UNIVERSITY FOR DEVELOPMENT STUDIES

FOLIAR APPLICATION OF PHOSPHORUS, SULPHUR AND MICRONUTRIENTS OF ZINC AND IRON ON GROWTH AND YIELD OF RICE (*Oryza sativa* L.) UNDER RAINFED AND IRRIGATION IN THE GUINEA SAVANNA ECOLOGY OF GHANA

WILFRED KOJO KOKONU

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FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES

DEPARTMENT OF CROP SCIENCE

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BY

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THESIS SUBMITTED TO THE DEPARTMENT OF CROP SCIENCE, FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

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DECLARATION

Except for references to other people's work that I have fully recognized, I hereby certify that this thesis is the result of my own original work and that no part of it has been presented for the granting of a degree in this University or elsewhere.

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Statement of the Supervisors

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

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ABSTRACT

Rice (*Oryza sativa* L.) is a widely cultivated cereal crop in varied environments. It is grown for its high-quality grains that are high in carbohydrates. Rice production has employed more than 20 million African farmers, and it is estimated that rice provides a living for roughly 100 million people. A field experiment was carried out at two locations during the 2020 farming season, to examine the relative responses of rice to soil P and foliar P, and if foliar P application could compensate for lower soil applied P rate. In addition, if foliar Zn, Fe, and S applications might boost rice grain output. The study was a 2 x 8 factorial experiment laid out in randomized complete block design with three replications. The locations were Nyankpala and Bontanga under rainfed lowland and irrigation conditions respectively, and the nutrient formulations included: NPK1, NPK1+Zn+S+Fe, NPK1+Zn+Fe, NPK1+Zn, NPK2, NPK2+P+Zn+S+Fe, NPK2+P+Zn+Fe and NPK2+P+Zn. AGRA rice variety, which has a maturity period of 125 to 130 days was tested under both irrigated and rainfed lowland rice growing conditions. Results showed foliar P performed better in growth and yield responses compared to soil applied P, whilst irrigation ecology generally enhanced parameters more than the rainfed ecology. Rice yield increased with application of foliar S and the micronutrients, Zn and Fe; whereas foliar P application compensated for lower soil applied P. Grain yield was improved by combinations of micro- and macro-nutrients. Overall, higher responses in rice production were best supported by four treatments: NPK2+P+Zn, NPK1+Zn+S+Fe, NPK1+Zn, and NPK1+Zn+Fe. As such, farmers at both ecologies could improve rice production with the inclusion of foliar application of Zn, S, and Fe in their fertilization programme in order to maximize grain yield.

DEDICATION

I dedicate this research to Sarah Nana Ama Quist Kokonu and Wilhelmina Afya Ohenewaa Quist Kokonu.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Rice (*Oryza sativa* L.) is a staple food for the vast majority of the world's population. It is, however, a poor provider of certain mineral nutrients that humans require, particularly Fe and Zn (Yuan et al., 2013). Rice is one of the most important cereals in the world, and it may be grown in several environments, including lowland, irrigated, and upland. Rice is grown for its high-quality grains, which are high in carbohydrates (Djomo et al., 2017). According to reports, Ghana imports nearly half of its rice needs each year, and attempts are being made to expand rice output through the introduction of technologies that increase rice yield and productivity, hence reducing rice importation. Rice has been genetically improved through the use of hybrid types. However, the present semi dwarf inbred types break over the yield plateau (Ofori et al., 2020).

Rice production has employed more than 20 million African farmers, and it is estimated that rice provides a living for roughly 100 million people. More than 3 billion people utilize rice as their primary source of nutritional calories (Dauda, 2015). It is mostly grown by farmers in small plots of land of less than one hectare and is a key source of food for the rural populace (Ref). Rice is widely regarded as the most versatile and diversified crop on the planet. Since 1973, rice consumption in West Africa has been gradually increasing at a pace of 6% per year. As a result, the continent now consumes far more rice than it produces, necessitating massive imports (Dauda, 2015). Rice has overtaken maize as Ghana's second most significant food staple, and its consumption continues to rise as the country's population, urbanization, and consumer habits change (Ref). Annual output fluctuations are primarily attributable to changes in the area (ha) planted to rice rather than yield variations (t/ha) (MOFA, 2009).

The soil's type, season, character, and composition, as well as the degree of yield, have a significant impact on rice nutrient requirements, absorption and removal. The early panicle-initiation stage has been observed to absorb nearly half of the overall nutritional requirements (50 percent of N, 55% of K, and 65% of P) (Roy et al., 2006). The rice crop absorbs 20 kg N, 11 kg P_2O_5, 30 kg K_2O, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo, and 52 kg Si to create one ton of paddy. Although larger quantities of K, Ca, Mg, Si, Fe, Mn, and B remain in the straw, grain partitioning of N and P is higher (3:1) than straw partitioning. In straw and grain, S, Zn, and Cu are distributed quite evenly (Roy et al., 2006). To achieve great grain yield levels, modern rice cultivars require an adequate number of essential nutrients. In 2010–2011, rice accounted for 14.3% (24.7 Mt) of the total 172.2 Mt fertilizer ($N+P_2O5+K_2O$) used globally. The percentages of nitrogen (N), phosphorus (P), and potassium (K) were calculated as 15.4, 12.8, and 12.6, respectively (Chauhan et al., 2017). According to reports, phosphorus is one of the primary nutrient elements necessary in rice nutrition, out of a total of 16 vital elements. P affects natural and agricultural ecosystems more than any other major plant nutrient. P is the second most limiting nutrient after N in most soils around the world, and it is unavailable to plants in most soil conditions. There would be no living things if there was no P in the environment. It is a nutrient that both plants and animals require (Amaral et al., 2013). In tropical soils, phosphorus shortage is a significant nutritional issue. P-deficient soils are uncommon in the tropics, and those that are don't usually necessitate huge amounts of P fertilizer. Some of its beneficial effects on plant growth include root stimulation, early flowering, ripening, and encouraging ideal grain production (Atakora et al., 2015). The plant's tolerance to low P content, phosphorus absorption power per unit root weight, and the distribution of absorbed phosphorus between the root and the shoot were found to be the main determinants of low phosphate tolerance. Phosphorus is a critical nutrient, particularly in Africa, where an estimated 50% of cropland is deficient in the mineral (Atakora et al., 2015).

Potassium is an important mineral for plant growth and overall health. Potassium promotes pest and disease resistance in crops by avoiding lodging. Potassium promotes an increase in the number of spikelets per panicle, as well as the percentage of complete grains and the weight of 1000 grains. In high yielding rice systems, potassium is frequently the most limiting nutrient after nitrogen (Chauhan et al., 2017). Despite the fact that the crop absorbs a lot of K, a lot of it gets lost in the straw. Traditional rice varieties have a poor reaction to K. Improved varieties, on the other hand, frequently respond to K when fed enough N and P. On sandy soils, the sensitivity to K is frequently stronger (Roy et al., 2006). Potassium is essential for lignification of vascular bundles, which makes K-deficient plants more susceptible to lodging and disease. Because the onset of K scarcity is visible as a color change in lower leaves, the symptoms of K deficiency in rice are sometimes confused with those of N deficiency. Common signs of K deficiency in rice include chlorosis of the interveinal areas and margins of the lower leaves beginning at the leaf tip, stunted plants with little or no reduction in tillering, droopy and dark green top leaves, and chlorosis of the interveinal areas and margins of the lower leaves beginning at the leaf tip. Potassium deficiency causes rice grains to shrink in size and weight, resulting in a direct yield drop (Chauhan et al., 2017).

Sulphur (S), which accounts for over 90% of organic S in plants, is involved in amino acid and protein synthesis, as well as enzymatic and metabolic processes. Sulphur (S) deficits are fast accumulating in areas under oilseeds and pulses due to increased S removal by crops (Kumar Singh et al., 2012). Rice's Sulphur demand changes depending on nitrogen availability. When S becomes limited, adding N has little effect on plant yield or protein levels. Rice plants require Sulphur early in their development. If it restricts early growth, the quantity of tillers and final output will be lowered. The roots of most plants take Sulphur in the oxidized sulphate form. Rice's potential to absorb sulphide is uncertain, but because its tissues are sensitive to low amounts of sulphide, it is unlikely to represent a substantial Sulphur source for the plant (Kumar Singh et al., 2012).

Soil fertilization, foliar sprays, and seed treatment are the three most frequent techniques for providing micronutrients to crops, but fertigation is also an option. Each method has the ability to change plant micronutrient nutrition both directly in the treated plant and indirectly in offspring plants due to seed enrichment generated by the parent's micronutrient treatment. Micronutrient sprays applied to the leaves have been successful in achieving both goals. As a result, treating seeds with micronutrients could be a straightforward and economical way to improve micronutrient plant nutrition (Johnson et al., 2005).

Zn and Fe deficiency are common health issues in humans. With over 1.6 billion people suffering from iron deficiency worldwide, it is the most common nutritional condition (Kadam et al., 2018). Deficits in micronutrients are becoming more common. It's critical to recognize and correct them wherever they appear. In rice fields, Zn and Fe deficiencies are common, particularly on high pH soils, with Fe being more prevalent in highland rice. Fe deficiency, on the other hand, can be remedied by foliar sprays of 1% ferrous sulphate every 2–3 weeks (Roy et al., 2006). When micronutrients are in short supply, the growth and yield of crops are severely depressed. Micronutrient shortage makes it impossible for plants to benefit fully from NPK fertilizer treatment. Micronutrient deficiency affects human health, farmers' economic standing, and the environment in 50% of the world's soils and many crops, reducing the amount and quality of food available (Siddika et al., 2016).

1.2 Problem Statement

In most African countries, rice demand outstrips supply, as a result, massive amounts of goods are imported at a high cost in foreign currency to suit domestic needs. The difficulty of Ghana to achieve rice self-sufficiency is linked to substantial problems throughout the rice production chain, resulting in low grain output (Haruna, 2019). Low-quality production technology and the prevalence of agriculture in highland agroecosystems are two factors that contribute to Ghana's low grain output (Haruna, 2019). The government's efforts to enhance fertilizer usage on farms have been ineffective since it is still reported to be low. Fertilizer consumption by farmers in the sub-region is said to be quite low, resulting in low productivity of farmers' fields, according to fertilizer subsidy programs undertaken in Ghana and other West African countries. Micronutrients and other essential elements for plant growth and development are inadequate in many mineral fertilizers used in Ghana. However, more research is needed on the effects of using micronutrients in combination with NPK in rice production in micronutrient-deficient soils. There is a paucity of knowledge on the foliar spray method of fertilizer application, which necessitates additional research. The limiting micronutrient (s) must be identified in order to boost crop productivity, and the soils should be replenished with the addition of those nutrients in a properly balanced fertilizer program.

1.3 Justification

Micronutrient deficits are becoming an increasingly important limiting factor in annual crop yield. Zn, Cu, B, Mn, and Fe deficiencies have been observed in annual crops such as rice, corn, wheat, soybean, and common bean (Alloway,2008). Increasing crop yields has become a need in modern society in order to keep up with the world's growing population. Following the 1970s recommendation, various NPK recommendations were made. The Soil Research Institute recommends 120-40-40, which is utilized in the Planting for Food and Jobs initiative. This can be accomplished by addressing issues such as inadequate soil fertility in lowland soils. Rice crop yields could be increased by using balanced, integrated fertilizer formulations with added micronutrients (Haruna, 2019).

This study seeks to know if application of S and two micronutrients Zn and Fe application will enhance rice yield components and yield. The study also seeks to know if the three nutrients will compensate for yield if the P rate is reduced.

1.4 Objectives

- To determine whether rice responses better to soil or foliar P, under both rainfed lowland and irrigation conditions?
- To examine if foliar application of P compensates for reduced soil applied P, under both rainfed lowland and irrigation conditions?
- To access if foliar Zn, S, and Fe application will boost rice yield and yield component over NPK, under both rainfed lowland and irrigation conditions?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany and systematics

The genus *Oryza*, which includes farmed rice, as a wild grass, it is expected to have existed for at least 130 million years. *Oryza* has 24 species and a chromosomal number of 2n=24. The Asian rice, *Oryza sativa*, which is the most extensively produced rice, and the African rice, *Oryza glaberrima*, which is the primary rice species of rice research development, are both diploids (Obeng-Ofori, 2015). Asian rice (*O. sativa*), unlike its African counterpart (*O. glaberrima*), produces high yields with little lodging or grain cracking. Based on ecological conditions, *Oryza sativa* L. is classified into two subspecies: indica and japonica (Obeng-Ofori, 2015).

2.2 Vegetative organs

Rice plants range in height from dwarf mutants (0.3 to 0.4 m tall) to floating variants (over 7 m tall), with most commercial cultivars standing between 1 and 2 m tall. Roots, culms, and leaves are the vegetative organs. A tiller is a plant branch that bears the culm, leaves, roots, and sometimes a panicle (Opio, 2019).

2.3 Roots

Rootlets and root hairs are seen on the fibrous roots. Seminal roots are thinly branched and barely last a few days after germination. Adventitious roots emerge from nodes and are most encountered in the earliest stages of development. The secondary adventitious roots are widely branched and formed from the subterranean nodes of the juvenile culms. As the plant matures, coarse adventitious prop roots sprout in whorls from nodes above ground level (Opio, 2019).

2.4 Culm

The plant stem is known as the culm. The culm is encased in the leaf sheath and does not emerge until the panicle has headed and a little bit of it is exposed. A sequence of nodes and internodes make up the culm. Internode elongation is often less than 1mm during vegetative growth, and the culm remains close to the ground (Smith, 2003). The three to five highest internodes extend during reproductive growth to raise the panicle above the leaf sheaths. As a result, the fully grown culm has both an unelongated and an elongated section. The primary culm is the initial plant stem that emerges during vegetative growth and before tillering. It has a genetically predetermined number of leaves that develop during the growing season (Smith, 2003).

2.5 Leaves

A leaf blade plus a leaf sheath makes up a leaf (lamina). A pair of auricles and a ligule meet at their intersection. The leaf sheath's basal section is linked to a nodal plate. The leaf sheath is a cylinder-shaped elongated leaf that encloses developing new leaves. It aids in the vegetative growth of the plant and acts as a storage region for starch and sugars prior to heading (Smith, 2003). The sheath contributes 30 to 60% of shoot breaking strength during re-productive growth, which helps to sustain the stem. It encloses and shields the developing panicle and is photosynthetically active. The leaf blade is long and lanceolate, with a midrib on either side and broad and small parallel vein. The principal organ for photosynthesis and transpiration is the leaf blade. The surface of the leaf blade can be glabrous, intermediate, or pubescent. With each higher position on the main culm, the length of the complete leaf (sheath + blade) grows. The length of the blade relative to that of the sheath also increases at higher stem positions. Maximum leaf length is reached in the uppermost three to five leaves. The flag leaf is the culm's last leaf to emerge (Smith, 2003).

2.5 Floral organs

The floral organs are shoots that have been changed. The panicle, or terminal shoot, of a rice plant is a determinate inflorescence. It is carried on the culm's uppermost internode, which is commonly referred to as a peduncle, and consists of the base, neck, nodes, branches, and axis (rachis). The panicle branches out in a racemose pattern, with each node on the main axis producing primary branches, which then produce secondary branches (Opio, 2019). The pedicelled spikelets are carried by the secondary branches. Spikelets, which are made up of two sterile lemmas: the rachilla and the floret, divide the inflorescence. A floret is made up of the lemma, palea, and surrounding flower. The perianth is represented by the lodicules, while the flower consists of six stamens and a pistil (Opio, 2019).

2.6 Growth stages of the rice plant

The vegetative growth phase of the rice plant is marked by active tillering, a gradual increase in plant height, and regular leaf emergence, with the length of this phase determining the cultivar's growth duration. It starts with grain germination, when the radicle or coleoptile emerges from the germinating embryo, and continues with the pre-tillering stage, when the endosperm contents are absorbed by the growing seedling, forming seminal and lateral roots, as well as the first few leaves (Opio, 2019). Tillering begins with the emergence of the first tiller from an axillary bud at one of the lowest nodes and proceeds in a sigmoid curve until the maximum number of tillers is attained. After that, some tillers die, and the total number of tillers falls until it reaches a plateau. Lower internode elongation can begin much sooner than or at the same time as the reproductive phase (Opio, 2019). The reproductive phase might begin before or after the maximum number of tillers has been reached, or at the peak of tillering activity. The panicle primordium, which appears as a hyaline structure 1-2 mm long with a fuzzed tip after a few days and is visible to the naked eye as a hyaline structure 1-2 mm long with a fuzzed tip, marks the beginning of this phase. The booting stage, marked by a bulge in the rapidly elongating culm, shows an increase in the size of the young panicle and its upward extension into the upper leaf sheaths. Following that, the panicle emerges/exerts from the flag leaf sheath, which is also known as heading (Opio, 2019).

