UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF SOIL AND FOLIAR APPLICATION OF ZINC AND SULPHUR ON GROWTH AND YIELD OF RICE (*Oryza sativa* L.) UNDER IRRIGATED AND RAINFED CONDITIONS

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FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCE

DEPARTMENT OF CROP SCIENCE

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BY

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DECLARATION

I, Sayibu Mashud Dawuni, hereby declare that, with the exception of references to the work of other researchers, which have been duly acknowledged, this work is the result of my own research and that this thesis has not been presented for any degree here or elsewhere, in whole or in part.

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(Student)	Signature	Date

Supervisors’

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

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ABSTRACT

In Sub-Saharan Africa, rice is a staple food as well as a cash crop for both commercial and smallholder farmers. However, the yield is very low, because of inherent low soil fertility, as well as poor agronomic techniques. Multiple-location studies were conducted at Botanga (irrigated) and Nyankpala (rain-fed) to determine the most effective way to apply Zn and S to rice and to assess the effect of Zn and S, on rice grain yield. The treatments evaluated were foliar spray of NPK [Zn + S], NPK [S], NPK [Zn] and soil application of NPK + Zn + S, NPK + S, NPK + Zn, NPK [No Micronutrients] and Control [No Fertilizer]. A Randomized Complete Block Design with three replications were used to evaluate the treatments. Number of tillers, plant height, leaf area (LA), chlorophyll content, panicle weight, days to 50% flowering, days to 50% maturity, straw weight, grain yield and thousand (1000) paddy rice weight were among the parameters measured. The use of NPK in combination with zinc and sulphur improved measured growth and yield attributes while also shortening the time taken by the rice plant to blossom and mature. The soil application NPK in addition to Zn and S produced the maximum grain yield, which was comparable to foliar spray of NPK in combination of Zn and S. The application of NPK, secondary elements and micronutrients should be used to optimize yield in rice production systems.

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DEDICATION

This work is dedicated to my entire family, particularly my mother, wife, and children.

I adore you all!!!!!

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LIST OF ACRONYMS

Acronym	**Meaning**
AGRA	Alliance for Green Revolution in Africa
ANOVA	Analysis of variance
BRRI	Bangladesh Rice Research Institute
CARD	Coalition for Africa Rice Development
DMRT	Duncan’s multiple range test
FAO	Food and Agriculture Organization
FASDEP	Food and Agricultural Sector Development Policy
GAIN	Global Alliance for Improved Nutrition
GDP	Gross Domestic Product
IDFC	International Fertilizer Development Centre
IMF	International Monetary Fund and implemented
IRRI	International Rice Research Institute
JICA	Japan International Cooperation Agency
LSD	Least Significant Difference
MOFA	Ministry of Food and Agriculture
NRDS	National Rice Development Strategy
PFJ	The Planting for Food and Jobs
SAP	Structural Adjustment Programme
SARI	Savanah Agricultural Research Institute
SEM	Standard Errors of the Means
SSA	Sub-Sahara Africa

SSARP……………………………. Sustainable Social Action for the Reduction of Poverty

USDA……………………………. United Sates Department of Agriculture

WAT……………………….………...Weeks after transplanting

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Rice grain continues to be one of the most nutritious foods, feeding over one-third of the worldwide population (Zhao *et al.,* 2020). It contributes approximately 715 per capita calories, 27% plant nutritional protein and 3% dietary fat on a daily basis among the masses in Africa (Mohammed, 2021). In Ghana, it is a vital diet for both rural and urban inhabitants, and it is rapidly displacing conventional crops, including root, tuber, and cereal crops such as maize and millet. Between 2016-2017, the average rice consumption per person in Ghana was approximated to be around 35kg/year, with consumption in 2017/18 estimated at 1.0 million Mt (GAIN, 2018).

Rice plant can be produced in a diverse range of climate regions owing to its wide adaptability (Mohammed, 2021). Its cultivation spreads from irrigated terraces in Asia, through the vast, highly automated operations in the Americas and then to rain-fed activities in Africa. The vast majority of global rice production is accounted for by Southeast Asia, the United States, and Southern Europe (Thomas *et al.,* 2021). However, in SSA, rice production is primarily driven by urbanization and shifting consumer desires. It is critical for rural food security in households as well as the country's economy. Regardless of its importance, smallholder farm returns are insignificant, and in several places, local rice production has not been sufficient to meet rising demand, with imports filling the gap (Thomas *et al.,* 2021). From the findings of Vida (2020), rice is in high demand as an intrinsic of the country's food balance, which can be attributed to swift population growth, cooking convenience and storage, and favoured by consumers. Other that could contribute for the increase in consumption is the variety of ways rice may be cooked and consumed. Unlike most other Ghanaian meals, rice can be made and consumed in a variety of ways, including rice water, ‘waakye’, and several others, that could explain the rising demand. According to Vikram *et al.* (2019), rice is essential for reducing poverty and hunger as well as a vital crop for maintaining food security via increased production.

In addition, MoFA (2020) stated that, rice demand has surpassed maize as the second most critical national food in Ghana. The demand has greatly exceeded supply to the point where local rice growers find it difficult to satisfy the country's surging demand. Meanwhile, Nyarko and Kassai (2017) stated that, an SSARP study confirms the total yearly demand for rice in Ghana is approximately 700,000 metric tonnes, while local production accounts for only 150,000 resulting in a 550 metric tonnes deficit that is shipped into the country each year. Furthermore, Kwasi (2015) revealed that, rice importation has been increasing since 1980, and it now accounts for about 50% of all rice consumed in Ghana. As a result, approximately 200% of domestic production has been imported to fill gaps and satisfy Ghanaians' rice cravings (Tanko *et al.*, 2019). Indeed, Ghana's rice self-sufficiency has been proven to have declined from 38% in 1999 to 24% in 2006 (Acheampong *et al.,* 2017). However, research from MoFA (2020) indicates that, Ghana's rice output grew from 48,800 tonnes in 1970 to 925,000 tonnes in 2019, averaging about 9% increase per annum. This indicates a significant potential for development and output in the country's domestic rice sector. Despite this success, demand for rice still outstrips supply. This sobering statistic has rekindled appeals from the food and agriculture sectors for experts in the field to come up with fresh and creative ways to boost rice cultivation in Ghana.

The country's ambition is to boost productivity while reducing its reliance on expensive rice imports. Due to this, numerous attempts and intervention strategies have been made in order to overcome this challenge. These interventions include the use of high-yielding varieties and intensive agriculture. Consequentially, farmers have been given two high-yielding varieties, AGRA and JASMINE 85, with little thought given to the soils in which the rice plant will grow. According Islam *et al.* (2023) intensive farming, which consists of high-yielding rice as well as other crops, depletes the soil of plant nutrients. Improper use of organic fertilizers weakened soil health, resulting in lower crop yields (Islam *et* al., 2023). It is a well-known fact that, rice does well in soils that can supply both micro and macronutrients, in the proper proportions. The regime of plant nutrients found in the soil is the most important factor influencing crop success or failure (Ali *et al.*, 2020). Sulphur and zinc are the two of the most important secondary and micronutrients in rice growth. Sulphur and zinc deficiencies are more frequent in most rice fields across the world, and yield reduction is frequently blamed on a lack of sulphur and zinc (Owahedunnaby, 2021).

Sulphur deficiency is most prevalent in waterlogged areas or when rice is grown on low land (Li *et al.*, 2023). Crop yield and value are known to suffer in sulphate-deficient soils unless sulphate-containing fertilizers are applied. Meanwhile, Islam *et al.* (2016) noted that, when a high dose of sulphur was applied along with the recommended dose of NPK fertilizer, the maximum straw and grain yields of rice were significantly higher. Rice's sulphur requirement varies with nitrogen availability. When sulphur becomes scarce, adding nitrogen to the soil has no effect on plant yield or protein levels. Rice plants require sulphur early in their growth cycle; limiting sulphur early in the growth cycle reduces tiller number and, as a result, final yield (Islam *et al.*, 2016). According to Reddy *et al.* (2022), zinc is a critical nutrient for a variety of enzymes that are involved in a variety of metabolic reactions in plants. Zinc also participates in gene expression and protein synthesis. Meanwhile, Senthilkumar *et al.* (2023) stated that, Zn deficiency is a common micronutrient disorders in lowland rice, and using zinc in addition to NPK fertilizer improves rice yield significantly in most scenarios.

1.2 Problem Statement and Justification

A variety of variables could be blamed for Ghana's dwindling rice production. Ghanaian farmers frequently use NPK fertilizers while ignoring the importance of secondary and micronutrients in rice production. However, Islam *et al.* (2023) found that, overuse of NPK fertilizers causes nutrient deficits and depletes soil micronutrients. The author observed that plants cannot grow well unless all of the necessary plant nutrients are present in adequate ratios. Moreover, Zingore *et al.* (2022) also stated that using purely NPK organic fertilizer for rice cultivation is no longer attainable because it depletes the soil's inherent secondary and micronutrients. Nutrient elements play important and diverse roles in a wide range of physiological processes, including enzyme activation, protein synthesis, reactive oxygen detoxification, species gene expression and control, and reproductive development (Kopriva *et al.*, 2019). Furthermore, rice farmers in Ghana are accustomed to traditional soil fertilizer application to crops which is more common than foliar spraying. But soil application affects plant nutrient availability due to soil type and complex soil interactions (Dhaliwal *et al.*, 2022).

Foliar administration of nutrients, particularly the more expensive major and minor nutrients, can be delivered to agricultural plants via foliar spraying, allowing the nutrients to reach the site of action (Bindraban, *et al.,* 2015). Foliar feeding is becoming recognized as an important fertilization technique in modern agriculture, especially under moisture-limited conditions. This technique optimizes nutrient utilization, allowing deficits to be corrected more quickly. Numerous studies have discovered that foliar fertilizer treatment benefits a variety of crops. In three experimental fields, Phuphong *et al.* (2018) investigated the influence of Zn foliar spray on rice yield and zinc content. Although foliar zinc treatment had no effect on grain production in any of the fields, it did increase grain zinc content by 41% in one field and 30% on average in the other three.

Phasinam *et al.* (2022) assessed that, crop yields are decreasing with the application of the same type and quantity of nutrients. Many macronutrient interventions have been implemented over the years to increase rice production (Vanlauwe *et al.*, 2015). While research on micro- and secondary-nutrient potentials in Ghana has been limited, it has been extensive in Sub-Saharan Africa (Kumar *et al.*, 2018). Moreover Senthilkumar *et al.* (2023) propounded that, soil sulphur content in rice farms should be analysed to ascertain the appropriate amount to be utilised to boost rice yield and grain quality. However, there is limited study on the effects of combining micro and secondary nutrients with existing NPK formulations on rice productivity and quality in Ghana. Thus, the purpose of this experiment was to determine the most efficient method of administering Zn and S in rice, as well as the assessing the effects of Zn and S, on grain yield of rice.

1.3 Research Objectives

1. To determine best method of Zn and S application.
2. To ascertain which of the nutrients impact on grain yield in rice.

1.4 Organization of the study

This work is divided into six chapters. The work's introduction, problem description, justification and organization are all covered in the first chapter. Chapter two examines relevant literature. Chapter three is the study's methodology, which includes data gathering techniques and discussions. The fourth chapter reports the outcomes or findings, whiles the fifth chapter of the work discusses the results or findings. Finally, chapter six focuses on the study's conclusion and recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and domestication

Chen *et al.* (2019) noted that domesticated rice (*Oryza sativa* L.) comes in two varieties, i.e., *O. sativa* (Asian rice) and *O. glaberrima* (African rice). Rice (*O.* spp) is thought to be Asia's first domesticated crop. Rice grains that had been preserved have been discovered in China as early as 3000 BC. between 1000 and 750 BC. The earliest rice sample was discovered in the Hastinapur district of India. The majority of rice varieties can be found in the Southwest Himalayas, which are thought to be the crop's origin. The author further argues that the genus *Oryza* contains 24 species, 22 of which are wild, with the remaining two, *O. sativa* and *O. glaberrima,* being farmed. However, *O. sativa* is planted across all rice-growing regions of the world, whereas *O. glaberrima* is cultivated only in West Africa.

Asia and West Africa may therefore be the centres of origin of cultivated rice. The Asian rice is classified as japonica, indica, aus, tropical and aus tropical (Beye *et al.*, 2023). Meanwhile, Choi *et al.* (2017) discovered that the single-origin model suggests China, whereas the multiple-origin model indicates India. Asian rice is intently linked to a variety of wild annual and perennial species known as *O. nivara* and *O. rufipogon*, whereas African rice is bred from the annual *O. barthii* (*O. breviligulata*), which is related to the perennial *O. longistaminata* (Yelome *et al.*, 2018). Using these variations, it is simple to identify the ancestral pools from which modern rice was derived. *O. rufipogon* (a perennial species), *O. nivara* (an annual species), or possibly both, are thought to be the close relatives of *O. sativa*. In the 1960s, rice became a major crop in Ghana, when it was mainly cultivated in the country's northern regions, accounting for approximately 61% of national production. The major rice varieties produced in Ghana are *O. sativa* and *O. glabberima* (Lacchini *et al.*, 2020).

2.2 Rice ecology

Rice can be planted in a variety of environmental habitat types, such as wetland and dryland fields, landscaped hillside slopes, and even deep water up to 4 meters beneath the surface (Randall *et al.*, 2019). However, the majority of rice farming takes place in the humid subtropics (both warm and cool), warm humid tropics and warm subhumid tropics. Rice-growing environments can be divided into four ecosystems depending on the availability of water: irrigated lowland, rain-fed lowland, rain-fed upland and flood-prone upland (Zewdineh, 2019). According to Zakaria *et al.* (2020), the rice plant is widely cultivated in all significant environmentally and climatically situated areas in Ghana, with the Northern, Upper East, Western, Brong Ahafo, and Volta regions having the highest levels of production. Rain-fed upland, rain-fed lowland, and irrigated lowland are Ghana's three main production ecologies. A total of 6% of the arable land is covered by upland systems, 78% of the land is covered by lowland rain-fed systems, and 16% is covered by irrigated systems (MoFA, 2020).

2.3 Rice production

Rice is by far the most important crop worldwide among low- and middle-income countries. Southeast, East, and South Asian nations from Pakistan to Japan are particularly known for their rice production (Zewdineh, 2019). However, Conway (2019) stated that the Green Revolution led to an increase in rice output throughout the latter three decades of the 20th century in developing countries. Paddy rice production increased during that time period. The majority of this increase was due to increased yields and cropping intensity, though some was due to new land being brought under cultivation or shifting from other crops to rice. The introduction of the dwarfing gene, as well as increased use of fertilizer, irrigation water and other inputs, could be attributed to a large portion of the yield increase (Zewdineh, 2019). From the works of Pathak *et al.* (2018), rice is now grown in many countries all over the globe. Meanwhile, Bissah *et al.* (2022) proposed that roughly 90% of the world's rice is grown in Asian nations. Between 2001-2005, overall rice production in West Africa was approximately 6.24 million tonnes.

In Ghana, rice cultivation has been practiced by Ghanaian farmers for ages (Acheampong *et al.,* 2017). However, Azumah *et al.* (2018) stated that, the majority of Ghana's rice production occurs in the north. Northern Ghana covers approximately 98,000 km^2 of land, with 16,000 km^2 intensively farmed and 8,000 km^2 less intensively farmed. Northern Ghana has over 400,000 hectares of lowland rice production capacity but only 3,000 hectares are currently in production due to a lack of sector investment. Ghana has a competitive advantage in paddy rice production when compared to other African countries. However, due to high processing costs and insufficient transportation networks, it is uncompetitive in the market in terms of rice processing and distribution when compared to imported rice (Nyarko *et al.*, 2017).

