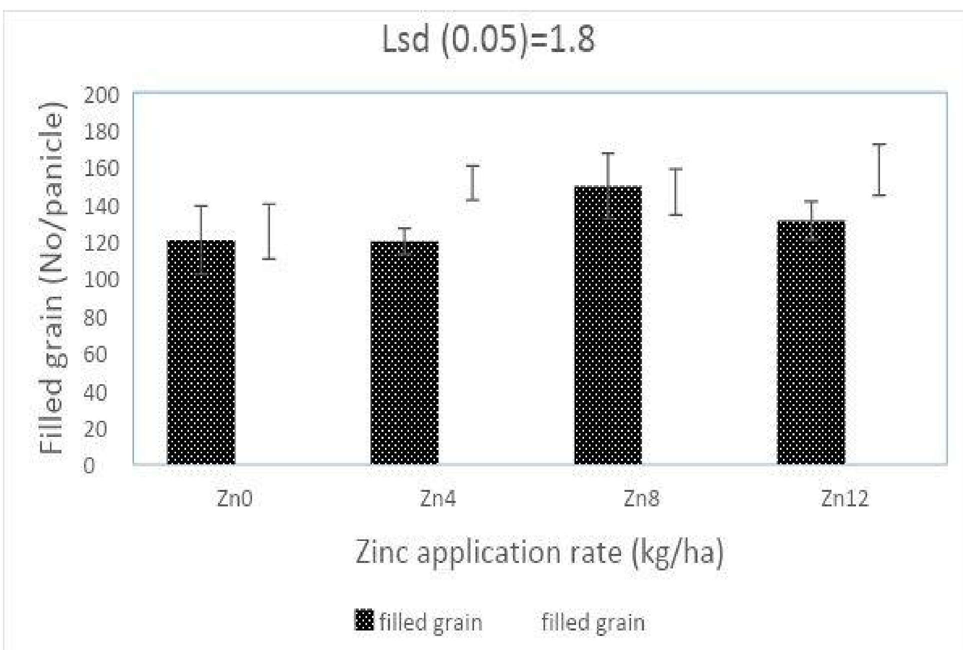

Fig. 5. Interaction effect of zinc application rate and land use type (fallowed and continuously cropped soil) on filled grain of AGRA rice in northern Ghana during the 2019 cropping season. Bars represent standard error of means (SEM). Zn0- zinc at 0 kg/ha, Zn4-zinc at 4 kg/ha, Zn8-zinc at 8 kg/ha, Zn12-zinc at 12 kg/ha

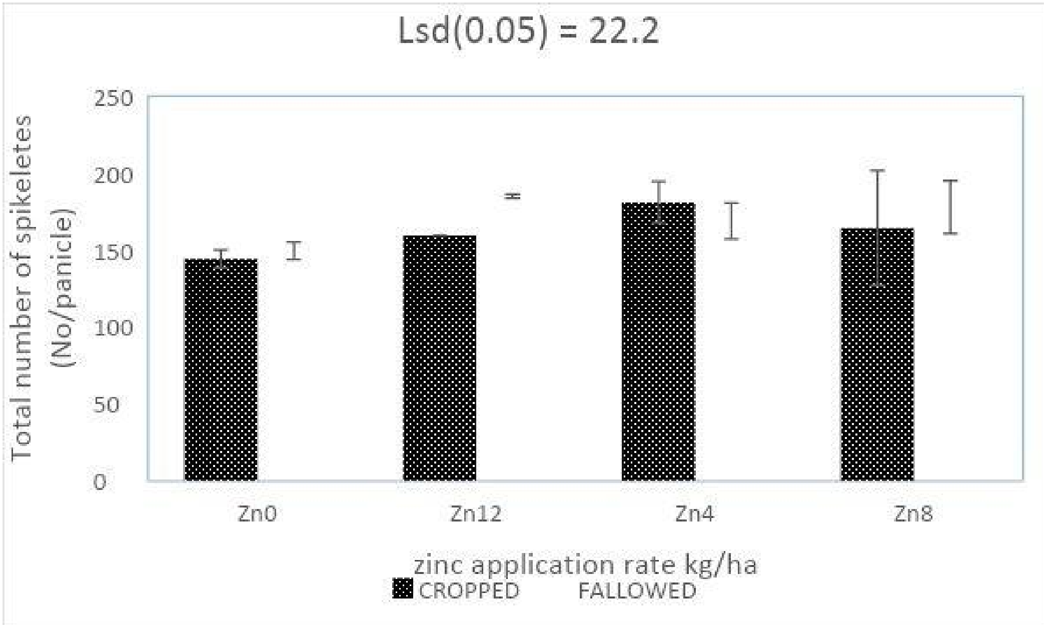

Fig. 6. Interaction effect of zinc application rate and land use type (fallowed and continuously cropped soil) on total number of spikelet of AGRA rice in northern Ghana during the 2019 cropping season. Bars represent. (SEM). Zn0- zinc at 0 kg/ha, Zn4-zinc at 4 kg/ha, Zn8-zinc at 8 kg/ha, Zn12-zinc at 12 kg/ha

