UNIVERSITY FOR DEVELOPMENT STUDIES

INFLUENCE OF ZINC AND SULFUR MICRONUTRIENTS ON GROWTH AND YIELD OF RICE (*Oryza sativa* L.) ON CONTINUOUSLY CROPPED AND FALLOWED LANDS IN THE GUINEA SAVANNAH ZONE OF GHANA

VIDA BISILKI

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DEPARTMENT OF AGRONOMY

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

AUGUST, 2020

DECLARATION

I hereby declare that the work is the result of my own research, and the thesis either in full or part has never been presented in any other institution for a degree. All other references made from the research have been cited accordingly.

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I hereby declare that the preparation and the presentation of the thesis was supervised in accordance with the guidelines on supervision laid down by the University for Development Studies.

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ABSTRACT

Even though zinc and sulfur have been long postulated as plant nutrients that can boost the yield of rice, their application has been given little attention in efforts made to increase rice productivity in Northern Ghana. In this research, fertilizers were applied to rice crop on fallowed and continuously cropped rice fields in Northern Ghana in the 2019 cropping season. Soil samples were collected from fallowed and continuously cropped rice fields at Wungu and Kokubila in the Walewale District of the North East region of Northern Ghana for soil Physico-chemical properties. Pot experiment was conducted at the technology park of the Savannah Agricultural Research Institute at Nyankpala, near Tamale-during the 2019 cropping season. The objective of the study was to determine the influence of zinc and sulfur on growth and yield of rice on these two land use types. It was a 2 x 4 x 4 factorial experiment laid out in a randomized complete block design with three replications. 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. Initial Physico-chemical analysis indicated that the soils 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 compared to the cropped soil. Results showed grain and straw yields were maximized by the combined application of 12 kg Zn/ha and 30 kg S/ha for both soils. Tiller number at 12 weeks after transplanting were significantly enhanced by the application of 30 kg S/ha for the fallowed and cropped land use types. Panicle count, number of filled grains, total number of spikelets and percent filled grains were promoted with the application of at least 8 kg Zn/ha for both soils. Grain yield of rice positively and highly correlated with 1000 seed weight (r = 0.71***).

DEDICATION

This thesis is dedicated to my brother Enoch Bisilki and lovely father Kojo Bisilki.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Rice (*Oryza sativa* L.) is known to be the staple food of the developing world and occupies about 11% of the total arable area (Guimaraes, 2009; IRRI, 2010) 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 (Roy *et al*., 2011). Under diverse ecological conditions, rice is being cultivated in almost all the five continents of the world, with a projection in per capita consumption of about 54.1 kg (RMM FAO, 2018).

The per capita consumption of rice in Ghana within the early years was 9 kg compared to other sub - Saharan countries which had per capita consumption of 25 kg (Akanko *et al*., 2000; Van Oort *et al*., 2015). The initial low consumption in the early years was due to selective preference by the rich and its consumption during certain festive occasions. However, reports by Nwanze *et al*. (2006), showed that rice has become the fastest-growing food source in the whole of Africa, and consumption kept increasing as the years pass by leading to increases in its demand. This increase in demand for rice as a component of the food balance in the country can be likened to rapid growth in population, ease of cooking and storage and change in consumer preference (Bimpong, 1998; MOFA, 2009). Even though the reasons above partly explain the increase in demand and consumption, researchers like Nabhan (2004); Tian *et al*.(2009) and Bienner *et al*.(2010) reported that other reasons that could account for the increment in consumption could probably be the diversity in which rice can be prepared and eaten. Unlike other local Ghanaian dishes that are eaten as they are, rice can be prepared and eaten in several ways which include, rice water, Jollof, rice balls, rice and beans, and many others which could also account for the increment in consumption. For these reasons, GUPTA *et al*.(2014) identified rice as a vital component in poverty alleviation, hunger eradication and a valuable product for ensuring food security through improved production. Also, a report by the Ministry of Food and Agriculture showed that rice has become the second most important major food after maize in the country (MOFA, 2010). The high demand for rice has outstripped production, such that the Ghanaian producers are unable to meet the increasing demand for rice in the country. For example, a report by the Sustainable Social Action for the Reduction of Poverty (SSARP) in Ghana revealed that Ghana's annual demand for rice is roughly 700,000 metric tonnes while domestic production is only about 150,000, leaving a shortfall of 550 metric tonnes which is imported every year (Nyarko and Kassai, 2017; Quaye *et al*. (2010). Also, the executive secretary of the Ghana Rice interprofessional Body (GRIB, 2019), observed that local rice production and consumption is declining due to its unattractiveness to buyers and sometimes unavailability, while imports are increasing due to the high demand of the crop in our daily menus (Zhao *et al*., 2010). It is known that the importation of rice has been on the increase since 1980 and always contributes to 50% of all consumed rice in the country (Diako *et al*., 2010 and 2011). There has been consequent importation to about 200% of local production in order to compensate for shortfalls and satisfy the rice hunger of Ghanaians (Tanko *et al*., 2019). In fact, rice self-sufficiency in Ghana is reported to have fallen from

38% in 1999 to 24% in 2006 (CIRAD, 2007; Acheampong, *et al.*, 2017). The growing concerns of high annual importation bills on rice necessitated the Government of Ghana to announce a ban on rice importation into the country until 2022 (Forkuor, 2020). This stark statistics has renewed calls from the Food and Agriculture sector, for industry experts to devise new innovative ways to improve the production of rice in the country.

Ghana's vision is to increase productivity and curb the continual importation of rice at higher costs. As a result, many efforts and interventions have been introduced in order to achieve this goal. These efforts includes practicing intensive agriculture and the use of high yielding varieties. In line with this, two high yielding varieties, AGRA and JASMINE 85, have been released to farmers with little attention given to the soils on which the crop grows. Meanwhile, Sanchez and Van (2010) stressed on the need to develop high yielding crop varieties along with practice of good agronomic practices in the best soil ecology for the plant's survival. Sanchez and Van (2010) recommended that crop yields in Africa could be boosted when the soil is properly managed. It has also been reported by John *et al*.(200l) that exhaustive agriculture, which involves high yielding varieties of rice and other crops, leads to substantial removal of plant nutrients from the soil.Inappropriate use of chemical fertilizers has also resulted in weakening of soil health and hence reducing crop productivity (United Nations University Institute of Advanced Studies (UNU-IAS, 2008). However, the rice plant or crop is known to grow well in soils that are capable of supplying all essential nutrients; both micro and macronutrients in right proportions.The major factor contributing to the success or failure of the crop is the regime of plant nutrients found within the soil (Sharma *et al*, 2010). Amongst the required essential nutrients, sulfur and zinc are known to play beneficial roles in increasing the productivity of rice (Mahmood *et al.*, 2006). Reduction in yield of rice is often blamed on zinc and sulfur deficiency. Sulfur insufficiency primarily rises in waterlogged conditions or in low land rice cultivation (Neue and Mamaril, 1985; Zhao and Mcgrath, 1994 and Horneck *et al.*, 2011). In sulfur deficient soils, both yield and value of crops are known to suffer unless sulfur-containing fertilizers are included in the treatment. A research conducted by Singh *et al*.(2013), indicated that maximum grain yield and straw yield of rice were significantly higher when a high dose of sulfur along with the recommended dose of NPK fertilizer was given.

The sulfur requirement of rice varies according to the nitrogen supply. When Sulfur becomes limiting, the addition of nitrogen does not change the yield or protein level of plants. Sulfur is required early in the growth of rice plants. If it is limiting during early growth, then tiller number and therefore final yield will be reduced (Fismes *et al*., 2000).

Low zinc (Zn) soils are common worldwide (Brennan 2005; Ashworth and Alloway, 2004). Zinc is a significant element for multiple enzymes that are accountable for many metabolic reactions in crops (Li *et al*., 2013). Zinc is also engaged in both the expression of genes and the synthesis of proteins. Cakmak (2008) believed that zinc deficiency could inhibit the activity of a number of antioxidant enzymes that harm membrane lipids, proteins, and nucleic acids. Zinc deficiency is the most widespread micronutrient disorder in lowland rice and the application of Zn along with NPK fertilizer increases the grain yield drastically in most cases (Rahman *et al*., 2007).

1.2 Problem statement and justification

A number of factors may account for the decline in the production of rice in Ghana. Rice producers in Ghana tend to use nitrogen, phosphorus, and potassium (NPK) fertilizers widely while neglecting the use of other important nutrients such as the secondary and micronutrients. On the contrary, White and Zasoski (1999) and John *et al*. (2001) have reported that the extensive use of nitrogen, phosphorus, and potassium fertilizers (NPK) over time, 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 and Giller (2006) also stressed on sulfur deficiency in soils which have become prevalent in many nations, due to the practice of intensive agriculture using fertilizers that are rich in NPK. Rhadhika *et al*. (2013) concluded that the use of sole NPK fertilizer for rice production is no longer practical, since this practice tend to deplete inherent secondary and micro nutrients from the soil.

Furthermore, rice farmers in Ghana often cultivate rice on one piece of land for several years without allowing the land to fallow in order to replenish inherent nutrients and hence this practice depletes the available nutrients and leads to low productivity over time. Wei *et al*. (2006) and Dass *et al*. (2017) 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 being utilized, conveyed and harvested from soil to plants. Somani (2008) reported a higher incidence of micronutrient deficiency in crops due to continuous cropping, resulting in loss of fertile topsoil and loss of nutrients through leaching.

Yields are declining with the use of the same amount and type of nutrients (Sahrawat *et al*., 2010). Many interventions on macronutrients to increase rice production and productivity over the years have been undertaken (Kihara *et al*., 2017; Vanlauwe *et al*., 2015). While the potential of both micro and secondary nutrients have been explored in other sub Saharan countries by researchers like Kumar *et al.* (2018), the potential of micro and secondary nutrients has received little attention in Ghana. It has been recommended by Rahman *et al*. (2007) that Sulfur content in soils be assessed in rice fields in order to determine the required quantity to be applied to increase grain yield and improve the quality of the crop. Maximum grain and straw yield of rice were found to be significantly higher when a high dose of sulfur at 60 kg/ha along with the recommended dose of NPK fertilizer was applied (Singh *et al*., 2013; Kumar *et al*., 2018). However, little research work exists on micro and secondary nutrients inclusion with current NPK and how these affect rice yield and quality in Ghana.

1.3 Objectives

Main objective

- ✓ To determine the influence of sulfur as a secondary nutrient and zinc as a micronutrient on the growth and yield of rice on a fallowed land and continuously used land.

1.3.1 Specific objectives

- To assess the impact of sulfur as a secondary nutrient on growth and yield of rice under fallowed and continuously cropped soils.
- To assess the impact of zinc micronutrient on growth and yield of rice under fallowed and continuously cropped soils.
- To assess the differential effect of fallowed and continuously cropped soils on the growth and yield of rice.
- To determine the interaction effect of Zinc and Sulfur on the growth and yield of rice under fallowed and continuously cropped soils.

1.3.2 Significance of study

To improve the growth and yield of rice in Northern Ghana through the application of sulfur as a secondary nutrient and zinc micronutrient.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of rice

Rice is one of the world's most significant food plants and the main calorie source for over half of the world's population. There are two types of rice grown, *Oryza*. O. *Sativa*, Asian rice grown worldwide because of its elevated yield potential and *Oryza glaberrima* grown in West Africa on a tiny scale with other 17-20 wild species (Nayar, 2014). The genus *Oryza* originated in Gondwanaland about 130 million years ago and various species were dispersed in various continents with the Gondwanaland break-up (Chang, 1976). During the green revolution, rice production improved rapidly mainly due to the introduction of high yielding varieties.

The Asian cultivated rice (*Oryza sativa* L.) was introduced into West Africa in the late 15th century by Europeans. The Asian rice is believed to have originated from india and then spread through to china (Fuller, 2009). There has been a lot of arguments concerning the exact origin of Asian rice and a number of reserchers have recounted multiple origins for the crop. However, Molina *et al*. (2011) suggested the Yangtze of China as the principal origin of Asian rice from where it spread through south and south east Asia to other parts of the world. This is also supported by Huang *et al*. (2016) who reported of a single origin of domestication of rice in China.

Five wild *Oryza spp* occur in West Africa (Vaughan, 1994; Clayton *et al*., 2005). *Oryza longistaminata* and Roehr have the widest distribution. They occur both in aquatic and wetlands.

Asian rice is believed to have been introduced to Africa by Alexander the Great in 332 BCE after he conquered Egypt but it was not until 639 CE that it became established after the Arabs introduced its cultivation to Egypt (Luh and Chang, 1991). The Arab travellers for instance took it to Egypt and Morocco and former colonial masters from Portugal and the Netherlands brought it to West Africa, including Ghana. The plant has been cultivated in West Africa for the past 3000 years and is very common in the Sahara during wetter periods. At the beginning of the 17th century, Asian rice was found in almost all the continents of the world.

Rice however, became an important crop in Ghana in the 1960s where it was mostly grown in the northern part of the country, contributing to about 61% of national production (Asare, 2000).

The main rice types produced in Ghana are *Oryza sativa* and *Oryza glabberima* (ODI, 2003; Mokuwa *et al*., 2013). Rice production takes place in all the regions in Ghana, and this cover all the major ecological and climatic areas including the interior savannah area, the high rain forest zone the semi-deciduous rain forest area with peak production in the northern, Upper East, Western, Brong Ahafo, and Volta region (ODI, 2003; Donkor and Awuni, 2011).

2.2 Rice growth and development

According to Counce *et al.* (2000), the rice plant has three developmental growth stages which include:

2.2.1 The vegetative stage

This involves germination and emergence of the seedlings, production of leaves and the establishment of seedlings and tillering. The vegetative growth stage of rice under favorable environmental conditions covers about half of the total growth period in the tropics (Fageria, 2007). Rice germination, like many other plants, is a complex physiological process affected by temperature and amount of water in the soil. The germination process involves all events in which the embryo is activated from its dormant stage to a modified active form. Good germination of rice is achieved when the seeds are healthy for the occurrence of total germination rate. With adequate moisture in the soil, germination of rice seeds is controlled by the soil temperature (Tilebeni *et al*., 2012). Temperature regulates the rice seed dormancy, affecting progress towards completion once the rice seed is stimulated to grow. Rice seeds usually require lower temperature for germination in the temperate environments compared with tropical conditions like Ghana. Optimum temperature for germination is normally around 15℃ and 30℃ while maximum is between 30 to 40℃. There are significant differences between genotypes of rice for seed germination with respect to cardinal temperatures (Tilebeni *et al*., 2012). Depending on the variety type, germination of rice seed can also be affected by the amount of oxygen and light available. Majority of higher plant species cannot germinate under anaerobic conditions. This is however not the case for rice seed as it is able to germinate successfully even without access to oxygen, a condition called anaerobiosis.

Coleoptile is the sheath that protects the leaves of emerging shoot of rice. It is pushed from the base towards the soil surface by the mesocotyl, a short stem below the coleoptile. Emergence of rice seedlings is therefore stimulated by the elongation of these organs which are also regulated by both genetic and environmental factors.

Xiong *et al*. (2017) found Ethylene to play a role in enhancing rice seedling emergence, also causing elongation of the mesocotyl and coleoptiles. Together with jasmonic acid, ethylene, they also found, controls elongation and promotes the seedling emergence in the soil. Shiratsuchie and Takanashi.(2001) studied differences in the rate of seedling emergence among rice cultivars. They employed a large number of rice cultivars for clarifying the differences between rates of seedling emergence. About 30 cultivars with a high emergence rate at 14 days after sowing were selected. The results of the experiment showed no significant difference in emergence rate between non-glutinous and glutinous cultivars. Rather they found higher soil water potential resulting in higher emergence rate at 28 days after sowing and also shorter time to the emergence of seedlings.

Water management on seedling emergence is very imperative as this can cause delayed emergence. The number of floating and turned down seedlings can also be markedly high under flooding when the rice seeds are sown directly without nursing. The percentage of delayed emergence in the rice plot reduces in the order of flooded, wet and drained plots. Sato and Maruyama (2002) found drainage during seedling establishment can improve seedling emergence and establishment, regardless of sowing depth and seed coating with CaO.

Tillers are branches that develop from leaf axils at each elongated node of the main shoot or from other parts of the rice plant during vegetative growth and they grow independently on adventitious roots (Krishnan *et al*., 2011). The processes of tillering is in two stages; there is first the formation of an axillary bud at each leaf axil, and then followed by later outgrowth.

The tillering stage of rice begins at the fifth leaf stage. The first tiller is usually visible and emerges from the axillary bud of the second leaf on the culm. The process continues when the sixth leaf emerges. The second tiller appears from the axillary bud of the third leaf and continues in a synchronous manner (Moldenhauer and Slaton *et al*., 2001). Li *et al*. (2003) noted that the rice tiller is a specialized grain-bearing branch, which occurs on the unelongated basal internode and grows by means of its own adventitious roots. The process of tillering increases in a sigmoidal-shaped curve up to the stage where the maximum tiller number is reached. The main culm may be quite difficult to notice from the tiller at that point. Usually after maximum tillering, there is further production of tillers, which are more effective (Moldenhauer and Slaton, 2001). During the late tillering stage, a proportion of the tillers generally die off because of competition.