2.4 Uses and importance of rice

Rice is a major dietary food that provides immediate energy. As a matter of fact, Duraiswamy *et al.* (2022) stated that the rice grain has no evidence of toxicity or pathogenicity associated with its use as a human food crop. However, anti-nutrients such as phytic acid, trypsin inhibitors and hemagglutinins (lectins) present in the bran portion may have low toxicity levels. Rice bran is one of nature's most abundant sources of vitamins, minerals and antioxidants. It is considered acrid, oleaginous, tonic, aphrodisiac, fattening, diuretic and beneficial to the gallbladder (Odoom, 2020). Rice straw and bran for animal feed, rice husks for fuel, and broken rice used as a snack drink are some of the rice products (Yadav *et al.,* 2020). Nearly 15 million people are employed in the value chain of rice as it serves as a cash crop (Onya *et al.,* 2019). When consumed, rice provides 21% energy, 15% protein, 70–80% carbohydrates, 1.2-2 minerals, and certain vitamins (Kumar *et al.,* 2018). Owing to this, MoFA (2020) noted that population growth, urbanization, and changes in consumer preferences have elevated rice to be the second major vital foodstuff following maize, and its consumption is predicted to rise further as a result of population growth and urbanization.

2.5 Governmental interventions, policies and programmes on rice production in Ghana

Ghana's food policy, like that of many other African countries, has changed dramatically after the 2008 financial crisis. CARD was founded in 2008 with the goal of doubling Africa's rice output. Ghana agreed to participate in this endeavour and developed the National Rice Development Strategy (NRDS) for the years 2008 to 2018. However, unavailability of inputs (seed and fertilizer), insufficient harvesting and post-harvest control techniques, and weak domestic rice marketing strategies are among the key limitations to the advancement of Ghana's rice value chain. The NRDS tackles these restrictions by implementing specific solutions like as automation, greater inland valley agriculture and effective use of existing irrigation infrastructure, as well as varietal development and enhanced seed production and usage. This led to the plan's establishment of theme areas such irrigation and water management systems, post-harvest handling and marketing systems, and seed systems (MoFA, 2020).

Ghana presently has 22 public irrigation systems. The Vea irrigation system, the Afife irrigation system, the Tono irrigation system, and the Kpong irrigation system (Angelucci *et al.*, 2019). The irrigation schemes outlined here are used in both rice and vegetable production. In order to provide a legal foundation for advancing rural development and modern agriculture, FASDEP I was established in 2002. By raising local output to 370,000 metric tonnes through FASDEP I, it was intended to reduce rice importation by 30% through 2004. But the establishment of FASDEP II in 2007 and its implementation in 2009 prevented this objective from being achieved (Angelucci *et al.*, 2019).

2.6 Major production constraints

The access to food products has increased dramatically in recent years, because of the accelerating patterns of population expansion and the upsurge in people's wealth. This demand-supply mismatch is a major danger to world food security. Growing wealth is accompanied with human diets that use more natural resources per capita. This reality, along with rising population, has the potential to double or quadruple world demand for food crops within two generations (Serraj *et al.*, 2019). Some African and Asian countries consume more than 100 kilograms of rice per person each year. The United Nations predicts that the global population will rise from six to eight billion between 2000 and 2025 (WHO, 2021), necessitating a 40% increase in rice output by 2025 because of the severe decline in rice yield throughout the 1990s (Fahad *et al.,* 2018). However, efforts to increase rice output are hampered by biotic and abiotic limitations, as well as crop management failures (Fahad *et al.*, 2019).

2.6.1 Insect pests and diseases of rice

All parts of the rice plant are attacked by a plethora of insect pests at various phases of development across the world, resulting in considerable growth and production losses (Belete *et al.,* 2018). Yield losses due to disease ranges from 2-74% depending on the varieties, season, weather condition and stages of infection (Laha *et al.*, 2017). However, Mondal *et al.* (2017) stated that, pests cause a 25% loss in rice. Insects and spiders dominate the land-dwelling arthropod group. Rice pests that are predators and non-pest insects that visit rice habitats for other reasons are all examples of terrestrial arthropods (Dominik *et al.*, 2018).

In the rice fields, there are around 800 bug species; of these, about 100 of these types of insect pest attack rice, whereas the remaining are all beneficial. Approximately 20 rice plant insect pests, such as grain gall midges, sucking insects, stem borers, defoliators, and plant hoppers, inflict significant economic losses either via direct feeding or as vectors for transmitting rice diseases. The physiology of the grains is disrupted by these insects' feeding on plant fluid sap from the stem and immature seeds, which ultimately lowers agricultural output (Anderson *et al.*, 2019). Meanwhile, Swain *et al.*, 2019 revealed that, diseases have an impact on rice production by reducing output due to viral, bacterial and fungal pathogen attacks. The majority of the main rice diseases are seed-borne. The majority of rice illnesses are transmitted by seed, resulting in massive crop losses. Numerous biotic variables, such as diseases that are more prevalent and pervasive than others like narrow brown leaf spot, leaf scald, glume discolouration, false smut, stack burn, and sheath rot, influence the production of rice in Ghana (Bashyal *et al.*, 2019)

2.6.2 Fertilizer use in Sub-Saharan Africa

According to Muzari (2016), Sub-Saharan African agriculture is characterized by an excessive dependence on primary agriculture, poor soil fertility, and a limited use of external agricultural inputs. Farm inputs, such as fertilizers, seeds and technology usage are all on the decline. If Africa wants to solve its food supply issue, soil fertility management needs to improve. Mineral fertilizers and better management methods are critical to reaching this level of efficiency. The importance of fertilizer application is well acknowledged, since plants growing in soil with newly applied fertilizer have a superior response to vegetative growth and output (Snoeck *et al.*, 2016). Inorganic fertilizer will continue to be a crucial part of any agricultural development strategy or plan that intends to increase food production (Stewart *et al.*, 2020). Dube *et al.* (2020) noted that the majority of African agriculture is to blame for plant nutrient deficiency, which is a significant biophysical constraint on crop yield.

According to Schröder *et al.* (2018), in the years ahead, low fertilizer use will lead to nutrient mining and the continuous use of marginal lands, both of which will have far more destructive effects than raising fertilizer use. Many writers have proposed that SSA fertilizer consumption be increased by 15% or more annually due to considerable soil nutrient loss, inadequate soil productivity management, and low utilization of mineral fertilizer (Bationo *et al.*, 2018). In Ghana, the FAO fertilizer program was highly active, which most likely contributed to the rise in fertilizer use.

Nevertheless, the typical rate of fertilizer uses per hectare of farmed land remained modest. Fertilizer consumption started to fall in 1984 as a result of the Structural Adjustment Program's implementation and the removal of the majority of agricultural subsidies, including fertilizer subsidies. It rose in the second part of the 1990s as the national economy improved, but then dropped due to new financial issues and the devaluation of the cedi. Nonetheless, it returned to the level of the early 1980s in 2002. However, it is nearly half of SSA and a quarter of Africa's overall rate, at around 5 kg/ha of cultivated land (Martey *et al.*, 2019).

Surprisingly, plant nutrients are being taken out of the soil and lost considerably more often than they are being added, which results in a constant loss of soil nutrients. Traditional, soil-depleting farming practices continue to be used extensively (ME Trenkel, 2021). Almost all of Ghana's crop balances have a nutrient deficit (Darko *et al.*, 2020). This results in a reduction in potential production and a steady depletion of the soil. Even though the benefits of mineral fertilizer are outlined explicitly in development plans, Ghana is lagging in putting them into practice. Approximately 8 kg/ha on average is applied, which is less than the dosages in Malawi and Kenya, which are 22 and 32 kg/ha, respectively (Fuentes *et al.,* 2012). According to Francis *et al.* (2019), soil fertility and production conditions differ greatly between geographical locations and between farms and fields within the same soil zone, hence, the general fertilizer use recommendations may be advantageous in some places but completely unprofitable in others. This is so because guidelines for using fertilizer vary depending on the location and circumstances. It is for these reasons that various broad recommendations for the use of fertilizers in Ghana have been erratic and unpopular with both farmers and agricultural experts. Two and a half bags of ammonium sulphate (AS) and triple superphosphate (TSP) per hectare are advised for pre-planting under irrigated or flooded circumstances, with an extra two and a half bags of AS for top dressing. Five bags of ammonium sulphate (AS) and five bags of single superphosphate (SSP) per hectare are suggested for split application in upland areas. A value-cost ratio (VCR) of about ten in flooded conditions can be produced, implying higher returns related to fertilizer use (FAO, 2005).

2.6.3 Nutrients status and imbalance of Ghanaian soils

Jayne *et al.* (2021) found that Sub-Saharan Africa's (SSA) soils are typically not particularly productive in comparison to those on other continents. They are frequently poor in sulphur, magnesium and zinc, and have low accessible nitrogen (Klikocka *et al.*, 2018). There are 23,853,900 ha of land in Ghana, of which 13,628,179 ha (57.1%) are suitable for agriculture. However, the majority of the soils are fairly low in fertility. Water stress is frequent during the growing season, and the coarseness of the soils affects their physical characteristics. Significant portions of the country's geographical area, especially the interior savannah zone, have seen considerable soil erosion and land degradation in several ways. Nitrogen and phosphorus are the two nutrients that are most inadequate, and nutrient depletion is common across all agro-ecological zones. When crops are harvested, nutrients from the soil are taken that have not been restored by the application of fertilizers, both organic and inorganic, that contain the corresponding levels of plant nutrients (IFPRI 2015).

The majority of Ghana's soils are formed by the weathering of parent materials. They are old and have deteriorated gradually over time. They frequently have low organic matter levels and poor fertility. Periodic burning of crop waste or competitive use of crop residue for construction, animal feed, or fuel prevents organic material accumulation. The lack of vegetation during the prolonged dry season makes most soils susceptible to erosion during the rainy season. In turn, this exacerbates the problem of low fertility. As a result, maintaining high crop yields requires careful soil management aimed at reducing and controlling erosion, enhancing the quantity of organic matter, and replacing and boosting plant nutrients lost through erosive loss and crop uptake (IFPRI, 2015).

2.6.4 Effect of nitrogen on growth and yield of rice

Anisuzzaman *et al.* (2021) propounded that judicious and appropriate fertilizer application may significantly boost rice production and quality. When compared to other nutrients, nitrogen is the nutrient that most severely restricts the growth and yield of rice crops (Djaman *et al.*, 2018). Nitrogen is particularly important during the early and mid-tillering, panicle initiation, booting and ripening stages of grain growth. It can also boost plant height, panicle number, spikelet number and full spikelet number, all of which are key factors that affect rice yield capacity (Zhou *et al.*, 2019). Moreover, Djaman *et al.*, (2018) noted that nitrogen affects rice yield through influencing photosynthesis, biomass build-up, tillering effectiveness, and spikelet development. The majority of farm lands across the world are weak in primary macronutrients (Sarkar *et al.*, 2016). Thus, in order for modern rice varieties to produce to their maximum capacity, nitrogen fertilizer is necessary (Chamely *et al.*, 2015). Improved cultivars of rice with high yields have better sensitivity to applied nitrogen, although their N requirement varies based on agronomic traits and cultivars in a variety of climates (Senthilkumar *et al.*, 2023). Excessive N application, on the other hand, might result in ground water contamination, higher production costs, lower yields and environmental damage (Djaman *et al.*, 2018).

According to Xu *et al.* (2023), increasing nitrogen rates increased grain yield in a linear fashion. Similarly, Singh *et al.* (2000) disclosed that, each N increment dosage boosted rice grain and straw yields significantly over the previous dose. As a result, the crop treated with 100 kilograms of nitrogen per hectare yielded the highest rice yield 2647 kg ha^{-1}. However, Bellido *et al.* (2000) carried out a field study to compare the effects of four nitrogen fertilizer rates (0, 50, 100, and 150 kg N ha^{-1}) on rice performance. They discovered that the total dry matter was significantly greater at the 100 and 150 kg N/ha. Hence, the use of nitrogen enhanced production (Shahzad *et al.*, 2019). Nitrogen treatment stimulated development and increased the build-up of dry matter during the early phases of crop growth. Dwibvedi (1997) saw a considerable improvement in growth, rice production, straw yield, and harvest index with nitrogen applications of 60 kg N/ha. Islam (1997) explored how nitrogen and phosphorus affected the development, production, and nutrient uptake of deep-water rice. The number of viable tiller m^{-2} and grain panicle^{-1} was significantly increased by nitrogen and phosphorus fertilization, leading to a significant rise in grain yield. The treatment's yield increased by 22% compared to the control when only 60 kg N/ha was added.

2.6.5 Effect of phosphorus on growth and yield of rice

Most agricultural soils frequently have phosphorus added to them in order to boost crop yield because it is an essential nutrient for crop development (Kvakic *et al.*, 2018). Phosphorus fertilizers have played an essential role in replenishing soil accessible P and boosting crop development. Early blooming, early ripening, and resistance to disease conditions are all facilitated by phosphorus. Lack of phosphorus can cause rice plants to take longer to mature and make them more vulnerable to illnesses (Dissanayaka *et al.*, 2018). Water soluble phosphate fertilizer interacts with several soil P pools in complex ways. This is especially true in the tropics, where many soils have a high P-fixing capacity. As a result, large amounts of P fertilizer are necessary to obtain acceptable agricultural yields. Phosphorus is quickly fixed by ions such as calcium (Ca), aluminium (Al), and iron (Fe), becoming sparingly accessible as a result (Johan *et al.*, 2021). A consistent P application in relatively high quantities is needed to ensure crop output, resulting in a rise in production costs. Phosphorus feeding for rice plants has been neglected more than nitrogen feeding because, under ideal soil conditions, rice's response to phosphorus fertilizer is much less noticeable than that of nitrogen. Many soils used for intensive rice farming, a phosphorus deficit is anticipated, and the introduction of superior rice cultivars will make matters worse (Noelle *et al.*, 2018).

Islam *et al.* (2010) carried out a field study in the Boro rice and T. Aman rice seasons to assess the influence of five levels of phosphorus (0, 5, 10, 20, and 30 kg P ha^{-1}) on four rice varieties. In the T. Aman rice season, P levels had no impact on rice production no matter the variety, but for the Boro rice season, a P effect was noticed among the P levels. The grain yield was greatly boosted by applying P at a rate of 10 kg/ha. However, there was no statistically significant difference between the applications of 20 and 30 kg P/ha for rice production. The optimal and economic P rate for T. Aman rice was 20 kg P/ha, but the optimal and economic P dosages for

Boro rice were 22 and 30 kg/ha, respectively. Hybrid entries (EH 1 and EH 2) used P more effectively than inbred cultivars. A negative P balance was noted up to 10 kg P/ha. Sahrawat *et al.* (2010) looked at how four potential upland rice varieties responded over a six-year period to 0, 45, 90, 135 and 180 kg TSP ha^{-1}. Fertilizer (TSP) was administered once in 1993, and its ongoing effects in 1994, 1995, 1996, 1997, and 1998 demonstrated that fertilizer (phosphorus) residues remained to boost grain yields in rice varieties after 1993, despite the fact that the reaction's amplitude steadily diminished over time.