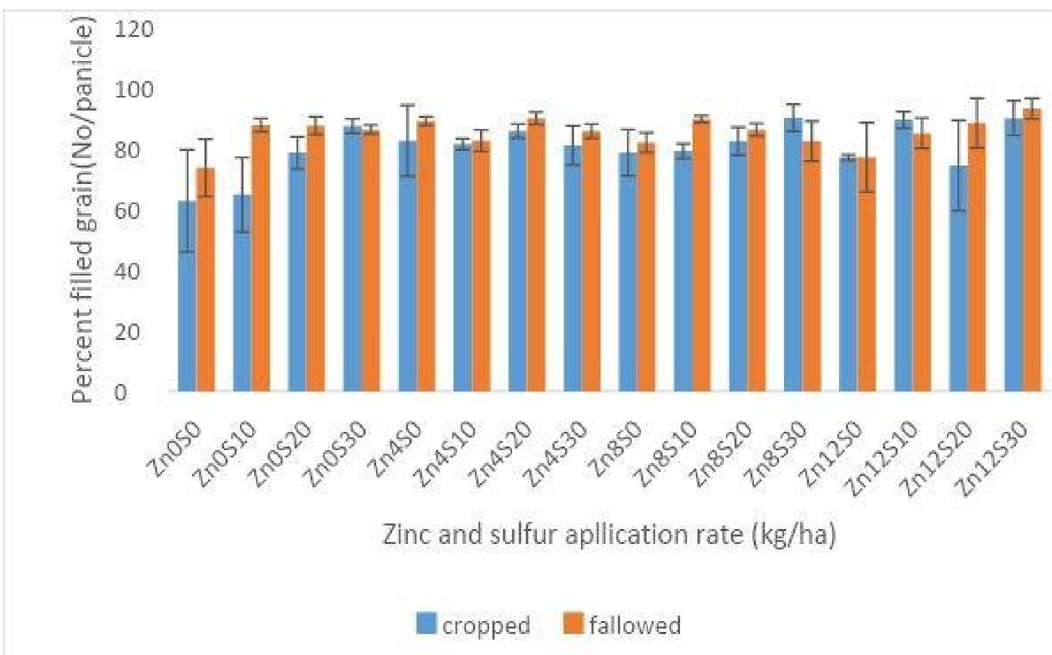

Fig. 7. Interaction effect of zinc and sulfur by land use types (fallowed and continuously cropped) on percent filled grains of AGRA rice. Bar represent (SEM). Zn0S0- zinc at 0 kg/ha, Zn12S30-Zinc at 12k/ha with sulfur at 30kg/ha