2.2.2 The reproductive stage

The second stage of rice development is referred to as the reproductive stage and this includes elongation of culms, emergence of flag leaves, booting and heading leading to flowering.

Panicle initiation marks the end of the vegetative phase and starts the reproductive stage of rice plant where actual panicle begins to form at the base of the stems. The reproductive stage of rice is characterized by culm elongation, booting, a decline in tiller number, emergence of the flag leaf, heading and flowering. The emerging panicle is microscopic and situated in the stem. Panicle initiation is described as the point where 3 out of 10 main shoots have a panicle 1 to 2 mm long above the internode. But this stage is difficult to detect with the naked eye due its microscopic size unless a longitudinal section is made through the culm (Whitworth *et al*., 2012). Panicle differentiation, the point where the newly forming panicle becomes visible continues (Linscombe, 2012).

Booting is the stage when growth and development of a panicle and the constituent parts are completed in the sheath of the flag leaf. The sheath of the flag leaf is referred to as the boot. During the booting stage, there is swelling of the flag leaf sheath, which is caused by an increase in the size of the developing panicle as it grows up the leaf sheath (Dunand and Saichuk, 2014). Booting stages include the early, middle and late boot stages, based on the amount of flag leaf sheath exposed above the collar of the leaf from which it emerges.

Heading is the period when the panicle starts to exert from the boot. The period of heading can last up to about 10 to days (Moldenhauer and Slaton, 2001). This is due to variations within tillers on the same plant and between plants in the field. The practical definition of heading date is when about 50 percent of the panicles have exserted from the boot. Therefore it is possible for some panicles to not be able to emerge fully from the boot. Poor exsertion of the panicles may also occur due to long periods of low sunlight three weeks before and after heading leading to poor grain filling. Panicles from certain cultivars of rice extend partially out of the boot while other cultivars extend 3 to 4 inches beyond the panicle base (Moldenhauer and Slaton, 2001).

During the stage of heading the panicle extends through the sheath of the flag leaf on the main stem, brought about by the gradual and continuous elongation of the uppermost internode. There is elongation of the uppermost internode which reveals more of the panicle above the sheath of the flag leaf. However as soon as the uppermost internode completes elongation, the full length of the panicle and a part of the uppermost internode are exposed above the collar of the flag leaf and the stem is fully headed. There is variation in the heading stage of growth in the rice field. Some main stems and tillers of other plants may be fully headed while other plants may have just started to head.

Flowering in rice includes inflorescence initiation, development of the flower structure up to the point of flower opening called anthesis. Like most grass plants, the structural units of the rice flower are spikelets and florets. The spikelet and the floret consists of a pair of lemma and palea, lodicules, stamens and a carpel. Both the lemma and palea organs are widely believed to be specific to grasses. Spikelet of rice contains fertile floret and a pair of sterile lemmas usually subtended by a pair of highly reduced glumes. The sterile lemma is widely believed to be visible in only Oryza species and some grass species (Yoshida and Nagato, 2011). The age and sometimes the location of the rice plant can influence the flowering season.

2.3 Ripening stage

The ripening or grain filling stage of rice follows ovary fertilization characterised by grain growth. The grain increases in size and weight as the starch and sugars are translocated from the culms and leaf sheaths. The ripening process of rice involves milk stage, soft dough stage, hard dough stage and maturity. During the milk stage, the developing starch grains in the kernel are soft. The interior of the kernel is filled with a white liquid which looks like milk. At the soft dough stage, the starch in the grain is now beginning to become firm even though still soft. At the hard dough stage, the whole grain becomes firm and almost ready for harvest, with moisture content still above 22%. The maturity stage is where the whole grain is hard and ready for harvest. This stage is reached at approximately 20 to 22% moisture. Uniform maturity is important for prompt harvesting and for high milling yields (Moldenhauer and Slaton, 2001).

2.3.1 Growth and yield parameters of the rice plant

Grain yield is determined by certain important agronomic traits which include, plant height, number of tillers and panicle formation or morphology. The total number of tillers include both productive and non-productive ones. In a study, the number of panicles produced is determined by the number of productive tillers which eventually influence the grain yield. Primary tillers and main stem contributed 95 to 100% of grain yield (Goos and Johnson, 2001). Fageria (2007) also reported that there was a high correlation between grain yield and the number of tillers determined at panicle initiation. Panicle elongation and the internode patterns influence the plant height. The height of a rice plant is usually dependent on the cultivar and the environment (Mani *et al*., 2008).

While researchers like Wu *et al*.(1998) found out that tillering in rice plant is determined by certain climatic factors like light, temperature, plant density, and nutrients; Wang and Li (2005) found out that the genetic make-up of the plant determines the number of tillers formed.

Under field conditions, application of nitrogen is the most effective way of enhancing tiller number because it increases the cytokinin within the tiller nodes and further enhances the germination of tiller pirmordium (Liu *et al*., 2011). Addition of

Nitrogen evokes significant effect on the growth tiller in rice (Sakakibara *et al*., 2006).

2.3.2 Economic importance of rice

Rice serves as the main source of food to East and South East Asia and is also known as the rice bowl of the world where more than 90% of the world rice is cultivated and consumed. Rice when consumed, supplies 21% energy, 15% protein, 70-80% carbohydrate, 1.2-2.0% mineral and some vitamins (Kumar *et al*., 2018). Global statistical data of FAO (2014) revealed that the global production of rice is 719.74 million tons with acreage of 160.6 million hectares of production of 475.5 metric tons. No wonder they described rice as an important hunger abolisher, decliner of poverty, guarantor of food safety and promotor of profitable growth through the improvement in productivity. Rice has become the most important food after maize and its consumption keeps increasing due to population growth, urbanization, and change in consumer preference (MOFA, 2009), and also employs about 2.5 million households. These attributed to the increment in global rice production from 200million tones of paddy rice in 1960 to over 678million tonnes in 2009 in Asia. China and India account for about 92% of the world's total rice production (Wikipedia, 2013). An increase in rice production is a result of the increase in rice demand. West Africa is about 6 million kilometer square in area and rice occupies about 8% of the total crop area. (Farahmandfar *et al*., 2009). The rate of increase in the consumption of rice in Africa has not been matched by corresponding increases in production and the demand-supply gap is spreading (Balasubramanian *et al*., 2007). Africa accounted for 32% of global imports in 2008 and currently spends about US$ 5 billion on imports (Seck *et al.*, 2013). This places a heavy demand on scarce foreign currency reserves of countries in the region, which are among the poorest in the world.

Ghana produces 30-40% of its rice needs (MOFA, 2010) and spends over 500 million US dollars annually on importation (IRRI, 2010). The per capita rice consumption in the country increased from 17.5 kg to 38 kg between the years 1999-2008 and is estimated to reach 63 kg by the year 2018 (MoFA, 2009; JICA, 2007).

2.3.3 Global production of rice

Rice production increased during the last three decades of the twentieth century due to the Green Revolution. The Green Revolution program that occurred between the 1940s and 1960s brought about massive increase in production mostly in the developing countries (Muthayya *et al*., 2014). Paddy rice production had increased to about 130% (Khush, 2004). New rice varieties introduced and cultivated with irrigation lands in half of the world's harvested area resulted to nearly 75% of the world's total rice production. In most parts of Asia, production levels have actually tripled compared to averages obtained before the Green Revolution (Muthayya *et al*., 2014).

Currently rice is produced in over a hundred countries. These countries produce over 715 million tons of paddy rice yearly providing about 480 million tons of milled rice (FAOSTAT, 2013). Asian countries produce about 90% of total rice production in the world (Muthayya *et. al*., 2010). China and India alone contribute about 50% of rice produced globally. Apart from China and India, the likes of Indonesia, Bangladesh, Vietnam, Myanmar, Thailand, the Philippines, Japan, Pakistan,Cambodia, Korea Republic, Nepal and Sri Lanka are major Asian rice producing countries (Muthayya *et al.*, 2012). Brazil, United States, Egypt and Madagascar are not producing rice in large quantities and together contribute only 5% to global rice production (Muthayya, *et al.*, 2014). In West Africa, Nigeria is the leading producer of rice in the sub region and accounts for about 5% of rice produced globally. The production capacity of the country is about 15 million tonnes. Total rice production in the whole of West Africa was about 6.24 million tonnes from 2001 to 2005. Production doubled in 20 years, from 2.76 million tonnes in 1985 to 5.75 million tonnes in 2005. Sierra Leone, Senegal, Benin, Nigeria and Guinea are countries where growth rate of rice production increased the most with respect to the sub region. The demand for rice in West Africa is reported to be higher than anywhere else in the world with high increases in production in the last decade resulting in the production of 15.5 million tonnes in 2016 up by 8% from 2015 production (FAO, 2017). This is projected to reach 18.3 milliontonnes in 2018.

In Ghana, rice is now the second most important staple food after maize due to increasing demand. Paddy rice production in Ghana over the years has seen some increases due to the area put under rice farming rather than variations in yield. For instance, between 1996 and 2005, production was in the region of 200,000 and 280,000 tonnes. The self-sufficiency ratio of rice in the country declined to 24% in 2006, making the country depend largely on imported rice to make up for domestic supply deficit. Production levels have risen steadily from then. Currently, Ghana's rice production stands at 688,000 Mt (MoFA, 2017) from a harvested area of 236 000ha with the Volta Region leading the production from 2014 to 2016.

2.4 Soil fertility regeneration under fallowed soils

The fallowed system of cropping refers to cropping measures where a cultivated land has been left bare without cultivation in order to replenish its inherent nutrients eighter by natural vegetation regrowth, cover cropping, and alley cropping. Fallow as a practice, associated with crop rotation, had its origins in Mediterranean agriculture (Karlen *et al*., 1994) and continues to be used throughout the semiarid and arid regions of West Asia and North Africa (Ryan *et al.*, 2008). Additionally, summer fallow has been practiced widely across the 15 western states of the United States and the farmed areas of the prairie provinces of Canada in response to widely varying precipitation from year to year. Fallow system of cropping helps in the improvement of soil fertility through the accumulation of litter which in turn enhances organic matter content in the soil as a result of minimum activities being carried out on a fallowed land in comparison to a continuously cropped soil Willy *et al*. (2019).

At the start of a fallow period, the fallow vegetation grows rapidly, from new seedlings and from the root systems already in place from previous crop and fallow periods. Nutrients are taken up from the surface soil and subsoil and are stored in the vegetation. They are in part returned to the soil through litter and rain wash from the aboveground vegetation. With intense biotic activity at the soil surface, litter decays rapidly and is transformed partly into SOM. At the same time, erosion is minimized, as is leaching, due to ground cover and rooting mass. Humus and litter layers increase until they reach an equilibrium between build and rate of oxidation.

Improved fallows have the potential to increase overall crop yields, while also offering services such as maintenance of microbial and insect diversity (Badianc *et al*., 2001; Sileshi and Mafongoya 2003) and buffering against nutrient leaching (Chikowo *et al*., 2004).

2.4.1 Importance of fallowing on crop growth and development

Improved fallowed periods have the overall tendency to increase crop yields as well as improving microbial and maintaining insect diversity (Badianc *et al*., 2001; Sileshi and Mafongoya, 2003) and also buffering against nutrient leaching (Chikowo *et al*., 2004). Tian *et al*. (2005) reported in their work that, in transforming shifting cultivation to a permanent cropping system, fallow with natural vegetation (natural fallow), herbaceous legumes (cover crop fallow), and woody legumes (alley cropping) can contribute to the maintenance of crop production and soil fertility. They, however, stressed that the length of fallow should not exceed two years. They reported that a fallow length of about two years is the best for a natural fallow system for west Africa. The main objective of practicing fallow is to stabilize the production of crops by forfeiting production in one season in anticipation that there will be at least partial compensation by increased crop production the next season (Nielson and Calderon, 2011).

Other objectives of fallowing are to maximize soil water storage through improved water intake, snow trapping, and decreased evaporation; maximize plant nutrient availability; minimize soil erosion hazards; and minimize energy and economic inputs (Greb, 1979)

2.4.2 Effects of fallowing on soil physico chemical properties

2.4.2.1 Organic matter content

The crucial indicator of soil quality, biological activity and also serving as a nutrient reservoir and nutrient aggregation is likened to the amount of soil organic matter (SOM) content in the soil (Doran and Parkin, 1996; Wienhold *et al*., 2006; Ryan *et al*., 2008). Fallowing plays a major role in the maintenance and buildup of soil organic matter due to litter fall and accumulation during the fallowed period. Buildup and maintenance of SOM is critical to soil productivity and generally corresponds to nutrient buildup. SOM increases the cation exchange capacity (CEC) of the surface soil which is especially important in kaolinitic soils. Of special importance, increasing SOM can reduce phosphorus fixation in soils with high iron and aluminum oxide content. In West African Alfisols, SOM accounts for 80% of CEC, and available P, K, Mg, Ca and CEC are highly correlated with SOM levels (Agboola, 1994). The big opportunity for management in such soil systems is that SOM is a renewable resource, whose level can be replenished by additions of organic inputs (Fernandes *et al*., 1997).

However, other reearchers (Biederbeck *et al*., 1984; Campbell and Souster, 1982; Campbell *et al*., 2000; Mikha *et al*., 2006; Rasmussen and Collins, 1991; Rasmussen and Parton, 1994; Peterson *et al*., 1998; Ryan and Pala, 2007; Williams, 2004), have reported that fallow cropping systems generally have negative impacts on soil organic matter content due to the reduction of crop residue production during the period of fallow. Frequent tillage and use of summer fallow small grain system deteriorated soil quality and decreased organic carbon but rather increased soil erosion and reduced the structural ability of the soil in northeast Iran (Golchin and Asgari 2008).

2.4.2.2 Other macro nutrients

Smika (1983); Campbell *et al*. (1990) and Cochran *et al*. (2006) reported that fallow period enhances the accumulation of nitrate through the mineralization of soil organic matter. Relatively high level of organic matter content in the soil supply adequate nutrition through N mineralization which is enhanced by aeration with tillage in combination with high soil moisture content during fallowed period. As a result, prolonged fallowed cropping systems on such soils tend to deplete soil nitrogen and hence requiring the addition of fertilizer nitrogen (Cochran *et al*., 2006).

Brand and Pfund (1998) reported in their work that there was rapid nutrient regeneration of about 36 to 57% of previous phytomass pools in a fallowed vegation . In a study looking at carbon and nutrient accumulation in secondary forests regenerating on pastures in Central Amazonia, Feldpausch *et al*. (2004) found that in a 14-year-old forest, most of the carbon and nitrogen had been stored within the soil, while the increased phosphorus, potassium, magnesium, and calcium resided more within the vegetation. These findings have important implications for management. When nutrients are accumulated in the vegetation rather than in the soil, there is a danger of nutrient stock depletion when biomass is exported or burned rather than being carefully recycled within the plot.

In comparing fallow tillage systems in Queensland, Australia, Standley *et al*. (1990) found greater losses of N, P, S, and K in the surface 10 cm of a vertisol after 7 yr of conventional tillage compared with no-till. They attributed the N losses to greater losses of NO_3^- leached below the 0.6 m sampling zone and greater denitrification with conventional tillage.

2.4.2.3 Micro-nutrients

Fallow no-till systems could increase P and micro-nutrients in the upper layers of soil.

Unger (1991), reported approximately 60% higher extractable P in the 0- to 4-cm soil layer from a wheat–sorghum–fallow system under no-till management compared with stubble mulch management in Texas**.**

Follett and Peterson (1988) showed the existence of tillage intensity effects on several nutrients from a loam soil in western Nebraska that had been in wheat–fallow production for 16 year. They found that total P, organic P, K, Zn, and Fe in the 0- to 5 cm layer declined with increasing tillage intensity (no-till > stubble mulch > moldboard plow). They attributed these results mainly to cycling of nutrients to the soil surface in plant parts and subsequent residue that was then mixed and diluted with soil from lower depths as tillage intensity increased.

Decreasing fallow frequency similarly increased levels of Zn, Mn, and Fe in the 0- to 5 cm layer but did not affect Cu or SO_4–S levels (Bowman and Vigil, 2000).

2.4.2.4 Bulk density

Beneficial soil physical changes occur in fallow system of cropping. The fine surface roots of the fallow vegetation mold the soil into soft and porous granules or crumbs, worms deposit their casts on the soil surface, and drainage channels are created. Such a soil surface permits rapid infiltration of water and resists erosion unless completely unprotected. SOM, especially in sandy soils, has a profound impact on soil structure.