2.7 Importance of rice

For a substantial section of the world's population, rice (*Oryza sativa* L.) is an important food crop. Rice is a staple meal in the diets of Asian, Latin American, and African peoples. Rice is farmed on every continent except Antarctica, spanning over 161 million hectares (generating over 680 million mt), however Asia produces the majority of the grain. Rice covers more than a quarter of the world's total cereal-producing land (Amaral et al., 2013).

Rice is crucial for food security and revenue generation in many areas throughout the world. For the majority of the world's population, Rice is a mainstay of the diet. For more than two-thirds of the world's population, it provides a vital source of carbohydrate. Rice farming provides a living for more than 100 million farm families around the world. Cassava, maize, and sorghum/millet all provide fewer calories and protein than rice. Millions of people in Sub-Saharan Africa eat it as a regular part of their diet (SSA). Over 90% of rice is consumed cooked, either boiled, steamed, or fried, and served with beans, gari, veggies, fish, meat, or stews (Haruna, 2019).

Rice pudding can be made from dry rice, rice flour, rice flakes, puffed rice, or rice pudding. Rice flour is used in pastry, rice cream, pudding, and confectionery. Rice has some inherent characteristics as a food crop that make it appealing to small-scale farmers, urban impoverished people, and the wealthy alike. It has a high carbohydrate content, which gives it energy. Rice is also accessible all year, giving it a better choice for food security than other crops. Many diverse recipes have been prepared with it in various countries across the world. Rice, a nutrient-dense crop mostly consumed by humans and a major source of energy and protein, supplies a significant portion of the necessary zinc and niatin intake for humans. Rice protein is the physiologically richest among grain proteins due to its high actual digestibility (88 percent). Rice is a necessary "wage" item for people who work in non-agricultural jobs, as well as an important part of religious ceremonies, festivals, and holidays (Haruna, 2019). Rice is a crucial component of the rural community's economic and social structure. Furthermore, the rice subsector is very exposed to exchange rate swings and has considerable balance-of-payments implications. Rice is widely accepted as a medium of exchange in the barter economy, and it is frequently used to buy coffee and cocoa, tempt labor, and purchase farm inputs and wage items. Laundry detergent is made from rice starch. Rice contains a diverse range of nutritional and medicinal qualities. Vitamins, calcium, and fiber are all abundant in this dish. Insoluble fiber included in rice whole grains protects against a range of cancers in the diet. Glutamic and aspartic acid are also abundant in rice (Haruna, 2019).

2.8 Rice production in the world

Rice output is expected to rise by 65 million tons by 2028, reaching 578 million tons. While output in affluent countries is forecast to rise only slightly (+1 Mt), output in emerging economies is expected to climb by 64 Mt. During the forecast period, Asia is expected to produce the majority of new world output, accounting for 56 Mt. The world's second-largest rice producer, India, is predicted to expand the fastest (+21 Mt), followed by Least Developed Asian countries (+11 Mt), Indonesia (+7.6 Mt), China and Vietnam (+4 Mt each), and Thailand (+3 Mt) (FAO, 2019).

Global rice consumption is expected to rise by 67 Mt by 2028. Rice is still a major dietary staple across Asia, Africa, Latin America, and the Caribbean, with direct human eating being the most common end-use. Due to population growth, total rice consumption is predicted to increase by 1.1 percent per year during the next decade, compared to 1.4 percent per year in the previous decade. Almost all of the expected additional consumption is accounted for by increased food demand in developing countries, particularly in Asia (+35 Mt) and Africa (+17 Mt). Rice consumption per capita is expected to plateau or rise somewhat in most Asian countries, where the majority of the harvest is consumed domestically. Over the next 10 years, India's government's social strategy to increase underprivileged households' food security through public distribution of food grains will add 4 kg to yearly per capita intake. Rice consumption is likely to expand more swiftly in Africa, where it is quickly becoming a staple food, with per capita consumption expected to rise by more than 5 kg over the forecast period. Rice consumption per capita is predicted to increase by one kilogram per year, to 55 kilograms per year, globally. Rice utilization is forecast to rise at a slightly faster rate than worldwide supply, lowering the global stocks-to-use ratio from 34 percent in the base period to 32 percent by 2028 (FAO, 2019).

2.9 Rice production in Africa

In Ghana, Gambia, Guinea Bissau, Guinea, Cote d'Ivoire, Liberia, Senegal, and Sierra Leone, rice is the basic diet. Rice is displacing conventional grain crops such as sorghum, millet, and maize in other countries. To close the gap between supply and demand, Sub-Saharan Africa (SSA) imported more than USD 3.6 billion in rice, mostly from Asia, in 2008 (Dauda, 2015). In contrast, Africa can no longer rely on imports because Asia is unlikely to be able to export rice in the foreseeable future, and may potentially become a net importer. Importing rice is no longer a viable approach, given the recent substantial fall in global rice availability and price increases. As a result, African countries should capitalize on their mostly untapped rice potential in order to increase domestic output (Dauda, 2015).

2.10 Rice production in Ghana

Rice is rapidly becoming an important food crop in Ghana. Its growing importance, demand and productivity are largely experienced in most local communities. According to the Millennium Development Authority on Economic Growth and Poverty Reduction reported that, rice accounts for nearly 13 % of 12 total cereal consumption in Ghana. As a growing diet and major staple, it is increasingly replacing other traditional staples of rural and urban dwellers. Rice output in Ghana increased at a steady rate of 13% per year between 1989 and 1996, owing to increasing acreage and yields from 0.9 kg / ha to 2.4 kg / ha (MOFA, 2009). Despite increased production, rice imports continue to rise, now totaling $200 million each year. As a result, the government's goal is to reduce rice imports by 30% through expanding domestic output (MOFA, 2009). The present production levels are low and there exists a high potential for increasing the production of rice to the level of self-sufficiency. For the year 2013, the current per capita consumption estimate is 35 kg. Between 2009 and 2013, milled rice production in the United States ranged from 270,000 to 405,000 MT, with 160.000 to 218,300 hectares under cultivation (MOFA, 2009).

2.11 Macronutrients

In Sub-Saharan Africa, low rice yields and big yield gaps have been linked to macronutrient deficits and inadequate nutrient management practices. In irrigated lowland rice systems, for example, N deficiency and poor response to N fertilizer have been found. The low response could be ascribed to delayed N fertilizer application, which is typical in many farmers' fields, as well as other sub-optimal crop management practices such as delayed planting time and weeding, as well as other soil constraints. Similarly, in lowland rainfed rice systems, N deficiency reduces yields (Vandamme et al., 2018). The amount of nitrogen fertilizer used on rice is proportional to the yield level. A common yield response is more than 20 kilograms of paddy or rough rice per kilogram of nitrogen. The amount of nitrogen that can be applied to traditional, tall rice cultivars is limited due to lodging vulnerability and low yield potential. Short, high-yielding varieties that are resistant to lodging, on the other hand, can benefit from more nitrogen. While traditional varieties may be justified in receiving up to 50 kg N/ha, high yield cultivars should receive 160 kg N/ha or more with good management and consistent water availability. Rice's nitrogen needs are also influenced by the planting season. During the dry season, irrigated high yield varieties may justify 30–40 kg N/ha more, when there is plenty of sunshine, than during the rainy season, when yields are lower (Roy et al., 2006).

In irrigated rice systems, P deficiency has been documented. Yield losses were linked to diminishing soil organic carbon and N-supplying capability in rainfed upland rice systems. In addition to these deficiencies, macronutrient constraints for rice production in SSA include insufficient fertilizer access due to farmer financial constraints, Nutrient management practices that are ineffective, as well as the use of "blanket fertilizer recommendations". Fertilizer application rates may be reduced due to a shortage of fertilizer access, resulting in an uneven NPK ratio of applied fertilizers (Vandamme et al., 2018).

The timing of N applications is essential when it comes to enhancing rice's N utilization efficiency. To maintain the N supply during the crop's growth, only a little basal treatment and up to three topdressings in the standing crop may be required. Split applications are especially critical to decrease leaching losses if total N requirements are high (particularly on permeable soils). The application strategy is crucial for reducing nitrogen losses and increasing the crop's nitrogen use efficiency, which is often less than 50%. The damp soil should be worked with the basal application. When applying ammonium or urea N, use the reduced form wherever practical. Because transmitting them into floodwaters is likely to result in large N losses, this is the case (Roy et al., 2006). The nutrient nitrogen is the one that most typically inhibits crop productivity around the planet. Every ton of rice removes approximately 20.4 kilograms of nitrogen, 3.6 kilograms of phosphorus, and 20.4 kilograms of grain. In the tropics, natural nitrogen derived from soil mineralization, biological nitrogen fixation by free-living and plant-associated diazotrophs, and wet and dry atmospheric depositions are used to produce a lowland rice yield of 2 to 3 tons/ha (Lar et al., 2007). The use of urea super granules can help with urea placement in the decreased zone. When crop nutrient intake is strong and the topsoil is covered by a mat of roots, nitrogen losses are reduced, they can be utilized as a top-dressing. Because upland rice is heavily reliant on rainfall and soil moisture reserves, yields are lower than in wetland rice. Because the soil is not inundated, the soil nutrient behavior of upland rice is comparable to that of other upland cereal crops. Depending on production potential, 50–100 kg N/ha may be justified. The entire nitrogen should be distributed evenly between a base and a top-dressing application. Even when N is provided, upland rice might suffer from N stress due to excessive leaching losses (Roy et al., 2006).

2.12 Nitrogen in plants

All proteins require nitrogen to function properly. Nitrogen deficiency is characterized by stunted development, sluggish growth, and chlorosis. In nitrogen-deficient plants, anthocyanin pigments accumulate on the stems, petioles, and undersides of leaves, resulting in a purple appearance on the stems, petioles, and undersides of leaves. Ammonium NH^{4+} is more likely to be the dominant nitrogen source in acidic environments such as boreal forests, where nitrification is less widespread. Because NH^{4+} is the only way to produce amino acids and proteins, NO_3 levels must be reduced. In many agricultural conditions, nitrogen is the limiting nutrient of high growth. Corn, for example, requires more nitrogen than other plants. Due to the mobility of nitrogen, older leaves display indications of chlorosis and necrosis before younger leaves. As amines and amides, nitrogen is transported in a soluble form. Due to the mobility of nitrogen, older leaves display indications of chlorosis and necrosis before younger leaves. As amines and amides, nitrogen is transported in a soluble form (Basuchaudhuri, 2016). For plants, nitrogen is one of the most mobile soil nutrients. Because nitrogen utilization efficiency (NUE) should be in the range of 40-60% for aerobic rice production, nitrogen management is required. The most basic agronomic method for increasing nitrogen use efficiency is to apply nitrogen at the proper time (Kumar et al., 2018).

2.13 Nitrogen uptake

Nitrogen increases plant height, panicle number, leaf size, spikelet number, and full spikelet number, all of which increase a rice plant's yield potential. The number of tillers that form during the vegetative state has a significant impact on the number of panicles that form. The number of spikelets and the number of filled spikelets are most likely determined during the reproductive stage. Split nitrogen treatments are used by farmers. It is possible to alter the number of applications submitted and the rate at which they are submitted. The crop can be linked to real-time demand thanks to the flexibility to change the number and rate. A broad pale green to yellow tinge to the plant is the first sign of nitrogen deficiency in rice. Nitrogen is first expressed in older leaves because it is translocated from older to younger leaves within the plant. Plant stunting, reduced tillering, and yield reduction result from long-term nitrogen deficiency (Basuchaudhuri, 2016). Nitrogen consumption following fertilizer broadcasting on rice field flood water occurs because the concentration of nitrogen in the flood water and surrounding soil solution is initially so high that uptake rates are not limited by root features. Because the NH^{4+} cation – the most frequent form of plant accessible N^{-} is absorbed on soil clays and organic matter, lowering the concentration in solution, the crop must rely on N in the soil when N in the flood water is depleted, whether through uptake or gaseous loss. As a result, the rate at which nitrogen is delivered to and absorbed by root surfaces may be a constraint on N acquisition (Basuchaudhuri, 2016).

Furthermore, morphological and physiological adaptations to anoxic soil conditions may impact the root's ability to take nitrogen. The concentration of nitrogen as NH^{4+} in a flooded soil solution should be one to two orders of magnitude lower than the concentration of NO^{3-} in the same amount of nitrogen in a dry soil. It is clear that as plants mature, nitrogen contents in various plant sections drop. During ripening, however, nutritional contents in the leaves and stem dropped dramatically. The slow rate of uptake, combined with the diluting effect of gradient nitrogen transfer to growing grains, may account for the decrease in nutrient concentration in plant parts over time (Basuchaudhuri, 2016).

2.14 Phosphorus

Food and fiber consumption is constantly increasing around the world as a result of rising global population and aspirations for a better quality of life, particularly in emerging economies. Phosphorus (P) is an essential plant nutrient that is crucial in crop production. Because of its genetic role in ribonucleic acid and function in energy transfers via adenosine triphosphate, P is required for all forms of life. Of all the required plant components, P, after nitrogen (N), has the biggest impact on natural and agricultural ecosystems. In most soils around the world, P is the second most limiting nutrient after N, and it is unavailable to plants under most soil conditions. There would be no living things if there was no P in the environment. It is a nutrient that both plants and animals require. It is required for life processes such as photosynthesis, glucose synthesis and degradation, and plant energy transfer. Furthermore, P is less prevalent in soil than other important nutrients such as nitrogen and potassium (K). Farming systems are changing, and farmers are emphasizing the importance of utilizing fertilizers properly to increase yield, reduce crop production costs, and reduce pollution. Furthermore, a significant portion of the absorbed P in grains is translocated by most cereals and legumes. Phosphorus addition to the soil is an important component of current crop production systems. There is no substitute for P in the development of crops and animals for food, fiber, and other important needs (Amaral et al., 2013).

Out of the 16 key elements necessary in rice nutrition, phosphorus is one of the most important. It promotes good grain formation and quality by stimulating root development, early flowering, and ripening, and stimulating root development, early flowering, and ripening. In tropical soils, phosphorus shortage is a significant nutritional issue. However, not all tropics soils are poor in P, and those that are do not always require high amounts of P fertilizer. Farmers may face financial difficulties if they apply huge volumes of phosphatic fertilizer on insufficient soils. Breeding cultivars tolerant to P shortage is an alternate technique for overcoming P deficiency in wetland rice soils, albeit under extreme conditions, it may not be effective. Rice, unlike other plant species, is extremely tolerant of low phosphate levels. They also discovered that three parameters caused variances in low phosphate tolerance: (1) plant tolerance to low P content, (2) phosphorus absorption power per unit root weight, and (3) phosphorus distribution between root and shoot. Phosphorus (P) is one of the most important but also one of the most limiting plant nutrients, especially in Africa, where an estimated 50% of cropland is P deficient. Smallholder farmers who rely on the crop for food security and revenue usually cultivate upland rice on these soils without or with minimal fertilizer input (Atakora et al., 2015).

While flooding improves soil P availability, due to crop removal over the years, the P concentration of many historic rice soils is low. This, together with increased P requirement from better cultivars, demands correct P fertilizer treatment. The optimal rate depends on the local conditions, but for traditional kinds, 20–40 kilogram of P_2O_5 per hectare is usually sufficient, whereas improved cultivars require 40–80 kg of P_2O_5 per hectare. In an intense rice–wheat rotation, if the wheat has been adequately fertilized, the rate of P application to rice can be lowered. This is because flooded rice can better use the residual P sprayed to wheat. When two rice crops are cultivated in succession throughout a year, as in monoculture, the dry-season crop frequently requires more P than the wet-season crop. To promote root growth and tiller formation, P should be applied as a basal dressing. For rice production, water-soluble P or a combination of water- and citrate-soluble P is usually the most efficient. Due to the poor availability of P in many highland rice soils, modest P treatments are necessary (Roy et al., 2006).

2.15 Functions of Phosphorus

Plants and animals require phosphorus to grow. P is required for plant development, photosynthesis, nucleus formation, and cell division are all examples of how sugar and starch are used. The role of P in energy transfer in plants is well known. It's a component of adenosine triphosphate, the chemical substance that's typically referred to as the living cell's energy currency. Phosphate molecules store energy from photosynthesis and carbohydrate metabolism for later use in growth and reproduction. P influences crop maturity as well as plant resistance to environmental stresses such as drought and disease. It also interacts with other nutrients, especially N and K, to boost grain yields (Amaral et al., 2013). P is a structural component of plant nucleic acids and chromosomes, as well as many coenzymes, phosphoproteins, and phospholipids, and it plays an important role in plant metabolisms such as cellular energy transfer. They point out that a sufficient amount of P is required for optimal growth, particularly during the early phases of plant development (Amaral et al., 2013). P's functions in growth and development can be classified as morphological, physiological, and/or biochemical. It stimulates early maturation of grains and legumes as well as seed quality. P has been reported as being present in practically all metabolic pathways in plants (Amaral et al., 2013).