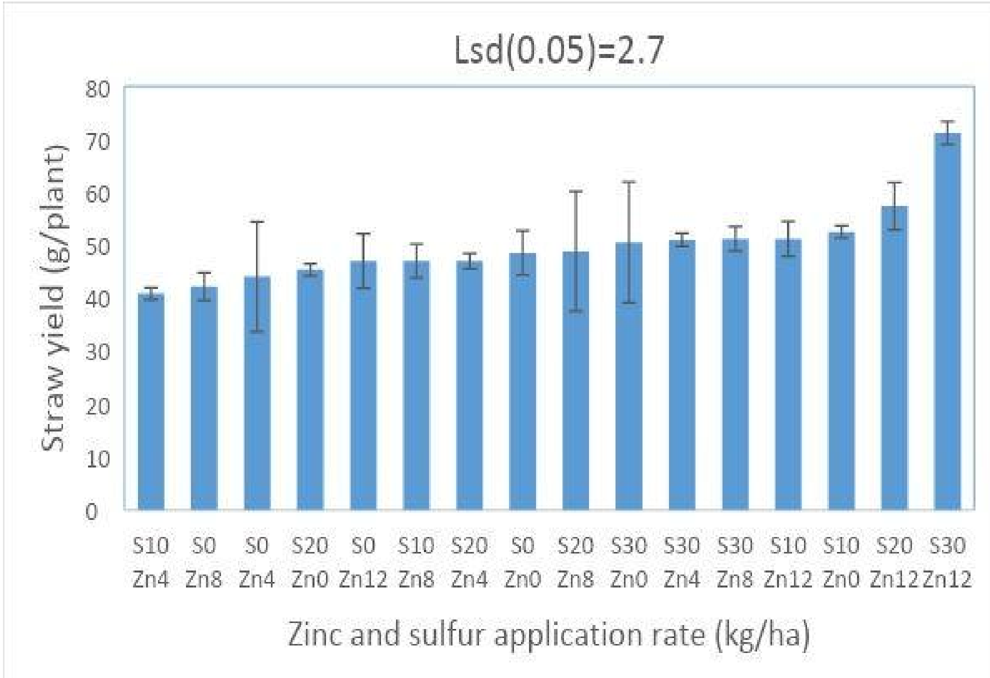

Fig. 8. Interaction effect of zinc and sulfur application rate on straw weight of AGRA rice variety in northern Ghana. Bars represent SEM

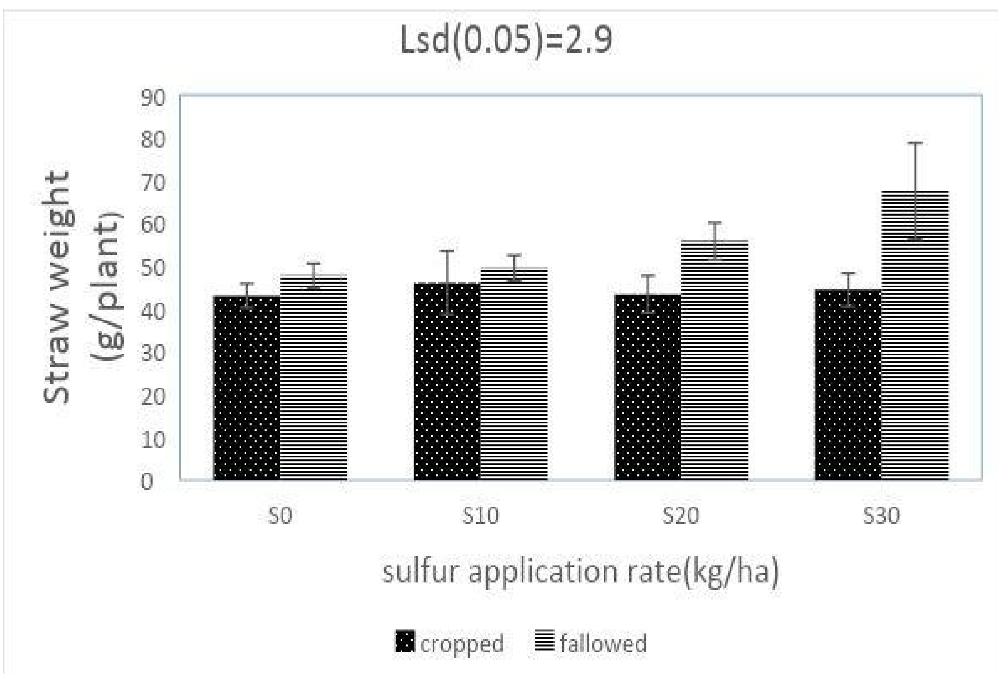

Fig. 9. Interaction effect of sulfur application by land use type (fallowed and continuously cropped) on straw weight of AGRA rice variety in northern Ghana. Bars represent SEM.S0-control, S10-sulfur at 10 kg/ha, S20-Sulfur at 20 kg/ha, S30-sulfur at 30 kg/ha