Physical properties such as hydraulic conductivity, bulk density, total porosity, and aggregate stability all decrease as SOM falls, as a result of the duration and intensity of cropping (Agboola, 1994)

Halvorson *et al*. (1997) reported greater bulk densities in no-till vs. conventional till wheat–fallow aft er a 15-yr study comparing the two systems in northeastern Colorado. Pikul and Aase (1995) analyzed the combined effects of tillage and cropping intensity on bulk density in northeastern Montana. They found that after 9 yr of cropping, the spring wheat–fallow conventional till system had higher bulk density in the surface to 12-cm layer than in either the annual spring wheat no-till system or the annual spring wheat system with fall and spring tillage.

Pikul *et al*. (2006) reported greater water-fi lled pore space for systems employing fallow compared with continuously cropped systems at two northern Great Plains locations, but mixed results regarding the effects of tillage on water-fi lled pore space.

2.4.2.5 Soil pH

Soil pH, organic carbon, available P and exchangeable ca, Mg and K decreased considerabely after 12 years of cultivation, even in a three year fallow subplot (Tian *et al*.,2005). A fallowed period of about zero to one year old reflected relatively high soil pH compared to three to four years of fallow period. The pH of soil declined in short term fallowed land of about zero to four years. In long term fallowed periods carbon and soil pH increased due to deposition of above ground biomass through litter fall and in-situ deposition of grasses which results in subsequent enrichment with bases (Choudery and Devi 2013).

2.5 Soil fertility regeneration under continuous cropping systems

Soil refers to the upper part of the land that supports the growth of living organisms, especially the growth of crops. And therefore the excellent growth or failure of a plant depends on the nutritional content and the ability of soil to support the development of the plant. Soil is known to be the main source of plant nutrients and the determinant factor to crop yield and supplies about sixteen essential nutrients. However, research has emphasized the gradual declination and removal of the inherent nutrients found within the soil making crop production unproductive and unyielding as it supposed to be. This gradual removal and loss of these inherent nutrients are being likened to the practice of intensive agriculture and introduction of high yielding varieties which tend to utilize much of these nutrients found within the soil, making the soil lose its productive nature.

2.5.1 Impact of continuous cropping on crop growth and development

There is a need to maintain soil fertility in order to achieve high paddy yields (Talpur *et al*., 2013). 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 (2000).

2.5.2 Effect of continuous cropping on soil physico chemical properties

2.5.2.1 Organic matter

Soil organic matter is known to be the richest source of soil nutrients and is mostly found on the topmost part of the soil. Looking at its location in the soil, it is can be easily taken and being utilized by crops during their growth, decreasing its content in the soil. The organic matter content (25 g /kg) in rice field before cultivation decreased to 20 g/kg after cultivation (Talpur *et al*., 2013).

2.5.2.2 Other macro nutrients

While all other macronutrients contents tend to decrease after the cultivation of rice, it has also been found by Talpur *et al*.(2013) that the content of nitrogen tends to be on the increase after harvest. This increment is likened to the application of nitrogen fertilizer during the cultivation of rice. The continuous application of nitrogen fertilizer to the soil tends to have adverse effects on the crop like increasing its susceptibility to pests, diseases, lodging, increasing unfilled grains and increasing soil pollution. However, Willy *et al*. (2019) also found in their work that, the total level of nitrogen, organic carbon c, and other micro and macronutrients decreased with the continuous use of land. More so, they also argued that, despite the negative impacts of continuous cultivation on soil properties, they also have other positive impacts on the soil properties like increasing soil phosphorous, zinc content and copper in the soil. They attributed this improvement in soil quality parameters to soil fertility and management practices undertaken by farmers during cultivation which involves the use of organic and inorganic fertilizers that are very rich in such nutrients.

Nutrient index changed from high in uncultivated plots to low in cultivated plots, indicating the removal of nutrients during cultivation. (Khadka *et al*., 2017).

2.5.2.3 Micro nutrients

The deficiency of micronutrients has become major constraint to productivity, stability and sustainability of soils (Bell and Dell, 2008). Weathering process and the prescence of minerals are the main determinant factors of available micronutrient contents in the soil. The prescence of major nutrients positively or negativelyaffect the uptake of micronutrients in the soil (Fageria, 2011). Continual application of fertilizers rich in phosphorous are known to reduce the uptake of micronutrients like zinc (Dadhich and Somani, 2007; and Kizilgoz and Sakin, 2010). Thus, indiscriminate use of macronutrients may affect uptake of micronutrients.

Application or supplementing the soil with some important micronutrients for rice growth has not been the interest of farmers compared to application of macronutrients like NPK over the past years; as a result, recent reports by most researchers have indicated the declining nature of inherent micronutrients in the soil from continual cultivation of rice indicating micronutrients utilization during their growth. Some findings include: The content of iron decreased from 84.37 to 68.24 mg Fe/kg, while that of copper decreased from 8.03 to 6.40 mg Cu/kg, manganese decreased from 19.41 to 12.93 mg Mn/kg and Zn decreased from 2.15 to 1.57 mg Zn/kg after cultivation of rice on the field (Talpur *et al*., 2013)

2.5.2.4 Bulk density

Bulk density refers to the weight of dry soil per unit volume. A soil that is more compact with less space will have a higher bulk density. Soil bulk density may have an impact on water infiltration into the soil, rooting depth of the plant, available water capacity, soil porosity, plant nutrient availability and the activities of soil microorganisms. Soil organic matter content, texture of the soil, soil mineral density and aggregates arrangement is known to be the determining factors of soil bulk density. Sridevi and Ramana (2016) found in their research that, there was a reduction in soil bulk density of rice soil after continuous cultivation, which involved the application of 25 or 50% recommended dose of fertilizer and 50% N through the application of farmyard manure and paddy straw. Kumaraswamy and Vasanthi (1999) also stressed on the benefit of incorporating organic matter to reduce soil bulk density. However, Blanco *et al*. (2011) found that, maximum bulk density in continuous cropping systems is a result of the accumulation of soil organic carbon near the surface of the soil.

2.5.2.5 Soil pH

Continuous cultivation of a land might significantlty decrease the soil pH making the soil acidic for crop cultivation. A research conducted by Li *et al*. (2016) indicated that pH of a continuously cropped soil significantly decreased. The reduction of soil pH was attributed to the continual addition of Nitrogen fertilizers during the cultivation of a crop. Nitrogen inputs being added to the soil might exceed that which could be used by soil micro organisms and the plants and hence leaving residues of nitrogen in the soil after each cultivation. The remaining nitrogen in the soil tend to cause soil acidification. These results are in line with those of other research works (Li *et al*., 2014, and Xu *et al*., 2009) which indicate that the soil pH on a continuously cropped field significantly decreased due to nitrogen accumulation.

2.5.3 Continuous cropping versus fallowing

Continuous cropping of crops on soil annually tends to produce much more crop residues and could gradually replenish some organic matter lost from fallowed cropping system (Bowman *et al*.,1999; Ortega *et al*., 2002). This could be as a result of continual exposure of land to fire outbreaks, soil erosions which tend to leach and wash away organic matter and other nutrients, making a fallow soil lower in soil organic matter content. It has been reported by Halvorson *et al*. (1997) that the bulk densities in a no-till and conventional tillage wheat-fallow systems were high.

Blanco-Canqui (2011) had reported that intensified cropping systems might also tend to have greater benefit than crop fallowed systems in terms of conservation of soil and water, improvement of other soil properties and increment in soil organic matter concentration as well as improving crop production. Diverse crop rotations and continuous cropping systems returned more above and below ground biomass to the soil than cropping systems with extended fallow periods (Blanco-canqui, 2011).

2.6 Micronutrients required for rice growth

Experts believe that the extensive use of NPK alone is counter-productive because soil fertility is determined by both macro and micronutrients. For instance, Kausar *et al.* (2001) have shown in their work that a favorable balance of macro and micronutrients is required for optimum crop production. They argue that the use of fertilizers that are low in micronutrients can result in low crop productivity over time. Though micronutrients are required in small quantities they are considered to be more essential. Since plants cannot complete their life cycle without these nutrients (Marschener, 1995). According to White and Zadoski (1999), micronutrient deficiency renders it impossible for a plant to gain maximum benefit from NPK applications. Qadir *et al*. (2013), also in their research work showed that the maximum number of tillers per square meter, spikelet per panicle and paddy yield was obtained with the combined use of zinc and boron. Whereas, the highest 1000-seed weight was recorded where three micronutrients (zinc, boron, and iron) were applied in combination. Hence, they recommended the use of boron alone or combined with zinc for obtaining a higher yield of rice.

According to Horneck *et al*. (2011) micronutrients are considered to be adequate in the soil if values obtained from soil analysis exceed that of 1 ppm or 1 mg/kg.

2.7 Status of Zinc in the soil

Globally, zinc is regarded after nitrogen, phosphorus, and potassium as the fourth major yield-limiting nutrient. It is one of the micronutrients that is found out to be highly deficient in West African soils, because of its high correlation between available zinc and total carbon and phosphorous and also low organic matter contents in the soil. Efforts to increase the contents of other macronutrients in the soil tend to limit zinc availability in the soil (Buri *et al.*, 2000). The deficient level of zinc for normal rice growth has been proposed to be 0.83 mg Zn/kg by Randhawa and Takar (1975) and 0.6 mg Zn/kg by Shukla *et al*., (2016). Rice grown in soils with zinc levels as low as 1.0 mg Zn/kg showed deficiency symptoms. Analysis of Diethylenetriamine Pentaacetic acid (DTPA) extractable Zn in soil showed that 40% of soil specimens were possibly deficient in zinc (Shukla *et al*., 2016). It has been assumed that the zinc deficiency is likely to rise from 49-63% by 2025 as most of the marginal soils being cultivated show the signs of zinc deficiency.

In the "global zinc areas," the average zinc content of Ghana soils and crops is somewhat on the low side. The smallest plant-soil zinc values were measured from samples from the Ashanti region, almost without exception (Mikko Sillanpa 1978).

2.7.1 Functions of Zinc in plants

Zinc is known to be the most vital and main mineral for the synthesis of protein and the expression of genes in crops (Cakmak 2000; Broadley *et al.*, 2007; Dixit *et al.*, 2012). As a result, it has been found out that, about 10% of enzymes in biological structures need zinc for their physical and efficient development. And hence making zinc mineral one of the most essential micronutrients for the growth and development of plants. Zinc mineral is absorbed in the ion ($Zn^{2+)}$ form by the roots of plants. And is highly related to plant enzymatic and nitrogen metabolism diversity. Zinc applied to soils tends to increase the growth of plants as found out by many researchers and it also plays an essential part in plant metabolic rate by affecting hydrogenase and carbonic anhydrase activities, stabilizing ribosomal fractions, and cytochrome synthesis. Zinc-activated plant enzymes are engaged in carbohydrate metabolism, cellular membrane integrity maintenance, protein synthesis, and auxin synthesis and pollen formation regulation.

The deficiency of zinc in the soil may affect plant growth that becomes obvious and visible like inhibited growth, chlorosis, and lower leaves, spikelet sterility or failure.

2.8 Factors affecting zinc uptake by plants

2.8.1 Effects of addition of Nitrogen fertilizers

The addition of nitrogen can influence the absorption of plants to Zinc mineral by plant in the soil. Application of Nitrogen to the soil even though increases the growth of a plant and its development also decreases the absorptions of zinc by plants. This may affect the response of plants to zinc by decreasing the root to shoot ratio (Brennan, 2005). Any factor, which increases plant growth without simultaneously increasing the rate of absorption or the size of the root system, will result in a decrease in the concentration of zinc in the plant (Brennan, 2005).

2.8.2 Soil pH

The pH of the soil is an important factor affecting the availability of zinc. Brennan (2005) noted that at high soil pH, zinc is more strongly absorbed on to the surface of soils and hence the availability of Zn to plants is reduced. That is, an increase in soil pH decreases zinc availability for plants uptake. On the other hand, the lowering of soil pH (acidification) increased the concentration of zinc available to plants. Over the soil pH range of 5.5 to 7.0, the zinc concentration in plants may decrease by 3 to 4 times for each one-unit increase in soil pH. High pH also causes the metal to hydrolyze to the hydroxyl species (MOH+), which are absorbed more strongly by the soil. Ammonium based fertilizers may increase zinc uptake by decreasing soil pH (Brennan, 2005).

2.8.3 Organic matter content

High organic matter content in the soil can contribute to crop zinc deficiency as Zinc can bind organic compounds that are inaccessible for plant uptake, making zinc less accessible for plant roots uptake (Gyimah, 2012).

Organic carbon can bind significant amounts of metals, especially copper, which has a high affinity to the types of functional groups associated with organic compounds. Organic carbon at a greater pH than lower pH values is more soluble (Gyimah, 2012).

2.9 Method of zinc application and deficiency symptoms

Zinc is a very important micronutrient that is linked with the enzyme activities and other biochemical activities of the plant. Marschner (1986), found out that zinc deficiency in the soil could cause many disorders that include, shortening of plant internodes, interveinal leaf chlorosis, the death of growing points, and the built-up of tiny distorted leaves. Blaylock (1995) emphasized that the deficiency of zinc in navy beans delayed pod maturity. The presence of signs differs with ecological conditions, age of the crop, severity and deficiency phase, as well as the availability of other nutrients, according to Brennan (2005). According to Slaton *et al*. (2001), Zinc deficiency can be corrected in four different ways which include, its application to the soil directly, foliar application method or applications to the vegetative parts; coating of the seed into zinc fertilizer also known as a seed dressing, dipping of seedlings into zinc solutions and many other methods Influence of zinc application on rice.

2.9.1 Influence of zinc on rice growth parameters

Hussain *et al*. (2005) in their research found out that highest plant height (123 cm) and panicle length (24.4 cm) was meaningfully obtained at the application of zinc in combination with boron and molybdenum, whereas the lowest plant height and panicle length was obtained from the control plot which did not receive any zinc application.

More so, Khan and Qasim (2007) concluded in their findings that, increasing the concentration of zinc in the soil effectively have an impact on rice crop. They found out that the application of zinc at 10 kg/ha meaningfully increased plant height to about 74.38 cm and an increment in effective tillers to about 17.4 with the lowest plant height recorded in the control plot. As a result, increment in growth parameters could be attributed to the sufficient supply of zinc that might have improved the availability and uptake of other important nutrients leading to the improvement in the growth and development of the rice plant.

The application of zinc at 5 mg/kg also gave maximum dry matter 2.98 g/pot at tillering and (40.93 g/pot) at the emergence of the panicle and this was about 44 to 60% greater in comparison to the control plot. (Muthukumararaja and Sriramachandrasekharan, 2012).

While the least tillers /plant (10), plant height (60.1 cm) and plant dry matter (41.1 g/plant) was recorded in the control plot which received no zinc application, on the contrary, there was an increment in plant height (68.2 cm), tillers/plant (17) and plant dry matter (50.1 g/plant) when 0.5 zinc sulfate was sprayed at panicle initiation, booting and one and two weeks after flowering as reported by Boochuay *et al*. (2013).

Also, according to Kabeya and Shakar (2013), the application of 30 kg $ZnSO_4$ gave the highest plant height (125 cm) SPAD value (57) in rice highest straw dry matter (28 g) with the least number recorded in the control.

2.9.2 Influence of zinc on nutrient uptake and in the soil

The application of zinc in the soil significantly increased its content in the soil over the control treatment. Concentrations increased from 0.89 to 1.53 mg Zn/kg at tillering and then also increased from 0.69 to 1.45 mg Zn/kg at panicle initiation and then 0.66 to 1.24 mg Zn/kg at harvest. Linear regression analysis showed that DTPA-zinc at tillering, panicle initiation and harvest recorded 98.31, 96.34 and 93.12% indicating the essentiality and adequacy of available of DTPA-zinc at the early stages of rice development (Muthukumararaja and Sriramachandrasekharan 2012).

2.9.3 Influence of zinc on rice quality parameters

The application of zinc at different rates to the soil significantly improved its concentration and uptake in rice and straw. However, the application of zinc at 7.5 mg Zn/kg gave the highest uptake and concentration in rice grain. The concentration of zinc in the rice grain ranged from 22.36 to 46.57 ppm while that of straw ranged from 19.74 to 43.95 ppm as a result of the application of zinc to the soil. An increase in the concentration of zinc in the rice grain straw might be due to the application of zinc to the soil thereby increasing its absorption and uptake by the plant (Muthukumararaja, 2012).

2.10 Sulfur nutrition in rice

Sulfur is known to be one of the most important and beneficial nutrients responsible for increasing the productivity of rice. Even though it the fourth most important plant nutrient after NPK, it also the third widely deficient plant nutrient. It is an essential component of protein and the synthesis of protein and responsible for the synthesis of certain amino acids like methionine, cysteine, and other plant hormones like thiamine and biotin. However, rice cultivated in waterlogged and lowland fields is known to be prone to sulfur deficiency.

Plants absorb sulfur in the sulfate ion (SO_4^{2-}). The requirement of sulfur for optimum plant growth and development ranges between 0.1 and 0.5% on a dry weight basis of plants and its relative requirement increases in the order of graminae <leguminoceae <cruciferae *(*Kumar *et al*., 2018).