2.6.6 Effect of potassium on growth and yield of rice

An essential plant nutrient for healthy plant development and growth is potassium. It is the component of plant nutrition that is most abundant in agricultural plants (Sardans *et al.*, 2021). Potassium deficiency is increasingly becoming a limiting issue in soils that were previously thought to have adequate accessible potassium. Paddy output has increased as a result of the introduction of modern rice varieties and enhanced soil and fertilizer management strategies (Islam and Muttaleb, 2016). As a result, NPK nutrient loss (kg/ha) is steadily rising (IRRI, 2016). Mostofa *et al.* (2009) carried out a pot experiment to analyze the impact of four potassium dosages (0, 100, 200, and 300 kg/ha). At 100 kg/ha of K, plant height, tiller count, and dry matter output were at their greatest levels. Natarajan *et al.* (2005) analyzed the performance of rice cultivars with varying K levels in main plots using two rice cultivars, KRH2 and DRRHI, and three potassium levels (0, 40, and 80 kg/ha) in sub-plots. The findings clearly demonstrated that cultivar KRH2 performs better with various levels of potassium.

2.6.7 Sulphur deficiency

Apart from nitrogen, phosphorus and potassium, sulphur is the fourth most important macronutrient for plant development and function; its total amount in plant tissues ranges from 0.3% to 7.6% (Zenda *et al.*, 2021). Sulphur, as a component of the amino acids' cysteine and methionine, is highly desirable for protein main structure and enzyme function (Njira *et al.,* 2015). Also, it plays a critical role in rice development and growth, such as nitrogen utilization, chlorophyll formation, and photosynthesis signaling processes (Shah *et al.*, 2022). Low sulphur levels have an impact on crop quality and productivity. A mild sulphur deficit may have little impact on yield, but it has a great impact on quality (Etienne *et al.*, 2018).

Modern agriculture, which uses crop intensification and better cultivars with higher nutritional demands, is characterized by nutrient depletion and imbalances (Singh *et al.*, 2017). The rapid decline in available soil S is primarily caused by high-yielding cultivars' higher crop removal, greater cropping intensity, and insufficient soil replenishment as a result of the utilization of S-free fertilizers (Admasu, 2019). Depending on the availability of nitrogen, rice has different sulphur needs. The addition of N does not alter plant yield or protein content when S becomes limiting. Early on, in the growth of rice plants, sulphur is needed. Early growth restriction will decrease tiller count and consequently yield components (Zayed *et al.*, 2017). Available sulphur should make up between 0.1% and 0.5% of the plant's dry mass for the best rice growth. This is likely to correspond to seed sulphur content of 0.18 to 0.19% of dry weight (Kalala *et al.*, 2016). Rahman *et al.* (2008) observed that, applying 40 kg S/ha resulted in greater assimilates following the start of the reproductive stage of rice than without S treatment, suggesting that S is strongly engaged in photosynthetic signalling pathways leading to seed formation. Numerous studies indicate that a sulphur shortage affects the biomass, general morphology, yield and nutritional value of the plants (Prakash *et al*., 2022).

2.6.8 Zinc deficiency

One of the minerals required for the growth and development of rice is zinc (Kumar *et al.*, 2017). Moreover, Cakmak *et al.* (2023) stated that Zn is an essential ingredient needed by rice for numerous biochemical and metabolic processes, such as cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll generation, enzyme activation, membrane integrity, carbohydrate metabolism, cell wall development, gene expression, and respiration. Zinc insufficiency is currently recognised as the most common nutritional problem in lowland rice (Palanog *et al.*, 2019). Almost all rice-producing nations have documented zinc insufficiency (Dipa *et al.*, 2020). Upon transplanting rice seedlings, various zinc deficiency symptoms start to show up two to three weeks later (Shrestha *et al.*, 2020). Deficiencies in rice reveal themselves as dusty brown patches on the young leaves of dwarfed plants, irregular plant development, decreased tillering, and higher spikelet sterility Joshi (2018). Direct-sown seeds may fail to germinate, or transplanted rice seedlings may perish in circumstances of chronic zinc shortage (Mohan *et al.*, 2017).

According to Nadeem *et al.*, (2019), Zn deficiency is among the most significant nutritional stressors affecting rice cultivation in Asia. This trend is prevalent throughout the world; more than 50% of the soil used to grow grains is deficient in zinc (Esfandiari *et al.*, 2016). Zinc deficiency is a key worry for rice farming because it often leads to output decreases of 10-60%; thus, in extreme cases, plant mortality and stand loss might occur. Zinc deficient rice plants have poor root respiration, particularly in submerged soils. Zinc is abundant in fine-textured red and black clay soils, but coarse textured alluvial soils are deficient. Similarly, zinc deficiency is found in severely worn coarse grained red, lateritic and calcareous soils. Zinc deficiency in rice results in Khaira disease, a deficiency illness (Reddy *et al.*, 2018).

2.6.9 Effect of zinc and sulphur on crop yield

Singh *et al.* (2017) propounded that, Zn and S application to rice crop will greatly improve rice growth and yield parameters. The authors conducted research to see how different zinc and sulphur concentrations affected the growth and production of rice (*O. sativa* L.) grown in sodic soil. Experiments were carried out using four levels of sulphur (0, 15, 30, and 45 kg/ha) and four levels of zinc (0, 5, 10, and 15 kg/ha), with 45 kg/ha of sulphur and 10 kg/ha of zinc producing the highest yield. Their work showed that rice yield attributes and yield were considerably greater under 15 kg Zn/ha. The count of shoots per hill, plant height (cm), accumulation of dry matter, yield qualities, and grain and straw yield per ha of rice crop all exhibited remarkable increases after 45 kg S/ha of sulphur application.

Waikhom *et al.* (2018) investigated the effects of sulphur and zinc on rice yield characteristics, rice yield, and rice economics. Four rates of sulphur (0, 15, 20, and 25 kg/ha) and zinc (0, 5, 10, and 15 kg/ha) were used as treatments. They claimed that 20 kg of S and 15 kg of Zn per hectare were the optimal amounts for effective tillers, filled grains per panicle, grain yield, straw output, and harvest index.

Moreso, Ram *et al.* (2014) conducted field research on wheat (*Triticum aestivum* L.) and rice (*O. sativa* L.) during the 2010 and 2011 farming seasons. Gypsum and phosphogypsum were used to treat the rice at levels of 0, 30, and 60 kg S/ha each, while elemental sulphur was used to treat the wheat at levels of 0, 15, and 30 kg S/ha. Regardless of the source, sulphur treatment had a positive and significant effect on the aerobic rice growth characters, sulphur utilization efficiency, yield parameters, and grain yield. When sulphur was provided through gypsum or phosphogypsum, rice grains and straw absorbed more of it. Also, S applied through gypsum at a rate of 30 kg S/ha gave the best agronomic, crop recovery, and physiological efficiency. Gypsum treatments with 30 kg S/ha and 60 kg S/ha of phosphogypsum, respectively, increased rice grain yields by 9.5, 11.2, 8.7, and 10.7%. Despite being statistically inferior to sulphur treatment at 30 kg S/ha, sulphur treatment at 60 kg S/ha produced the highest net returns. With a cost-benefit ratio of 30 kg/ha through gypsum, sulphur use produced the most benefits.

Furthermore, the administration of Zn increased the bioavailability of Zn, as seen by decreased phytate levels and phytate to Zn molar ratios. The maximum bioavailable Zn concentrations were estimated for foliar (30%) and soil applications (28%). Zn seed priming provided the greatest net advantages under both tillage methods. They concluded that Zn feeding via various ways increased wheat production, profitability and grain bio-fortification under PT and ZT systems.

2.7 Effect of soil micronutrients on human nutritional health

Joy *et al.* (2015) noted that as humans eat animals that eat plants, their diets are either entirely or partially plant-based. Consequently, a micronutrient deficiency in humans due to inadequate soil may be caused by a micronutrient scarcity in food crops. Micronutrient insufficiency, particularly of Zn, is common in countries across the globe where staple diets are mostly grains and tubers cultivated in nutrient-poor soils. This is the leading cause of childhood stunting and mortality. However, micronutrient fertilization of agricultural crops (agronomic fortification) may help resolve crop nutritional quality and related micronutrient dietary problems in human health, in addition to increasing crop production for human consumption (Joy *et al.*, 2015).

There are obviously alternatives to agronomic fortification for the supply of human micronutrients. These include plant breeding and genetic engineering (bio-fortification), postharvest bio-fortification of food as carried out by the food industry, and the use of micronutrient supplements. However, as they require numerous tiresome processes, bio-fortification solutions are frequently long-term in nature (germplasm screening, varietal crossing, molecularly assisted selection, and phenotyping of new crop breeds). Furthermore, in order to produce crops with improved micronutrient absorption and tissue transport, the complex multi-genetic stages required in transferring nutrients from the soil to grains or edible leaves would have to be counter. Depending on the plant, bio-fortification, particularly through genetic engineering, may be hindered by the similarity of many micronutrient uptake pathways, resulting in opposing nutrient interactions, or by the co-uptake of harmful heavy metals such as Cd (Slamet-Loedin *et al.*, 2015). It has been proven that micronutrient fertilization, such as Zn, can rapidly boost the nutritional content of crops as compared to bio-fortification (Jaiswal *et al.*, 2022). It's interesting to note that several crops have seen a decline in their micronutrient content recently, especially grains and vegetables (Marles *et al.*, 2017). Two factors could account for this pattern: utilizing high-yielding crop cultivars (Monasterio and Graham, 2000) and continuously depleting soil micronutrients through agricultural production without replenishment through fertilization, particularly in developing nations (Jones *et al.,* 2013).

According to Dimkpa and Bindraban (2016), the higher crop biomass, grain yield, and/or harvest index (i.e., the proportion of grain biomass to total biomass) that commonly accompany NPK use on high-yielding cultivars would result in a dilution of the micronutrient abundances in the aerial plant parts, lowering the amount greatly transferred to the edible portions of the crop, mainly grains in the first situation. The successful implementation of Zn fertilization, along with experimenting with the timing and transit of application in wheat and rice, has led to dramatic simultaneous outcomes for crop yield and nutritional quality, proving the effectiveness of Zn micronutrient fertilization to address the pervasive Zn deficiency in soils and, consequently, in humans. Other nations, notably Turkey, achieved good outcomes (Zou *et al.* 2012). Although these zinc-related findings point to the potential importance of micronutrient fertilizers in addressing hidden hunger, more empirical research, such as studies on the efficacy of all micronutrients and the majority of staple crops, is still needed. As seed companies continue to enter emerging agricultural markets around the world, it is becoming increasingly important to encourage the use of such high-yielding cultivars with micronutrient inputs to increase their level in the plant (Dimkpa and Bindraban, 2016).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

During the 2020 cropping season, which ran from June to October, two field trials were set up in Nyankpala lowland valley and the Botanga irrigation field in northern region of Ghana. Specifically, Tolon and Kumbungu districts, are both districts located in the Guinea savanna ecological zone, with the former lying between latitudes 9.25° and 10.03333° North and longitudes 0.9666667° and 1.416667° West, and sharing borders to the north with Kumbungu, North Gonja, Central Gonja, and Sagnarigu Districts. The district is marked by a single rainy season that begins in April, peaks in July and August, and ends in October and November. From November through March, the dry season begins, with daily highs of 33°C to 39°C and night-time lows of 20°C to 26°C. The mean rainfall is 1,043 mm (Larweh and Abukari, 2022; Ansah and Issaka, 2018)

The Kumbungu district is located on a latitude of 9.5633700° North and longitude -0.9490400° West. Its northern, western, southern, and eastern borders are formed by Moagduri district, Tolon and North Gonja districts, Sagnerigu district, and Savelugu municipal. The weather conditions are similar in both districts (Larweh and Abukari, 2022). The average rainfall data on the fields during the experiment were 358 mm and 449 mm for Nyankpala rainfed valley and Botanga irrigated field respectively.

3.2 Experimental design and treatments

A randomized complete block design was used for the trial, which contained eight treatments with three replications each. The treatment structure is shown in Table 1.

Table 1: Treatments and fertilizer application rates

	Rate of application	Soil basal application (g)			Top dressing (g)			
					Soil		Foliar Applied	
Treatment	**N-P-K-Zn-S (kg/ha)**	**NPK (23-10-5)**	**MOP**	**$ZnSO_4$**	**SA (soil)**	**Urea**	**$ZnSO_4$**	**K_2SO_4**
Control	0-0-0-0-0	0	0	0	0	0		0
NPK [No Micro]	120-40-40-0-0	1000	100.4	0	0	152.2		0
NPK [S]	120-40-40-0-10	1000	0	0	0	152.2		135.9
NPK [Zn + S]	120-40-40-2.5-10	1000	0		0	152.2	27.5	119.2
NPK [Zn]	120-40-40-2.5-0	1000	100.4		0	152.2	27.5	0
NPK + S	120-40-40-0-10	1000	100.4	0	103	104.7		0
NPK + Zn + S	120-40-40-2.5-10	1000	100.4	27.5	90.4	110.5		0
NPK + Zn	120-40-40-2.5-0	1000	100.4	27.5	0	152.2		0

3.3 Land preparation and planting

All experimental sites were ploughed, and the portions designated for the trials were marked out. Respectively, the area was then divided into three replications, each with eight plots measuring 5 m x 5 m and alleyways of 1 m and 2 m between plots and replications. SARI-certified Agra-rice seeds were nursed and transplanted after four weeks. One seedling per hill was transplanted manually at 20 cm x 20 cm spacing.

3.4 Application of treatments and cultural practices

Treatments were assigned to plots at random in each replication. Fertilizers were applied in a shallow furrow along the sides of the rows of crops for plots that received fertilizers through soil application using the side dressing technique. Fertilizer application was carried out in two and four weeks after transplanting. The foliar fertilizer application was done four weeks after transplanting using a knapsack sprayer. Demi water and detergent were used to make foliar fertilizer mixtures. Degan and Bisung herbicides were used to control weeds in the fields in two and four weeks after transplanting.

3.5 Data collection

Two weeks after transplanting, five plants were randomly selected for data collection from each treatment in both fields. The parameters measured were as follows:

3.5.1 Number of tillers per hill

Tillers on tagged plants in each plot were counted 4 WAT, 6 WAT and panicle stage (8 WAT). Effective tillers were also assessed at 8 WAT at panicle initiation. The means of the tiller count were calculated.

3.5.2 Plant height

At 4, 6, and 8 WAT, the height of the plants were determined using a tape measure. Mature plants' heights were measured from the ground up to the point of the tallest panicle, whereas young plants' heights were estimated from the ground up to the top of the tallest leaf. The average per plots were calculated and reported in centimetres.

3.5.3 Leaf area index

Five plants were randomly identified and tagged for easy identification and measurement of leaf area at 4 WAT and 6 WAT. The maximum width and length of every leaf on the middle tiller were measured, and the leaf area of every leaf was computed. The leaf area was estimated using the formula suggested by Yoshida *et al.* (1976), i.e., LA (cm^2) = L (cm) × W (cm) × K, where LA = Leaf area, L = leaf length, W = leaf width and K = 0.75. The leaf area was then divided by number of leaves per plant to obtained the leaf area index.

3.5.4 SPAD reading

The SPAD-502 Plus was used to assess chlorophyll concentration at 4, 6, and 8 WAT (flag leaf stage) by detecting leaf absorbance in the red and near-infrared areas of the spectrum. At the booting stage, spad values were measured on flag leaves. SPAD values were measured on the same day from 7:00 a.m. to 10:00 a.m. to minimize the impact of daily chloroplast mobility on spad values.

3.5.5 Days to 50% flowering

This was calculated by adding up the number of days that elapsed in each plot after transplanting until half of the plants there had at least one open bloom.

3.5.6 Days to 50% maturity

Days to 50% maturity were calculated by observing seedlings transplanted from both fields until 50% of the plants grains in each plot showed a visible yellowish colour.

3.5.7 Panicle weight

At harvest, ten panicles from each plot were collected. The initial weight of the panicles from each plot was taken in the laboratory using the digital weighing scale (camery). These panicles were then sun-dried for about 72 hours, and after which the final weighing was done using the same instrument. The mean values were recorded and used in the data analysis.