2.16 Potassium

Although the crop absorbs a lot of K, a lot of it stays in the straw. Responses to K have been minimal in conventional rice types. Improved varieties, on the other hand, usually respond to K, particularly when sufficient N and P are provided (Roy et al., 2006). K reactions are generally higher in sandy soils. While conventional types may only need 20–40 kg K_2O/ha, improved cultivars may need 60 kg K_2O/ha, especially in low-K soils. K fertilizer should be applied as a base dressing to most soils. Split K treatment is becoming more recommended on free-draining sandy soils with the risk for leaching. Potash fertilization should also account for the fact that, because K is less expensive than N and P, it may be just as profitable at lower response rates. Rice S insufficiency is becoming more frequent. Higher yields and hence more S removals, reduced use of organic manures, potential S leaching, and the general dominance of S-free fertilizers (urea, DAP, and MOP) in the product pattern are all causes. When AS or SSP are used in fertilization, the required S is often acquired from these sources (Roy et al., 2006).

2.17 Sulphur

Sulphur (S) is involved in the synthesis of amino acids and proteins, as well as enzymatic and metabolic reactions in plants, accounting for roughly 90% of organic S. Due to increasing S removal by crops, it is rapidly becoming deficient in places where oilseeds and pulses are grown. Rice's Sulphur demand changes depending on nitrogen availability. When S becomes scarce, adding N has little effect on plant yield or protein content (Maurya et al., 2020). Rice plants require Sulphur early in their development. If it restricts early growth, the quantity of tillers and, as a result, the final yield will be lowered. The oxidized sulphate form of Sulphur, on the other hand, is taken up by the roots of most plants. Although it is unknown whether rice can digest sulphide, we feel it is unlikely to be a significant source of Sulphur for the plant due to rice's sensitivity to low sulphide levels in its tissues (Maurya et al., 2020).

2.18 Micronutrients

Plant leaves absorb the most micronutrients when the micronutrient solution remains on the leaf as a thin coating. The addition of surfactant compounds that reduce surface tension to the nutrient solutions was required for thin film production. The movement of micronutrients into plant tissue appears to entail diffusion via the cuticle and uptake by leaf cells (Lahijani et al., 2020). Micronutrient deficits are becoming more widespread as rice production intensifies. It's critical to spot and correct them wherever they appear. In India, a Zn shortage in rice was initially discovered in the field (Wissuwa et al., 2006). Zinc deficiency affects over one-third of the world's population. More than half of children and pregnant women in developing countries are iron and zinc deficient. This condition is largely caused by a diet high in cereal-based foods. Brown rice has iron in the range of 6.3 to 24.4 mg/ kg, and zinc in the range of 15.3 to 58.4 mg/ kg. Polished rice, the most commonly consumed form, contains only 2 mg of iron and 12 mg of zinc per kilogram (Kadam et al., 2018).

In rice fields, Zn and Fe deficiencies are common, Fe is more common in highland rice, especially on high pH soils. If Zn is not supplied to the nursery, 10–12 kg Zn/ha zinc sulphate (21 percent Zn) can be administered prior to planting. Before the final puddling, it can be broadcast on the surface and integrated (Fageria & Stone, 2008).

Fe deficiency can be corrected by applying 2–3 foliar sprays of 1% ferrous sulphate once a week. Green manuring also aids in the reduction of Fe deficiency. Rice reacts in an unexpected way when exposed to Si (a non-essential beneficial element). In some nations, Si is used in soluble silicates and waste products containing Si. Si is supposed to enhance plant growth by increasing soil P availability, strengthening stems, offering insect resistance, and shielding plants from Fe and Mn toxicity (Roy et al., 2006).

2.18.1 Zinc (Zn)

Cereals are the primary source of zinc for the global population, particularly the rural poor. In contrast, the Zn content of cereal-based diets is far insufficient to suit human needs. Rice (*Oryza sativa* L.) has the lowest Zn content of any cereal, making the problem more worse for rice eaters (Garai et al., 2019). Zinc is one of the most important nutrients for plant growth, especially in rice grown in water (Sriramachandrasekharan, 2012). Zinc is essential for a number of biochemical processes, including cytochrome and nucleotide synthesis, enzyme activation, chlorophyll creation, membrane activity maintenance, and faster seed and stalk maturity. When the soil pH is low, there is a lot of organic matter in the soil, there is a lot of bicarbonate in the soil, and the land is heavily cropped, zinc deficiency is more likely. Zinc deficiency is caused by paddy soil that has been submerged for an extended period of time. On younger or middle-aged leaves, symptoms are common (Das, 2014).

In lowland rice, zinc insufficiency is the most common micronutrient problem, and applying Zn combined with NPK fertilizer enhances grain production considerably in most situations (Kumar Singh et al., 2012). Crops reduce Zn availability and uptake due to increased availability of Ca, Mg, Cu, Fe, Mn, and P during prolonged submergence. The most common micronutrient disease in rice is zinc insufficiency, but efforts to design cultivars with greater tolerance have been impeded by a lack of understanding of the genetic components that contribute to tolerance (Das, 2014). Zinc is extremely responsive to highly intensive cereal-based farming systems, aside from key minerals. Zinc is needed by several enzymes and is necessary for DNA transcription. Zinc is important for promoting vegetative development, especially in low-temperature environments and in the rhizosphere. For young and developing plants, a sufficient supply of zinc is a solid bet for optimum growth and development. In order to appreciate zinc's dynamic in the soil plant system, it must be determined. The primary variables of its availability in soil are pH and p content. Plant tissue P:Zn rations are also utilized to provide Zn translocation in the plant, particularly during seed formation (Sriramachandrasekharan, 2012). Zinc's functions are as diverse as the interface that limits its availability. It acts as a functional cofactor in a variety of plant enzyme processes and as a metal ingredient in enzymes. Plants with low auxin levels, such as indole acetic acid, show indications of zinc deficiency (IAA). Zinc is extremely important during the reproductive period, especially during conception. Surprisingly, pollen grain contains a lot of zinc. Only during fertilization is the majority of zinc transferred to seed (Kumar Singh et al., 2012). Seeds with high Zn concentrations have been shown to increase plant growth and development, especially in Zn-deficient soils, and foliar Zn spraying has been suggested as an efficient strategy for addressing Zn shortage and enhancing grain Zn concentration in rice. With the help of various Zn-regulating transporter proteins, the Zn sprayed by foliar fertilizers is absorbed by the leaf epidermis, remobilized, and transmitted into the rice grain via the phloem (Cakmak & Dell, 2018).

Around 10% of proteins in biological systems are considered to require Zn for structural and functional integrity. Zinc (Zn) is necessary for protein synthesis and gene expression in plants. It's also been discovered that it's needed as a cofactor in more than 300 enzymes. The generation of reactive oxygen species (ROS) during germination is well recognized, and Zn plays a key role in ROS detoxification in plant cells. For humans, zinc is an essential mineral nutrient. Zn deficiency, which is linked to inadequate dietary intake, is expected to affect one-third of the global population. Zinc deficiency has been related to a variety of human health issues, Delays in physical growth, immune system function, and learning ability, as well as DNA damage and cancer formation, are all common in youngsters. As a result, boosting the amount of Zn in stable food crops is a major humanitarian concern (Boonchuay et al., 2013).

2.18.2 Iron (Fe)

Iron content in soil ranges from 1% to 20%, with an average of 3.2 percent, although its normal concentration in plants is only 0.005%. Toxicity is a major constraint on lowland rice development due to iron deficiency, high pH, and aerobic soil. It affects the rice plant's physiology in a number of ways. The threshold iron toxicity concentration in plant tissue is influenced in part by the plant's overall nutritional state. Chlorophyll is formed with the help of iron (Das, 2014). Several studies have been published on the physiological effects of iron shortage in plants. Iron-induced chlorosis has been widely reported due to its function. Reduced stomatal conductance has also been linked to increased abscisic acid release, reduced leaf photosynthetic rate, lower quantum yield efficiency, and higher internal CO_2 concentrations due to iron insufficiency (Sakariyawo et al., 2020). Chlorosis between leaf veins is caused by an iron deficiency, and the deficiency symptom first occurs in young plant leaves.

Growth is halted because it does not appear to be translocated from older tissues to the tip meristem (Das, 2014). Yellowing of the interveinal space and chlorosis of growing leaves The main deficiency symptoms include reduced dry matter production, impaired sugar metabolism enzymes, and plants being stunted with narrow leaves. Interveinal chlorosis on the leaf surface, displaying a delicate reticulate network of green setting off chlorotic patches, is caused by iron deficiency in rice plants due to iron's relative immobility in rice plants (Walker et al., 2005). The main causes of iron deficiency are low iron concentrations in upland soil, coarse textured soil, low land soil with extremely low organic matter content, increased rhizosphere pH, and other variables. Though it is the most difficult and expensive micronutrient deficiency to treat, it can be addressed by spreading FeSO4 25 kg/ha between rows, utilizing iron-containing fertilizers, or spraying FeSO4 1% - 3% solution on the leaves. Iron poisoning is caused by excessive Fe uptake as a result of high Fe concentrations in soil solution (Das, 2014). The most typical iron toxicity symptoms are tiny brown spots on lower leaves that start at the tip and move towards the leaf, base, or complete leaf colored orange yellow to brown. Spots pile together on the leaf intervein, turning the leaves orange-brown and causing them to die. The leaves appear purple-brown if they are purple brown in color. Fe poisoning results in stunted growth and a lack of tillering. Iron toxicity can be reduced by seed treatment with Ca peroxide at 50 percent to 100 percent seed weight, intermittent irrigation and balanced fertilizing during the tillering stage (Das, 2014).

2.19 Effects of Foliar P, S, and Micronutrients Zn and Fe on Rice Plant Growth Parameters and Yield Components

2.19.1 Plant Height

The height of rice plants is an essential growth and development indicator. Height was used to quantify tillering, panicle initiation stage (PI stage), anthesis, and maturity. At all phonological stages, both minerals (Sulphur and zinc) had a considerable effect on rice plant height; however, the magnitude was not the same for each level, and it grew as growth went up to Anthesis before dramatically slowing down after that (Kumar Singh et al., 2012). Culm elongation of the rice plant causes the dry matter accumulation within the biomass. A quadratic link exists between dry matter buildup and grain production. Plant height is the main contributor to the biomass weight (Ranawake et al., 2014). Height growth is accompanied by an increase in the number, length, and size of other growth characteristics such as leaf number, length, and size, as well as dry matter accumulation. Plant growth is a sign of aging. With timely fertilizer application, plant heights were maximized (Haruna, 2019). It was discovered that combining micronutrients with macronutrients boosted plant height more than applying macronutrients separately (Islam et al., 2018).

2.19.2 Tillering

A rice tiller is a grain-bearing branch that grows independently of the mother stem (culm) by adventitious roots. It's produced by the unelongated basal internode. Tillering influences plant architecture and canopy growth for primary production by capturing incoming light (Opio, 2019). 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 most essential factor in yield is the number of tillers per plant or per unit area. The higher the number of tillers, particularly fertile tillers, the higher the yield. The genetics and environment influence a plant's ability to till. Micronutrients alone, in combination with macronutrients and spacing, had a favorable influence on the number of tillers, according to the results. These findings imply that micronutrients had a positive impact on the quantity of rice tillers (Islam et al., 2018).

2.20 Effective tillering.

Tillers are an important component of rice yield. Tillers that are effective are panicles that bear grains, which are the end goal of production. The more efficient the tillers, the greater the prospect of enhanced grain output (Haruna, 2019). This is a point where tiller number equals the number of panicles at maturity. Tillers developed after this stage do not form panicles. Cultivars vary in tiller number as well as in earliness and vigor of tillering. Some cultivars tiller very early and profusely; others show delayed and/or sparse tillering Plant spacing, and soil richness have an impact on tillering. The maximum tiller number is low (one to three tillers per plant) and is reached within 30 days after seedling emergence when seeds are drilled or spread thickly, and plant density is high. Tiller numbers rise (10 to 30 per plant) and tillering time is extended when planting density are low. As a result, the maturation of mature panicles may be delayed, and there may be a significant number of ineffective tillers (Smith, 2003)

2.21 Chlorophyll content in leaves

Photosynthesis is a global biological process that provides energy to plants and other living things. Chlorophyll is a crucial pigment involved in this process. Higher leaf chlorophyll content in plants has been linked to increased nitrogen availability in plants, as nitrogen is required for chlorophyll production. When nitrogen was given to rice, the chlorophyll concentration increased. As a result, the rate of photosynthesis increased, resulting in more sugar production (Yakubu, 2016). Iron helps in the formation of chlorophyll (Das, 2014). Iron (Fe) is required for the formation of chlorophyll in plant cells. It serves as an activator for biochemical processes such as respiration, photosynthesis and symbiotic nitrogen fixation (Lohry, 2007).

2.21.1 Leaf Area

Foliar application of Fe appears to have a significant function in N2 fixation and leaf area improvement due to nitrogen location in the chemical structure of chlorophylls and other micronutrients such as Zn. It promotes plant hormonal activity, which results in an increase in leaf area. It appears that micronutrient leaf treatment boosted rice output significantly when compared to the control and has a major impact on cluster formation and seed production (Lahijani et al., 2020).

2.21.2 Days to 50% flowering

Flowering lasts between 1 and 2 1/2 hours and occurs between the opening and closing of the spikelet (floret). Flowering normally begins the next day or the day after panicle effort, and is thus associated with heading. Both genetic and environmental variables influence the number of days it takes to flower. Different elements have an impact on rice blossoming: Planting of younger seedlings, closer spacing, conventional irrigation and conventional weeding induce early flowering. The temperatures higher than 34°C at the time of flowering induce floral sterility and decrease yields. Days to blooming and plant height have been shown to have a detrimental direct effect on grain output. High dry matter accumulation before heading and high translocation rate after heading are the main strategy in high yielding rice cultivars (Ranawake et al., 2014)

2.21.3 Shoot dry biomass/Straw yield

The determination of plant fresh and dry matter accumulation is a growth analysis tool used in agronomy research. Fresh biomass is especially crucial for horticultural crops, which place a premium on water content. The crop's dry matter explains the true growth dynamics of arable crops (Haruna, 2019).

2.21.4 Panicles per plant

The panicle number per hill increased dramatically as a result of the addition of micronutrients in addition to macronutrients and the adjustment of spacing. The application of S and Zn to rice has been shown to have a considerable impact on the number of panicles (Islam et al., 2018). The beginning of the panicle initiation/booting stage generates around half of the total dry matter and hence accounts for half of total nitrogen intake. When rice is fertilized with the proper amount of nitrogen, half of the total nitrogen is absorbed before half of the total dry matter is created. The remaining 30–50% of total N intake occurs after the commencement of panicle initiation. The rice panicle holds 60–70% of the above-ground nitrogen when mature. When P was added to P-deficient soils, rice root development, panicle number, and grain weight increased (Chauhan et al., 2017). Because the number of panicles per unit area is the most essential factor in rice yield, it's important to keep in mind that it accounts for 89 percent of grain yield (Opio, 2019).

2.21.5 Number of functional leaves

Plants that are in good shape develop leaves at a faster rate than leaves that are developing in a non-conductive environment. The genotypic character of variety is responsible for the variation in the number of functional leaves plant^{-1}. The combination of $ZnSO_4$ and $FeSO_4$ considerably increased leaf output. Micronutrients, which are the major element of chlorophyll, may be responsible for the crop's prolific leaf production. This, combined with nitrogen, which is the main constituent of chlorophyll, boosted the crop's photosynthetic efficiency, resulting in greater leaf counts. The availability of Zn & Fe in these treatments may explain the higher number of leaves produced (Kadam et al., 2018).

2.2.6 1000 seed weight

The influence of different treatments on boosting overall grain yield is determined by the weight of thousand grains. After nitrogen fertilizer at the active tillering and panicle initiation stages, the plant generated strong and vigorous panicles to absorb assimilates from the leaf and stem (Haruna, 2019). The environmental conditions to which the plants were exposed are superseded by the genetic features of the variety (Yakubu, 2016). Foliar application improved rice development and, as a result, key yield components including 1000-grain weight and panicle weight (Zayed et al., 2011).