Sulfur deficiency in the soil can be corrected by the application of sulfur fertilizers, which include, gypsum, ammonium sulfate, sodium sulfate, and many others. Even though the addition of these fertilizers seem to have a positive impact on crop growth, it has also been found by Yoshida and Chaudhry (1979), that tap water or irrigation water could also be a good and a highly available source of sulfur when supplied to the soil than sulfur supplied by fertilizers. This is because fertilizers are normally applied as basal dressing making them subject to reduction from the day of application than irrigation supplied tap water which is supplied to the plants almost daily and hence making it application less subject to reduction. They concluded that tap water supplies sulfur more than two times greater than the soil. And hence stressing the importance of irrigation water as a source of sulfur to the soil. Most soil sulfur is contained in soil organic matter and becomes available to plants when organic matter decomposes. Also sulfur is also vulnerable to leaching just like nitrogen. Plant available sulfur does not stick around or in the soil for a long time. This can either be taken up plants or leaches below the root zone, however the application of about 20 to 40 pound of sulfur can correct sulfur deficiency in the soils (Jim *et al*,2011). The application of sulfur at 100% NPK + 125% Sulfur through single superphosphate (SSP) greatly improved all growth parameters like plant height, tillers, panicle count as well as affecting and giving high grain and straw yield of 48.87 and 72.28 kg/ha respectively(Kumar *et al*., 2018).

Kineber *et al.* (2004), El-Eweddy *et al.* (2005) and Mazhar *et al.* (2011) also found that the application of sulfur significantly improved rice growth parameters.

2.11 Relationship and interaction between zinc and sulfur use efficiency

A synergistic or antagonistic outcome might be a result of an interactive effect between plant nutrients in the soil, and these might have an influence on the nutrient use efficiency of the plant. Fageria (2014) mentioned that interactions can occur when the supply of one nutrient affects the absorption and utilization of another nutrient. He also stated that nutrient interaction can affect plant growth and development when the supply of a determined nutrient is too low as compared to the applied ones. That is yield may only decrease when the supply of certain nutrients falls below the critical level. That is if the soil growth medium has an adequate supply of other essential nutrients compared to the added ones, plant growth may not be adversely affected even though the uptake of some nutrients may decrease. Nutrient interaction is known to be one of the important factors that affect the yield of annual crops (Fageria, 2014).

Sulfur is a nutrient that is known to interact with all other nutrients in the soil, that is micro, macro and secondary nutrients. Adequate level of sulfur in the soil enhances the uptake of nitrogen in the soil, while insufficient level of sulfur in the soil reduces nitrogen uptake (Fernando *et al*., 2009).Overall low plant Sulfur concentration values and striking response to Sulfur application strongly suggested that S deficiency primarily inhibites the efficient use of the indigenous and external supply of N for rice dry matter production (Tsujimoto *et al*., 2013). As S and N are both vital components of proteins, a balanced supply of these elements is important for efficient dry matter production (Tsujimoto *et al*., 2013)

2.12 Influence of sulfur and zinc on growth and yield of rice

Singh *et al*.(2017) reported that the application of sulfur and zinc micro nutrients significantly increased all growth and yield parameters of rice.

Dixit *et al.*(2012) worked on the topic, effect of sulfur and zinc on yield quality and nutrient uptake of hybrid rice in sodic soils. They used four levels of sulfur (0, 20, 40, 60 kg/ha) and four levels of zinc (0, 5, 10, 15 kg/ha) with NPK level at 150 kg/ha of urea, 60 kg/ha of Diammonium Phosphate (DAP), 40 kg/ha of Muriate of potash (MOP). They found that the application of 40 kg Sulfur per ha recorded significantly high grain and straw yield, protein content and S uptake. Similar positive response of hybrid rice to Zn application -1 was also noticed significantly up to the Zn dose at 10 kg/ha . Increasing doses of S and Zn enhanced significantly their uptake by hybrid rice crop. 40 kg/ha of sulfur in combination with 10 kg/ha of zinc gave the highest grain and straw yield, protein content and sulfur uptake.

Singh *et al.* (2013) worked on the topic, effect of sulfur and zinc management on yield, nutrient uptake, changes in fertility and economics in rice. Four levels of sulfur (0, 20, 30, 40 kg/ha) and four levels of zinc (0, 4, 5, 6 kg/ha) were used in their experiment. Their finding showed that 30 kg/ha of sulfur in combination with 6 kg/ha of zinc gave the maximum grain yield of about 7.72 tonnes/ha and high lentil yield. Highest nitrogen uptake was recorded in 6 kg of zinc while that of highest phosphorous and potassium uptake was recorded in 40 kg S/ha application.

Singh *et al.* (2017) researched on response of zinc and sulfur on growth and yield of rice (*0ryza sativa* l.) under sodic soil; four levels of sulfur (0, 15, 30, 45 kg/ha) and four levels of zinc (0, 5, 10, 15 kg/ha). 45 kg/ha of sulfur in combination with 10 kg /ha of zinc gave the best yield. Their results showed that yield attribute and yield of rice were increased significantly under 15 kg Zn/ha. Number of shoot per hill, plant height (cm), dry matter accumulation, yield attributes, grain and straw yield per ha of rice crop were increased significantly with sulfur applied at 45 kg S/ha

Rahman *et a*l. (2008) researched on the topic; effect of sulfur and zinc on growth, yield and nutrient uptake of BORO rice (2008). Three levels of sulfur (0, 10, 20 kg/ha) with three levels of zinc (0, 1.5, 3 kg/ha). 20 kg/ha of sulfur in combination with 3 kg/ha of zinc gave the best parameters of rice. They found that the highest grain (5.76 t/ha) and straw (7.32 t/ha) yields were recorded in sulfur at 20 and zinc at 3 kg/ha. Lowest grain yield (4.35 t/ha) were recorded in the control. The combined application of sulfur and zinc also increased sulfur and zinc contents as well as their uptake over the control

Kumar *et al.*, (2017) worked on the topic, response of sulfur and zinc on yield nutrients contents and quality of rice. Three levels of sulfur (0, 30, 60 kg/ha) and three levels of zinc (0, 3, 5 kg/ha). 60 kg/ha of sulfur with 5 kg/ha of zinc gave the best grain and straw yield. The application of sulfur up to 60 kg/ha increased sulfur and zinc content in grain and straw.

Waikhom *et al*. (2018).worked on the topic, effects of sulfur and zinc on yield attributes, yield and economics of rice. Four levels of sulfur (0, 15, 20, 25 kg/ha) and four levels of zinc (0, 5, 10, 15 kg/ha). They reported that the highest number of effective tillers, filled grains per panicle, grain yield, straw yield and harvest index was recorded in 20 kg S/ha and 15 kg Zn/ha.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of sites of the sampled soils

Soils were sampled within Walewale in the West Mamprusi district of north east region in Ghana. This area is located between longitudes 0° 35’ W and 1°45’W and latitude 9° 55’ N and 10° 35’ and found within the central northernmost part of the northern region. It has an undulating topography that is generally characterized by gentle slopes from the northeast to the southeast with some isolated visible outcrop and uplands of not more than 10% slope.

It has a similar climate to that of the northern region. This area is characterized by prolonged dry season and very short wet season. The wet or rainy season occurs from May to October, with an annual rainfall of 950 to 1200 m (WMDA, 2003).

Soils found within this area are usually the alluvial type that is savannah gleysols in the major valleys and drainage courses, and predominantly in the west of the districts along the basins of the White Volta. The soils are deep fine-textured and suitable for the cultivation of wide range of crops and suitable for mechanized farming (WMDA, 2003).

The vegetation of this area is characterized by the guinea savannah woodland which includes short trees, grasses, and shrubs. The soils are susceptible to waterlogged conditions during the rainy seasons.

Fallowed land located within the Wungu Township was scouted on the 23/03/19. This land according to history had not been cultivated before. Reports of nearby farmers indicated that the field becomes waterlogged during the rainy season, hence making it difficult for the cultivation of any other crop. Farmers tried cultivating maize on an allocated portion of the field during the 2018 cropping season but it was quite unfortunate the maize was overtaken by water during the rainy season though the plants showed good growth signs at the early stages. The field from observation was covered with shrubs that were scattered, had dark soil color, and contained observable quantities of plant debris.

Continuously cropped field: this field was located within the Kukobila Township. It was scouted on the 13/04/2019. Rice has solely been cultivated on this field for the past 10 to 15 years with the continual application of NPK fertilizer. The soil color looked greyish and contain observable quantities of stones.

3.2 Description of experimental site

The trial was conducted from July to November during the 2019 cropping season at USAID feed the future technology park of the Savannah Agricultural Research Institute (SARI), Nyankpala in the Northern Region of Ghana. Geographically, the experimental site is located 16 kilometers west of Tamale at a latitude of 09° 25" and longitude 01° 00" and an altitude of 183 meters above sea level. It has a flat land surface.

This area experiences a unimodal rainfall pattern of about 1000 mm annually (SARI, 2013). 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.

3.3 Collection of soil samples and physico- chemical analysis

Using the soil auger, both (Fallowed and Continuously cropped) soils were sampled using the zigzag method at a depth of 20 cm before planting to determine the soil bulk density and other soil physicochemical properties. Collected samples were oven-dried, crushed and sieved through a 2 mm sieve in order to obtain even particles for the determination of the nutritional status of the soil as well as the physical properties.

Plate 1: Soil sampling techniques with auger and shovel

3.3.1 Soil bulk density determination

Soil bulk density was determined using the Fox and Hanify (1959) method. Core samples were used to pick up the soil samples from the fields. Soil samples within the core samplers were pushed out into smaller basins and oven-dried at 105 ˚C for 48 hours. The weight of the oven-dried samples was taken and recorded. The volume of the core sampler was calculated by taking both the diameter (5.5 cm) and height (4 cm), by using the formula

Volume of cylinder = $\pi r^2 h$……………………………………….Equation 1

Where π = 3.142

R= radius

H= height of cylinder

The calculated volume for the core sampler was 95.05 cm^3. Bulk density of the soil was calculated using the formula:

Bulk density = $\frac{weight\ of\ oven\ dried\ soil}{volume\ of\ core\ sampler}$ ………………………….Equation. 2

Plate 2: Bulk density determination in the laboratory

3.3.2 Determination of soil pH

The pH of the soil was determined using the method by Lierop and Mackenzie (1977).The apparatus used in determining the pH included pH meter, glass electrode, 50 ml beakers, stirring rod, spatula and distilled water.

The soil pH was determined in the ratio of 1:2.5 (soil: water) in deionized water. 10 g of air-dried soil was weighed and kept into a 50 ml beaker. 25 ml of the deionized water was added to the soil in the beaker. The suspension was then being stirred vigorously for about 20 minutes and later allowed to stand for about 30 minutes where most of the clay particles had settled down the suspension. pH meter was calibrated with two standardized solutions at 4 and 7 respectively. The electrode of the pH meter was then inserted into a partially settled solution. The pH values were then read and recorded.

3.3.3 Determination of total organic carbon (C)

The total organic carbon was determined using the method by Apel *et al*.,(1998) 2.0 g of fine air-dried soil sample was weighed into a 250 ml Erlenmeyer flask. 10 ml of 1.0 N potassium dichromate was then added to the solution followed by 20 ml of concentrated sulfuric acid. The mixture was then swirled to ensure that the solution was in contact with all the soil particles. The flask content was then allowed to cool on an asbestos sheet for about 30 minutes. 100 ml of distilled water and 10 ml of orthophosphoric acid was then added to the solution. 2 to 3 drops of diphenylamine indicator was then added and titrated with 1.0 N ferrous sulfate solution until the color changed to blue and then to green as the endpoint. The titre value was then recorded and corrected for the blank solution.

3.3.4 Determination of total nitrogen

Total nitrogen was determined using the Kjeldahl method which has been used by other researchers including Vinoth *et al*. (2015). A known weight of the soil sample was poured into a digestion flask followed by the addition of 5 ml of Kjeldahl digestion mixture (concentrated sulfuric acid with selenium as catalyst). The soil was then digested in the mixture by heating at 360 to 410℃ until the mixture became clear and colorless. The flask was allowed to cool and then the mixture was totally transferred into 100 ml volumetric flask and then topped up with distilled water. 20 ml of the aliquot was then transferred into the Kjeldahl distillation apparatus and then 20 ml of 40% NaOH was added. 75 ml of distillate was then collected over 10 ml of 4% Boric acid in a 100 ml conical flask. The collected distillate was titrated with 0.1 N HCl till light green color changed to pink. N value was then calculated using the formula:

Weight of Nitrogeninhesoil = $\frac{14*(A-B)*C}{1000}$……………………………Equation. 3

Where A = $volume\ of\ standard\ Hcl\ used\ in\ sample$

B = $volume\ of\ standard\ Hcl\ used\ in\ blank\ titration$

C = $normality\ of\ standard\ Hcl$

3.3.5 Determination of available phosphorous

Available phosphorus of the soil was determined using the method of Watanabe and Olsen (1965). Available phosphorus was determined by weighing 5 g of the air-dried soil into shaking bottles followed by the addition of 35 ml of BRAY 1 solution (0.025 normal HCl and 0.03 normal NH_4F) and then shaken on a mechanical shaker for about 8 minutes at 3000 rpm and filtered using the Whatman No. 42 filter paper to obtain a clear solution. 1 ml of the standard solution was then pipetted into a set of clean test tubes and topped up with distilled water and mixed thoroughly. 2 ml of blue color reagent and 1 ml of ascorbic acid was then added to the mixture and mixed well. Using a visible range UV/VIS spectrophotometer the color was measured at 650 nm after six minutes. Absorbance versus P concentration (ppm) was plotted and then unknown samples were read, while ppm p was obtained by interpolation on the graph plotted.

3.3.6 Determination of exchangeable cations (calcium, magnesium, potassium)

Exchangeable cations were determined using the procedure adopted by Gill man (1979). 5 g of 2 mm sieved air-dried soil was weighed into a 100 ml shaking bottle. 50 ml of 1.0 ammonium acetate solution was then added to it and cocked and shaken on a mechanical shaker for 2 hours. The shaken mixture was then filtered using the Whatman N0. 42 paper to obtain a clean and clear filtrate. Potassium from the filtrate was then measured using the flame photometer. Calcium and magnesium were measured from the filtrate using the atomic absorption spectrophotometer.

3.3.7 Determination of particle size distribution

The particle size distribution of the soil was determined by the modified Bouyoucous hydrometer method described by Day (1965). 51 g of air-dried soil was weighed and transferred into a 250 ml beaker. 50 ml of prepared calgon solution and 100 ml of distilled water were then dispensed into the soil and shaken on a mechanical shaker overnight to soak and disperse soil particles, the mixture was then transferred into a sedimentation cylinder and topped up with 1-liter deionized water. A blank of sodium hexametaphosphate was then made and treated similarly as the sample. The particle sizes were then measured by, placing the cylinders on a flat surface. A hydrometer was immediately placed into the suspension and slid slowly into the suspension until it was floating. The first reading on the hydrometer was taken at 40 seconds after the cylinder was set down (H1). The hydrometer was then removed and the temperature of the suspension taken with a thermometer (T1 in˚C). The next hydrometer reading was taken after 5 hours (H2) and then the temperature taken in that order (T2 in˚C). Particle size distribution was then calculated by using the information in Table 1 as:

Table 1: Calculation for particle size

H1a	T2	B	C	% Sand	D	E	F	%Clay	G	% Silt
H1H1	T1	T1-68X0.2	a+b2	100-(2Xc)	H2	T1-68X 0.2	D-2	F+Ex2	sand+ clay	100-G

Where,

H1 = average of the first two hydrometer readings

T1 = average of the first two of the temperature readings (˚C)

H2 = second temperature reading

T2 = second temperature reading (˚C)

The texture class was obtained using the textural triangle.

3.3.8 Available sulphur

Available S was determined using the Barium sulfate precipitation method by Singh, Chhonkar and Pandey (1999). 20 g of soil sample was weighed in a 250-ml conical flask. Followed by the addition 100 ml of monocalcium phosphate extracting solution (500 mg P/litre) and shaken for 1 hour and filtered through No. 42 filter paper.10 ml of the clear filtrate is then kept in a 25-ml volumetric flask followed by the addition of 2.5 ml of 25 percent HNO3 and 2 ml of acetic-phosphoric acid. About 22 ml of the solution is then diluted, stoppered in the flask and shaken well. The suspension is then allowed to stand for 15 minutes followed by the addition of 1 ml of gum acacia-acetic acid solution up to a volume of 25 ml, and then inverted and set aside for 90 minutes. Invertion is repeated for about 10 times followed by the measurement of the turbidity at 440 nm.

3.3.9 Available Zinc

Available zinc was determined using the Diethylenetriamine pentaacetic acid (DTPA) extraction method by (Lindsay and Norvell, 1978).