3.5.8 Straw yield

The 2 × 2 m metallic quadrant harvest was weighed in the laboratory in its fresh state. The harvested straw was sun-dried for 72 hours before being weighed again with the same device, which formed the dry weight of the straw in each net plot. The collected values were converted to kilograms per hectare (kg ha^{-1}).

3.5.9 Grain yield

The grain yield was determined using the same procedure as the straw yield. In the laboratory, the initial weights and grain moisture of the harvested produce in each plot were determined. The harvested paddy was threshed, winnowed, and weighed. The grain's moisture content was measured using Dicky Johns' multi-grain moisture meter. However, the method developed by Paudel (1995) was used to optimize grain yield to 14% moisture. Gain yield (kg ha^{-1}) at 14% moisture =

$\frac{(100-MC)\times Plot\ yield\ (kg)\times 10000\ (m2)}{(100-14)\times net\ plot\ area\ (m2)}$. Where MC denote the moisture content in percentage of the grains.

3.5.10 One thousand (1000) paddy weights

After harvesting, each plot had 1,000 rice kernels tallied. The weight of the 1000 grains was measured and recorded using a digital weighing scale. For the purpose of calculating the samples' dry weight, they were oven-dried for 48 hours at 80°C.

3.6 Data analysis

The analysis of variance (ANOVA) was performed on the data using the 12th version of GenStat statistical software. The least significant difference (LSD) and Duncan's multiple range test were used to differentiate between the means.

CHAPTER FOUR

4.0 RESULTS

4.1 General observation

Two weeks after transplanting, the irrigated field got flooded for about 4-5 weeks. This may affect the performance of some of the data parameters compared to the rain-fed site (plate).

Plate 1: Irrigated field under two weeks flood due to heavy rain fall

4.2 Number of tillers per hill

The number of tillers per hill is significantly ($P < 0.001$) influenced by treatments. At 4 WAT, both foliar (NPK [Zn + S]) and soil (NPK + Zn + S) were not statistically different from each other as they produced similar number of tillers. These two treatments greatly increased the number of tillers compared to the other treatments (Figure 1).

At 6 WAT, fertilizer and location interaction had a significant ($P < 0.041$) effect on the tiller number. In irrigated Botanga site, the soil applied NPK + Zn + S was noted to have recorded significantly more tillers, but statistically not different from its foliar counterpart (NPK + [Zn + S]) and the remaining treatments (Table 2). However, at Nyankpala rain-fed field, foliar treatment of NPK [Zn + S] outperformed all the treatments. Foliar Zn in combination of NPK applied at Nyankpala rain-fed field performed similarly as NPK + Zn + S. It did not matter how sulphur was applied, foliar or soil applied S gave similar results. A similar observation was also made in Botanga irrigation field. It was observed that the tiller numbers induced by foliar [Zn + S] at Nyankpala rain-fed site was not different from that produced by the treatment at the Botanga irrigated field (Table 2).

At 8 WAT, when effective tiller was taken it was observed that application of zinc and sulphur through soil (NPK + Zn + S) significantly gave the highest number of tillers than NPK [Zn + S] and the other treatments (Figure 2). The individual application of S and Zn gave the same results no matter the form of delivery. The same can be said about S which did not show superiority over NPK with Micronutrients (Figure 2).

Furthermore, the number of tillers generated per hill in the irrigated field at Botanga was much higher than in the rain-fed area at Nyankpala. Tillers obtained at Botanga irrigation site were 12 while that of Nyankpala rain-fed field were 11.

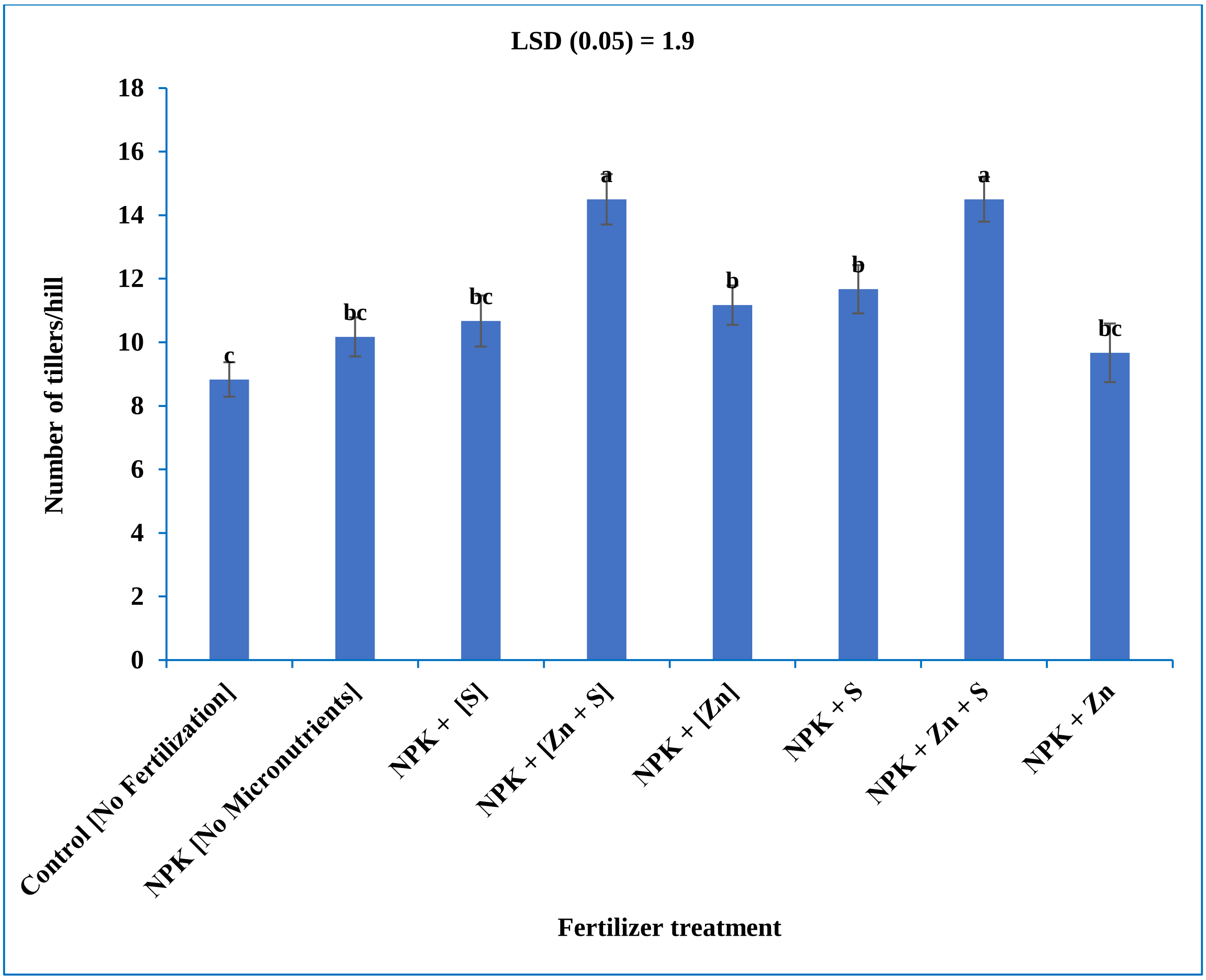

Figure 1: Influence of soil and foliar Zn and S addition to NPK on rice tillering at 4 WAT. Bars represent (SEM)

Table 2: Influence of soil and foliar Zn and S addition to NPK on rice tillering under two locations at 6 WAT

LOCATION	TREATMENT	6 WAT
Botanga	Control [No Fertilization]	12de
	NPK [No Micronutrients]	14cd
	NPK [S]	14cd
	NPK [Zn + S]	18ab
	NPK [Zn]	14cd
	NPK + S	16bc
	NPK + Zn + S	20a
	NPK + Zn	15bc
Nyankpala	Control [No Fertilization]	10e
	NPK [No Micronutrients]	12de
	NPK [S]	14cd
	NPK [Zn + S]	18ab
	NPK [Zn]	15bc
	NPK + S	14cd
	NPK + Zn + S	16bc
	NPK + Zn	10e
***P.* value**		**0.04**
Lsd (0.05)		**2.78**
% *Cv*		**11.20**

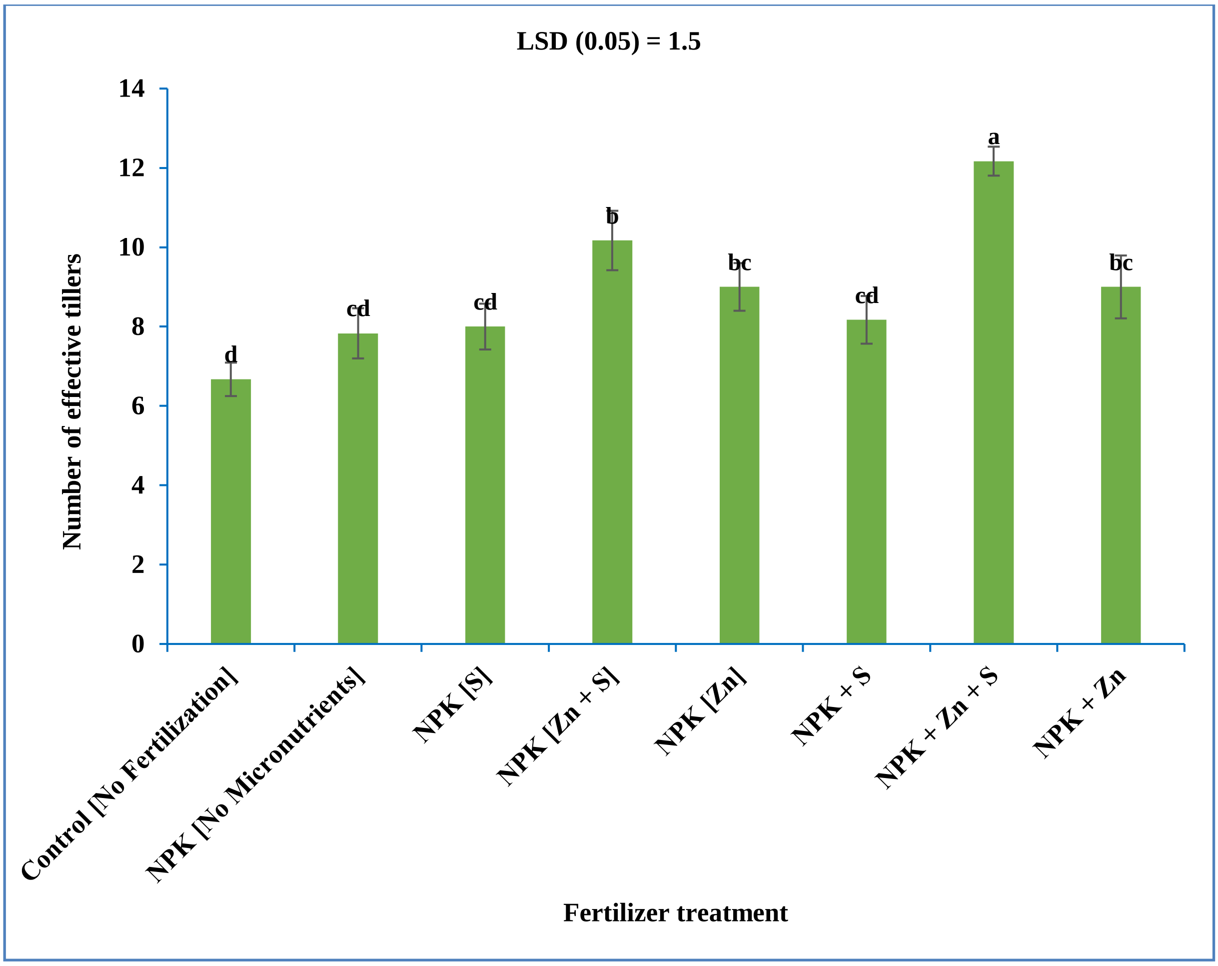

Figure 2: Influence of soil and foliar Zn and S addition to NPK on rice effective tillering. Bars represent (SEM)

4.3 Plant height

The fertilizer and location interaction had no significant effect on plant height ($P > 0.05$) in the three height-measurement periods. However, at 4 WAT, 6 WAT, and 8 WAT plant height was significantly ($P < 0.001$) impacted by fertilizer treatments (Figure 3). From week 2 to 4 there were two cluster of treatments. The foliar spray and soil application [Zn + S] made up one cluster, and the remaining cluster was comprised of the other six treatments. Both foliar spray and soil applied (NPK [Zn + S] and NPK + Zn + S) recorded higher height than the other treatments (Figure 3). By the panicle initiation stage at 8 WAT, three clusters emerged, the control treatment had separated out from the second cluster of six treatments. The foliar and soil applied [Zn + S] remained significantly higher than the other six treatments. It was observed that the individual application of S and Zn, either soil or foliar delivery was not significantly different from NPK [No micronutrient] (Figure 3).

Rice that was grown at irrigated Botanga were significantly higher (105 cm) than those grown at Nyankpala rain-fed (98 cm) during all data recording weeks.

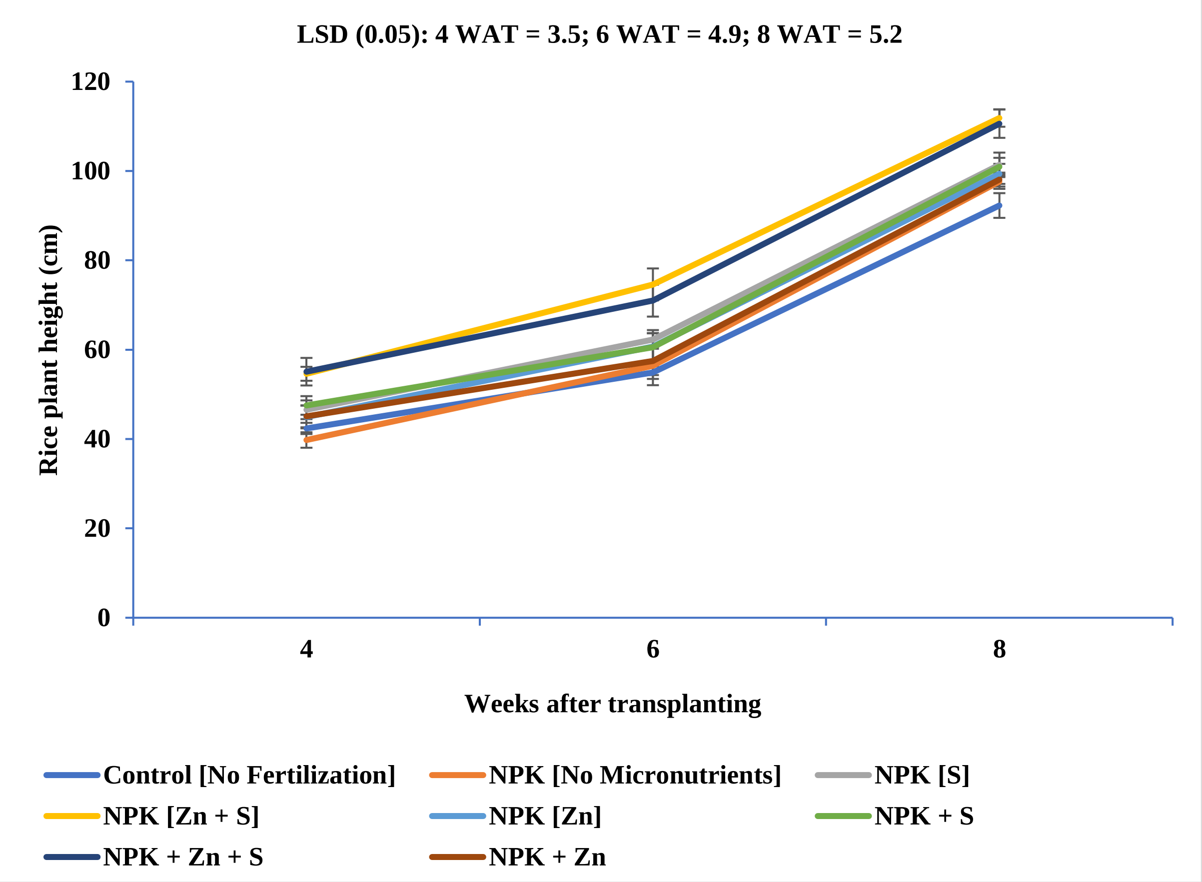

Figure 3: Influence of soil and foliar Zn and S addition to NPK on rice plant height. Bars represent (SEM)

4.4 Leaf area index

The fertilizer treatments had a significant ($P < 0.045$) influence on leaf area. At 4 WAT soil applied NPK + Zn + S, was not significantly different from foliar applied NPK [Zn + S]. The individual application of S and Zn through foliar or soil did not show significant difference from the sole application NPK [No Micronutrients] (Figure 4). This trend was repeated at 6 WAT. Soil and foliar applied NPK in combination with zinc and sulphur experienced vigorous leaf grown making the computed LAI greater than the rest of the treatments. Foliar application of S and Zn individually was not significantly different from its counterparts. The control plot consistently recorded the lowest LAI value (Figure 4).