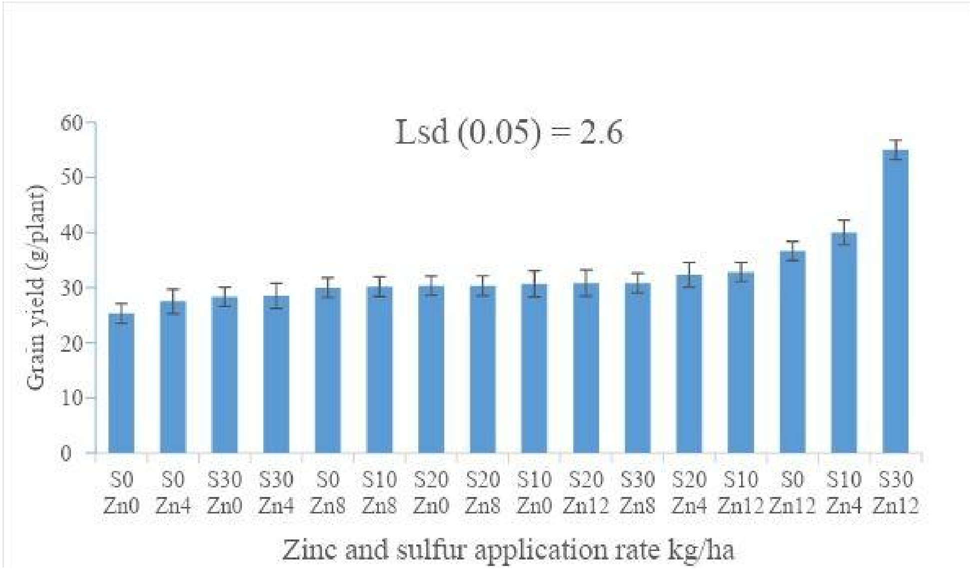

Fig. 10. Interactive effect of zinc and sulfur application rate on grain yield of AGRA rice in Northern Ghana during the 2019 cropping season. Bars represent SEM

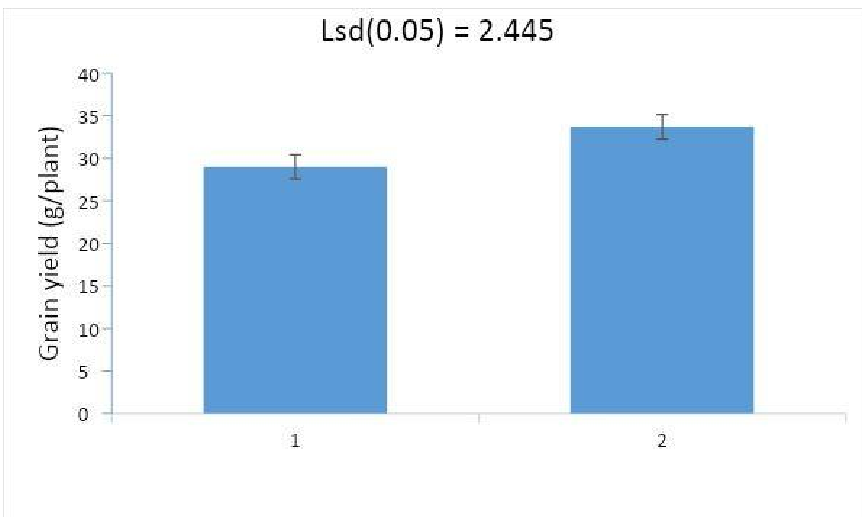

Fig. 11. Effect of fallowed and cropped land use type on grain yield of AGRA rice in Northern Ghana during the 2019 cropping season. Bars represent SEM

There was also a sole factor effect of land use type on grain yield of rice (Table 3). The main effect of land use (*p*=.*02*) significantly affected grain yield. Such that the fallowed soil gave the higher grain yield (35 g/pot) than the continuously cropped land use type (27 g/pot) (Fig. 11).

Correlation analysis of growth and yield parameters of rice in northern Ghana in the 2019 cropping season.

The results on the correlation analysis between rice growth parameters are presented in Table 4. The results showed that, rice tiller number after 8 weeks of planting was negatively associated with the height of the plant, panicle length as well as 1000 seed weight but positively correlated with panicle count, straw yield and grain yield.

The correlation was however not significant for the height of the plant and yield. The negative correlation between rice tiller after 8 weeks of planting and panicle length as well as 1000 seed weight was expected because at early stage of the growth of the plant, it was not matured enough to have had lengthy panicle or grains. Also, the height of the rice plant had a significant and positive correlation with panicle length and yield. This was also expected because, as the plant increases in height, it matures and the Panicle length and yield is expected to increase. Moreover, panicle count and panicle length both had a positive significant correlation with yield. This implies that, as the number of panicle count or length per plant increases, it is more likely to increase grain yield the more and vice versa.

Finally, the weight of 1000 seed was also found to be positively associated with yield. Higher yield per stand is expected to produce more grains which reflects in more weight per 1000 seeds.

3.7 Regression Analysis

The results from linear regression analysis between 1000 seed weight and grain yield indicated that 1000 seed weight could be used to determine grain yield, which accounted for 49.5% of variance in gain yield. The best prediction equation was developed as grain yield (GY) = (0.2735 × 1000 seed weight) +13.197. The R^2 value of 0.377 shows that there is a strong positive relationship between 1000 seed weight and grain yield since all points are close to the line ofbest fit (Fig. 12).