3.4 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 2). The experiment involved three factors with different levels. Soil 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.

3.5 Rice variety and source

5 kg of AGRA rice was obtained from the rice improvement program of the CSIR-Savannah Agricultural Research Institute (SARI).

3.6 Source of treatment and application

Sulfur fertilizer was obtained in the form of sodium sulfate (Na_2SO_4) from a research center in Japan. Zn fertilizer was obtained in the form of zinc oxide (ZnO) from Fregesco limited located at Tip- Toe junction, new town road Kokomlemle in the greater Accra region (Table 2).

Table 2: 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 Ghanain the year 2020

Treatment code	Fallowed land (Kg/ha)	Cropped land (kg/ha)	Description (kg/ha)
T1	Zn0S0	Zn0S0	control
T2	Zn0S10	Zn0S10	Zinc at 0+sulfur at 10
T3	Zn0S20	Zn0S20	Zinc at 0+sulfur at 20
T4	Zn0S30	Zn0S30	Zinc at 0+sulfur at 30
T5	Zn4S0	Zn4S0	Zinc at 4+sulfur at 0
T6	Zn4S10	Zn4S10	Zinc at 4+sulfur at 10
T7	Zn4S20	Zn4S20	Zinc at 4+sulfur at 20
T8	Zn4S30	Zn4S30	Zinc at 4+sulfur at 30
T9	Zn8S0	Zn8S0	Zinc at 8+sulfur at 0
T10	Zn8S10	Zn8S10	Zinc at 8+sulfur at 10
T11	Zn8S20	Zn8S20	Zinc at 8+sulfur at 20
T12	Zn8S30	Zn8S30	Zinc at 8+sulfur at 30
T13	Zn12S0	Zn12S0	Zinc at 12+sulfur at 0
T14	Zn12S10	Zn12S10	Zinc at 12+sulfur at 10
T15	Zn12S20	Zn12S20	Zinc at 12+sulfur at 20
T16	Zn12S30	Zn12S30	Zinc at 12+sulfur at 30

Table 3: Summary of fertilizer calculations for fallowed and continuously cropped soil used for studying the influence of zinc and sulfur on growth and yield of AGRA rice in Northern Ghana in the year 2020

Fertilizer type	Calculated quantity per pot For fallowed soil	Calculated quantity per pot for cropped soil
NPK 15-15-15	0.5882 g	0.6667 g
Urea	0.3836 g	0.4347 g
TSP	0.1918 g	0.2174 g
Total		
Sulfur at 10kg/ha	0.1303g	0.14769 g
20/ha	0.2606 g	0.2954 g
30 kg/ha	0.3909g	0.443g
Total		
Zinc at 4 kg /ha	0.0146 g	0.01659g
Zinc at 8 kg/ha	0.029286 g	0.03319 g
Zinc at 12kg/ha	0.043929 g	0.049787 g

Find the detailed calculations for the experiment in appendix 1.

3.6.1 Mode of micronutrient application

Calculated quantities of both zinc in the form of zinc oxide and sulfur in the form of sodium sulfate for the fallowed and continuously cropped fields (Table 3) were weighed using an electronic sensitive scale. Weighed quantities of zinc oxide were directly applied to the soil before planting.

While that of weighed quantity of sodium sulfate was applied to the seedlings two days after transplanting into the pots. There were differences observed in the fertilizer calculations required for the two different soils. With that of the fallowed soil requiring a smaller amount of fertilizer than that of the continuously cropped soil (Table 3).

3.7 Preparation of the pot experiment

3.7.1 Preparation of pots for soil

Ninety six (96) pots were bought from the tamale market. Holes were perforated into each pot (one hole per pot) using an iron rod that had been inserted into fire for easy penetration. One hole was perforated because the rice crop is a water-loving plant. The two different soils were kept separately in the buckets.

3.7.2 Collection of soil samples

Using the pickaxe, shovel, and sacks, soil samples were dug at the center within the two different fields. On the 6th of April 2019, soil samples were dug from the fallowed field, while that of soil samples from the continuously cropped field were collected on the 13th of April 2019. Samples from the two fields were collected differently because of the bulkiness and for the purpose of ease of identification.

In the process of soil collection, an area of land of about 1 acre each was marked out on the two fields, then using the pickaxe and shovel, soil samples were dug and collected from near depth of 20-30 cm. Forty eight (48) different samples, weighing averagely 10 kg were collected from each of the fallowed field and the continuously cropped field, making a sum of 96 samples. Collected samples were conveyed from the Walewale district to the site of the experiment.

3.7.3 Preparation of soil for the pot experiment

The collected soil samples were sun-dried about 6 hours to obtain an even dryness within the samples. Using a sieve of 2 mm, sundried soil samples were sieved to obtain an equal texture and to get rid of other debris that could contribute to the weight.Using an electronic scale, 10 kg of the soil was weighed into the buckets respectively.

3.7.4 Layout and labeling of pots

Treatments were inscribed on papers onto the pots. The pots containing fallowed soils were then set up and separated from the pots containing the continuously cropped soil. Pots were arranged according to treatments and in replications. Each replication contained sixteen treatments. Three replications were used for all. A walking distance of about one meter was left between blocks and that of 0.5 m was left between pots to allow for ease of movements.

3.7.5 Nursery and transplanting

Seedlings were nursed differently for the two different soils using the respective soil type. A large volume of soils was fetched into two different pots. Continuously cropped soil was fetched into a different pot while that of the fallowed soil was fetched into another pot. The soils on the surface of the pot were leveled. Equal amounts of measured seeds were evenly distributed unto the surface of the leveled soil and covered with similar layer of soil. The nursed seeds were watered and then kept in the nursery. Nursing of seedlings was done on the 30th of July 2019.

Seedlings were transplanted three weeks later on the 20th of August 2019. One seedling per pot was transplanted.

3.8 Management practices

The management practices that were carried out during the research included:

3.8.1 Weeding

Using the hand hoe, weeds around the experimental site were cleared before the setup of the experiment and during the time the project was ongoing. Also, weeds that grew within the pots were removed with the hand to ensure neatness in the field.

3.8.2 Watering

As the experiment was under rain-fed conditions, the rain ceased at an early stage of the experiment. So watering was done to supplement rainfall. The plants were watered three times every week with 5 liters of pipe-borne water. This was necessary because the applied water tended to evaporate easily. The plants were watered from the 8th week of tillering until maturity.

3.8.3 Insect pest control

Nets were used to cover the whole rice field from the flowering stage to maturity to prevent the devastation caused by birds. This was done because birds were the major pests that could cause losses to the field.

3.8.4 Fertilizer application

The plants received 30 kg N/ha, 30 kg P/ha and 30 kg K/ha as basal application using NPK 15-15-15 fertilizer. In addition 30 kg P/ha was applied as basal using triple superphosphate (TSP). Urea fertilizer was used to top dress at a rate of 60 kg N/ha at heading and booting stage to give overall application rate as 90-60-30 Kg NPK/ha.

3.9 Collection of plant data

Plant data collected included, tiller number, panicle count, plant height, panicle length, filled and non-filled grain number per panicle, 1000 seed weight, grain yield, and straw yield.

3.9.1 Tiller number per plant

Tiller number per plant was determined by manually counting all the tillers formed by the plants at 4 weeks after transplanting (WATP), 8WATP and 12WATP.

3.9.2 Panicle count at maturity

Number of panicles formed by plants at maturity were manually counted and recorded for all treatments and replications.

3.9.3 Plant height at maturity

Plant height was determined using a tape measure, placed from the base of the plant to the tip of the longest panicle and recorded for all the treatments and replications.

3.9.4 Panicle length

Using a pair of scissors, panicles from all the treatments and their replication were harvested in order to record their length. The length was recorded by stretching the panicle on a 30 cm measuring rule from the last node to the tip of the last grain.

3.9.5 Percent filled and non-filled grain per panicle

Filled and matured grains from panicles were manually counted and recorded while that of empty and non-filled spikelets from the same panicles were also counted and recorded for all the treatments.

The percentage of filled grains was then determined using the formular;

$$\frac{filled\ grains}{total\ spikelets} * 100$$

3.9.6 1000-seed weight

1000 seeds from the harvested panicles were manually counted and weighed using a sensitive mass scale and recorded accordingly.

3.9.7 Grain yield

Panicle from the individual plants was harvested using a pair of scissors. Harvested panicles were threshed to remove grains from the panicles. Weight of grains was taken using an electronic scale.

3.9.8 Straw yield

Harvested straw from each plot were summed up and weighed using an electronic scale and recorded accordingly.

3.10 Data analysis

The data collected were subjected to analyses of variance (ANOVA) using the Genstat edition 12.1 statistical package. Multiple means of separation were done using the least significance difference at and 5% level.

CHAPTER FOUR

4.0 RESULTS

4.1 Description of the experimental soils

The soil from the continuously cropped field was observed to contain a lot of stones with few plant debris. This could be as a result of consistent ploughing and cultivation leading to high decomposition of organic matter, erosion and leaching activities. Soils of the fallowed field on the other hand contained a lot of plant debris with few stones. The continuously cropped soil was brownish in color, while that of the fallowed soil was darkish.

Plate 3: Fallowed soil **continuously cropped soil**

Initial soil analysis showed that both the cropped and fallowed soils were sandy loam in texture (Table 4). 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.

Table 4: Initial soil analysis at a depth of 0-20 cm for the fallowed and continuously cropped soil that were used to study the effect of zinc and sulfur on growth and yield of rice in Northern Ghana in the year 2020

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 Rhandawa and Takkar (1979) and Shukla *et al*. (2016). Sulfur critical level is as determined by Buri *et al*. (2000)

4.2 Tiller number at 8WATP

There was no three way interaction effect on tiller number at 8WATP, but there was a significant *($p < 0.05$)* two way interaction effect of sulfur application rate by land use type on tiller number at 8WATP (Table 5). Tiller numbers were highest at zero (0 kg/ha) rate of sulphure on the fallowed soil and lowest at 0 kg/ha rate of S on the cropped soil (Figure 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 Sulphur application rate.

Table 5: 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 the 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.

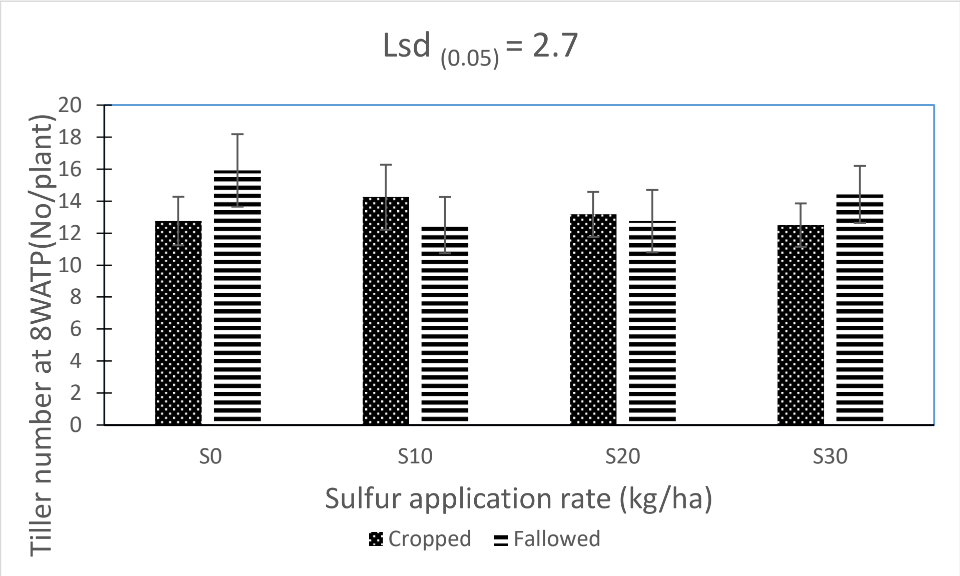


Figure 1: Interaction effect of land use type (fallowed and cropped) by sulfur application on tiller number of AGRA rice at 8WATP. Bars represent standard error of means (SEM). S0-control, S10-sulfur at 10 kg/ha, S20-Sulfur at 20 kg/ha, S30-sulfur at 30 kg/ha

4.3 Tiller number at 12WATP

There was no three way interaction effect and two way interaction effect of land use type, sulfur and zinc on tiller number at 12WATP, but rather Sulphur as a sole factor had significant effect on tiller number at 12WATP (Table 5). The maximum tiller number was recorded at 30 kg S/ha (Figure 2). The second highest tiller number was also 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 Sulphur application.

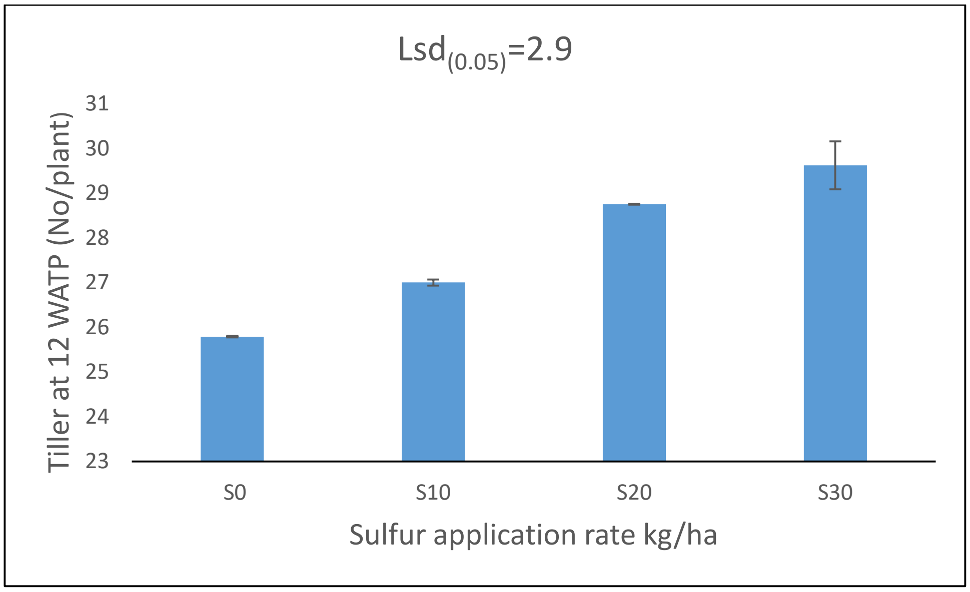
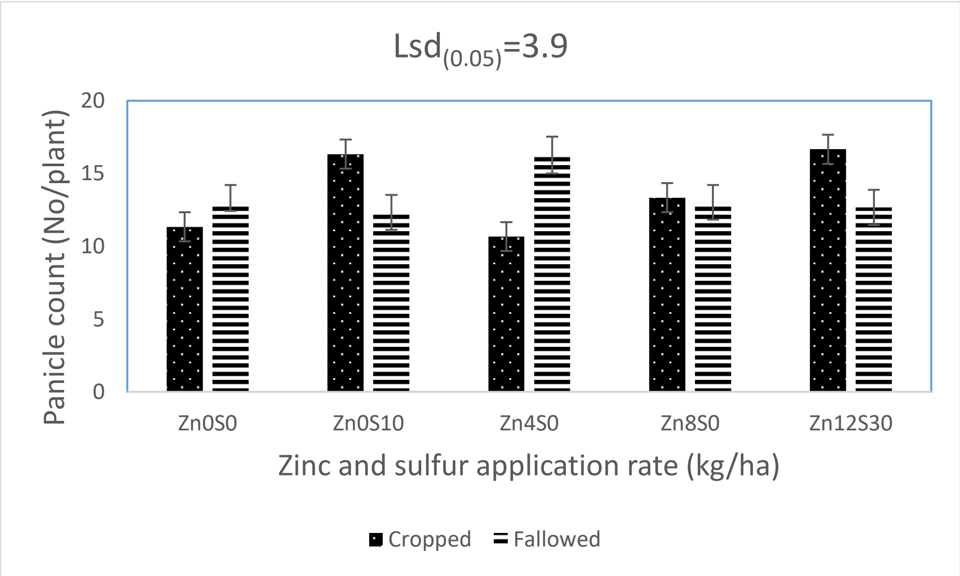


Figure 2: Effect of sulfur application rate on tiller number of AGRA rice at 12WATP. Bars represent (SEM). S0-control**, S10-**sulfur at 10 kg/ha**, S20-**Sulfur at 20 kg/ha**, S30-**sulfur at 30 kg/ha**.**

4.4 Panicle count

There was a three way interaction effect of sulfur and zinc by land use type on panicle number of AGRA rice (Table 5). Interaction of zinc and sulfur on the fallowed and continuously cropped land use types significantly (*p<0.05*) affected panicle count. The combined application of 12 kg Zn/ha and 30 kg S/ha on continuously cropped soil gave higher panicle number of 14. Similar results were obtained with 8 kg Zn/ha by 0 kgS/ha and 0 kg Zn/ha with 10 kg S/ha on the same soil (Figure 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 to the maximum of 18. The least number of panicles was recorded in the control plot for both land use types.