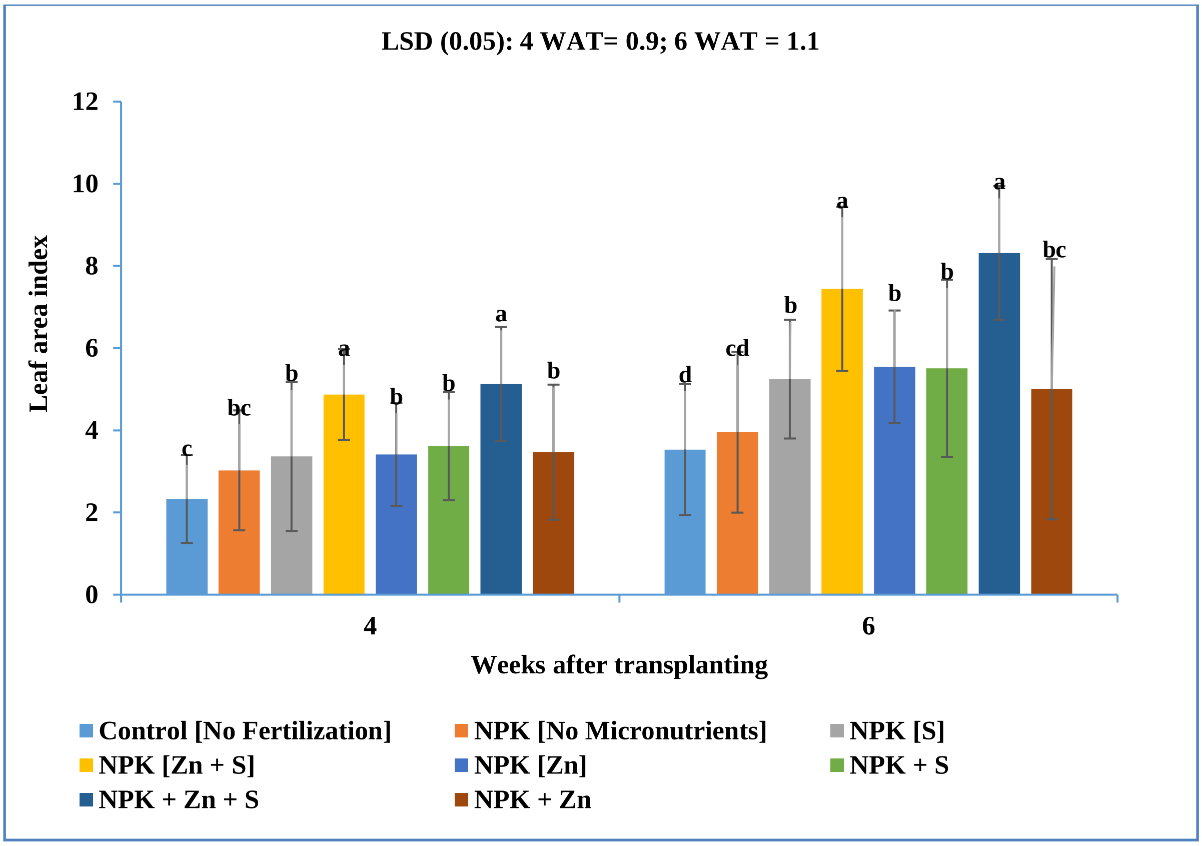

Figure 4: Influence of soil and foliar Zn and S addition to NPK on leaf area index. Bars represent (SEM)

4.5 SPAD reading

The results of the analysis of variance demonstrated that the fertilizer treatment had a significant ($P < 0.05$) impact on the crop's greenness at 4 WAT, 6 WAT, and 8 WAT (flag leaf). In week 4, the fertilizer treatment had similar spad reading which were significantly different from the absolute control (Figure 5). By week 6, the plots that received the combination of Zn and S via both methods (foliar and soil) exhibited better greenery than the rest of the treatments (Figure 5). Individual application of S and Zn did not show any significant difference among them and NPK without micronutrient application. At 8 WAT, only the NPK + Zn + S showed a significant difference compared to the remaining treatments (Figure 5).

The irrigated fields at Botanga consistently were greener and gave higher spad values than the rain-fed fields at Nyankpala (Figure 6).

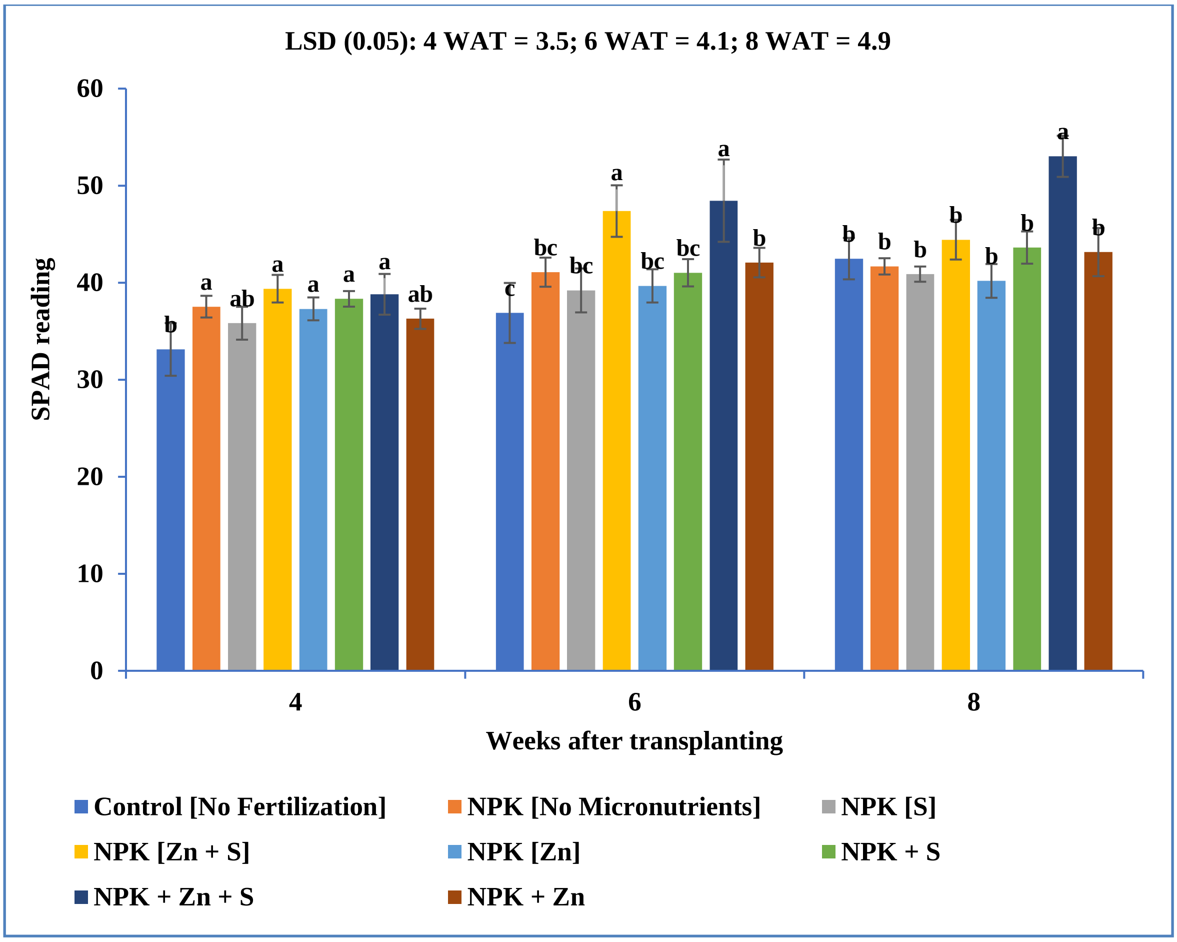

Figure 5: Influence of soil and foliar Zn and S addition to NPK on chlorophyll content at 4, 6 and 8 WAT. Bars represent (SEM)

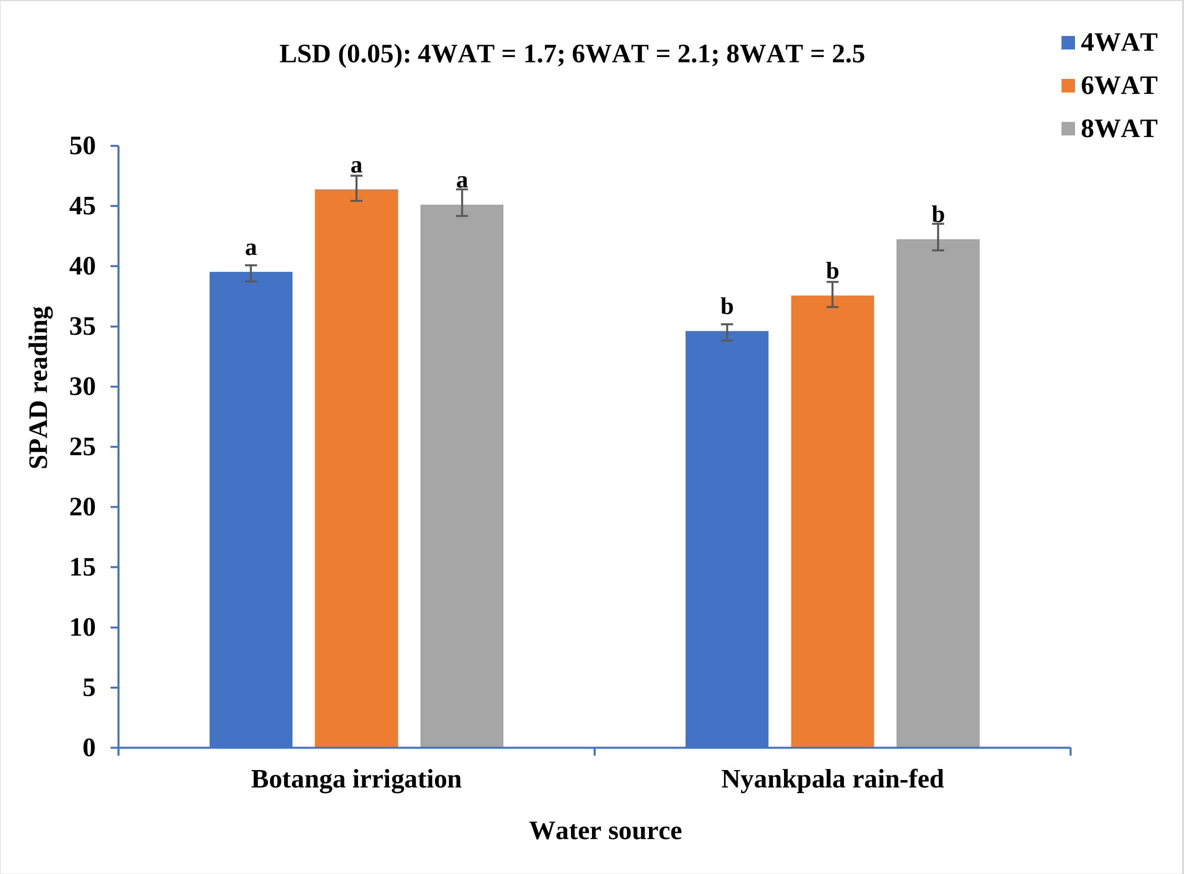

Figure 6: Effect of water source on rice chlorophyll content under two locations. Bars represent (SEM)

4.6 Days to 50% flowering

The number of days to 50% blooming was significantly ($P < 0.036$) affected by the fertilizer and location interaction ($P = 0.036$). When applied to the Botanga irrigation field, the NPK and soil-applied Zn + S recorded the shortest days to 50% blooming, which was statistically different from the other treatments (Table 3). The control treatment had a comparable number of days to 50% blooming as the foliar and NPK [No Micronutrients] treatments. In both fields, the Zn and S applied through soil flowered earlier than those delivered by foliar. The exception was NPK + Zn which took similar number of days as the foliar treatments (Table 3).

Table 3: Influence of soil and foliar Zn and S addition to NPK on days to 50% flowering

LOCATION	TREATMENT	DAY TO 50% FLOWERING
Botanga	Control [No Fertilization]	89a
	NPK [No Micronutrients]	87a
	NPK [S]	89a
	NPK [Zn + S]	89a
	NPK [Zn]	89a
	NPK + S	84b
	NPK + Zn + S	83b
	NPK + Zn	83b
Nyankpala	Control [No Fertilization]	80c
	NPK [No Micronutrients]	80c
	NPK [S]	78c
	NPK [Zn + S]	80c
	NPK [Zn]	78c
	NPK + S	76d
	NPK + Zn + S	76d
	NPK + Zn	78c
***P.* value**		**0.04**
Lsd (0.05)		**2.36**
% *Cv*		**1.7**

4.7 Days to 50% maturity

The fertilizer treatments had significant ($P < 0.012$) influence on the days to 50% maturity. The foliar and soil applied [Zn + S] in combination with NPK caused early maturity of the grains. The foliar applied S and Zn delayed maturity. Sulphur and Zinc applied to the sol did not differ significantly in terms of how many days they took to reach 50% maturity (Figure 7).

Statistically, in terms of water source, Nyankpala rain-fed field had the shortest number of days which differed statistically from the Botanga irrigation field (Figure 8).