4. DISCUSSION

4.1 Physico-Chemical Properties of Soils (Fallowed and Continuously Cropped Soil)

4.1.1 Soil pH

The observed mean soil pH of 5.92 and 6.87 for the cropped and fallowed lands respectively (Table 2), are within limits that are ideal for rice cultivation and comparable to the results of Li et al. [30] and Tian [31]. The pH of the cropped land was acidic compared to the fallowed land which was almost neutral in pH. The decrement of soil pH or the acidification of the cropped soil could be attributed to field management practices such as the addition of nitrogen with fertilizers containing acidic radicals including application of urea and sulfate of ammonia, a common practice for rice growers in the area and which has been reported elsewhere to be associated with acidifying conditions [32]. Nitrogen inputs to the soil might exceed that required by soil microorganisms and crop demand, thus leaving residues of nitrogen in the soil after each cultivation. The remaining nitrogen in the soil tend to go through oxidation reactions that result in soil acidification [33]. These results are in line with other research works by Xu et al. [34] which indicated that soil pH on a continuously cropped field significantly decreased due to nitrogen accumulation. The pH of the fallowed soil was high because in long term fallowed periods, carbon and soil pH increase due to deposition of above ground biomass through litter fall and in situ deposition of grasses which results in subsequent enrichment with basic cations [35].

4.1.2 Bulk density

The observed bulk densities for the cropped and fallowed soils are 1500 kg/m^3 and 1700 kg/m^3 respectively (Table 3) and are good for rice cultivation as pointed out by Blancho et al. [36]; Sridev and Ramana [37. The fallowed soil had a higher bulk density compared to the continuously cropped soil. This could be as a result of undisturbed and unbroken gravels and dry matter accumulation over the 15 years, increasing soil compaction and hence reducing pore space and increasing the density. This observation is in line with that of Halvorson et al. [38] who noted that the bulk density of a fallowed land is greater than that of a cropped land. Sridev and Ramana [39] found in their research that, there was a reduction in soil bulk density of rice soil after continuous cultivation. Kumarswamy [40] also stressed the benefit of incorporating organic matter and concluded that continuous cropping and inclusion of organic matter reduce soil bulk density.

4.1.3 Organic carbon

The organic carbon percentage of the fallowed land was higher than that of the continuouslycropped land (Table 3). The high organic carbon percentage could be attributed to litter accumulation in the fallowed soil and slower rate of decomposition, as cultivation could accelerate organic matter degradation [40]. Soil organic matter is known to be a rich source of soil nutrients and is mostly found in the top soil.

Table 4. Correlation analysis for the study of influence of zinc and sulfur on growth and yield of AGRA rice under fallowed and continuously cropped rice field in Northern Ghana in the year 2020

	Tiller number	Height	Paniclecount	PanicleLength	1000 seedweight	Strawyield	Yield
Tiller @8wapHeight	1.00-0.12	1.00					
Panicle	0.42***	0.03	1.00				
Count Panicle	-0.19*	0.29***	0.01	1.00			
Length 1000	-0.26**	0.15	-0.14	0.29***	1.00		
seed weight Straw	0.21**	0.10	0.07	0.01	-0.04	1.00	
Yield Yield	0.04	0.20**	0.38***	0.29***	0.71***	0.04	1.00

, ** and * represents 5%, 1% and 0.1% significance level respectively*

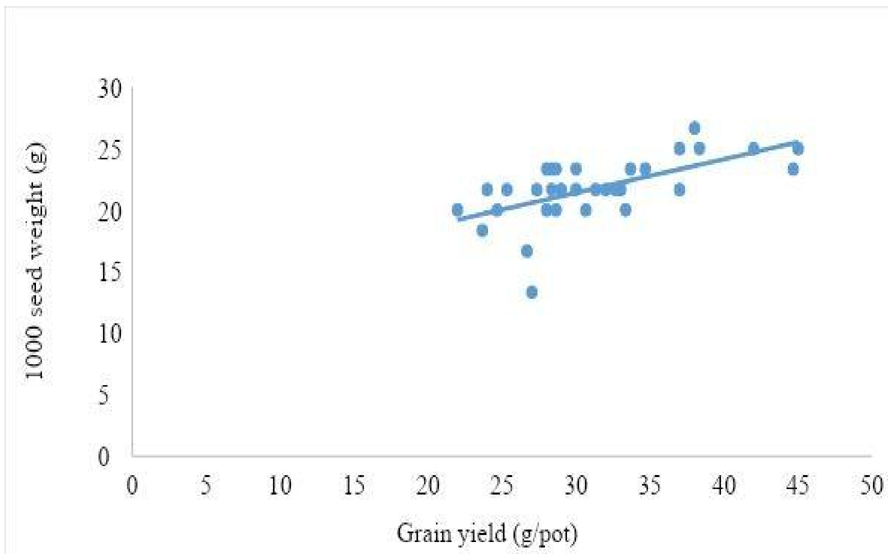

Fig. 12. Regression analysis between grain yield and thousand seed weight

During cropping, due to good tilth, adequate aeration and microbial population and activities, organic matter decomposition increases to release nutrients to the soil which are taken up by the high population of crop root hairs in the top soil. In a related observation in another study, the organic matter content (25 g OM /kg soil) in rice field before cultivation decreased to 20 g OM/kg soil after cultivation [41].