The interaction of zinc by sulfur on panicle count shows sixteen treatment effects; whose representation were not clear to read. The best five treatments have been selected and represented here to show the trend of response. However the whole graph is represented under neath as well



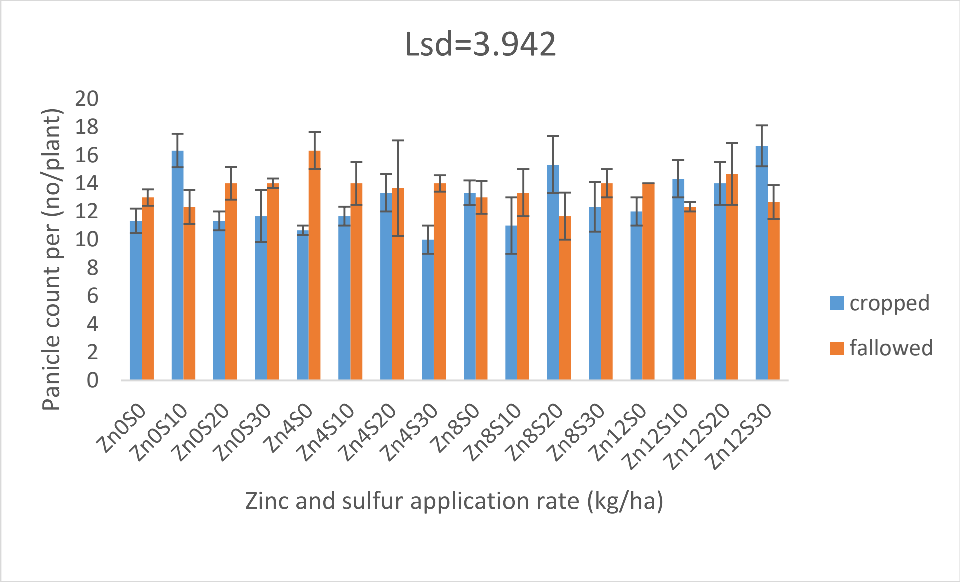


Figure 3: Interaction effect of zinc application rate, sulfur application rate and land-use type (continuously cropped and fallowed soils) on panicle count of AGRA rice cultivated in Northern Ghana during the 2019 cropping season. Bars represent (SEM). Zn0S0- control plot, **Zn0S10**- Zinc at 0 in combination 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.

4.5 Panicle length

There was no three way interaction effect of treatment factors on panicle length of AGRA rice, but rather there was a two way interaction effect of land use type by zinc application rate on panicle length (Table 5). There was also no one way significant effect of sulphur on panicle length. Interaction of land use type with zinc application rate significantly (*p<0.001*) 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 result recorded in 12 kg Zn/ha (25.5 cm) on the same soil (Figure 4). No zinc application or the control plot recorded the shortest panicle length (24 cm).

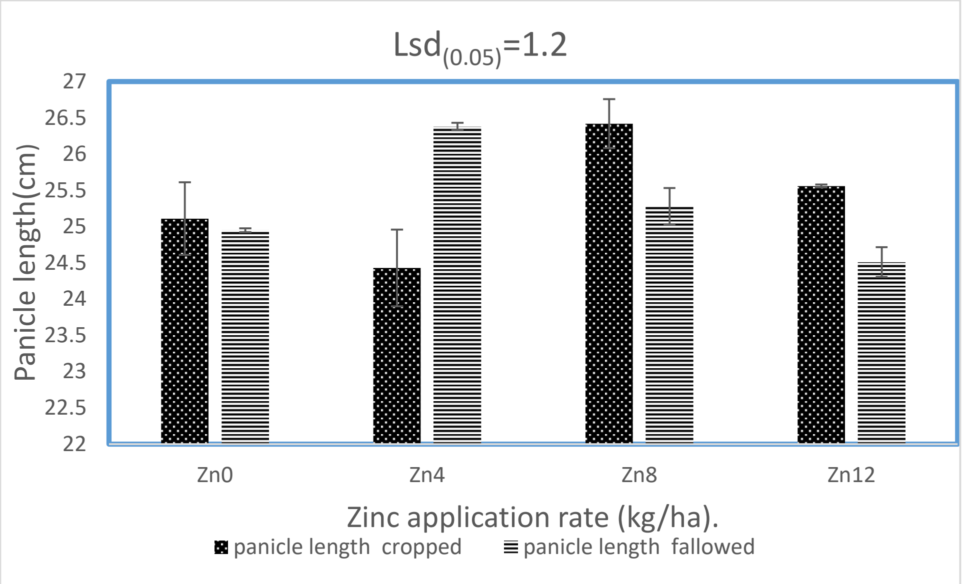


Figure 4: Interaction effect of zinc application rate and land use type (fallowed and continuously cropped soil) on panicle length of AGRA rice in northern Ghana during the 2019 cropping season. Bars represent (SEM). Zn0- control**, Zn4-**zinc at 4 kg/ha**, Zn8-**zinc at 8 kg/ha**, Zn12-**zinc at 12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

4.6 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 panicle length. Sulphur as a sole factor did not also significantly affect filled grain (Table 5). 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) (Figure 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).

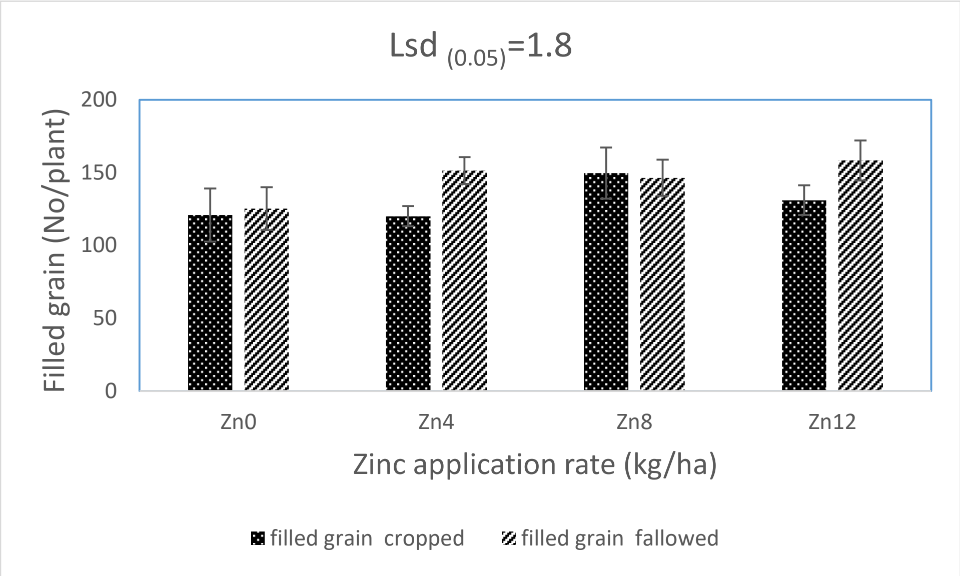


Figure 5: Interaction effect of zinc application rate and land use type (fallowed and continuously cropped soil) on filled grain of AGRA rice in northern Ghana during the 2019 cropping season. Bars represent standard error of means (SEM). Zn0- control**, Zn4-**zinc at 4 kg/ha**, Zn8-**zinc at 8 kg/ha**,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

4.7 Total spikelets

There was no three way interaction effect of treatment factors on total spikelets per panicle of AGRA rice. But rather there was a two way interaction effect of zinc by land use type on Total spikelets. Sulfur as a sole factor did not also significantly affect total spikelet number (Table 5). The interaction of land use with zinc application rate significantly (*p<0.050*) affected the total number of spikelets formed. Maximum spikelete number was recorded by the application rate of 12 kg Zn/ha for both land use types (Figure 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 spikelets were recorded by no zinc application in both land use forms.

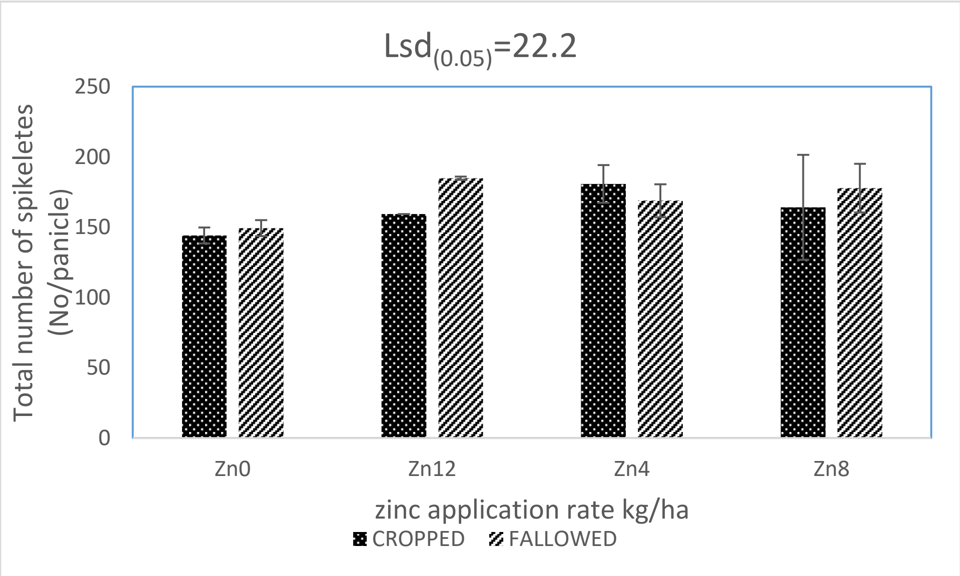
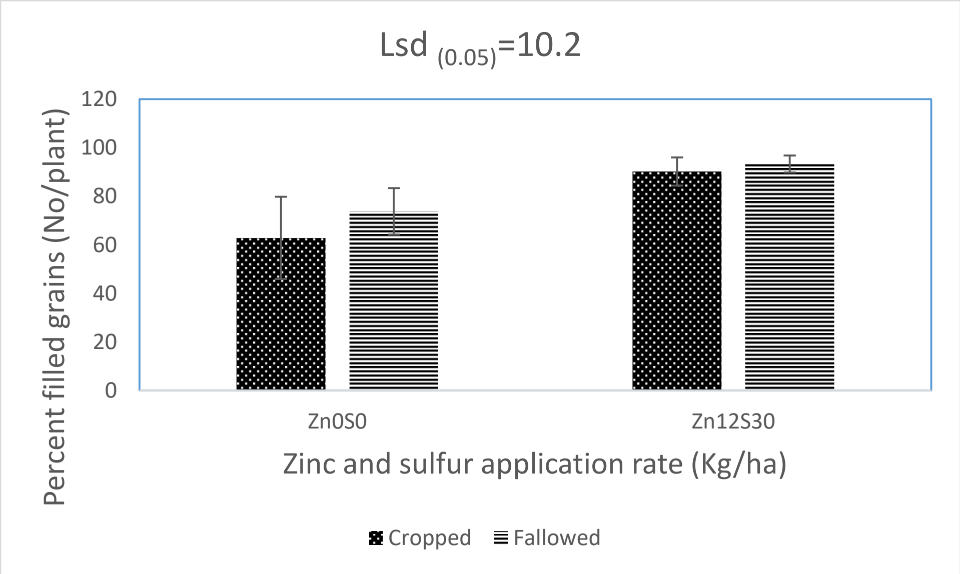


Figure 6: Interaction effect of zinc application rate and land use type (fallowed and continuously cropped soil) on total number of spikelet of AGRA rice in northern Ghana during the 2019 cropping season. Bars represent.(SEM). Zn0- control**, Zn4-**zinc at 4 kg/ha**, Zn8-**zinc at 8 kg/ha**, Zn12-**zinc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

4.8 Percent filled grain

There was three way interaction effect of treatments on percent filled grains of AGRA rice (Table 5). 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 grains (Figure 7). The control plot recorded the least number of percent filled grains (60% filled).

The interaction of zinc by sulfur on percent filled grains shows sixteen treatment effects; whose representation were not clear to read. The best two treatments were selected and represented here to show the trend of response. However the whole graph presentation is placed underneath.



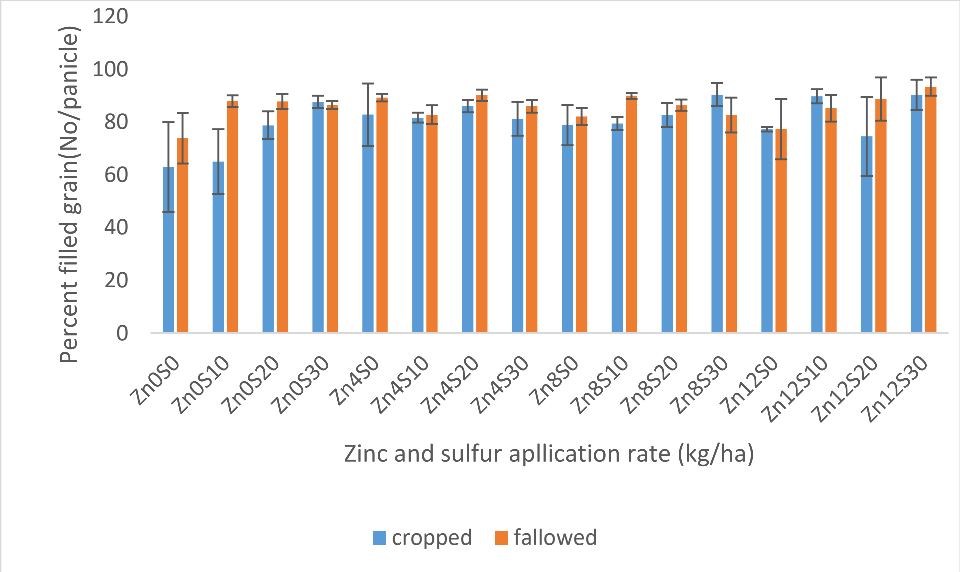


Figure 7: Interaction effect of zinc and sulfur by land use types (fallowed and continuoiusly cropped) on percent filled grains of AGRA rice. Bar represent (SEM).***Zn0S0***-*control*, ***Zn12S30***-*Zinc at 12k/ha with sulfur at 30kg/ha*

4.9 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 of AGRA rice (Table 5). The interaction of zinc and sulfur application rate significantly (*p<0.05)* affected the straw yield at harvest. The highest straw weight was recorded by 12 kg Zn/ha and 30 kg S/ha (80 g/pot) (Figure 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 5). The interaction of land use type by sulfur application also significantly (*p<0.001*) affected the weight of straw. Highest straw weight was recorded by 30 kg S/ha on fallowed and cropped soils (70 g/pot) (Figure 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).

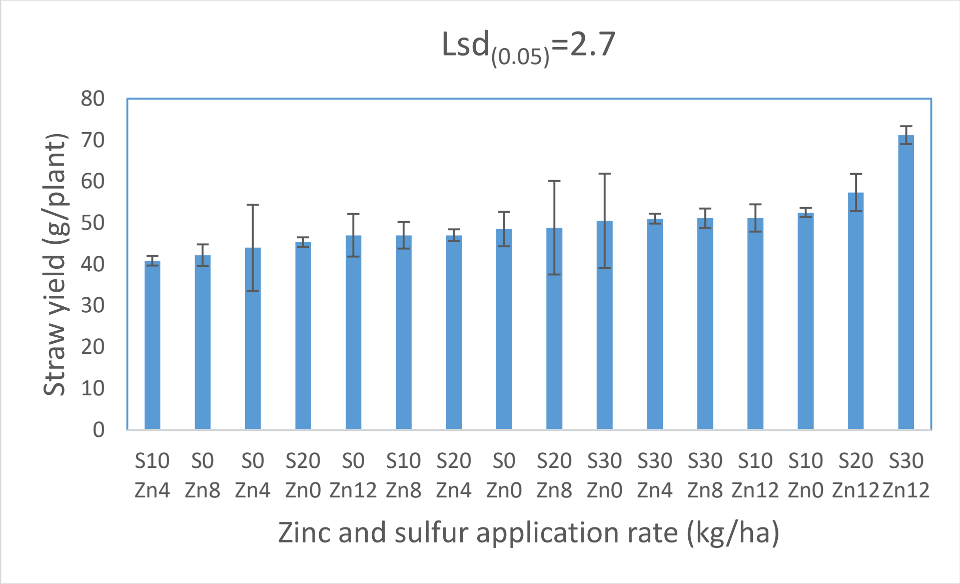


Figure 8:Interaction effect of zinc and sulfur application rate on straw weight of AGRA rice variety in northern Ghana. Bars represent SEM.