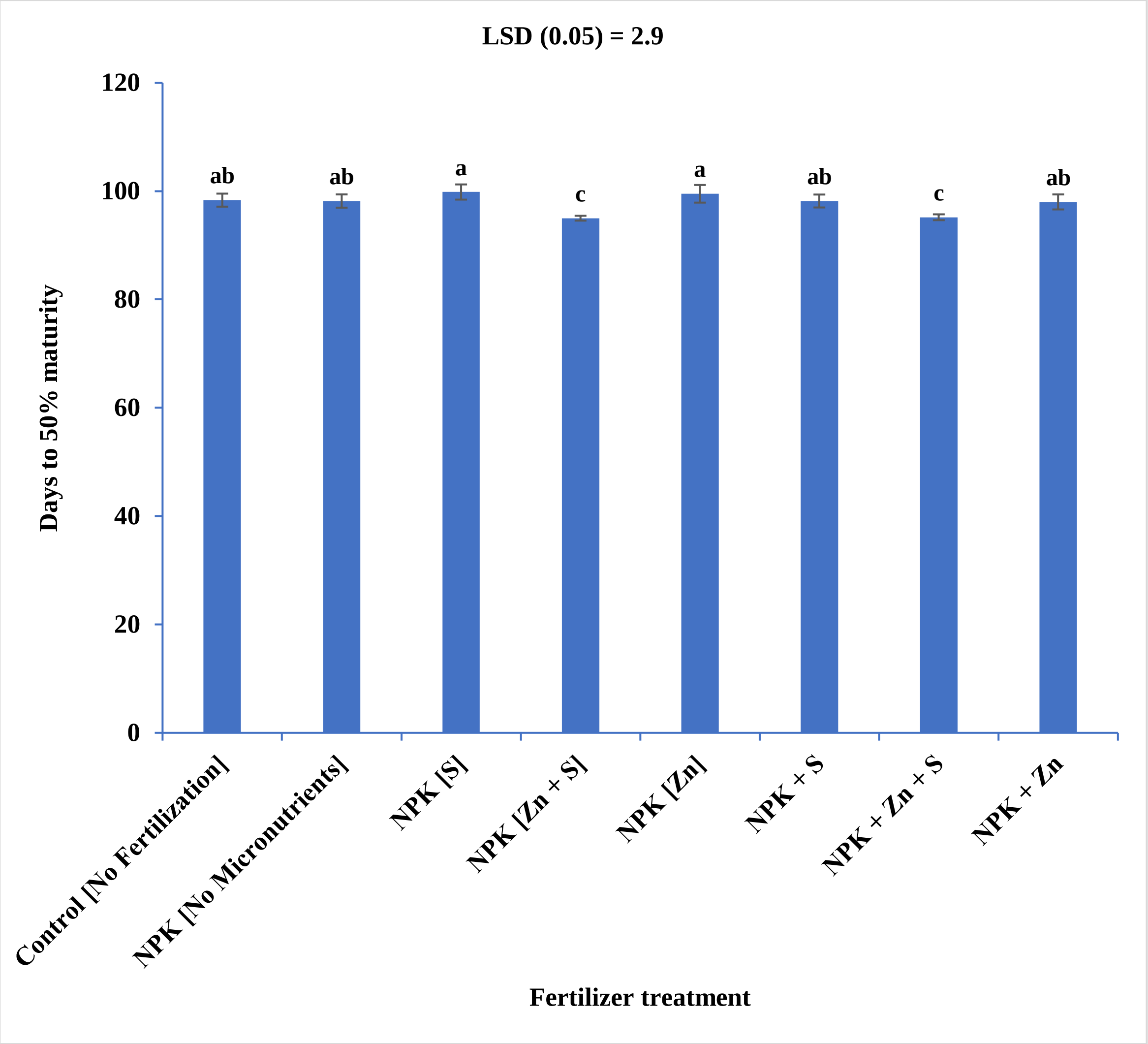

Figure 7: Influence of soil and foliar Zn and S addition to NPK on days to 50% maturity. Bars represent (SEM)

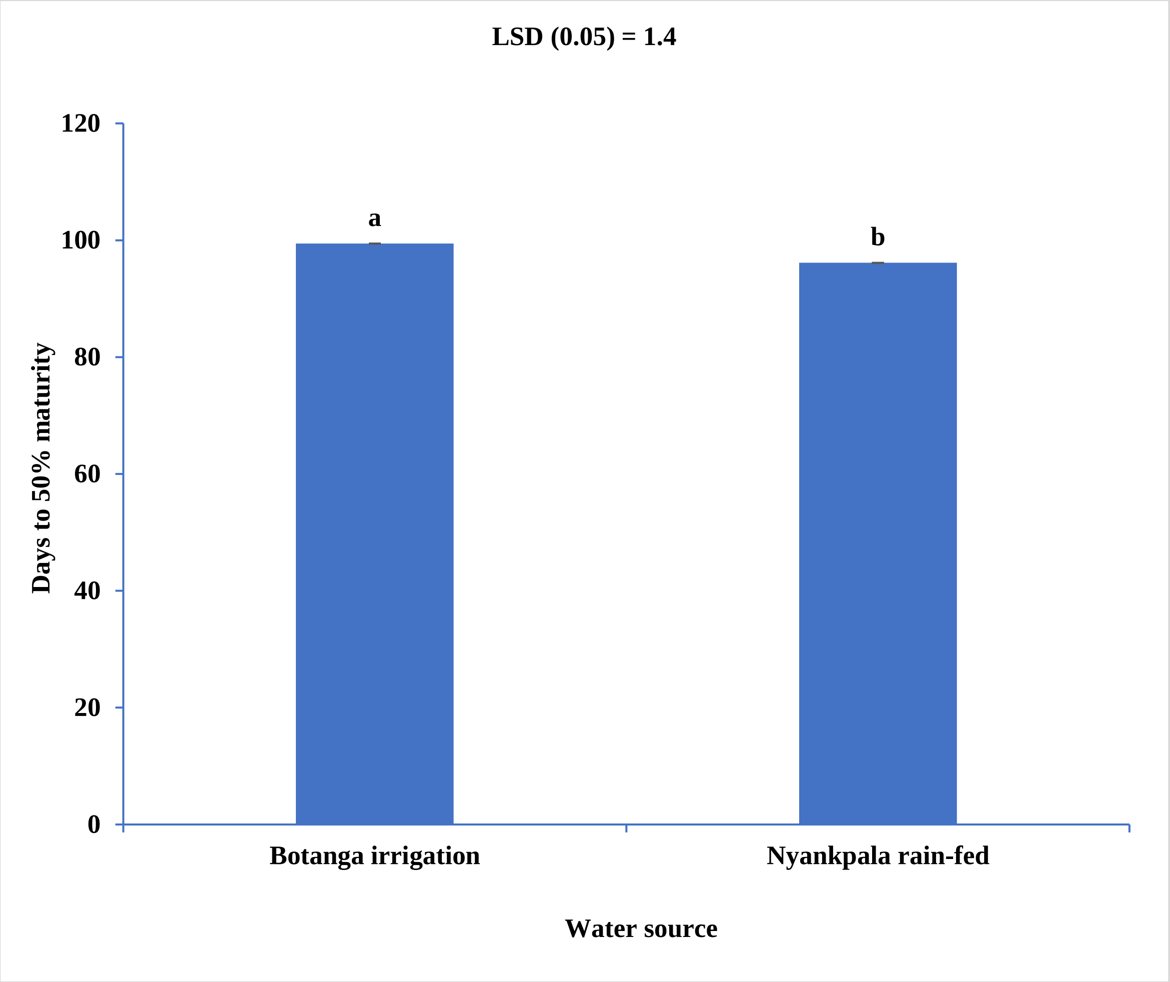

Figure 8: Effect of water source on days to 50% maturity under two locations. Bars represent (SEM)

4.8 Panicle weight

The interaction of location and fertilizer had no significant (*P* = 0.214) impact on panicle weight, but fertilizer treatments had a significant (*P* < 0.001) negative impact on panicle weight. When NPK + Zn + S was administered to the soil, it greatly outperformed its foliar counterpart (NPK [Zn + S]) in terms of producing the heaviest panicles (Figure 9). The soil and foliar (NPK [Zn] and NPK + Zn) treatments did not differ significantly. Similar observation was made on sulphur applied through both methods (foliar and soil) which were similar to NPK [No Micronutrients] (Figure 9).

In terms of the water source, rice grown on Botanga irrigation field had greater panicle weight which was statistically distinct from Nyankpala rain-fed field (Figure 10).

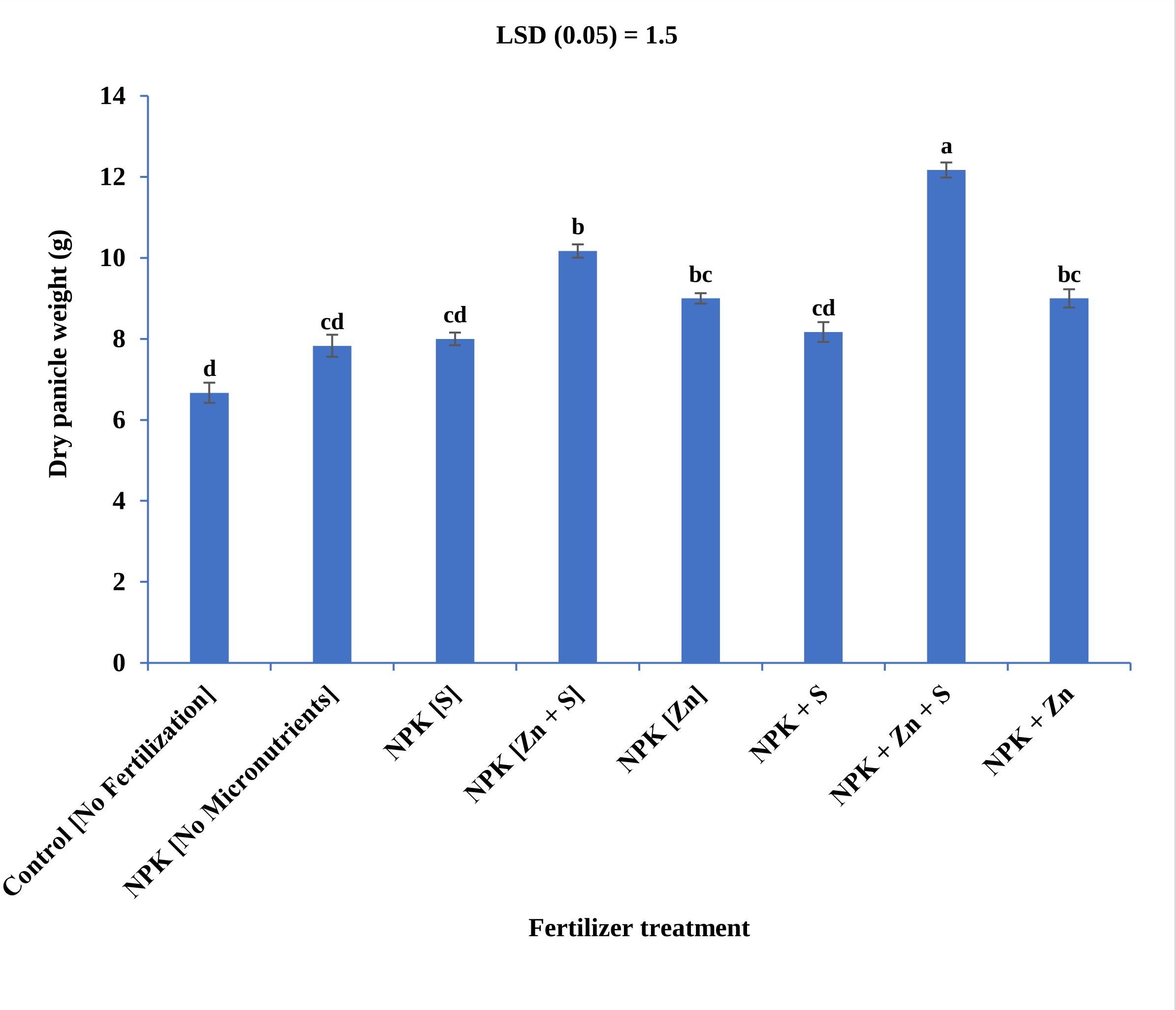

Figure 9: Influence of soil and foliar Zn and S addition to NPK on average ten dry panicle weight. Bars represent (SEM)

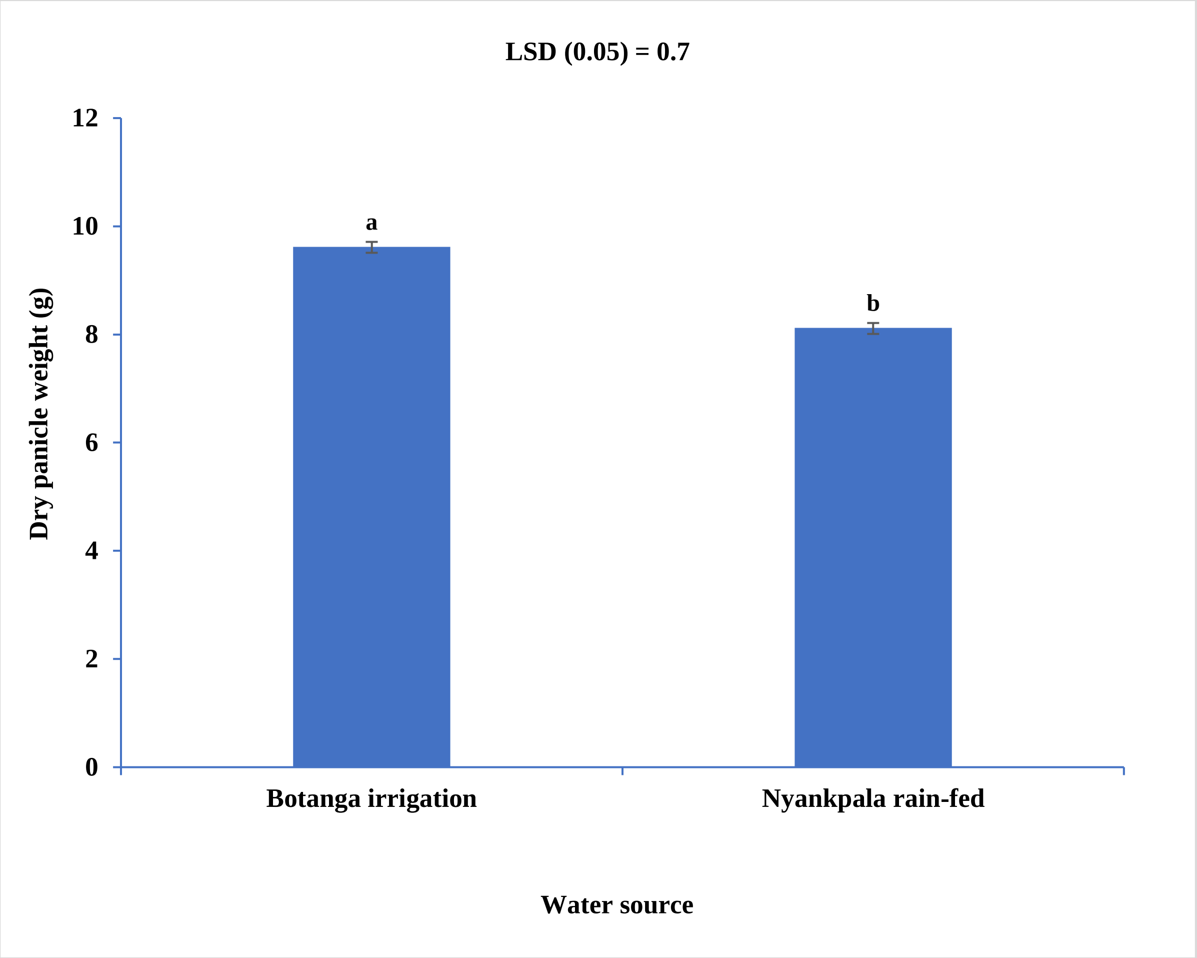

Figure 10: Effect of water source on dry panicle weight under two locations. Bars represent (SEM)

4.9 Fresh and dry straw weight

The fertilizer treatments had a significant ($P < 0.001$) influence on the straw biomass (Figure 11). The soil and foliar applications of Zn and S in combination with NPK (NPK + Zn + S and NPK + Zn + S) elicited statistically the same effect on straw biomass. The two were outstanding in stimulating straw production though the soil applied (Zn + S) had the same effect as S and Zn individually applied by foliar. Foliar applied S together with NPK was significantly better than the soil counterpart (NPK + S) (Figure 11). On the other hand, soil applied NPK + Zn also outperformed foliar spray NPK + [Zn] in fresh straw production. Similar patterns were obtained in the dry straw biomass as [Zn + S], both soil and foliar, performed better than the other treatments. The Zn and S applied individually did better than the sole NPK (Figure 11).