4.2 Level of Zinc and Sulfur in the Soil

The levels of zinc in the fallowed and continuously cropped land were 0.82 and 0.3 mg/kg respectively and were very low compared to the required amount for the growth of rice (above 1 mg/kg) (Table 3). This could be due to the low Zn content of Ghanaian soils and consequently for crops that may require external Zn input for high crop productivity [42,43]. Moreover, the level of zinc could also be low even in the fallowed soil because of the high organic matter content in the soil. High organic matter content of soils could contribute to crop zinc deficiency as organic compounds can bind Zinc nutrients and make the nutrients inaccessible for plant uptake, thereby making Zn less accessible to plant roots [44]. In addition, the low zinc content could be as a result of application of high amounts of macro nutrients which in turn tend to limit zinc availability in the soil [29]. The critical level of zinc for normal rice growth has been proposed to be 0.6 mg Zn/kg soil to 0.83 mg Zn/kg soil Takkar et al 1975, [27].

The level of sulfur, 65 and 67 mg S/kg, in the cropped and fallowed lands respectively were adequate, since the values were above the critical level of 5-20 mg S/kg soil [29]. This confirms the findings of Johnson and Fixenl. *[45]* that the level of sulfur in arid and semi-arid regions is adequate for cropping due to minimal leaching and supply from precipitation. The sulfur content also seemed to be adequate in both soils because of the adequate organic matter content in both soils, which serves as a major source of sulfur to the soil when it decomposes [46].

4.2.1 Impact of fallowing and continuous cropping on soil fertility

The continuously cropped land was generally low in most soil nutrients but higher in nitrogen compared to the fallowed soil. The increment in nitrogen on the continuously cropped soil compared to the fallowed could be due to additional amount of nitrogen fertilizers being applied to field crops during cultivation. This confirms the findings of Talpur et al. [41] that the nitrogen content, aside from every other soil nutrient content, tend to increase after cultivation that involves addition of N fertilizers. The reduction in all other nutrients could be as a result of the effect of continuous cultivation and nutrient uptake by preceding crops. Dobberman and Fairhurst [47] reported in their study that intensified mono-cropping of rice for several years reduced grain yield and led to the depletion of soil nutrient status in long term experiments conducted in Asia. Willy et al. [48] also found in their work that, the total level of organic carbon C, and other micro and macronutrients decreased with the continuous use of land for cropping. This could have accounted for higher nutrients in the fallowed soil compared to the cropped soil.

4.2.2 Tillering at 8 and 12WATP

The observed respective two-way (sulfur effect by land use type) interaction and one way (sole sulfur application) effect on tillering at 8 and 12 WATP (Table 3, Fig. 1, Fig. 2) are in line with findings of Kineber et al. [49], El-Eweddy et al. [50], Mazhar et al. [51], Kumar et al. [52] and Zayed et al. [53]. The findings are however in contrast to the findings of Wu et al. [54] who argued that tillering in rice plant is determined mostly by climatic factors like light, temperature, plant density, and nutrients. Wang and Li [55] also reported that the genetic make-up of the plant determines the number of tillers formed.

Tiller number did not respond to additional amount of sulfur at 8WATP (Fig. 1). This observation could be attributed to adequate sufficient amount of sulfur for the initial vegetative growth. However, at the 12WATP, tiller number responded to incremental amounts of sulfur as high up to 30 kg S/ha under both land use types. This phenomenon explains the fact that, sulfur nutrient easily gets leached down the soil, because of its inability to stick to the soil for a long time. Hence even though, inherent amount was adequate (67 and 65 mg S/kg) for fallowed andcropped soils respectively (Table 2), plants could not effectively utilize it and had to respond to added amounts up to 30 kg S/ha.

Tillering is the product of expanding auxiliary buds and is closely associated with nutritional condition of the mother culm. During the tiller's growth, it gets improved by application of some nutrients, especially sulfur which is an essential component of protein and required for the synthesis of proteins that are needed for tissue development. Sulfur also plays a role in the synthesis of certain amino acids like methionine, cysteine, and other plant hormones like thiamine and biotin and these are major components required for enhancing tillering in rice.

More so, adequate level of sulfur in the soil enhances the uptake of nitrogen, a major nutrient which plays significant role in evoking tiller number because of its ability to increase the cytokinin within the tiller nodes which further enhances the germination of tiller primordium [56]. The observed finding in this study is in line with the findings of Salvagiotti et al. [57] who found that, adequate levels of sulfur in the soil enhances the uptake of nitrogen in the soil, while insufficient levels of sulfur in the soil reduces nitrogen uptake.