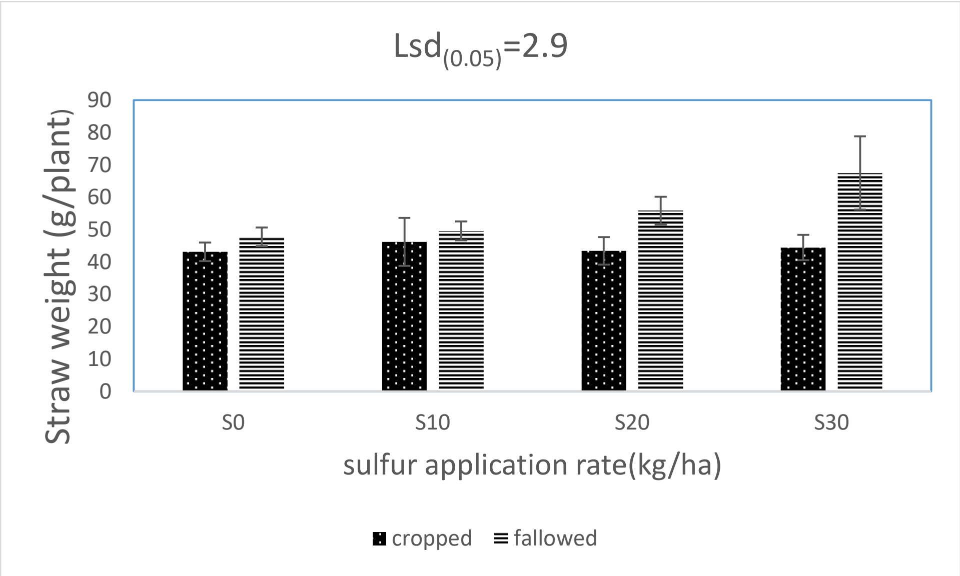


Figure 9: Interaction effect of sulfur application by land use type (fallowed and continuously cropped) on straw weight of AGRA rice variety in northern Ghana. Bars represent SEM.S0-control**, S10-**sulfur at 10 kg/ha**, S20-**Sulfur at 20 kg/ha**, S30-**sulfur at 30 kg/ha**.**

4.10 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 (Table 5). The interaction of zinc and sulfur applications significantly (*p<0.05*) affected grain yield. The combined application of 30 kg S/ha and 12 kg Zn/ha recorded the highest grain yield (60 g/pot) (Figure 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).

There was also a sole factor effect of land use type on grain yield of rice (Table 5). The main effect of land use (*p<0.05*) signifigcantly 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) (Figure 11).

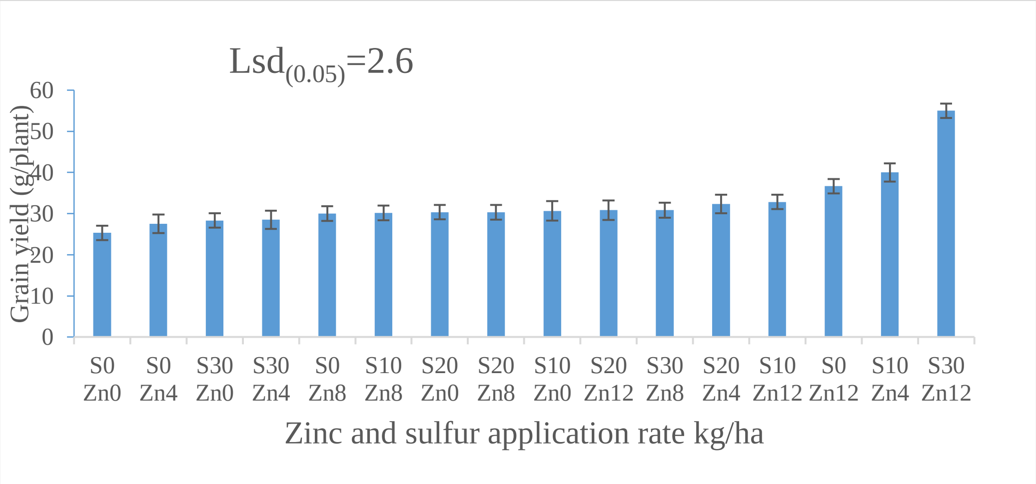


Figure 10: Interactive effect of zinc and sulfur application rate on grain yield of AGRA rice in Northern Ghana during the 2019 cropping season. Bars represent SEM.

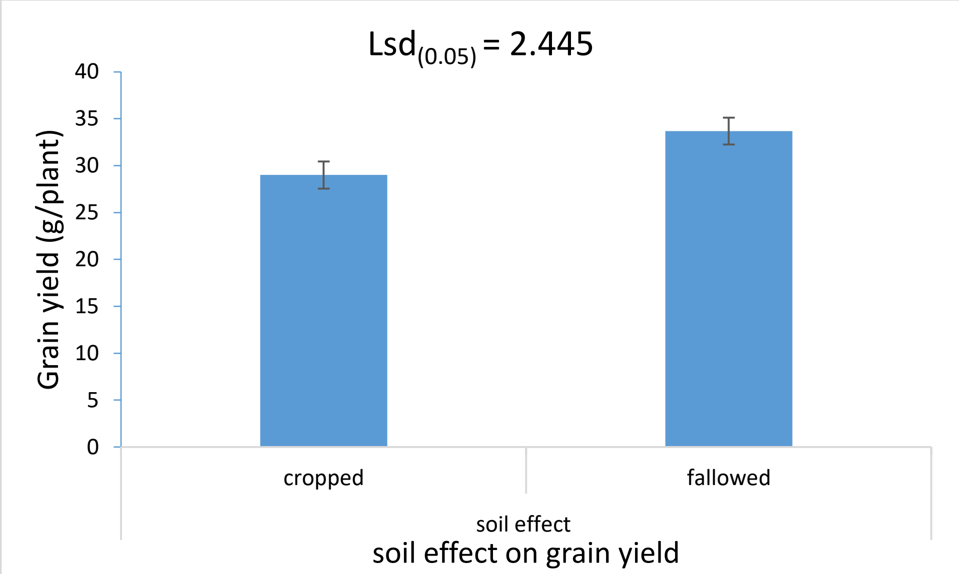


Figure 11: Effect of fallowed and cropped land use type on grain yield of AGRA rice in Northern Ghana during the 2019 cropping season. Bars represent SEM.

4.11 Plant height and thousand grain weight at harvest

There was neither three way, two way nor one way interactive effect of treatments on plant height and thousand grain weight at harvest (Table 6).

Table 6: Comparative performance of zinc and sulfur treatments on plant height and thousand seed weight of AGRA rice under fallowed and continuously cropped rice fields in Northern Ghana during the year 2020

	Treatments	Plant height (cm)	1000 seed weight (g)
Fallowed	control	96.00	13.33
Fallowed	Zinc at 0+sulfur at 10	96.67	21.67
Fallowed	Zinc at 0+sulfur at 20	94.33	20.00
Fallowed	Zinc at 0+sulfur at 30	95.67	23.33
Fallowed	Zinc at 4+sulfur at 0	96.00	16.67
Fallowed	Zinc at 4+sulfur at 10	99.33	25.00
Fallowed	Zinc at 4+sulfur at 20	96.00	21.67
Fallowed	Zinc at 4+sulfur at 30	94.33	21.67
Fallowed	Zinc at 8+sulfur at 0	91.67	23.33
Fallowed	Zinc at 8+sulfur at 10	95.67	25.00
Fallowed	Zinc at 8+sulfur at 20	95.33	23.33
Fallowed	Zinc at 8+sulfur at 30	100.33	21.67
Fallowed	Zinc at 12+sulfur at 0	101.67	25.00
Fallowed	Zinc at 12+sulfur at 10	99.67	25.00
Fallowed	Zinc at 12+sulfur at 20	98.33	23.33
Fallowed	Zinc at 12+sulfur at 30	98.33	21.67
Cropped	control	92.67	18.33
Cropped	Zinc at 0+sulfur at 10	93.33	21.67
Cropped	Zinc at 0+sulfur at 20	96.33	21.67
Cropped	Zinc at 0+sulfur at 30	99.67	23.33
Cropped	Zinc at 4+sulfur at 0	100.33	23.33
Cropped	Zinc at 4+sulfur at 10	94.33	26.67
Cropped	Zinc at 4+sulfur at 20	96.00	21.67
Cropped	Zinc at 4+sulfur at 30	99.67	21.67
Cropped	Zinc at 8+sulfur at 0	86.00	21.67
Cropped	Zinc at 8+sulfur at 10	94.00	20.00
Cropped	Zinc at 8+sulfur at 20	96.00	20.00
Cropped	Zinc at 8+sulfur at 30	95.33	20.00
Cropped	Zinc at 12+sulfur at 0	97.00	21.67
Cropped	Zinc at 12+sulfur at 10	95.00	20.00
Cropped	Zinc at 12+sulfur at 20	98.33	20.00
Cropped	Zinc at 12+sulfur at 30	96.67	23.33
% CV		**5.2**	**8.3**
P value		**0.701**	**0.836**
LSD 5%		**8.1**	**6.5**

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

The results on the correlation analysis between rice growth parameters are presented in (table 7). The results showed that, rice tiller after 8 weeks of planting was negatively associated with the height of the plant, pinnacle length as well as 1000 seed weight but positively correlated with panicle count, straw yield and 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 that 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 will relate in more weight per 1000 seeds.

Table 7: 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	Panicle count	Panicle Length	1000 seed weight	Straw yield	Yield
Tiller @8wap	1.00						
Height	-0.12	1.00					
Panicle count	0.42***	0.03	1.00				
Panicle Length	-0.19*	0.29***	0.01	1.00			
1000 seed weight	-0.26**	0.15	-0.14	0.29***	1.00		
Straw yield	0.21**	0.10	0.07	0.01	-0.04	1.00	
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

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Physico-chemical properties of soils from fallowed and continuously cropped soil

5.1.1 Soil pH

The observed mean soil pH of 5.92 and 6.87 for the cropped and fallowed lands respectively (Table 4), are within limits that are ideal for rice cultivation and comparable to the results of Li *et al*. (2016) and Tian *et al*. (2005). 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 (Li *et al*., 2014). Nitrogen inputs to the soil might exceed 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 (Li *et al*., 2010). These results are in line with other research works by Xu *et al*. (2009) 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 base (Choudery and Devi, 2013).

5.1.2 Bulk density

The observed bulk densities for the cropped and fallowed soils are 1500 kg/m^3 and 1700 kg/m^3 respectively (Table 4) and are good for rice cultivation as pointed out by Blanco-Canqui *et al*. (2011); Sridevi and Ramana (2016).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 confirms the findings of Halvorson *et al*. (1997) that the bulk density of a fallowed land is greater than the cropped land. Sridevi and Ramana (2016) found out in their research that, there was a reduction in soil bulk density of rice soil after continuous cultivation, which involved the application of 25 or 50% recommended dose of compound fertilizer and 50% N through the application of farmyard manure and paddy straw. Kumaraswamy and Vasanthi (1999) also stressed the benefit of incorporating organic matter to reduce soil bulk density.

5.1.3 Organic carbon

The organic carbon percentage of the fallowed land was higher than that of the continuously cropped land (Table 4). 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 (Lajtha *et al*., 2014). Soil organic matter is known to be a rich source of soil nutrients and is mostly found in the top soil. 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 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 (Talpur *et al.*, 2013)

5.1.4 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 1mg/kg) (Table 4). This could be due to the low Zn content of Ghanaian soils and consequently in crops that may require external Zn input for high crop productivity (Mikko Sillanpa 1978; Sadick *et al*., 2015). 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 and thereby making Zn less accessible for plant roots uptake (Gyimah, 2012). 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 (Buri *et al.*, 2000). 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 Randhawa and Takar (1975), and Shukla *et al*. (2016).

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 Buri *et al*. (2000). This confirmed the findings of Gordon *et al. (*1990) 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 (Jim *et al*., 2011).

5.1.5 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*. (2013) 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 cropping. Dobberman and Fairhurst (2000) reported 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*. (2019) also found out 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.

5.2 Tillering at 8 and 12WATP

The observed two-way (sulfur effect by land use type) interaction and one way (sole sulfur application) effect on tillering at 8 and 12 WATP (Table 5, Figure 1, Figure 2) is comparable to the findings of Kineber *et al.* (2004), El-Eweddy *et al.*(2005), Mazhar *et al.*(2011), Kumar *et al.*(2018) and Zayed *et al*. (2013). The findings are however in contrast to the findings of Wu *et al*. (1998) who reported that tillering in rice plant is determined by certain climatic factors like light, temperature, plant density, and nutrients. Wang and Li (2005) 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 but rather responded to adequate levels in the soil (Figure 1). This observation could be attributed to adequate sufficient amount of Sulphur for the initial vegetative growth. However, at the 12WATP, tiller number responded to additional amount 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 it's 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 and cropped soils respectively (table 4), 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 protein. 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.

Moreso, 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 (Sakakibara *et al*., 2006). The observed finding in this study is in line with the findings of Fernando *et al*. (2009) 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*. (2013) 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 (Tsujimoto *et al*., 2013) 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 (Ram *et al*., 2014; Waikhom *et al*., 2018).

5.3 Panicle count (No/plant)

The observed three way effect of treatments on panicle count (Table 5, Figure 3) are comparable to the findings of Waikhom *et al*. (2018). The increase in panicle number which contribute to economic yield could be attributed to the adequate supply of zinc and sulfur to the soil 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*. (2012). The application of sulfur also enhanced tillering which correlates directly with number of panicles formed (Table 7). This result agreed with the findings of Singh *et al*. (2012), who found out in their work that the application of zinc and sulfur improved or gave highest panicle number/plant.

5.4 Yield parameters

The observed improvement in yield parameters like panicle length, filled grain, total spikelets and percent filled grains (Figure 4, Figure 5, Figure 6 and Figure 7) in response to zinc application are comparable to the findings of Tabassum *et al*. (2013). They found that the yield attributes increased significantly with increasing levels of zinc over control (no zinc application).

Yield parameters of the rice plant are mainly components of the sink size (Li *et al*., 2018). Sink size is a component of the sink strength which is improved or determined by enzymatic activities within the sink tissue (Li *et al*., 2018). These enzymatic activities are known to control the photosynthate utilization in the sink size (Li *et al*., 2018). Once these enzymatic activities are improved, a greator 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 (Shukla and Behera, 2011). These functional qualities of zinc enables it to improve upon the enzymatic activities within the sink size, leading to the 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 (2009) and Yadi *et al*. (2012), 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 carbondioxide in the panicle (Abid *et al*., 2002 and Hafeez *et al*., 2013). As also explained by Hafeez *et al*. (2013) who found that the action of zinc activity reduces spikelet sterility, and increased total spikelets and panicle length. Khan and Qasim (2007) also observed a reduction in the number of filled grains per panicle at 0 kg Zn/ha compared to higher rates of application.

5.5 Straw yield

Straw yield increased in response to adequate supply of zinc and sulfur (figure 8) which is comparable to the findings of Kumar (2018). 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 was mainly due to enhanced rate of 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 nutrients uptake that eventually promote growth of the crop. These results were in close conformity with the finding of Liu *et al*. (2011). 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 the findings of Singh *et al*. (2017), 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 nutrients has not been mined hence contributing to the weight of straw. This confirms the findings of Willy *et al*. (2019) on the beneficial effects of fallowed land.

5.6 Grain yield

The grain yield was significantly increased with different levels of nutrients application (Figure 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 that is plot which received zero rate of Zn and zero rate of S (control). These findings are comparable to findings of Dixit *et al.* (2012); Singh *et al*. (2013); and Kumar *et al*. (2018).

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 (Mauriya *et al*., 2013; Li *et al*., 2018). 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 (Jim *et al*, 2011).

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 Singh *et al*. (2017) 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*. (2013) 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 (2000). However, Willy *et al*. (2019) emphasized on the grain yield beneficial effects of a fallowed soil.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

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.

6.2 Recommendation

From the research, it is recommended that

- For optimum growth and yield of the rice crop, 30 kg S/ha and 12 kg Zn/ha should be applied.
- Since the study was a pot experiment, recommendations to farmers cannot be based on these findings alone, as such it is recommended that field experiments be conducted to confirm the findings of the study.
- 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.