Statistically, Botanga irrigation field produced greater fresh straw biomass (3581 kg/ha) and dry straw biomass (2152 kg/ha) than Nyankpala rain-fed field which recorded low fresh (3103 kg/ha) and dry (1677 kg/ha) straw biomass (Figure 11).

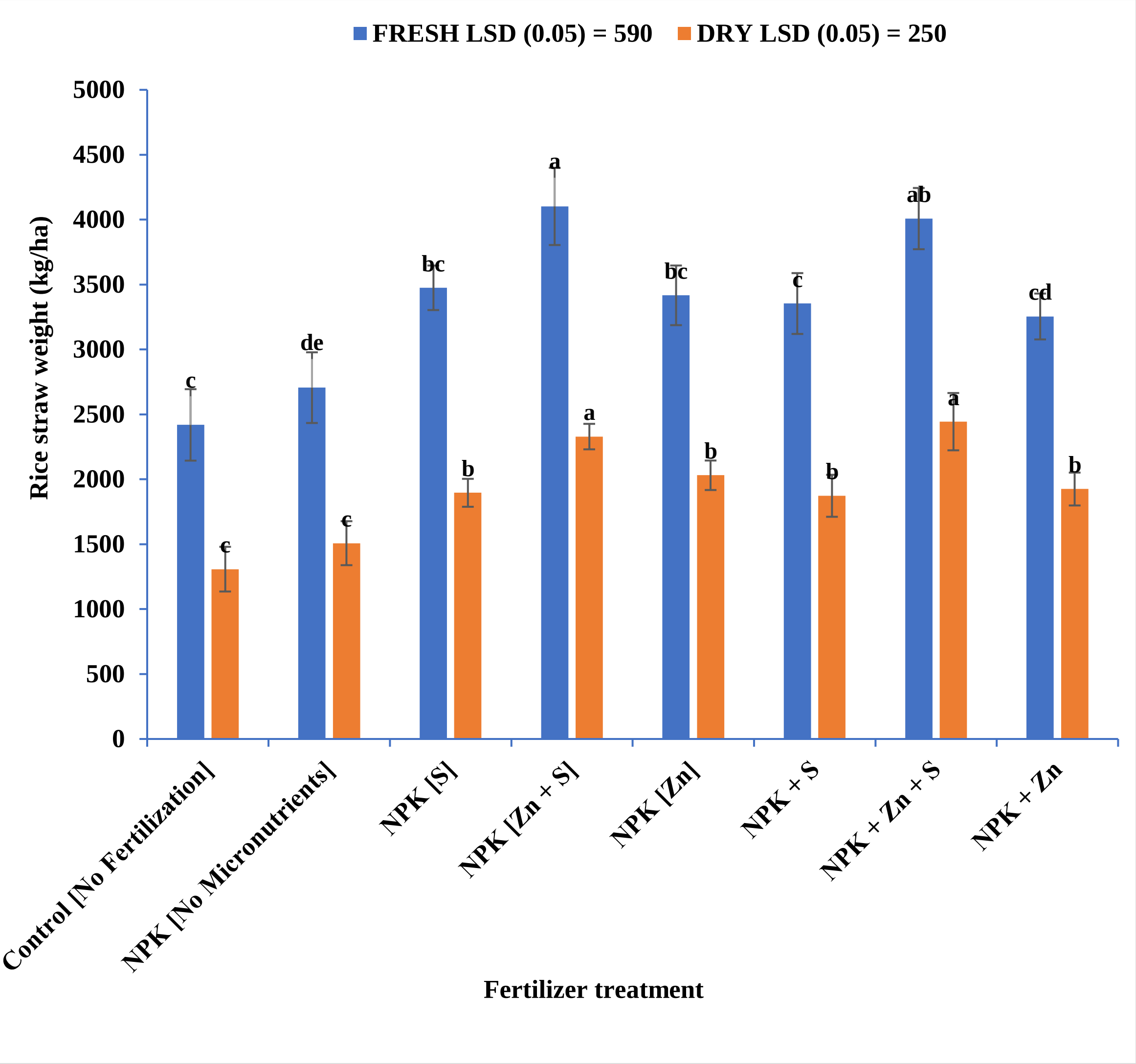

Figure 11: Influence of soil and foliar Zn and S addition to NPK on fresh and dry straw weight. Bars represent (SEM)

4.10 Grain yield

The location and fertilizer interaction significantly ($P = 0.048$) influenced grain yield (Figure 12). Yields across the different treatments were relatively higher at Botanga when compared with Nyankpala. The soil applied zinc and sulphur in combination, produced significantly higher grain than the counterpart delivered by foliar (Figure 12). When the yield due to soil (Zn + S) was compared for the two sites, it was observed that yield at Botanga was double that of Nyankpala (Figure 12). At Botanga, the yield from the other treatments, apart from soil (Zn + S) were not significantly different from the sole NPK without any S or Zn addition. However, at Nyankpala, it was foliar applied [Zn + S] that was significantly different from the sole NPK. The addition of Zn and S to NPK individually either by foliar or soil did not stimulate higher yield than sole NPK (Figure 12).

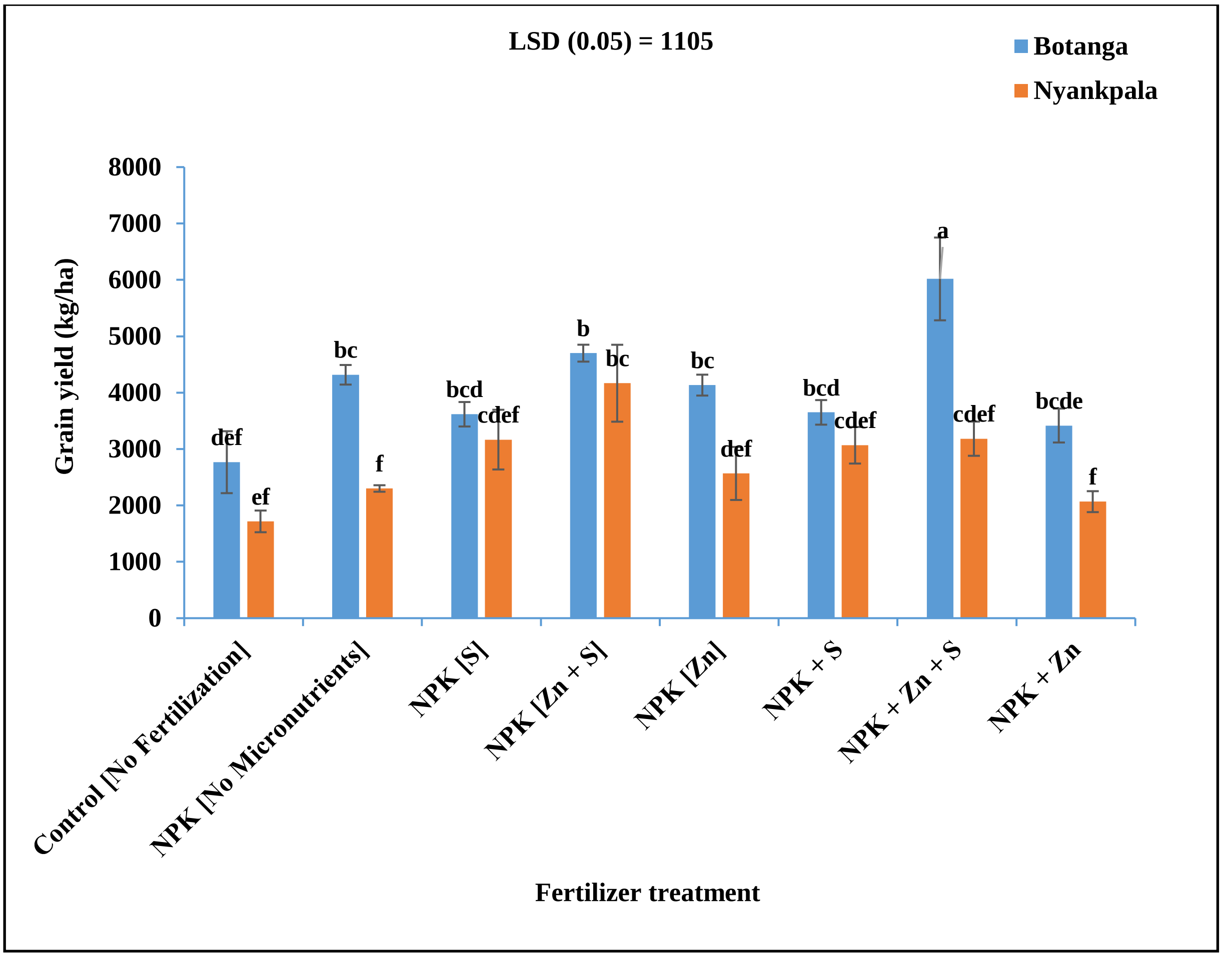

Figure 12: Influence of soil and foliar Zn and S addition to NPK on rice grain yield. Bars represent (SEM)

4.11 One thousand (1000) paddy rice weight

The location and fertilizer interaction showed significant difference ($P < 0.001$) in 1000 grain weight. A combination of NPK + Zn + S, gave the highest fresh and dry 1000 grain weight at Botanga irrigation field. The three foliar treatments performed better than sole NPK at Botanga. Soil [S] and Soil [Zn] were also not significantly different from the sole NPK and the control (Table 4).

In contrast, the Nyankpala rain-fed revealed that there were not significantly difference between the fertilizer incorporated with Zn and S and the sole NPK, they were however different from the control. The dry 1000 grain weight followed the fresh grain weight pattern (Table 4).

Table 4: Influence of soil and foliar Zn and S addition to NPK on 1000 fresh and dry paddy rice weight

LOCATION	TREATMENT	1000 FRESH WEIGHT (g)	1000 DRY WEIGHT (g)
Botanga	Control [No Fertilization]	24.13cde	22.37ef
	NPK [No Micronutrients]	24.53cde	22.30ef
	NPK [S]	26.27ab	23.67cd
	NPK [Zn + S]	26.33b	24.90ab
	NPK [Zn]	26.30b	23.33cdef
	NPK + S	25.77bc	23.37cdef
	NPK + Zn + S	27.70a	25.23a
	NPK + Zn	25.07bcd	23.20def
Nyankpala	Control [No Fertilization]	23.50e	20.87g
	NPK [No Micronutrients]	24.03de	22.13f
	NPK [S]	25.53bcd	23.67cd
	NPK [Zn + S]	25.03bcd	23.13def
	NPK [Zn]	25.20bcd	24.47abc
	NPK + S	24.90bcde	23.50cdef
	NPK + Zn + S	24.37cde	23.90bcd
	NPK + Zn	25.33bcd	23.30cdef
***P.* value**		**0.03**	**0.01**
Lsd (0.05)		**1.33**	**1.09**
% *Cv*		**3.2**	**2.8**

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of the fertilizer treatments on growth parameters

Tillering is an important morphological feature in cereals because it influences the quantity of panicles or ears produced in the final stand. Tillering in cereals is heavily influenced by mineral nutrition. Tillering increased in cereals (rice, wheat, barley and oats) in a quadratic relationship with plant age (Haruna, 2019). The tiller proliferation and subsequent panicle development are influenced by genetics, environment and plant nutrition. All the plots except the control, recorded some good number of tillers at 4 WAT and 6 WAT.

At the Botanga irrigation site, foliar [Zn + S], was similarly the most effective treatment for promoting tillering, with soil delivered (Zn + S), performing best. Furthermore, Botanga irrigation field recorded more tillers than the Nyankpala rain-fed field. The results of expanding auxiliary buds are tillering and panicle initiation, which are strongly linked to the mother culm's nutritional status during its initial growth phase and are enhanced by the use of sulphur because it boosts the effectiveness of other nutrients, notably nitrogen and phosphorus (Vida (2020). According to (Hawkesford *et al.*, 2023), sulphur, as a necessary constituent of proteins, must be applied because protein synthesis is dependent on it. The authors argued that it facilitates the production of other plant hormones like thiamine and biotin, as well as specific amino acids like methionine and cysteine, which are essential for improving tillering in rice productivity. Again, an extensive amount of sulphur in the soil improves nitrogen uptake, a significant nutrient that plays an important role in eliciting tiller number due to its capacity to enhance cytokinin in the tiller nodes, which then improves tiller primordium initiation. The overall outstanding reaction of the tiller count to sulphate treatment certainly indicates that sulphur deficiency essentially prevents the best utilization of both internal and external nitrogen sources for the synthesis of rice dry matter. A fair supply of these elements is essential for effective dry matter formation, as sulphur and nitrogen are both essential components of proteins (Liu *et al.*, 2022). The rise in tiller numbers due to Zn fertilizer application might be ascribed to Zn's involvement in increasing physiological activities such as photosynthesis and plant nutrient translocation, which resulted in an increase in tiller counts. These findings coincide with those of (Hassan *et al.*, 2019). The rise in effective tillers, which contribute to economic yield, could be likened to sufficient zinc and sulphur supply to crops, resulting in improved crop growth at 8 WAT. The intake of sufficient quantities of sulphur and zinc throughout the growth cycle has a synergistic impact on increasing effective tillers, which form panicles. The results are in conformity with findings of Vida (2020). The results reveal that Zn and S when combined and delivered to crop either foliar or soil have synergistic effect on tillering. The soil applied (Zn + S) as basal had enough time to be utilized and that may be the reason why it recorded higher effective tiller than the foliar counterpart.

Moreover, both sulphur and zinc combined applied through soil and foliar had a significant impact plant height of rice at all weeks measured. When the sulphur and zinc were applied individually through soil or foliar their effect was not different from the control treatments (Abel *et al.*, 2021). Sulphur has been linked to the mediating of plant metabolic processes, which might have resulted in enhanced photosynthesis and, as a result, plant height. Sulphur has been shown to be essential for rice development, since it is required in sufficient amounts for glucose absorption and impacts chlorophyll and photosynthesis production. The results agreed with findings of (Hassan *et al.*, 2019)

Zinc is known for speeding enzymatic activity and auxin metabolism in plants. Awan *et al.* (2021) also arrived at similar conclusions about zinc function in plant growth. Zinc application to rice in the form of zinc sulphate has been reported by Hassan *et al.* (2019) to have improved plant height. The combination of zinc and sulphur applied by foliar or soil had tremendous effect on plant height. These results were similar to tillering observed in the preceding paragraph.