Similar observations have been made by Tsujimoto et al. [58] who revealed that, the overall striking response of tiller number to sulfur application strongly suggests that sulfur deficiency primarily inhibits the efficient use of the indigenous and external supply of nitrogen for rice dry matter production. They [58] therefore concluded that, sulfur and nitrogen are both vital components of proteins, and a balanced supply of these elements is important for efficient dry matter production. These findings are also supported by earlier research works [59,60].

4.2.3 Panicle count (No/plant)

The observed three way effect of treatments on panicle count (Table 3, Fig. 3) are comparable to the findings of Waikhom et al. [60]. The increase in panicle number which contributes to economic yield could be attributed to the adequate supply of zinc and sulfur to the soil, thereby resulting in the improvement of crop growth. Also, the supply of zinc and sulfur throughout the growth period in adequate amounts have a synergistic effect in improving panicle count. The results are in conformity with findings of Arif et al. [61]. The application of sulfur also enhanced tillering which correlates directly with number of panicles formed (Table 4). This result agreed with the findings of Singh et al. [62], who also found in their study that the application of zinc and sulfur improved or gave highest panicle number/plant.

4.3 Yield Parameters

The observed improvement in yield parameters like panicle length, filled grain, total spikelets and percent filled grains (Figs. 4-7) in response to zinc application are comparable to the findings of Tabassum et al. [63]. They found that the yield attributes increased significantly with increasing levels of zinc over the control (no zinc application).

Yield parameters of the rice plant are mainly components of the sink size [64]. Sink size is a component of the sink strength which is improved or determined by enzymatic activities and the extent of physiological development within the sink tissue [64]. These enzymatic activities are known to control the photosynthate utilization within the sink [64]. Once these enzymatic activities are improved, a greater improvement of the sink size occurs which reflects in the yield parameters as well. Zinc nutrient is known to play specific functions in the plant, such as: maintenance of structural and functional integrity of biological membranes and facilitation of protein synthesis and gene expression [65]. These functional qualities of zinc enable it to improve upon the enzymatic activities within the sink, leading to an improvement of yield parameters via zinc application. Zinc is also the micronutrient known to be responsible for pollen formation and the production of seed which contributes to the improvement of yield parameters. The findings in the study is in line with those of Thejas [66] and Yadi et al. [67], who also reported that yield parameters were increased with increasing zinc application.

The increase in yield parameters with increasing zinc rate is also attributed to the role of zinc in improving the physiological functioning of the crop. Zinc influences the uptake of plant nutrients through enzymatic activity in the metabolic process and enhances better assimilation of carbon dioxide in the panicle [68] and [69]. As also explained by Hafeez et al. [69] who found that the action of zinc activity reduces spikelet sterility, and increased total spikelets and panicle length. Khan et al. [70] also observed a reduction in the number of filled grains per panicle at 0 kg Zn/ha compared to higher rates of application.

4.3.1 Straw yield

Straw yield increased in response to adequate supply of zinc and sulfur (Fig. 8) which is comparable to the findings of Kumar [52]. The highest straw yield (80 g/plant) were obtained in the combined application of 30 kg S/ha +12 kg Zn/ha, which was significantly higher than the control as well. The increase in straw yield may be explained by the enhanced growth parameters, photosynthesis and carbohydrate metabolism as influenced by sulfur application. It might also be due to the application of sulfur which provides better condition for the development of crops due to improved physico-chemical properties of the soil, as well as better synergy of sulfur in nutrient uptake that eventually promotes growth of the crop. These results were in close conformity with the finding of Kumar et al. [52]. Adequate supply of sulfur increased tiller number which is highly correlated to straw yield (r= 0.2108*), hence contributing to the increment of straw yield. This findings confirms those of others, including Vikas Singh et al. [71], who found that straw yield was significantly enhanced by the application of zinc and sulfur nutrients.

Land use type and sulfur application rate also enhanced straw yield. The fallowed land in combination with adequate sulfur supply boosted straw yield. The fallowed land increased straw yield because its inherent nutrients had not been extensively mined as in the case of the continuous farming. This confirms the findings of Willy et al. [48] who concluded that relatively high content of unmined micro nutrients in fallowed land serves as a benefit for fallowed soils.

4.3.2 Grain yield

The grain yield was significantly increased with different levels of nutrients application (Fig. 10). The combined application of 30 kg S/ha + 12 kg Zn/ha gave the highest grain yield which was double the yield obtained in treatments that received NPK fertilization but zero rate of Zn and zero rate of S (control). These findings are comparable to findings of Dixit et al. [72]; and Kumar et al. [52].