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APPENDICES

Appendix 2: Analysis of variance for tiller at 8WATP

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	2.44	1.22	0.12	0.266
REP*Units*stratum					
Soil	1	12.76	12.76	1.26	0.503
Sulfur	3	24.03	8.01	0.79	0.851
Zinc	3	8.03	2.68	0.26	0.040
Soil.Sulfur	3	88.86	29.62	2.93	0.126
Soil.Zinc	3	60.03	20.01	1.98	0.295
Sulfur.Zinc	9	111.68	12.41	1.23	0.948
Soil.Sulfur,Zinc	9	33.18	3.69	0.36	
Residual	62	626.90	10.11		
Total	95	967.91			

Appendix 3: Analysis of variance for tiller at 12WATP

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	44.77	22.39	0.94	
REP*Units*stratum					
Soil	1	70.04	70.04	2.95	0.091
Sulfur	3	213.75	71.25	3.00	0.037
Zinc	3	34.08	11.36	0.48	0.699
Soil.Sulfur	3	50.71	16.90	0.71	0.549
Soil.Zinc	3	49.04	16.35	0.69	0.563
Sulfur.Zinc	9	142.00	15.78	0.66	0.738
Soil.Sulfur,Zinc	9	273.54	30.39	1.28	0.267
Residual	62	1473.90	23.77		
Total	95	2351.83			

Appendix 4 : Analysis of variance for panicle count

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	16.188	8.094	1.42	
REP*Units*stratum					
Soil	1	8.167	8.167	1.42	0.237
Sulfur	3	6.833	2.278	0.40	0.756
Zinc	3	24.750	8.250	1.44	0.240
Soil.Sulfur	3	30.167	10.056	1.75	0.166
Soil.Zinc	3	51.00.83	17.028	2.97	0.039
Sulfur.Zinc	9	47.250	5.250	0.91	0.518
Soil.Sulfur,Zinc	9	108.250	12.028	2.10	0.043
Residual	62	355.812	5.739		
Total	95	648.500			

Appendix 5: Analysis of Variance for tiller number for panicle length

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	14.146	7.073	4.25	
REP*Units*stratum					
Soil	1	0.013	0.013	0.01	0.931
Sulfur	3	5.658	1.886	1.13	0.343
Zinc	3	9.719	3.240	1.94	0.132
Soil.Sulfur	3	7.219	2.406	1.44	0.238
Soil.Zinc	3	32.103	10.701	6.42	<.001
Sulfur.Zinc	9	8.225	0.914	0.55	0.833
Soil.Sulfur,Zinc	9	13.538	1.504	0.90	0.528
Residual	62	103.281	1.666		
Total	95	193.900			

Appendix 6: Analysis of variance for filled grain

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	3922	1961.3	4.37	
REP*Units*stratum					
Soil	1	5475.3	5475.3	12.20	<.001
Sulfur	3	2562.5	854.2	1.90	0.138
Zinc	3	9122.5	3040.8	6.78	<.001
Soil.Sulfur	3	2659.0	886.3	1.98	0.127
Soil.Zinc	3	5091.9	1697.3	3.78	0.015
Sulfur.Zinc	9	7019.5	779.9	1.74	0.099
Soil.Sulfur,Zinc	9	3496.3	388.5	0.87	0.560
Residual	62	27818.1	448.7		
Total	95	67167.7			

Appendix 7: Analysis of variance for total spikelets

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	6469.0	3234.5	15.99	
REP*Units*stratum					
Soil	1	1504.2	1504.2	7.43	0.112
Sulfur	3	938.6	312.9	0.54	0.655
Zinc	3	5313.1	1771.0	2.25	0.135
Soil.Sulfur	3	11454.4	3818.1	4.85	0.020
Soil.Zinc	3	3616.9	1205.6	2.09	0.114
Sulfur.Zinc	9	7291.5	810.2	1.41	0.212
Soil.Sulfur,Zinc	9	5095.8	566.2	0.98	0.466
Residual	62	27655.7	576.2		
Total	95	79193.8			

Appendix 8: Analysis of variance for Percent filled grain

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	13.48	6.74	0.21	
REP*Units*stratum					
Soil	1	570.39	570.39	17.74	0.052
Sulfur	3	413.48	137.83	3.44	0.024
Zinc	3	630.61	210.20	3.69	0.043
Soil.Sulfur	3	256.75	85.58	1.50	0.264
Soil.Zinc	3	193.22	64.41	1.61	0.200
Sulfur.Zinc	9	1137.98	126.44	3.15	0.005
Soil.Sulfur,Zinc	9	1594.18	177.13	4.42	<.001
Residual	62	1924.92	40.10		
Total	95	7482.72			

Appendix 9: Analysis of variance for straw yield (g)

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	130.75	65.38	0.98	
REP*Units*stratum					
Soil	1	2849.26	2849.26	42.72	<.001
Sulfur	3	1460.36	486.79	7.30	<.001
Zinc	3	1692.20	564.07	8.46	<.001
Soil.Sulfur	3	1473.53	491.18	7.36	<.001
Soil.Zinc	3	521.36	173.97	2,61	0.060
Sulfur.Zinc	9	1314.68	146.08	2.91	0.035
Soil.Sulfur,Zinc	9	760.01	84.45	1.27	0.273
Residual	62	4135.25	66.70		
Total	95	14337.41			

Appendix 10: Analysis of variance for grain yield

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	211.2	105.6	1.02	
REP*Units*stratum					
Soil	1	518.0	518.0	5.02	0.029
Sulfur	3	159.6	53.2	0.52	0.673
Zinc	3	418.2	139.4	1.35	0.266
Soil.Sulfur	3	166.9	55.6	0.54	0.657
Soil.Zinc	3	180.5	60.2	0.58	0.638
Sulfur.Zinc	9	1314.68	146.08	2.19	0.035
Soil.Sulfur,Zinc	9	1055.7	117,3	1.14	0.351
Residual	62	6392.1			
Total	95	9789.7			

Appendix 11: Analysis of variance for thousand grain weight

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	128.65	64.32	4.04	
REP*Units*stratum					
Soil	1	4.17	4.17	0.26	0.611
Sulfur	3	92.71	30.90	1.94	0.133
Zinc	3	63.54	21.18	1.33	0.273
Soil.Sulfur	3	47.92	15.97	1.00	0.398
Soil.Zinc	3	127.08	42.36	2.66	0.056
Sulfur.Zinc	9	226.04	25.12	1.58	0.142
Soil.Sulfur,Zinc	9	70.83	7.87	0.49	0.873
Residual	62	988.02	15.94		
Total	95	1748.96			

Appendix 12: Analysis of variance for plant height at harvest

Source of variation	d.f	s.s	m.s.	v.r	F pr.
REP stratum	2	77.58	38.79	1.57	
REP*Units*stratum					
Soil	1	7.04	7.04	0.28	0.596
Sulfur	3	160.92	53.64	2.27	0.101
Zinc	3	161.00	53.67	2.17	0.101
Soil.Sulfur	3	106.37	35.46	1.43	0.242
Soil.Zinc	3	104.46	34.36	1.34	0.249
Sulfur.Zinc	9	201.92	22.44	0.91	0.526
Soil.Sulfur,Zinc	9	157.46	17.50	0.71	0.701
Residual	62	1535.08	24.76		
Total	95	2511.83			

Appendix 12: Fertilizer calculations for influence of zinc and sulfur on growth and yield of AGRA rice under fallowed and continuously cropped fields in northern Ghana in the year 2020

<u>Calculating the mass of soil for 1 hectare of land for fallowed soil</u>

Calculated bulk density for fallowed land = 1.7 g/cm^{3} = 1700 kg/m^3

Plough depth = 20 cm = 0.2 m for rice crop

Volume of soil for 1 hectare of land = depth x area

= 0.2 m x 10000 m^2 = 2000 m^3

Bulk density = $\frac{mass}{volume}$

Mass of soil for 1 hectare of land

Mass = density x volume of soil

= 1700 kg/m^3 x 2000 m^3

= 3400000 kg

The mass of soil for a hectare of land on the fallowed soil = **3400000 kg**

NPK calculations for fallowed soils for the pot experiment

NPK 15 – 15 – 15 was applied at rates of 90 – 60 – 30 kg/ha

Quantity of soil per pot = 10 kg

Mass of soil for the fallowed land = 3400000 kg

For basal application

NPK was applied at 30 – 30 – 30 kg/ha

Quantity of fertilizer

$= \frac{rate}{grade} x100$

30/15 x 100

= 200 kg/ ha

If 200 kg of NPK fertilizer was to be applied to 1 hectare which has 3400000 kg of soil

Then quantity of fertilizer to apply to 10 kg of soil was estimated as

X = 200 x 10/ 3400000

X = 5.882 x 10^{-4} kg of NPK 15 – 15 – 15 per pot

= **0.5882 g of NPK 15 – 15- 15 per pot**

Calculating for remaining 60 kg of nitrogen

Using urea as a source of nitrogen

Urea = 46 % N

Quantity of fertilizer

60/46 x 100

130. 43 kg N for a hectare of land

If 130.43 of urea is to be applied to 3400000 kg of soil for a hectare

Then the quantity needed for 10 kg of soil per pot (X) is

X = 3.836 x 10^{-4} kg of urea per pot

X = 0.3836 g of urea per pot

Calculating remaining 30 kg of phosphorous using triple superphosphate

Tsp contains 46% of phosphorous as P_2O_5

Quantity of fertilizer per hectare

30/46 x 100

= 65. 22 kg of phosphorous for I hectare containing 3400000 kg of soil

Quantity of TSP needed for 10 kg of soil in a pot was

X= 1.9182×10^{-4} per pot

= 0.1918 g of p per pot

Micronutrient calculation for fallowed soil

Calculation for zinc on a fallowed land

Zinc was applied at rates of 0, 4, 8, 12, kg/ha to all pots

Zinc oxide (ZnO) was used as a source of zinc

% zinc in zinc oxide is 80.34

Quantity of soil for a hectare of fallowed land

= 3400000 kg

Quantity of zinc required

Zinc at 4 kg

4/80.34 x 100 = 4.978 kg for a hectare

For 10 kg of soil

If 4. 978 = 3400000

$X = 1.4641 \times 10^{-5}$ kg of zinc at 4 kg per pot

= 0.0146 g of ZnO at 4 kg/ha

Zinc at 8 kg per hectare

8/80.34 x 100 = 9.9571 kg to one hectare containing 3400000 kg of soil

For 10 kg of soil

$X = 2.9286 \times 10^{-5}$ kg of ZnO at 8 kg/ha

= 0.029286 g of ZnO

Zinc at 12 kg per hectare

12/80.34 x 100 = 14.936 kg/ha

14.936 = 3400000 kg of soil per hectare

$= 4.3929 \times 10^{-5}$ kg of ZnO 12 kg/ha

= 0.043929 g of ZnO

Calculation for sulfur on fallowed land

Source of sulfur will be sodium sulfate (Na_2SO_4)

It contains 22.57% sulfur

Sulfur will be applied at 0, 10, 20, 30 kg/ha

Quantity of soil for a hectare of fallowed land

= 3400000 kg

Quantity of Na_2SO_4 required

Sulfur at 10 kg

10/22.57 x 100 = 44.3066 kg for a hectare

For 10 kg of soil

X = 1.3031 x 10^{-4} kg of Na_2SO_4per pot

= 0.1303 g of Na_2SO_4

Sulfur at 20 kg per hectare

20/22.57 x 100 = 88.613 kg to one hectare containing 3400000 kg of soil

For 10 kg of soil

X = 2.606 x 10^{-4} kg Na_2SO_4 at 20kg/ha

= 0.2606 g of Na_2SO_4

Sulfur at 30 kg per hectare

30/22.57 x 100 = 132.9198 kg/ha

= 3.9094 x 10^{-4} kg of Na_2SO_4 30 kg/ha

= 0.3909 g of Na_2SO_4

FERTILIZER CALCULATIONS FOR CONTINUOUSLY CROPPED SOIL

Calculating the Mass of soil for 1 hectare of land for continuously cropped soil

Calculated bulk density for fallowed land = 1.50 g/cm^{3} = 1500 kg/m^3

Plough depth = 20 cm = 0.2 m for rice crop

Volume of soil for 1 hectare of land

Depth x area

0.2 m x 10000 m^2 = 2000 m^3

But density = mass/ volume

Mass of soil for 1 hectare of land

Mass = density x volume of soil

= 1500 kg/m^3 x 2000 m^3

= 3000000 kg

The mass of soil for a hectare of land on the fallowed soil = **3000000 kg.**

NPK CALCULATIONS FOR FALLOWED SOILS FOR THE POT EXPERIMENT

NPK 15 – 15 – 15 will be applied at a rate of 90 – 60 – 30 kg/ha

Quantity of soil per pot = 10 kg

Mass of soil for the fallowed land = 3400000 kg

For basal application

NPK will be applied at 30 – 30 – 30 kg/ha

Quantity of fertilizer

= RATE /GRADE X 100

30/15 x 100

= 200 kg/ ha

200 kg of fertilizer is to be applied to 1 hectare which has 3400000 kg of soil

If 200kg = 3400000 kg of soil per hectare

X = 10 kg 0f soil per pot

X = 200 x 10/ 3000000

X = 6.6667 x 10^{-4} kg of NPK 15 – 15 – 15 per pot

= 0.6667 g of NPK 15 – 15- 15 per pot

For 96 pots

0.6667 X 96 = 64 g of NPK 15 – 15 – 15 for the 96 pots

Calculating for remaining 60 kg of nitrogen

Using urea as a source of nitrogen

Urea = 46 % N

Quantity of fertilizer

60/46 x 100

130. 43 kg N for a hectare of land

If 130.43 of urea is to be applied to 3000000 kg of soil for a hectare

Then what quantity will be needed for 10 kg of soil per pot

130.43 = 3000000 kg of soil per hectare

X = 10 kg of soil per pot

X = 4.3477 x 10^{-4} kg of urea per pot

X = 0.4347 g of urea per pot

For 96 pots

41.74 g of urea for 96 pots

Calculating remaining 30 kg of phosphorous using triple superphosphate

Tsp contains 46 % of phosphorous

Quantity of fertilizer per hectare

30/46 x 100

= 65. 22 kg of phosphorous for I hectare containing 3000000 kg of soil

What quantity will then be needed for 10 kg of soil in a pot?

65.22 = 3000000 kg of soil per hectare

X = 10 kg of soil per pot

X= 2.174 x 10^{-4} per pot

= 0.2174 g of p per pot

For 96 pots

96 x 0.2174

= 20.87 g of p

MICRONUTRIENT CALCULATION FOR CONTINUOUSLY CROPPED SOIL

<u>CALCULATION FOR ZINC ON A CONTINUOUSLY CROPPED LAND</u>

Zinc will be applied at 0, 4, 8, 12, kg/ha to all pots

Zinc oxide (ZnO) will be used as a source of zinc

% zinc in zinc oxide is 80.34

Quantity of soil for a hectare for fallowed land

= 3000000 kg

Quantity of zinc required

Zinc at 4 kg

4/80.34 x 100 = 4.978 kg for a hectare

For 10 kg of soil

If 4. 978 = 3000000

X = 10 kg

X = 1.659 x 10^{-5} kg of zinc at 4 kg per pot

= 0.01659g of zinc at 4 kg per pot

Zinc will be applied to 12 pots

0.0165 x 12

= 0.199 g of zinc at 4kg per pot

Zinc at 8kg per hectare

8/80.34 x 100 = 9.9571 kg to one hectare containing 3400000 kg of soil

For 10 kg of soil

9.9571 = 3000000 kg of soil

X = 10 kg of soil

X = 3.3190 x 10^{-5} kg of zinc at 8kg per pot

= 0.03319 g of zinc at 8 kg per pot

For 12 pots

0.398 g of zinc at 8 kg for 12 pots

Zinc at 12 kg per hectare

12/80.34 x 100 = 14.936 kg/ha

14.936 = 3000000 kg of soil per hectare

X = 10 kg of soil per pot

= 4.9787 x 10^{-5} kg of zinc at 12 per pot

= 0.049787 g of zinc at 12 per pot

For 12 pots

12 x 0.043929

= 0.597g of zinc at 12.

CALCULATION FOR SULFUR ON CONTINUOUSLY CROPPED FIELD

Source of sulfur will be sodium sulfate (Na_2SO_4)

It contains 22.57% sulfur

Sulfur will be applied at 0, 10, 20, 30 kg/ha

Quantity of soil for a hectare for fallowed land

= 3000000 kg

Quantity of sulfur required

Sulfur at 10 kg

10/22.57 x 100 = 44.3066 kg for a hectare

For 10 kg of soil

If 44.3066 = 3000000

X = 10 kg

X = 1.4769 x 10^{-4} kg of sulfur at 10 kg per pot

= 0.14769 g of sulfur at 10 kg per pot

Sulfur will be applied to 12 pots

0.14769 x 12

= 1.77 g of sulfur at 10kg per 12 pot s

Sulfur at 20 kg per hectare

20/22.57 x 100 = 88.613 kg to one hectare containing 3000000 kg of soil

For 10 kg of soil

88.613 = 3000000 kg of soil

X = 10 kg of soil

X = 2.9537 x 10^{-4} kg of sulfur at 20kg per pot

= 0.2954 g of sulfur at 20 kg per pot

For 12 pots

3.54 g of sulfur at 20 kg for 12 pots

Sulfur at 30 kg per hectare

30/22.57 x 100 = 132.9198 kg/ha

132.9198 kg = 30s00000 kg of soil per hectare

X = 10 kg of soil per pot

= 4.4307 x 10^{-4} kg of sulfur at 30 kg per pot

= 0.443g 0f sulfur at 30 kg per pot

For 12 pots

12 x 0.443

= 5.32 g of sulfur at 30 kg for 12 pots