Micronutrients, the primary component of chlorophyll, in conjunction with nitrogen, the principal ingredient of chlorophyll, increase the crop's photosynthetic efficiency, resulting in higher leaf size and number (Kadam *et al.*, 2018). The results indicated that Zn + S applied through soil and foliar improved leaf area index (LAI) better. Sulphur applied to the crop through soil exhibited the similar performance as Zn + S. Sufficient sulphur availability aided plants in their strong leaf development and foliage. As a result, additional leaves with enlarged leaf blades were generated, increasing the leaf area and leaf weight (Narayan *et al.*, 2022). Enhanced leaf characteristics as a result of Zn treatment might be attributed to Zn's function in promoting better root growth via an increase in the number of dividing cells, which leads to higher leaf growth qualities. Furthermore, Zn improves important metabolic processes such as glucose metabolism, chlorophyll production, and ribosomal functioning (Mishra *et al.*, 2019). The increase in leaf area by treatment having NPK with Zn and S most likely due to enhanced plant leaf expansion. Increase in crop performance as a result of combination of micronutrients to NPK clearly demonstrates deficit of micronutrients in most soils (Voortman and Bindraban, 2015). IFDC research trials in Africa cited in Dimkpa and Bindraban (2016) demonstrated the importance of nitrogen, phosphorus, and potassium or nitrogen and phosphorus in addition to sulphur, zinc, and boron in crop performance. In general, NPK in combination with Zn or S, either soil or foliar application, increased the photosynthetic activity and leaf area of the crop. The results are supported by Senthilkumar *et al.* (2023) who reported that the use of micronutrient in addition to NPK fertilizer enhanced rice growth parameters.

The SPAD meter reading indicates the chlorophyll concentration of the plant and can be used to determine the N status of rice crops (Mehrabi *et al.,* 2022). The relevance of NPK in promoting chlorophyll formation is illustrated by the fact that all plots treated with NPK reported significantly greater chlorophyll content than the untreated control. Protein, enzyme, and chlorophyll synthesis all depend on the availability and delivery of nitrogen, while P and K are necessary for the development of a vigorous plant root system and N absorption, respectively. By week six after planting, i.e., four and two weeks after soil and foliar application of Zn + S respectively, it was observed that Zn + S delivered through both path ways impacted on chlorophyll development. In the later stage, only soil applied Zn + S impacted on chlorophyll development. Plants absorb sulphur and zinc fertilizer, using it for a variety of metabolic processes to create the chlorophyll necessary for optimal growth and development (Bhantana *et al.*, 202). Crops that cooperated and contributed to the structure and synthesis of chlorophyll may have absorbed these nutrients, leading to improved yield characteristics. These results are in line with the findings of (Dimkpa and Bindraban, 2016)

According to Haruna (2019) the crop's dry matter explains the true growth dynamics of arable crops. Straw yields improved as a result of sufficient Zn and S supplies. The simultaneous treatment of Zn and S (NPK [Zn + S]) delivered through both foliar and soil led to the greatest straw yield. Foliar application of Zn and S individually also performed closer to their combined application and delivered by foliar. The combined application of sulphur and zinc boosted photosynthesis and carbohydrate metabolism, which contributed to the overall straw production. Combination of sulphur and zinc stimulated chlorophyll development as seen figure 5 and 6. This spectacular performance of zinc and sulphur translated into straw weight. The roles of sulphur together with zinc in promoting straw yield of rice have been reported (Kumar *et al*., 2018). The discussion so far shows the significance of zinc and sulphur application on plant growth in both pathways of delivery to rice in this two ecologies, rain-fed and irrigation.

5.2 Influence of Zn and S application on earliness to flowering and maturity

As revealed by the results, the location and fertilizer treatment correlated. At Nyankpala, soil applied S and Zn + S, were the earliest to flower while at Botanga irrigation site the soil applied S, Zn and Zn + S, flowered earlier than the foliar, but the days to flowering were longer than that of Nyankpala rain-fed site. The availability of water throughout the growth and development periods might have contributed to the Botanga trials having longer time to flower.

In terms of maturity, it appeared that the foliar treatments generally matured later. The combined effect Zn and S may have played a major part in the enhancement of physiological processes that resulted in the early beginning of blooming. The findings agreed with Raj *et al.* (2022) and Zhang *et al.* (2021) who reported that mango crops sprayed with micronutrients encouraged early flowering and the application of zinc to rice decreased the maturity period.

5.3. Influence of Zn and S application on grain yield parameters

The application of zinc and sulphur along with NPK had an impact on panicle size, which is a significant factor in determining grain output, particularly when the crop was delivered to it via soil. Sulphur has been reported to have enhanced shoot development and dry matter accumulation which led to increased panicle and paddy weight (Zhang *et al.,* 2019). The contribution of Zn to yield attribute trait enhancement might be the result effective Zn participation in several metabolic processes involved in the development of healthy seeds (Haider *et al.*, 2018). The combined effect of Zn and S in physiological process involved in panicle development was pronounced and was spectacular when delivered to the crop through soil.

In the irrigated site at Botanga, soil applied Zn + S, was the best treatment influencing grain yield and 1000 grain weight whiles at the rain-fed Nyankpala, the foliar Zn + S, was the best treatment promoting grain yield. Could it be that water requirement for maximal uptake of the sulphur and zinc might have been limited at the rain-fed site making foliar delivery the better option for the crop as compared with Botanga where the irrigation ensure consistent water supply thereby relying on soil delivered Zn and S?

A study has shown that when micronutrients were combined with NPKS, grain yield and yield contributing characteristics such as plant height, number of effective tillers hill^{-1}, number of grains panicle^{-1}, and rice's dry matter yield performed better than when NPKS was applied alone (Siddika *et al.*, 2016). Sulphur and zinc have been reported to have had a significant effect on the number of panicles/m^2 which increases the rice's economic output (Abel *et al.*, 2021). This could be likened to the cumulative impact of a well-balanced and appropriate intake of macro and micro nutrients on rice metabolism.

The source strength, sink strength, and flow capacity are the three primary determinants of grain increase in the rice plant. Zinc and sulphur are known to have a beneficial influence on these key variables, which in turn have a significant impact on grain production. Sulphur and zinc are known to influence metabolite movement, improving the potency of the source and sink in plants (Li *et al.*, 2018). Sulphur's function in contributing to improved rice growth and yield may have led to higher straw and grain production, as sulphur promoted chloroplast protein synthesis, leading to greater photosynthetic efficiency, which boosted yield. Zinc contributes to higher straw production by boosting plant nutrient absorption from the soil and therefore providing it to the aerial portions of the plant, resulting in more reproductive growth and grain production (Awan *et al.*, 2021). In all the results of the findings could be likened to Dimkpa and Bindraban (2016) who eluded that a well-balanced and appropriate intake of macro and micro nutrients in rice plant increases both growth and yield parameters.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The goal of this study was to determine the most efficient method of administering Zn and S to rice as well as assess the impacts of Zn and S, on grain production. The results of this study demonstrated that:

- In terms of tillering, it can be concluded that when there is interaction, soil applied Zn + S, was more effective in irrigation site while foliar Zn + S, was the best treatment in rain-fed ecology.
- Assessment of the treatments in effective tiller number revealed that soil applied Zn + S, promoted it better than the foliar counterpart and that the individual application of S and Zn was not better than the sole NPK application
- Soil and foliar applied Zn + S, had similar effect on plant height and they were better than their individual applications.
- Foliar and soil applied Zn + S, did not show difference in their effect on leaf area. The two treatments were better than all other treatments except soil applied sulphur.
- Both soil and foliar applied Zn + S, impacted on greenery of rice but towards the later stage soil applied Zn + S, dominated the other treatments.
- Panicle size was impacted on by the combined application of Zn + S, especially when delivered to the crop by soil.
- The co-treatment of zinc and sulphur, NPK + Zn + S, delivered both foliar and soil, resulted in the greatest straw production. Foliar application of S and

Zn individually also performed closer to their combined application and delivered by foliar.

- In the irrigated site at Botanga soil applied Zn + S was the best treatment that promoted grain yield and 1000 grain weight whiles in the rain-fed Nyankpala, the foliar Zn + S was the best treatment influencing grain yield.
- Generally, the combined application of Zn + S was better than their individual application. When there is interaction between location and fertilizer, the irrigated ecology favoured soil application of Zn + S while rain-fed ecology supported foliar application. Narrowing to fertilizer treatment, it can be concluded that soil applied NPK + Zn + S impacted on most of the parameters studied.

6.2 Recommendation

The researcher makes the following recommendations on the basis of the findings:

- Application of NPK [Zn + S], should be adopted for yield optimization in rice production systems.
- In irrigation ecology [Zn + S] should be applied by soil whiles in rain-fed ecology they should be applied by foliar.
- The study needs to be repeated to refine the results in order to rule out the effect of the drought during the farming season.

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APPENDICES

Appendix 1: Analysis of variance for number of tillers per hill at 4WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	2.667	1.333	0.50	
REPS.*Units* stratum					
LOCATION	1	22.688	22.688	8.58	0.006
TREATMENT	7	185.979	26.568	10.05	<.001
LOCATION.TREATMENT	7	22.812	3.259	1.23	0.316
Residual	30	79.333	2.644		
Total	47	313.479			

Appendix 2: Analysis of variance for number of tillers per hill at 6WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	8.167	4.083	1.47	
REPS.*Units* stratum					
LOCATION	1	38.521	38.521	13.90	<.001
TREATMENT	7	234.479	33.497	12.08	<.001
LOCATION.TREATMENT	7	47.646	6.807	2.46	0.041
Residual	30	83.167	2.772		
Total	47	411.979			

Appendix 3: Analysis of variance for number of tillers per hill at 8WAP (Effective tillers)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	0.500	0.250	0.16	
REPS.*Units* stratum					
LOCATION	1	27.000	27.000	17.80	<.001
TREATMENT	7	118.583	16.940	11.17	<.001
LOCATION.TREATMENT	7	15.667	2.238	1.48	0.214
Residual	30	45.500	1.517		
Total	47	207.250			

Appendix 4: Analysis of variance for plant height at 4WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	19.520	9.760	1.09	
REPS.*Units* stratum					
LOCATION	1	764.803	764.803	85.19	<.001
TREATMENT	7	1228.753	175.536	19.55	<.001
LOCATION.TREATMENT	7	78.877	11.268	1.26	0.305
Residual	30	269.340	8.978		
Total	47	2361.292			

Appendix 5: Analysis of variance for plant height at 6WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	16.11	8.05	0.46	
REPS.*Units* stratum					
LOCATION	1	1719.61	1719.61	98.13	<.001
TREATMENT	7	2070.91	295.84	16.88	<.001
LOCATION.TREATMENT	7	120.50	17.21	0.98	0.462
Residual	30	525.73	17.52		
Total	47	4452.85			

Appendix 6: Analysis of variance for plant height at 8WAP (panicle stage)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	17.00	8.50	0.44	
REPS.*Units* stratum					
LOCATION	1	653.43	653.43	33.44	<.001
TREATMENT	7	1839.50	262.79	13.45	<.001
LOCATION.TREATMENT	7	38.43	5.49	0.28	0.956
Residual	30	586.18	19.54		
Total	47	3134.55			

Appendix 7: Analysis of variance for leaf area index at 4WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	7.2039	3.6020	5.35	
REPS.*Units* stratum					
LOCATION	1	50.7351	50.7351	75.33	<.001
Fertilizer	7	35.8295	5.1185	7.60	<.001
LOCATION.TREATMENT	7	0.4869	0.0696	0.10	0.998
Residual	30	20.2053	0.6735		
Total	47	114.4608			

Appendix 8: Analysis of variance for leaf area index at 6WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	5.3456	2.6728	3.18	
REPS.*Units* stratum					
LOCATION	1	112.0210	112.0210	133.32	<.001
Fertilizer	7	109.5466	15.6495	18.62	<.001
LOCATION.TREATMENT	7	15.8310	2.2616	2.69	0.027
Residual	30	25.2076	0.8403		
Total	47	267.9518			

Appendix 9: Analysis of variance for Chlorophyll content at 4WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	8.167	4.083	0.47	
REPS.*Units* stratum					
LOCATION	1	287.141	287.141	32.76	<.001
TREATMENT	7	168.159	24.023	2.74	0.025
LOCATION.TREATMENT	7	72.859	10.408	1.19	0.339
Residual	30	262.913	8.764		
Total	47	799.239			

Appendix 10: Analysis of variance for Chlorophyll content at 6WAP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	1.45	0.73	0.06	
REPS.*Units* stratum					
LOCATION	1	931.92	931.92	75.62	<.001
TREATMENT	7	671.11	95.87	7.78	<.001
LOCATION.TREATMENT	7	171.27	24.47	1.99	0.091
Residual	30	369.69	12.32		
Total	47	2145.44			

Appendix 11: Analysis of variance for Chlorophyll content at 8WAP (flag leaf)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	46.32	23.16	1.30	
REPS.*Units* stratum					
LOCATION	1	97.76	97.76	5.47	0.026
TREATMENT	7	680.95	97.28	5.44	<.001
LOCATION.TREATMENT	7	114.94	16.42	0.92	0.506
Residual	30	536.07	17.87		
Total	47	1476.03			

Appendix 12: Analysis of variance for days to 50% flowering

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	0.792	0.396	0.20	
REPS.*Units* stratum					
LOCATION	1	808.521	808.521	405.10	<.001
TREATMENT	7	176.979	25.283	12.67	<.001
LOCATION.TREATMENT	7	35.313	5.045	2.53	0.036
Residual	30	59.875	1.996		
Total	47	1081.479			

Appendix 13: Analysis of variance for days to 50% maturity

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	0.792	0.396	0.07	
REPS.*Units* stratum					
LOCATION	1	130.021	130.021	21.69	<.001
TREATMENT	7	134.312	19.188	3.20	0.012
LOCATION.TREATMENT	7	31.479	4.497	0.75	0.632
Residual	30	179.875	5.996		
Total	47	476.479			

Appendix 14: Analysis of variance for panicle weight

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	0.500	0.250	0.16	
REPS.*Units* stratum					
LOCATION	1	27.000	27.000	17.80	<.001
TREATMENT	7	118.583	16.940	11.17	<.001
LOCATION.TREATMENT	7	15.667	2.238	1.48	0.214
Residual	30	45.500	1.517		
Total	47	207.250			

Appendix 15: Analysis of variance for fresh straw weight

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	3137604.	1568802.	6.26	
REPS.*Units* stratum					
LOCATION	1	2749222.	2749222.	10.97	0.002
TREATMENT	7	13856533.	1979505.	7.90	<.001
LOCATION.TREATMENT	7	468877.	66982.	0.27	0.962
Residual	30	7516354.	250545.		
Total	47	27728590.			

Appendix 16: Analysis of variance for dry straw weight

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	770046.	385023.	8.54	
REPS.*Units* stratum					
LOCATION	1	2701566.	2701566.	59.91	<.001
TREATMENT	7	6001689.	857384.	19.01	<.001
LOCATION.TREATMENT	7	674242.	96320.	2.14	0.070
Residual	30	1352767.	45092.		
Total	47	11500309.			

Appendix 17: Analysis of variance for grain yield

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	932188.	466094.	1.06	
REPS.*Units* stratum					
LOCATION	1	20215052.	20215052.	46.03	<.001
TREATMENT	7	25735781.	3676540.	8.37	<.001
LOCATION.TREATMENT	7	7237031.	1033862.	2.35	0.048
Residual	30	13174479.	439149.		
Total	47	67294531.			

Appendix 18: Analysis of variance for one thousand fresh grain weight

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	5.3712	2.6856	4.23	
REPS.*Units* stratum					
LOCATION	1	12.6075	12.6075	19.84	<.001
TREATMENT	7	26.8333	3.8333	6.03	<.001
LOCATION.TREATMENT	7	11.4258	1.6323	2.57	0.034
Residual	30	19.0621	0.6354		
Total	47	75.3000			

Appendix 19: Analysis of variance for one thousand dry grain weight

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
REPS stratum	2	2.6979	1.3490	3.17	
REPS.*Units* stratum					
LOCATION	1	2.1675	2.1675	5.10	0.031
TREATMENT	7	39.7867	5.6838	13.37	<.001
LOCATION.TREATMENT	7	10.5658	1.5094	3.55	0.007
Residual	30	12.7487	0.4250		
Total	47	67.9667			