The main determining factors of grain increase in the rice crop are the source strength, sink strength and flow capacity. Sulfur and zinc as nutrients are known to exert a positive effect on these determinant factors which ultimately have positive effect on grain yield. Sulfur and zinc are known to influence translocation of metabolites and thereby improving source and sink strength in plants [73]; Li et al. [64]. The increase in grain yield with increasing Zn and S rates could also be as a result of the combined effect of supplied zinc and sulfur nutrients on metabolic processes of rice. Highest grain yield with application of 30 kg S/ha + 12 kg Zn /ha was obtained due to low inherent Zinc status of the soil (0.3 and 0.82 mg Zn/kg for cropped and fallowed respectively) which was below the optimum level (above 1 mg Zn/kg) required for rice production. The low level therefore enhanced response of rice to the Zn fertilizer application. Also, even though sulfur levels from the soil seemed to be adequate, the rice plants responded to a higher dose of sulfur application. This could be attributed to the fact that inherent soil sulfur does not stick to the soil for a long time but easily gets leached down the soil, making it inaccessible for plant usage [46].

Increment in grain yield could also be attributed to increased number of tillers, panicle count, panicle length, 1000 seed weight which increased linearly with grain yield respectively (r = 0, r = 0.2015**, r = 0.2854***, r = 0.7073 and r = 0.0436), such that Zn rate, S rate and land use type, as long as they affect these parameters contributed to increases in grain yield. This confirms the findings of Vikas Singh et al. [62] who reported that, grain yield increased because of the positive correlation between yield and yield parameters.

Grain yield responded in correspondence to land use types. The fallowed land increased grain yield compared to the continuously cropped land. This could be as result of depletion in soil nutrients through nutrient mining in the cropped soil. Talpur et al. [41] have emphasized the need to maintain soil fertility in order to achieve high paddy yields. In a related study, intensified mono-cropping of rice for several years reduced grain yield and led to the depletion of soil nutrient status in long term experiments conducted in Asia by Doberman and Fairhurst [47]. However, Willy et al. [48] emphasized on the grain yield beneficial effects of a fallowed soil.

5. CONCLUSION AND RECOMMEN DATIONS

Soil analysis between the two land use types; fallowed and continuously cropped, indicated and confirmed the removal and mining of soil essential and micro nutrients when a land is continuously cropped. This showed the need to improve on agricultural soils by either allowing the soil to fallow or practice other productive cropping systems to limit nutrient mining for improved crop productivity.

Almost all growth and yield parameters of rice significantly responded positively to added amounts of zinc and sulfur in the soil. Growth and yield parameters like tillering, panicle count responded effectively to added amount of sulfur. Application of 30 kg S/ha to the continuously cropped soil significantly increased tiller number. For the fallowed soil however, 10 kg S/ha was adequate to support early tillering although 30 kg S/ha was necessary for full season productivity.

Application of at least 8 kg Zn/ha to the fallowed soil gave the longest panicle, highest number of filled grains, and total spikelets. However the combined application of 30 kg S/ha and 12 kg Zn/ha significantly maximized grain and straw yield of rice in this study in northern Ghana. Yield increases up to about 100% were recorded where sulfur and zinc were applied to the crop compared to the control. The maximization of grain yield due to sulfur and zinc addition are attributed to the enhanced synergy in growth promoting parameters; which includes synthesis of protein and amino acids by sulfur and also the enhancement of physiological and environmental tolerance to disease, water stress, and the improvement in phosphorous and nitrogen uptake that promotes crop growth.
Both soils responded significantly to additional amount of sulfur and zinc, hence application of zinc and sulfur to a fallowed soil could be needed for better improvement of the rice crop.

Even though application of 30 kg S/ha and 12 kg Zn/ha maximized grain yield on both land use types, the fallowed soil recorded the highest grain yield than that of the continuously cropped soil. In conclusion, sulfur and zinc nutrients are therefore very important in the growth and development of the rice plant. And therefore need to be considered alongside NPK macro nutrients in order to maximize grain yield. For optimum growth and yield of the rice crop, 30 kg S/ha and 12 kg Zn/ha should be applied. Research on the influence of other essential micro nutrients should be carried out to see their effect on rice growth and development.

It has been found from this research that nutrients are being mined greatly when a particular land is used continuously. As such, it is recommended that farmers allow soils to fallow for about 15 years to replenish essential nutrients in the soil. It is therefore important to avoid over cropping a particular soil for a long period of time (over 15 years of cultivation) in order to maintain nutrient balance and at the same time prevent nutrient depletion from the soil.

Finally, it is therefore recommended that, before any nutrient would be added to the soil, initial soil analysis should be done before any addition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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