2.21.7 Paddy Yield

The key yield determinants are effective panicles, the fraction of complete grains, the number of spikelets per panicle, and the grain weight (Yakubu, 2016). Micronutrients are extremely important economically since a sufficient supply can help to ensure higher harvests. When micronutrients were used in conjunction with NPKS, grain yield and yield contributing features such as plant height, number of effective tillers/ hill, number of grains /panicle, and dry matter yield of rice performed better than when NPKS was used alone (Siddika et al., 2016). With graduated dosages of Sulphur and zinc, yield attributes were also considerably impacted. Both nutrients have a substantial impact on the number of panicles per square meter, which adds to the economic yield (Kumar Singh et al., 2012).

CHAPTER THREE

3.0 METHOD AND MATERIALS

3.1 The study regions' descriptions

In the Northern Region of Ghana, the study area included on-station research at the University for Development Studies (UDS) in Tolon District and on-farm research in the Botanga Irrigation Scheme in Kumbungu District. Nyankpala is located in the Tolon District of Ghana's Northern Region, 20 kilometers south-west of Tamale. Nyankpala is located at a height of 183 meters above sea level and is located in latitude 09° 25'N and longitude 00° 58'W. (SARI, 2013). The district of Tolon covers a total area of 2,741 km^2. Nyankpala is bordered to the north by Kumbungu, to the west by North Gonja district, to the south by Central Gonja district, and to the east by Sagnerigu Municipality (Martey et al., 2013).

The Botanga Irrigation Scheme, which is managed by GIDA, is the largest irrigation scheme in the Northern Region. It is located 34 kilometers northwest of Tamale, the regional capital, in Botanga, Kumbungu District. It is located between N 9°30' and W 1°04' latitude and longitude. The Ghanaian government began construction on the system in 1980 and finished it in 1986. It was built to provide year-round crop production for farmers in the catchment region while also providing jobs for the youngsters in the area. In 1985 and 1986, test crops were planted, with full crop production beginning in 1987. It has an irrigable area of 800 hectares and a developed area of 495 hectares. In the irrigable area, sandy loam is the most common soil type. The dam was built on the Botanga River, a tributary of the White Volta. The design consists of an earthen dam that feeds water to the field by gravity, as well as two (2) off-takes and a spillway, which is set to control the reservoir's top water level. The major crop grown is rice (*Oryza sativa*), whilst the minor crops include onion (*Allium cepa*), tomatoes (Lycopersicon esculentum), okra (*Hibiscus esculentus*) and pepper (*Capsicum frutescens*) (Tendeku et al., 2017).

3.2 Climate and vegetation

The experimental location has only one cropping season, which is commonly referred to as the rainy season. Every year, the cropping season begins in May and finishes in October. From November to April, the rainy season is immediately followed by a long period of dry weather. Nyankpala had 919 mm of yearly rainfall in 2017, with an average monthly distribution of 77 mm. However, the temperature dispersion is very constant, with a lowest temperature of 19.7 degrees Celsius and a maximum temperature of 40.7 degrees Celsius, with a monthly mean of 26.5 degrees Celsius and a monthly mean relative humidity of 62 percent (Dauda, 2015).

The hottest months of the year are March through May, just before the rainy season begins. The district's vegetation consists of grasslands interspersed with guinea savanna wood area, which is distinguished by drought-resistant trees like as acasia, Mango, baobab, shea nut tree, dawadawa, and neem. Bush fires, which rage through the savanna woodland every year, also have an impact on the vegetation. The fundamental source of this condition is the constant burning of natural vegetation, which exposes the soils to high levels of precipitation. The landscape is rolling, with a few depressions thrown around. The region is drained by various rivers and streams, notably the White Volta, and there are no significant high points in the area. The soil is generally sandy loam, except in the lowlands, where alluvial deposits can be found (Haruna, 2019).

3.2 Experimental design and treatment

The field study was a 2 x 8 factorial experiment laid out in a randomized complete block design (RCBD) with three replications. The two locations were Nyankpala and Botanga under rainfed lowland and irrigation ecologies, whilst the eight nutrient formulations were as indicated in Table 1. 1 m and 2 m alleyways respectively were given between adjacent treatment plots and blocks. Each plot measured 5 m x 5 m and a total of 24 plots were seeded per location. The AGRA cultivar was the test crop, which has a maturity period of 125 to 130 days.

This trial was caried out during 2020 cropping season. NPK fertilizer was applied at two rates of 120-40-40 and 120-20-40 kg N, P_2O_5 and K_2O/ha. At 14 days after transplanting, basal application of 80-40- 40 or 80-20-40 kg N, P_2O_5 and K_2O/ha was applied, and 40 kg N/ha was top dressed before flowering. The Foliar P, Zn, S and Fe was applied around 90% ground cover at 4WAT.

Table 1. Nutrients as formulated from various combinations of NPK, P, S, Zn, Fe, using the addition model.

Treatment	**Basal application**			**Top dressing**			
	Soil applied			**Foliar applied**			
	N	**P**	**K**	**TSP**	**Zn ($ZnSO_4$)**	**Fe ($FeSO_4$)**	**S (KSO_4)**
NP1K	120	40	40	0	0	0	0
NP1K+[Zn+S+Fe]	120	40	40	0	2.5	5	10
NP1K+[Zn+Fe]	120	40	40	0	2.5	5	0
NP1K+[Zn]	120	40	40	0	2.5	0	0
NP2K	120	20	40	0	0	0	0
NP2K+[P+Zn+S+Fe]	120	20	40	10	2.5	5	10
NP2K+[P+Zn+Fe]	120	20	40	10	2.5	5	0
NP2K+[P+Zn]	120	20	40	10	2.5	0	0

3.3 Data Collection

3.3.1 Plant Height

Five plants were randomly identified and tagged for easy identification for measurement of plant height at 2, 4, 6 weeks after transplanting (WAT) and panicle stage (8WAT). The height of juvenile plants was measured from the ground level to the tip of the tallest leaf, and the height of mature plants was measured from the ground level to the tip of the tallest panicle. Plant height was measured using the single hill sampling unit approach.

3.3.2 Days to 50 % flowering

When 50% of the plants in a plot flowered, the number of days to 50% blooming was calculated.

3.3.3 Number of tillers per hill

Tiller count were taken at 2, 4 and 6 WAT using the two-hill x two-hill sampling unit. Five spots within a plot were randomly selected at 2 WAT and tagged for subsequent measurements, with a long stick pinned in the center of the four hill places for simple sampling identification.

3.3.4 Days to 50 % maturity

When 50% of the plants in a plot matured, the number of days to 50% matured was calculated.

3.3.5 Panicle weight

Panicle weight was assessed by weighing five panicles chosen at random from the 2 × 2 plant hill stands and averaging the results.

3.3.6 Rice Straw weight

For each plot, rice straw was calculated by subtracting grain weight from shoot biomass during harvest.

3.3.7 Leaf Area

The length and maximum width of each leaf on the middle tiller was measured and leaf area of each leaf was computed. Five plants were randomly identified and tagged for easy identification for measurement of leaf area at 2, 4, 6 (WAT).

3.3.8 SPAD values

The SPAD-502 Plus (Konica Minolta, Inc., 2012) was used to detect leaf absorbance in the red and near-infrared regions of the spectrum to quantify chlorophyll content at 4, 6, and 8 WAT. By dividing light transmission intensities at 650 nm by 942 nm, SPAD-502 Plus determines a company-defined SPAD (Soil Plant Analysis Development) value. At the booting stage, SPAD values were measured on flag leaves using a chlorophyll meter SPAD-502. 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 (Naus et al., 2010).

3.3.9 1000 grain weight

Within each net plot, one thousand grains were randomly selected, counted, and weighed.

3.3.10 Dry shoot biomass and paddy grain yield

Rice grains were hand harvested with a sickle from a 5 m × 5 m net patch. The harvested plants were gathered along with the straw and panicles, transferred to the laboratory, and sun dried for three days in a row. Before being manually threshed and winnowed, the dried straw was weighed. The grain yield weight (kg) per plot was calculated by weighing the winnowed grains on a digital scale.

3.4 Data analysis

The data was analyzed using GENSTAT's two-way analysis of variance (ANOVA) and LSD was used to separate adjecting means (5%).

CHAPTER FOUR

4.0 Results

4.1 General observation

The irrigated field got flooded for one month after planting for two weeks and this could affect the performance of some of the parameters compared to rainfed (Plate 1).

Plate 1: Irrigated field under two weeks flood due to opening of Bagri Dam.

4.2 Plant height

The results of the analysis of variance showed location by nutrient were significant at 2, 4 and 6 weeks after transplanting (WAT) at ($P<0.01$), ($P<0.01$) and ($P<0.05$) respectively, but not at 8 WAT ($P>0.05$). Plant height at 2, 4 and 6 WAT was also significantly affected by location and nutrient. At 8 WAT, location significantly affected plant height ($P<0.001$), whilst nutrient did not ($P>0.05$). At 6 WAT, location by nutrient showed NPK1+Zn supported the tallest plant height of 68.38 cm at Nyankpala under rainfed conditions, although this value was similar to the highest (67.60 cm) obtained at Botanga under irrigation with NPK1+Zn+S+Fe (Figure 1).

However, at Nyankpala under rainfed, similar plant height was obtained with NPK1+Zn+S+Fe, NPK1+Zn+Fe, NPK1, and NPK2+P+Zn whilst NPK2 gave the least with 55.93 cm. Then at Botanga, location by nutrient at 6 WAT, under irrigation revealed the nutrient that gave similar plant height to the highest was NPK1+Zn+Fe, whilst NPK2+P+Zn+S+Fe supported the least with 56.66 cm. At 8 WAT, location revealed Botanga under irrigation, performed better with plant height of 104.56 cm compared to Nyankpala under rainfed with a height of 91.94 cm (Figure 2).

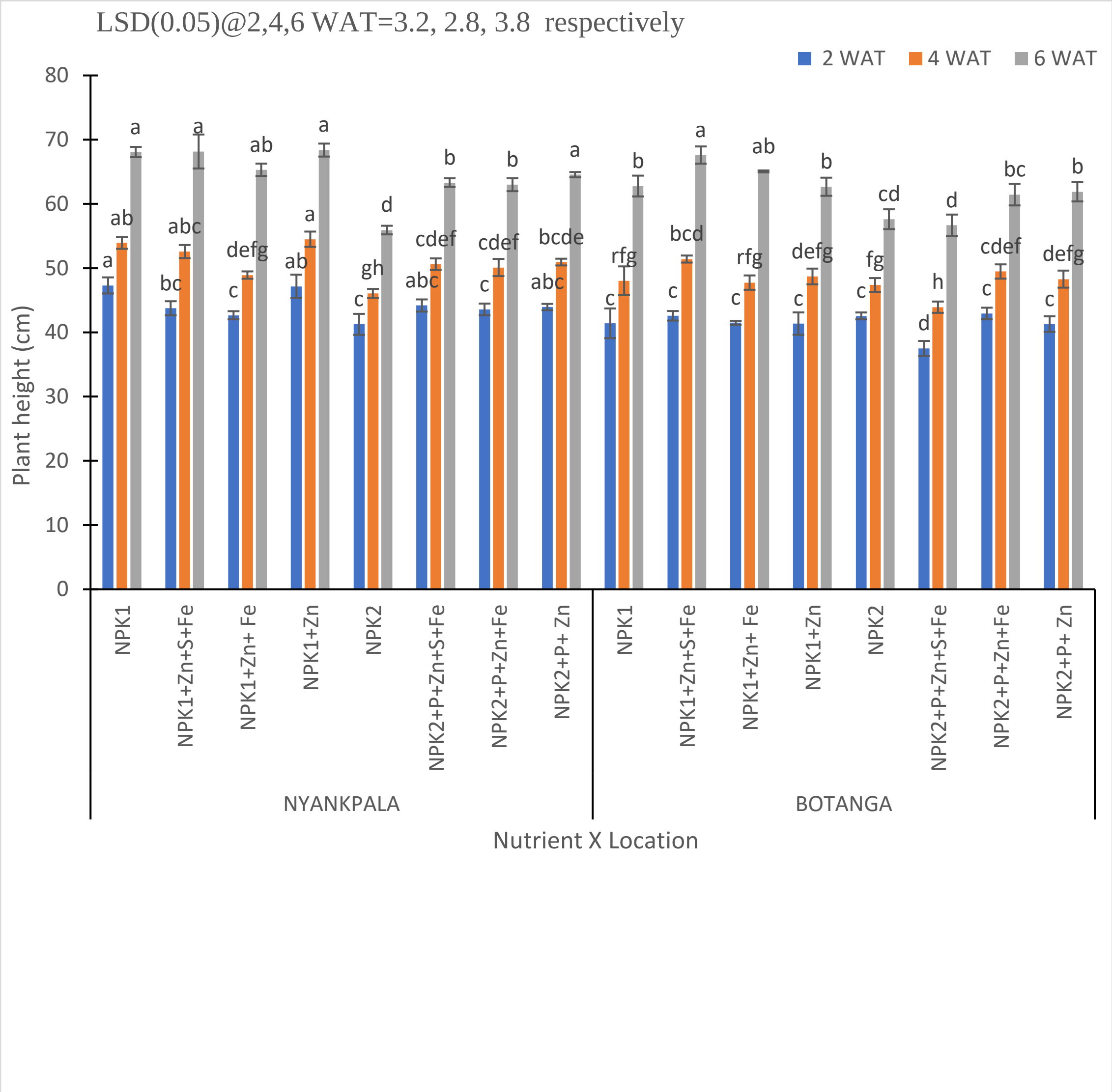

Figure 1. Location by nutrient effect on plant height under rainfed (Nyankpala) and irrigation (Botanga). Error bars represent standard error of means SEM.

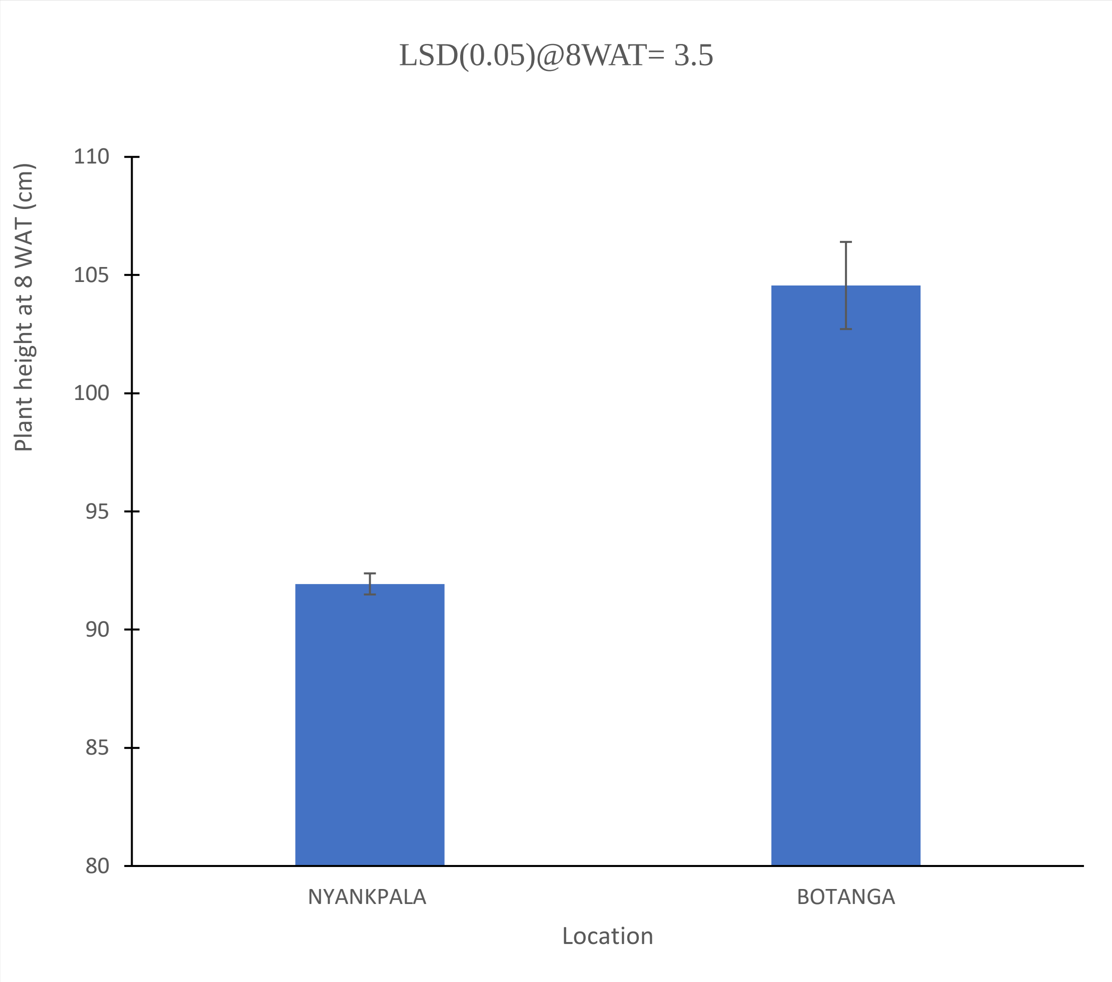

Figure 2. Plant height of rice as affected by location (rainfed (Nyankpala) and irrigation (Botanga)) conditions at 8 WAT. Error bars represent SEM.

4.3 Tiller count

At 2 WAT, Location by nutrient (P>0.05) had no effect on tiller count. However, location and nutrient influenced tiller count (P<0.001). Under both irrigation and rainfed, NPK1 at 2 WAT recorded the highest tiller count of 8.50 tillers per hill, whilst NPK2+P+Zn+S+Fe recorded the least with 5.97 tillers per hill (Figure 3). But location revealed Nyankpala under rainfed gave higher tiller count with tiller count of 7.37

per hill compared to Botanga under irrigation with a tiller count of 6.40 tillers per hill (Figure 4).

At 4 WAT, nutrient by location (P>0.05) showed no effect on tiller count. But location (P<0.05) and nutrient (P<0.001) had effect. Under both irrigation and rainfed conditions, NPK1 at 4 WAT recorded the highest tiller count of 15.17 tillers per hill, but NPK1+Zn+Fe, NPK1+Zn+S+Fe and NPK1+Zn gave similar tiller count whilst NPK2+P+Zn+S+Fe recorded the least (Figure 3). At 4 WAT, location revealed Nyankpala under rainfed gave higher tiller count with tiller count of 13.26 per hill compared to Botanga under irrigation with a tiller count of12.28 tillers per hill (Figure 4).

Then At 6 WAT location by nutrient effect (P>0.05) did not influence tiller count. On the other hand, location (P<0.05) and nutrient (P<0.001) impacted tiller count. At 6 WAT, NPK1+Zn recorded the highest tiller count of 21.60 tillers/hill but NPK1+Zn+S+Fe, NPK1 and NPK1+Zn+Fe gave similar count per hill whilst NPK2+P+Zn +Fe recorded the least (Figure 3). At 6 WAT, location revealed Nyankpala under rainfed supported higher tiller count with tiller count of 19.40 per hill compared to Botanga under irrigation with a tiller count of18.42 tillers per hill (Figure 4).

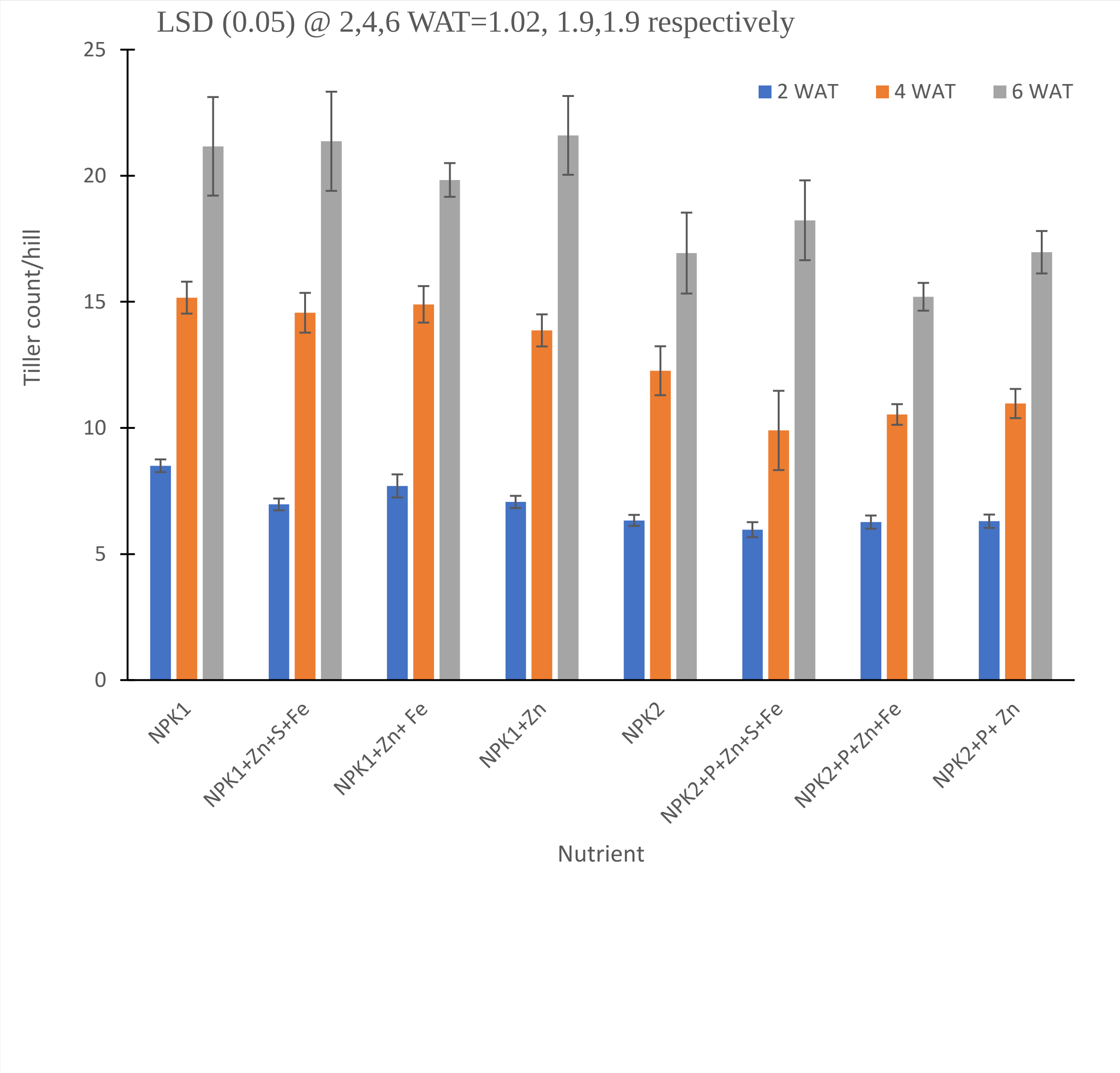

Figure 3. Nutrient effects on tiller count per hill at 2, 4 and 6 WAT at Nyankpala under rainfed and Botanga under irrigation. Error Bars Represent SEM.

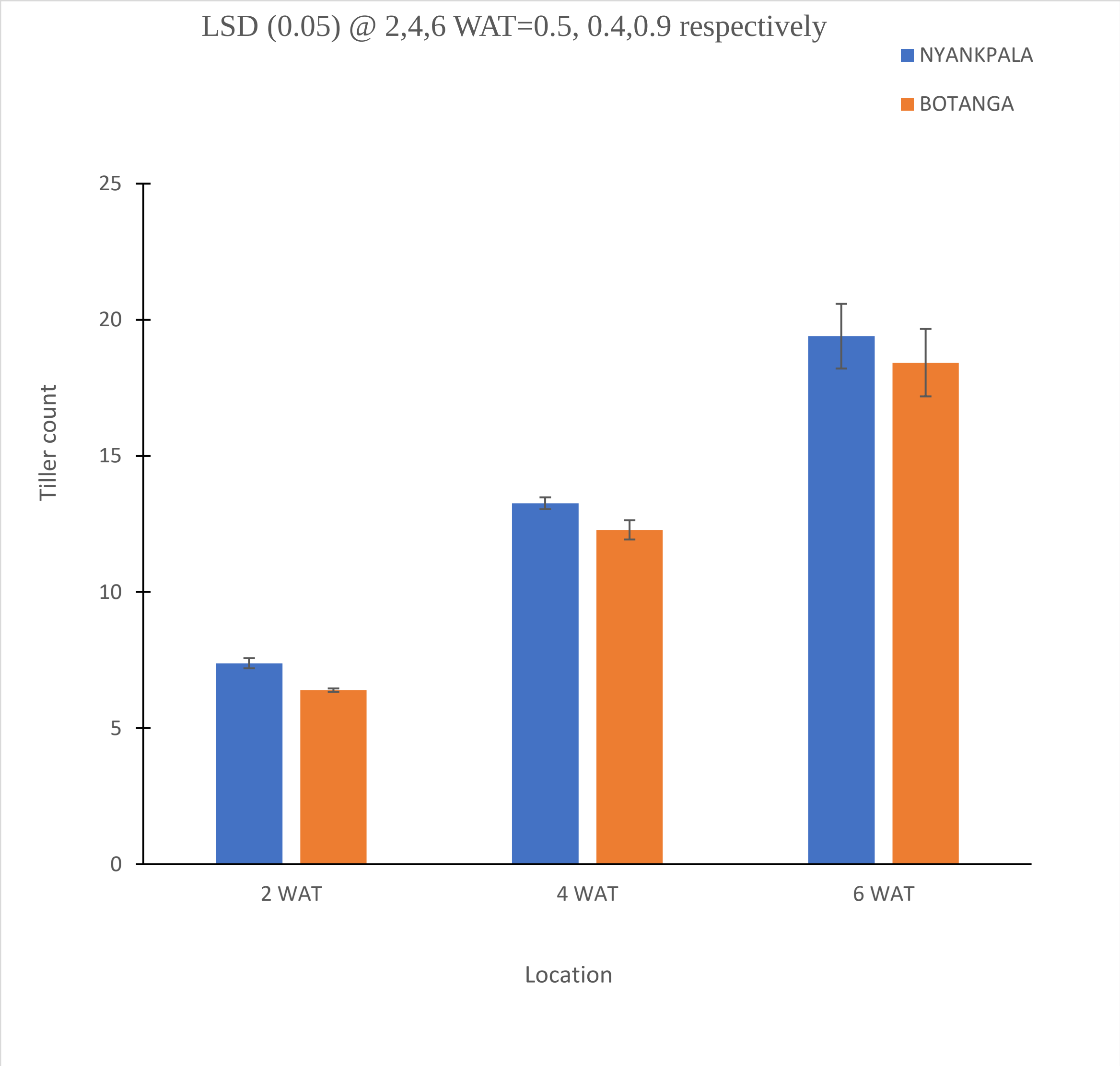

Figure 4. Location effects on tiller counts at 2, 4 and 6 WAT at Nyankpala under rainfed and Botanga under irrigation. Error Bars Represent SEM.

4.4 Chlorophyll Content

At 4 WAT, Location by nutrient ($P<0.05$) and nutrient ($P<0.05$) had effect on Chlorophyll content but not location ($P>0.05$). Location by nutrient at Nyankpala under rainfed, at 4 WAT, revealed NPK1+Zn recorded the highest SPAD value of 38.35 but, NPK1, NPK1+Zn+Fe, NPK1+Zn+S+Fe, NPK2+P+Zn+S+Fe and NPK2+P+Zn gave similar SPAD values and NPK2+P+Zn+Fe recorded the lowest SPAD value of 32.12 (Figure5). But location by nutrient at Botanga showed NPK1+Zn+S+Fe recorded the highest SPAD value of 37.15 but NPK1+Zn+Fe gave similar SPAD value and NPK2+P+ Zn recorded lowest SPAD value of 29.03.

At 6 WAT, location by nutrient ($P>0.05$) and location ($P>0.05$) did not influence Chlorophyll content but nutrient had effect ($P<0.01$) on Chlorophyll content. Treatment effect revealed NPK1+Zn+S+Fe recorded the highest SPAD value of 41.63 but NPK1+Zn+Fe gave similar SPAD value whilst, NPK2+P+Zn recorded the lowest of 33.68 of SPAD value (Figure 6).

At 8 WAT, location by nutrient ($P>0.05$) and nutrient ($P>0.05$) did not significantly impact Chlorophyll content but nutrient significantly ($P<0.001$) impacted Chlorophyll content. Location effect revealed Botanga under irrigation supported a higher SPAD value of 47.18 as compared to Nyankpala under rainfed with SPAD value of 33.84 (Figure 7).

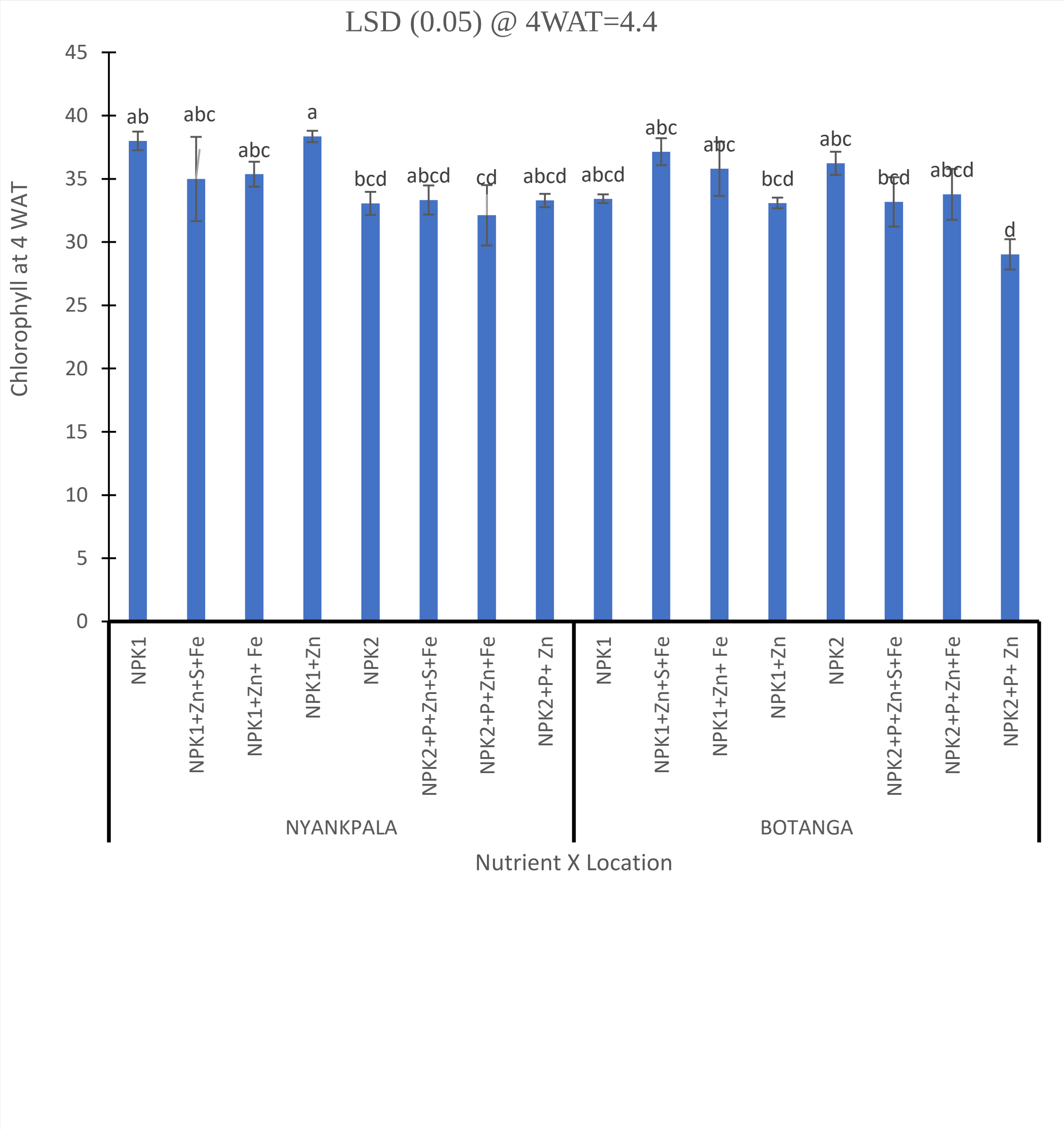

Figure 5. Interaction effect of Chlorophyll content between location and nutrient under rainfed (Nyankpala) and irrigation (Botanga). Error Bars Represent SEM.

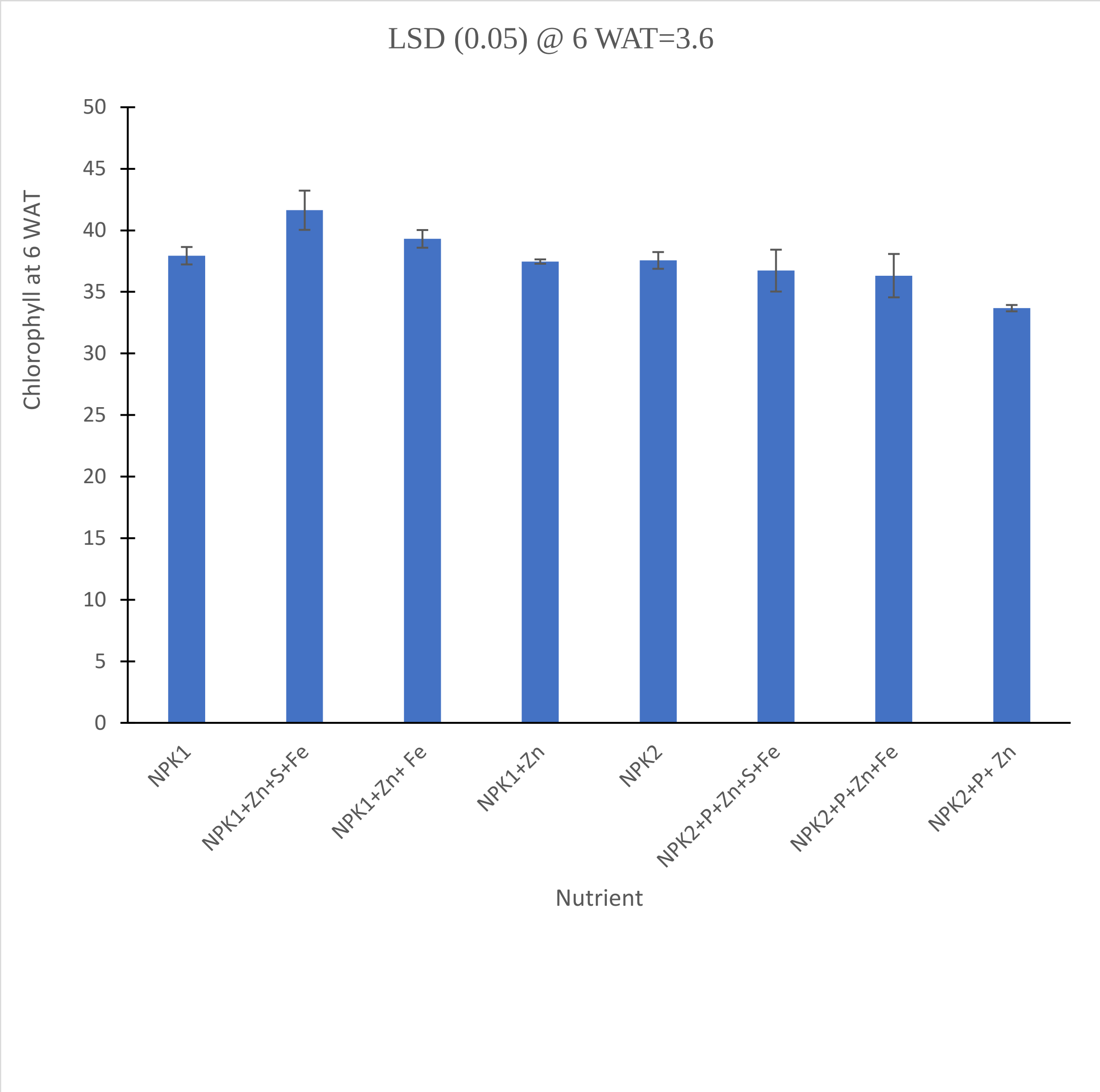

Figure 6. Nutrient effects on Chlorophyll content at Nyankpala under rainfed and Botanga under irrigation.

Error Bars Represent SEM.

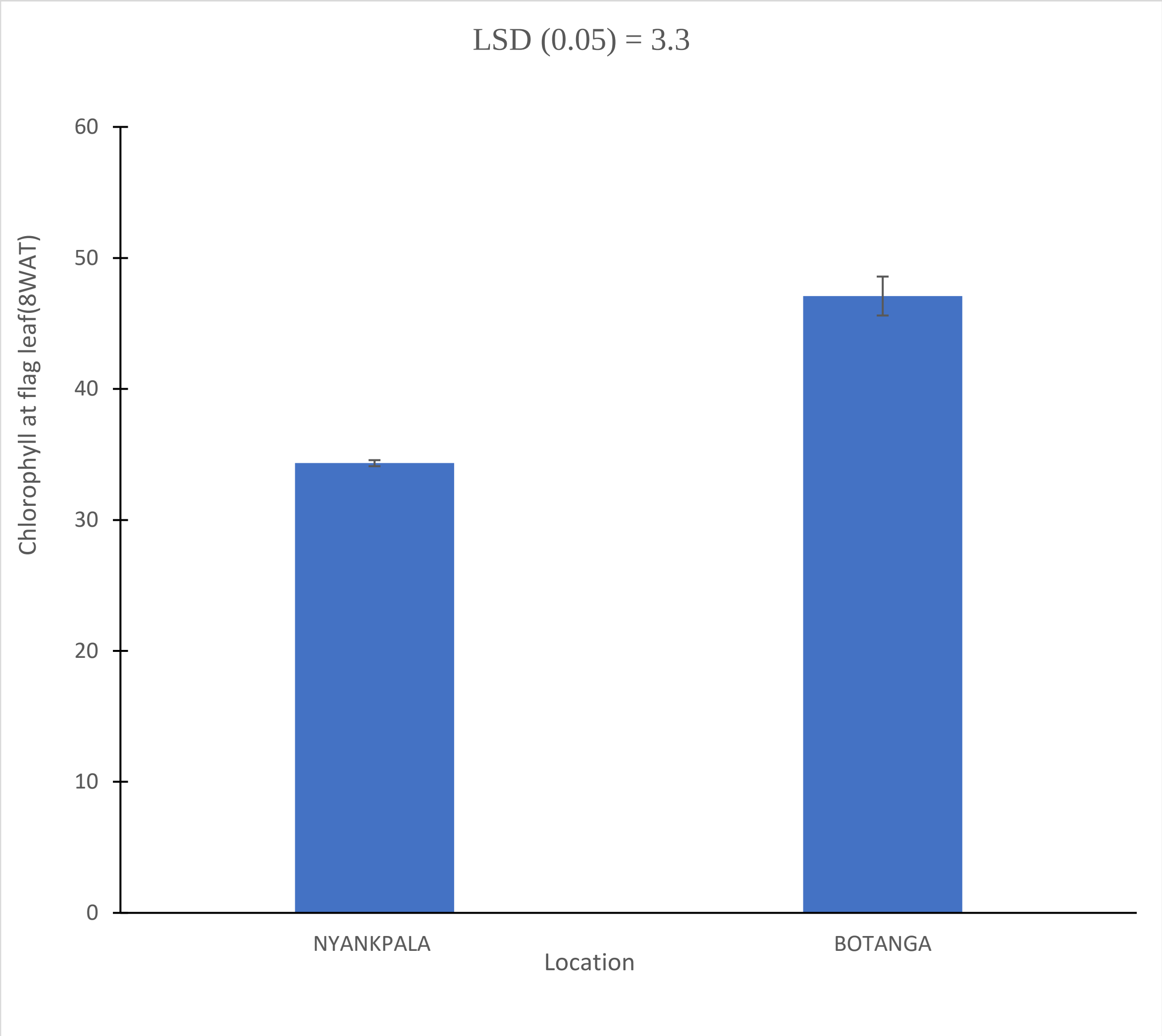

Figure 7. Location effects on chlorophyll content under both irrigated and rainfed
Bars represent SEM.

4.5 Days to 50% flowering

Location by nutrient and nutrient (P>0.05) did not have effect (P>0.05) on days to 50% flowering, but location significantly (P<0.001) had effects. Botanga under irrigation performed better with aa result of 84.08 days to 50% flowering than Nyankpala under rainfed with 79.08 (Figure 8).

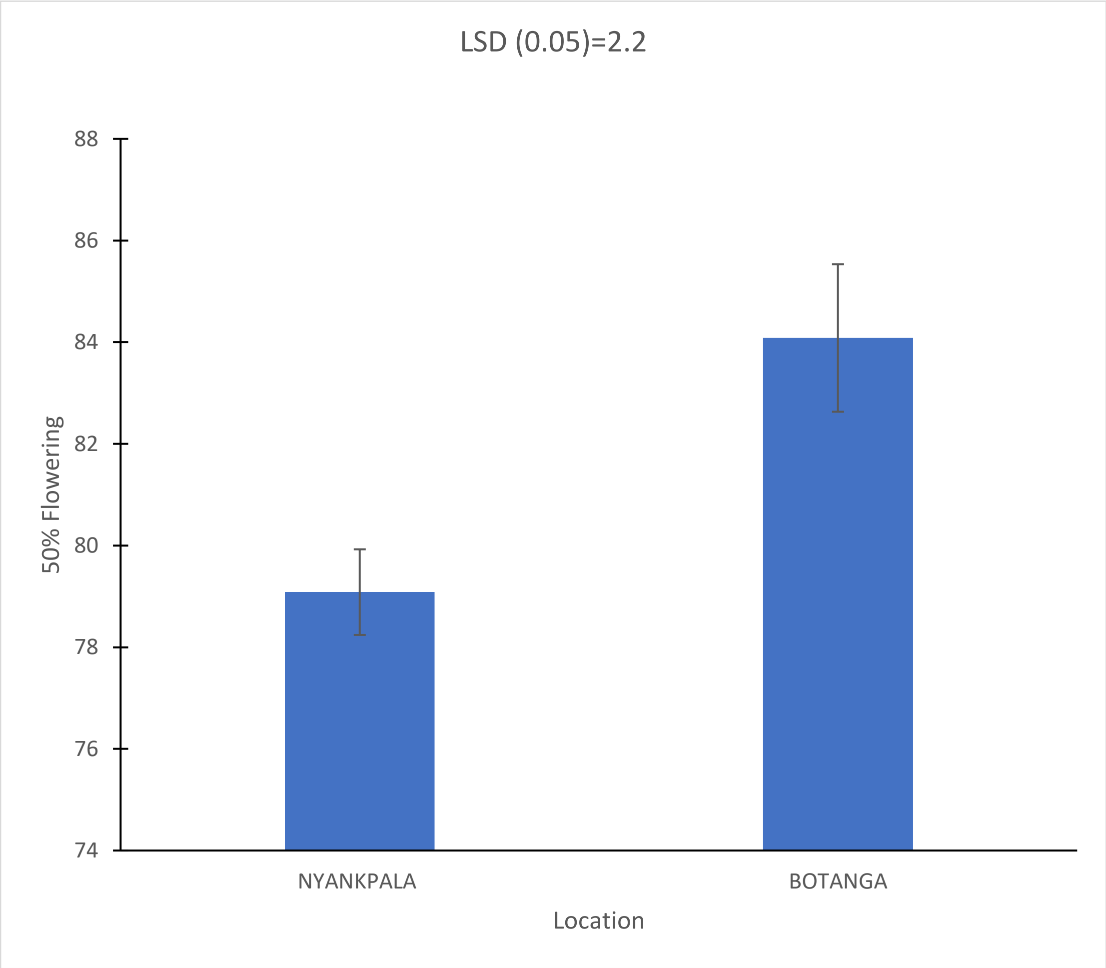

Figure 8. Location effects on 50% flowering under both irrigated (Botanga) and rainfed (Nyankpala).
Error Bars Represent SEM.

4.6 Days to 50% maturity

The results of the analysis of variance showed location by nutrient ($P>0.05$) did not significantly affect days to 50% maturity but nutrient ($P<0.05$) and location ($P<0.001$) had effect. NPK2 recorded the highest days to 50% maturity with a value of 112.67 but NPK1 and NPK2+P+Zn+S+Fe gave similar maturity, whilst NPK1+Zn recorded the lowest of 107.50 days to 50% maturity (Figure 9). Botanga under irrigation performed better with 111.29 days to 50% maturity than Nyankpala under rainfed with 106.46 (Figure 10).

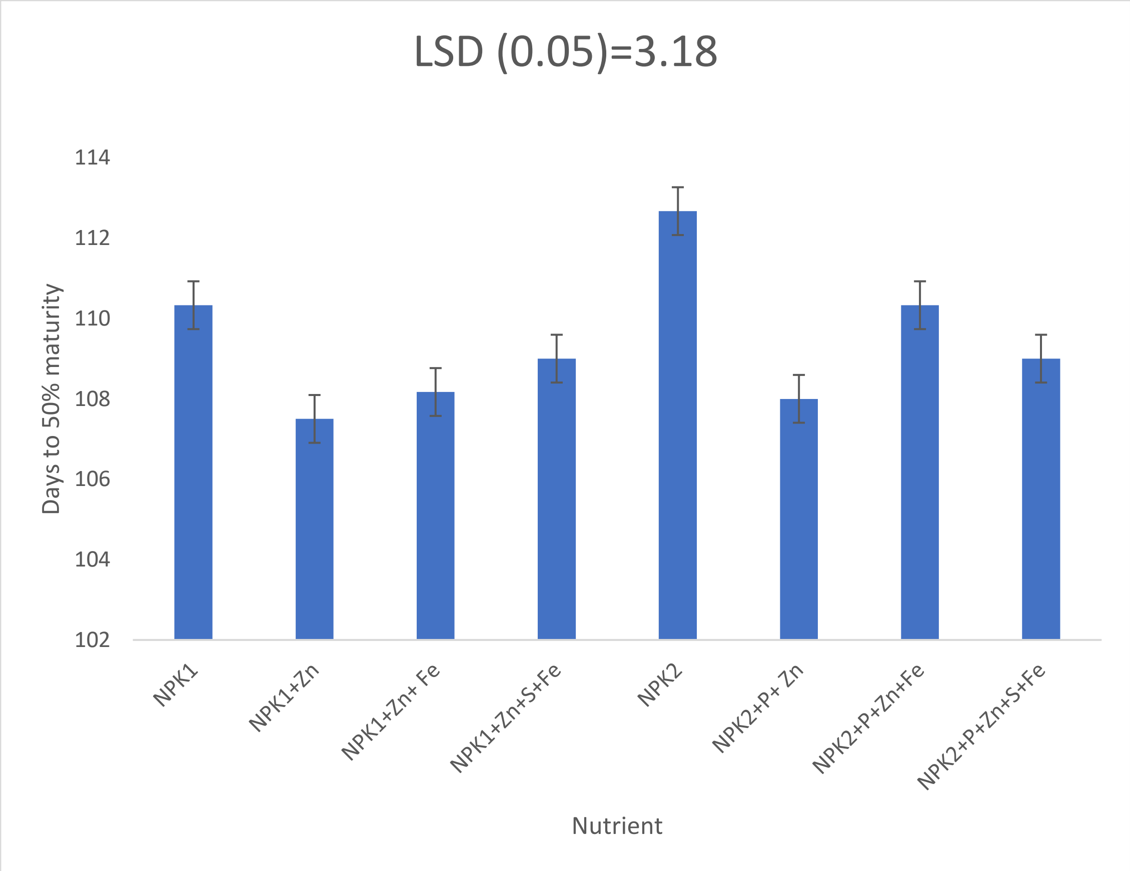

Figure 9. Nutrient effects on days to 50% maturity under both irrigated (Botanga) and rainfed (Nyankpala). Error Bars Represent SEM.

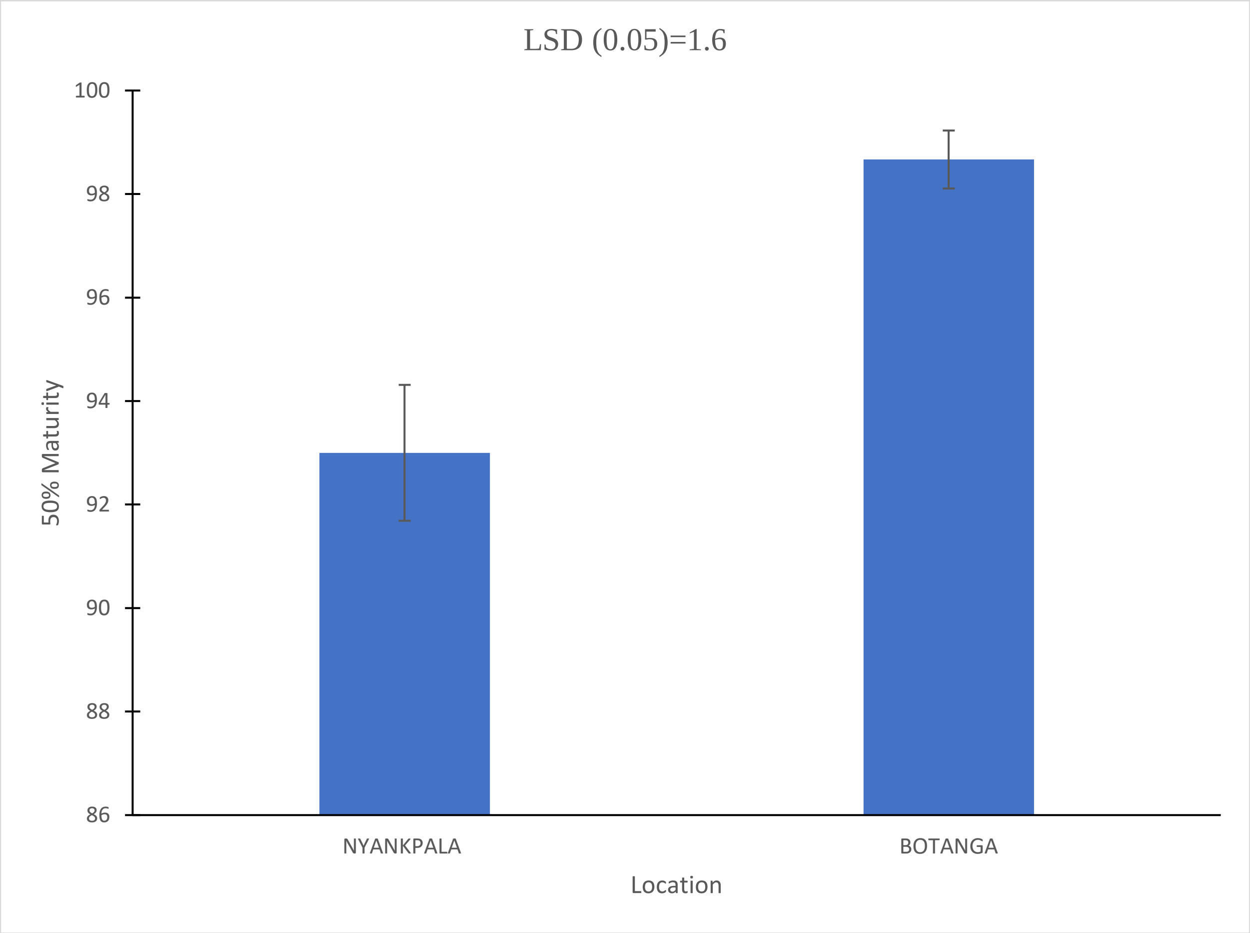

Figure 10. Location effects on days to 50% maturity under both irrigated (Botanga) and rainfed (Nyankpala). Error Bars Represent SEM.

4.7 Number of panicles per plant

Location by nutrient (P>0.05) and nutrient (P>0.05) did not have effect on number of panicles per plant but location (P<0.05) recorded effects. Nyankpala under rainfed performed better with 10.03 panicles per plant as compared to Botanga under irrigation with 6.40 panicles per plant (Figure11).

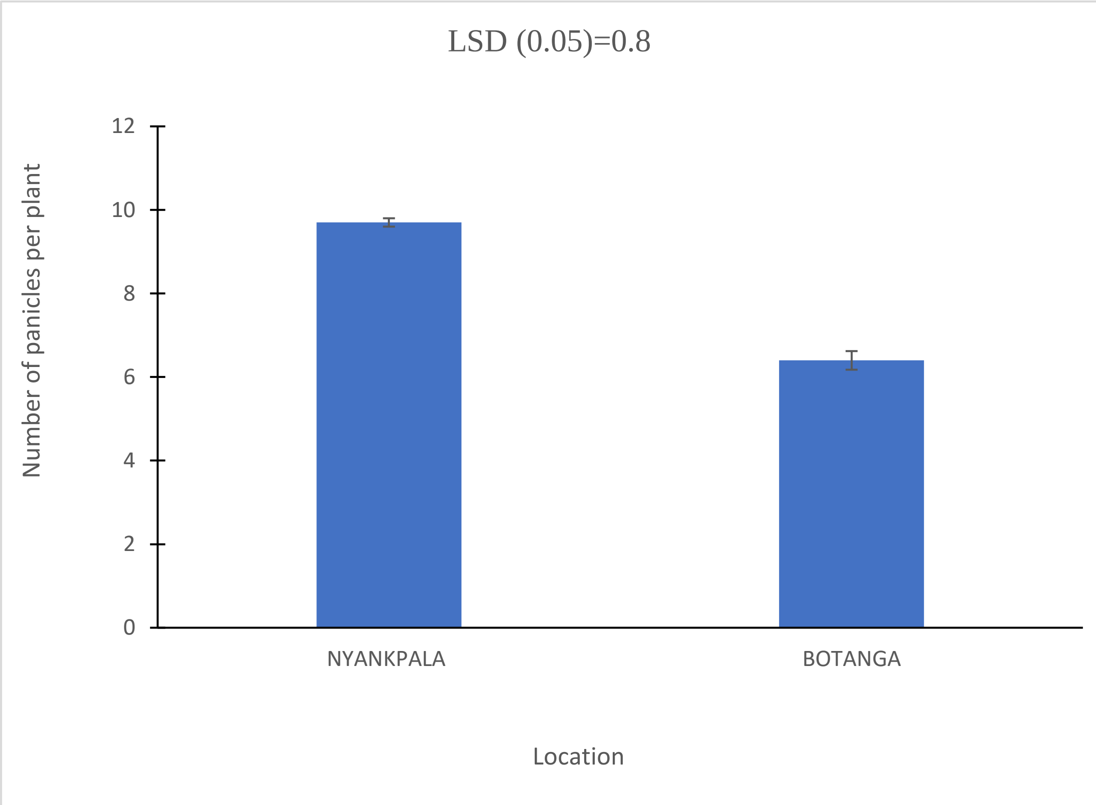

Figure 11. Location effects on number of panicles per plant under rainfed (Nyankpala) and irrigation (Botanga). Error bars represent SEM.

4.8 Panicle weight

Location by nutrient (P>0.05) and nutrient (P>0.05) did not have effect on panicle weight, but panicle weight recorded location (P<0.001) effects. Botanga under irrigation recorded the highest panicle weight of 35.98 g as compared to Nyankpala under rainfed with 24.93 g panicle weight (Figure12).

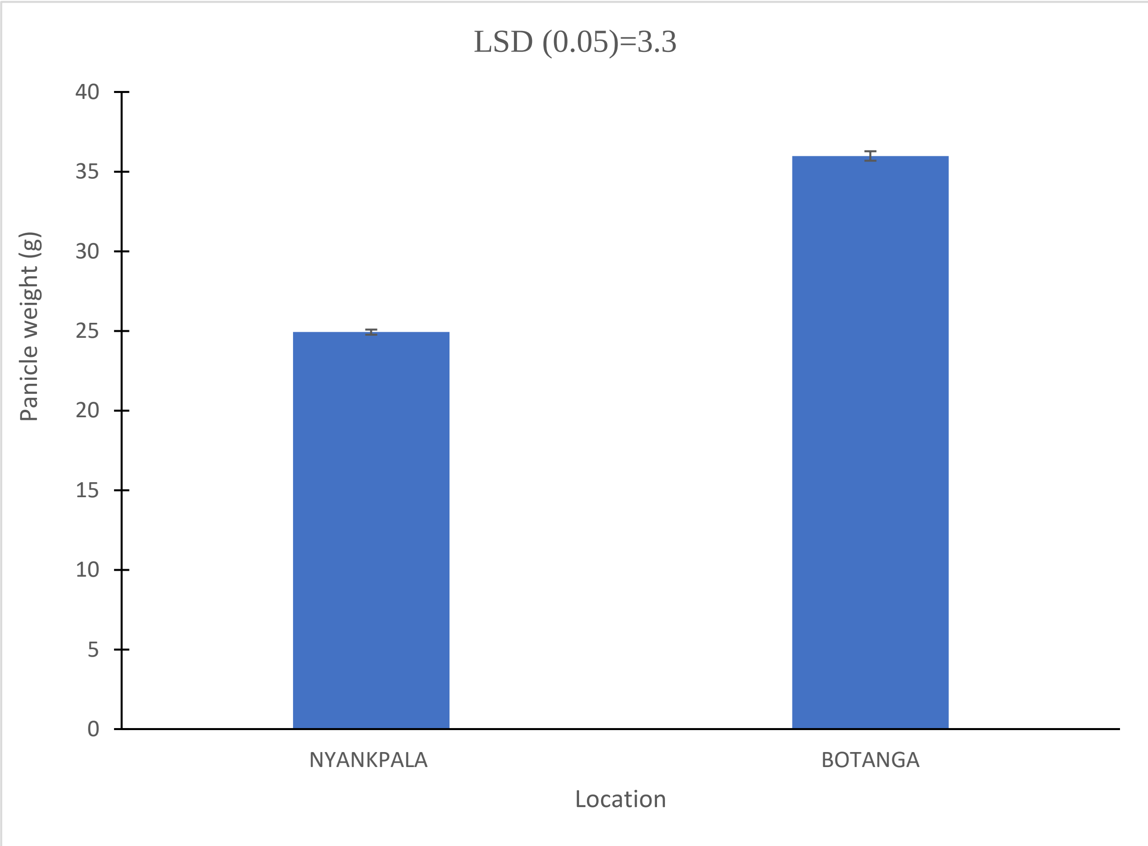

Figure 12. Location effects on panicle weight under rainfed (Nyankpala) and irrigation (Botanga). Error bars represent SEM.

4.9 Leaf Area

At 2 WAT, leaf area showed significant effect of location by nutrient ($P<0.01$); location ($P<0.001$) and nutrient ($P<0.01$). Location by nutrient at 2 WAT revealed that under rainfed (Nyankpala), NPK2+P+Zn recorded the highest leaf area of 34.26 cm^2, but NPK1 and NPK2+P+Zn+Fe gave similar leaf area, whilst NPK2 recorded the lowest (Figure 13).

At 4 WAT, Location by nutrient ($P>0.05$) and location ($P>0.05$) did not have effect on leaf area, but nutrient recorded ($P<0.01$) effects. At 4 WAT NPK2+P+Zn had the maximum leaf area of 30.87 cm^2, but NPK1 and NPK1+Zn+S+Fe gave similar leaf area, whilst NPK2 had the minimum leaf area 26.46 cm^2 (Figure 14).

At 6 WAT, leaf area showed significant effect of location by nutrient ($P<0.05$) and location ($P<0.001$) but not nutrient ($P>0.05$) effect. Location by nutrient at Nyankpala under rainfed revealed NPK1+Zn+S+Fe recorded the highest leaf area of 47.07cm^2 whilst NPK2 recorded the lowest leaf area of 28.20 cm^2 (Figure 14), but Botanga under irrigation showed NPK2 recorded the highest leaf area with 50.11cm^2 whilst NPK2+P+Zn+Fe recorded the lowest leaf area with leaf area 44.36 cm^2.

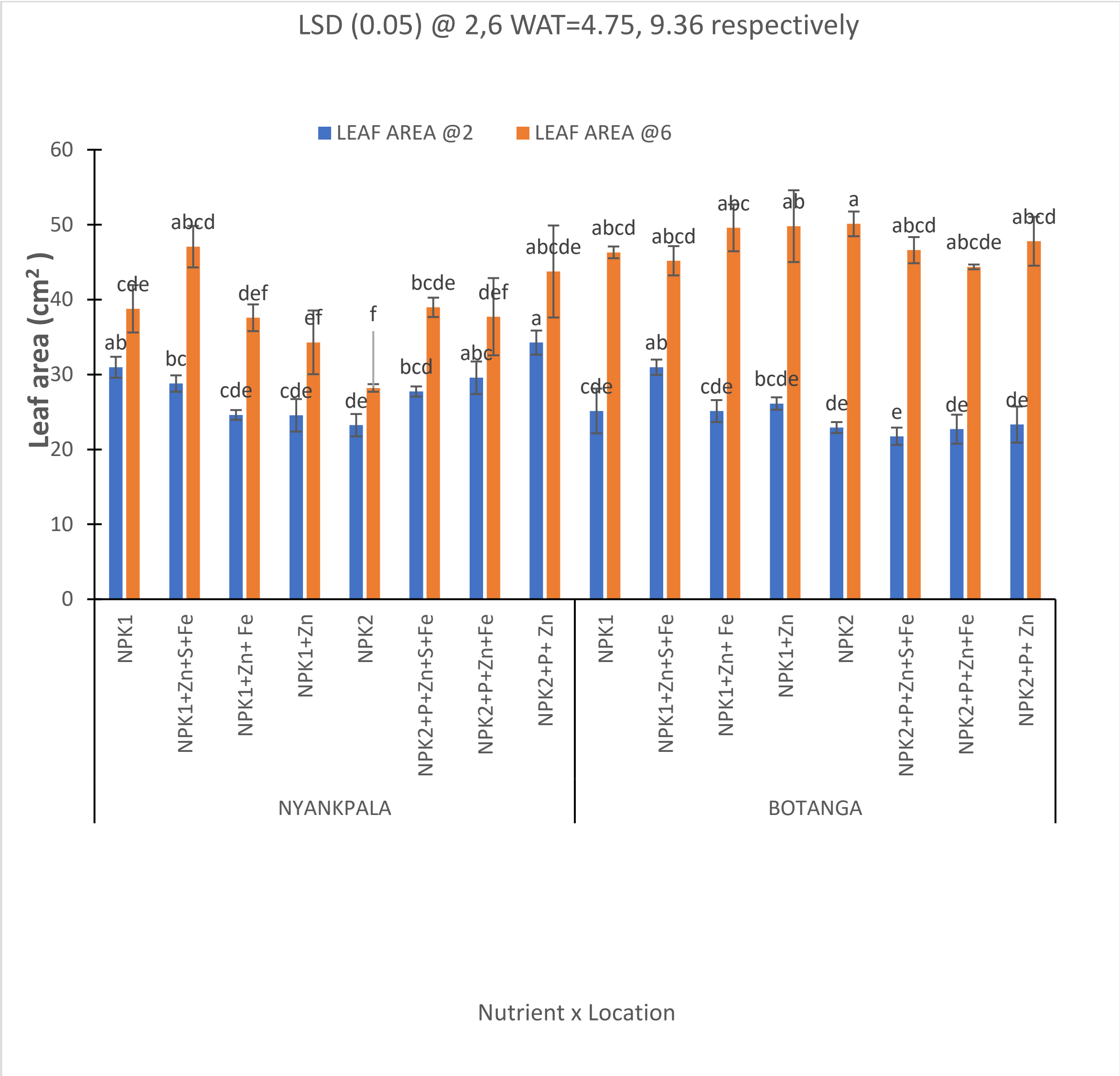

Figure 13. Interaction effects on leaf area under both irrigated (Botanga) and rainfed (Nyankpala). Bars represent SEM.

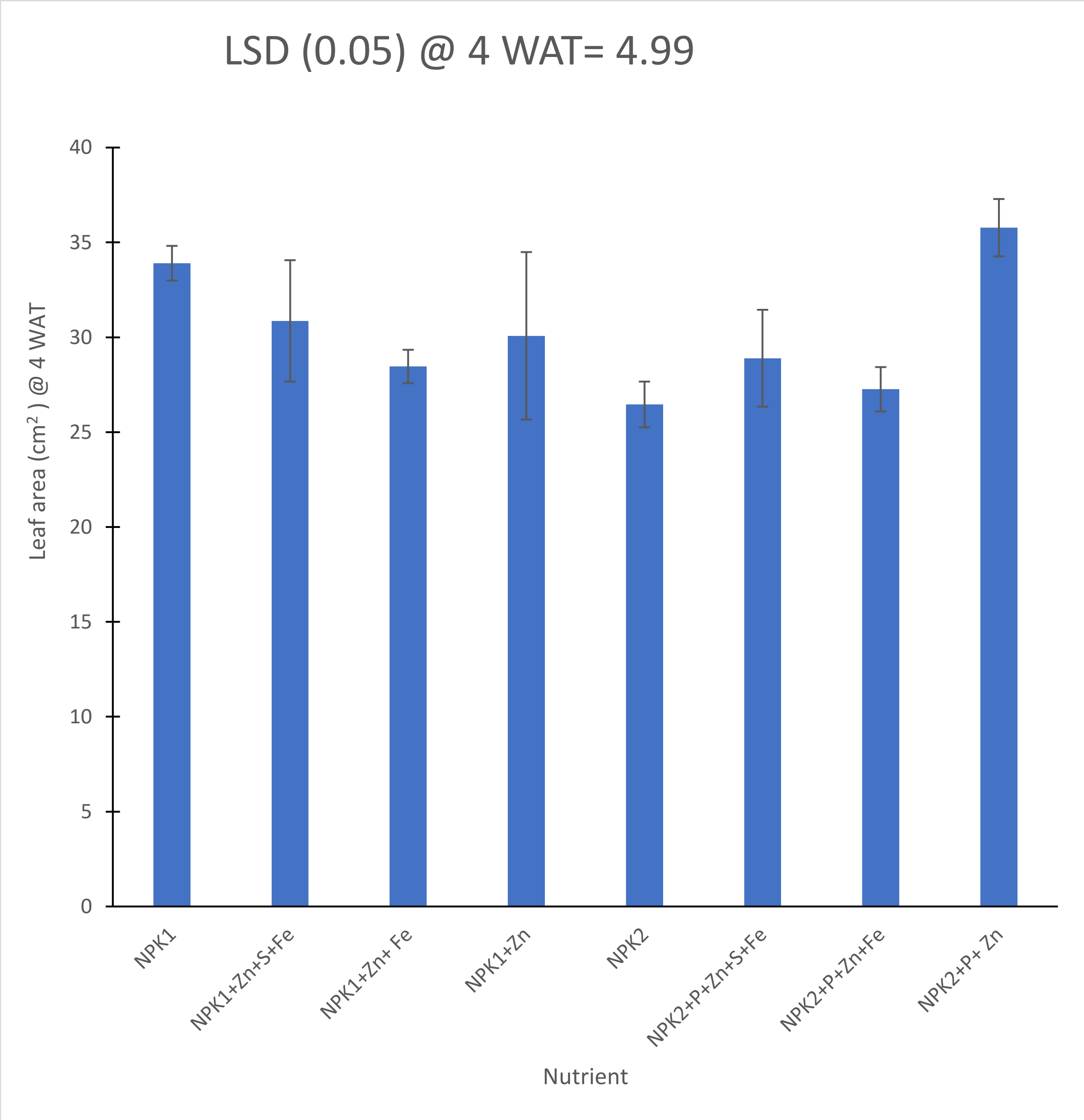

Figure 14. Nutrient effect on leaf area under rainfed (Nyankpala) and irrigation (Botanga).
Error bars represent SEM.

4.10 Fresh straw weight at harvest

Fresh straw weight at harvest did not show significant effect on location by nutrient (P>0.05) but influenced nutrient (P<0.01) and location (P<0.01) effect. The best performing nutrient was NPK_2+P+Zn with 8096 kg/ha but NPK_1+Zn, NPK1+Zn+S+Fe and NPK1 gave similar fresh straw at harvest, whilst the least was NPK2 with 5600 kg/ha (Figure 15). Location effects revealed that Botanga under irrigation showed better result with 7182 kg/ha as compared to Nyankpala under rainfed with 6155 kg/ha fresh straw at harvest (Figure 16).

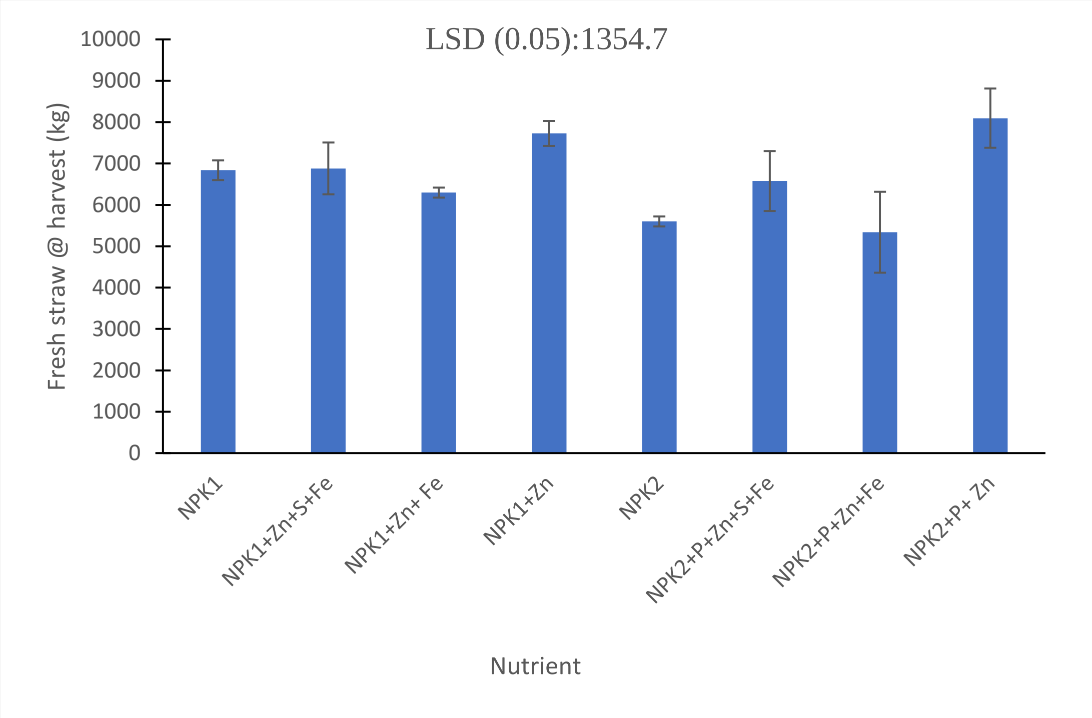

Figure 15. Nutrient effects on Fresh straw weight at harvest under both irrigated (Botanga) and rainfed (Nyankpala). Bars represent SEM.

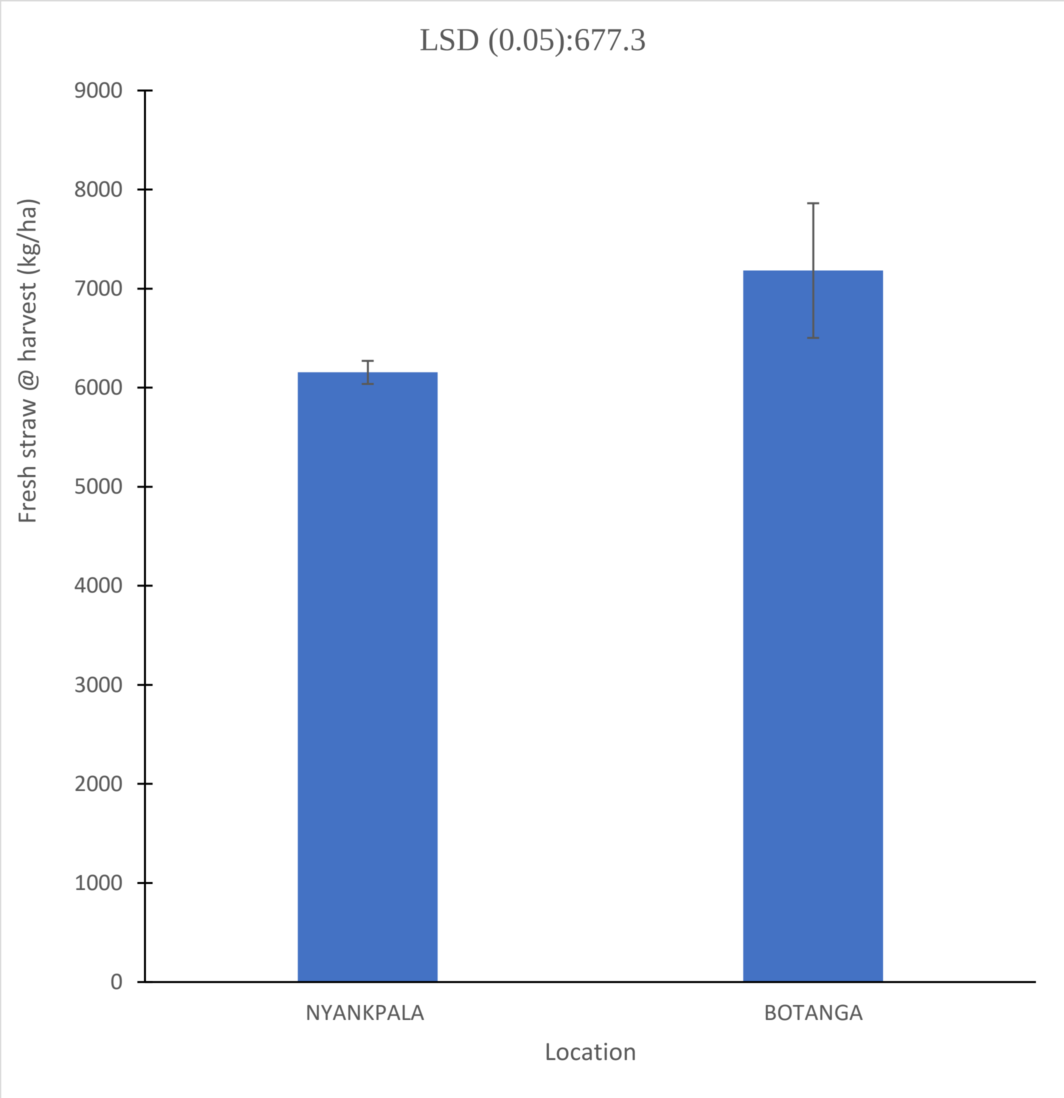

Figure 16. Location effects on Fresh straw weight at harvest under rainfed (Nyankpala) and irrigation (Botanga). Error bars represent SEM.

4.11 Sun dry Straw weight

Location by nutrient (P>0.05) and location (P>0.05) did not have effect on straw weight but nutrient significantly affected (P<0.01) straw weight. NPK1+Zn+S+Fe recorded the highest straw weight with 3252 kg/ha, but NPK2+P+Zn, NPK1+Zn and NPK1 gave similar results, whilst NPK_2 recording the lowest with 1875 kg/ha straw weight (Figure 17).

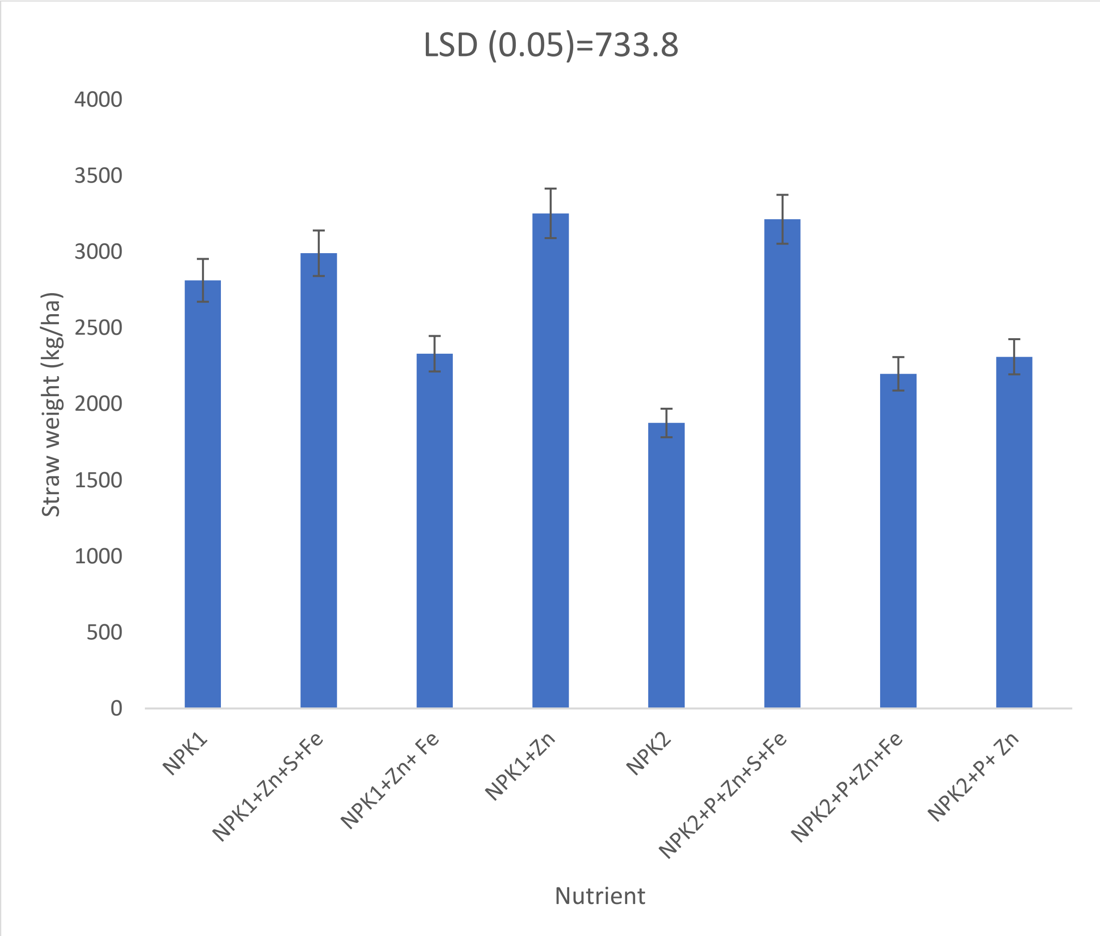

Figure 17. Nutrient effects on straw weight under both irrigated (Botanga) and rainfed (Nyankpala). Error Bars Represent SEM.

4.12 Dry straw at harvest

Dry straw weight at harvest did not show significant effect on location by nutrient (P>0.05), But location (P<0.01) and nutrient (P<0.001) varied on dry straw at harvest. NPK2+P+Zn recorded the highest dry straw at harvest with 5734 kg/ha but NPK1+Zn+S+Fe and NPK1+Zn gave similar dry straw at harvest whilst NPK2 recorded the lowest dry straw at harvest with 3429 kg/ha (Figure 18). Location effects revealed that Botanga (4861 kg/ha) under irrigation showed a better result as compared to Nyankpala (4147kg/ha) under rainfed (Figure 19).

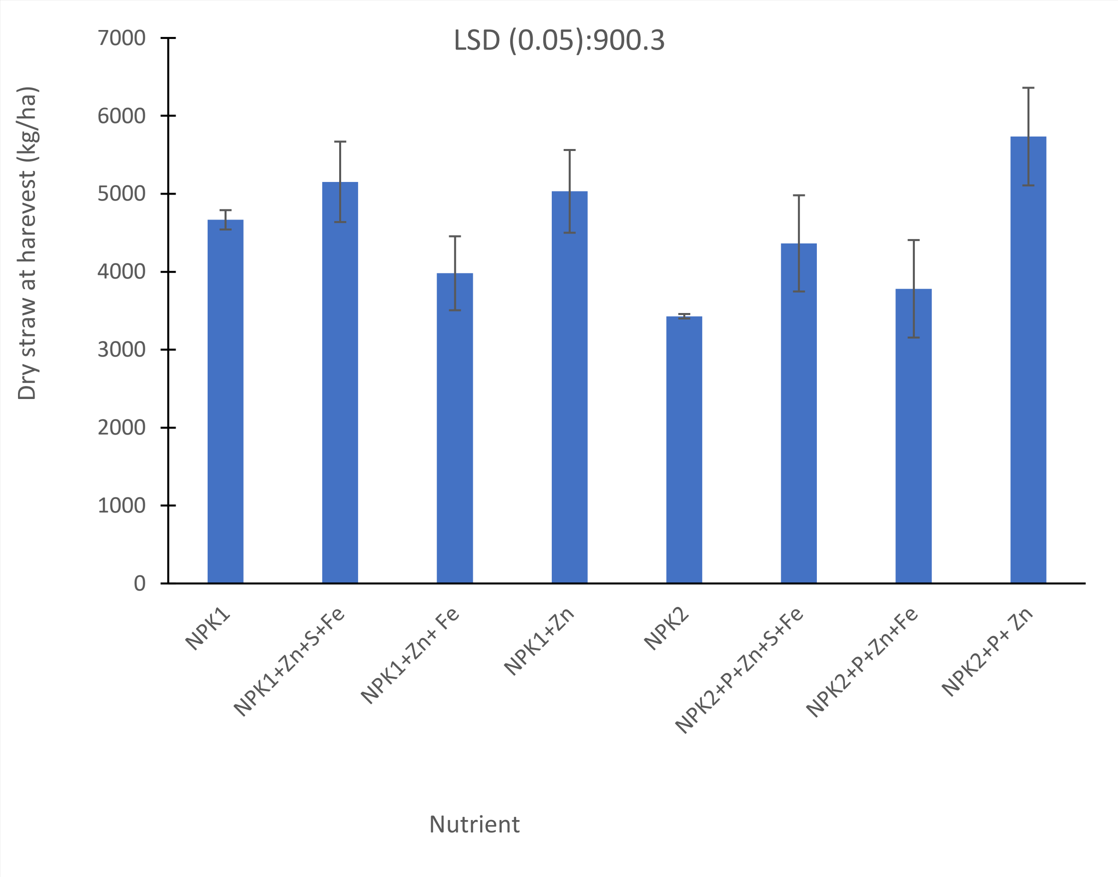

Figure 18. Nutrient effect on dry straw at harvest under both irrigated (Botanga) and rainfed (Nyankpala). Bars represent SEM.

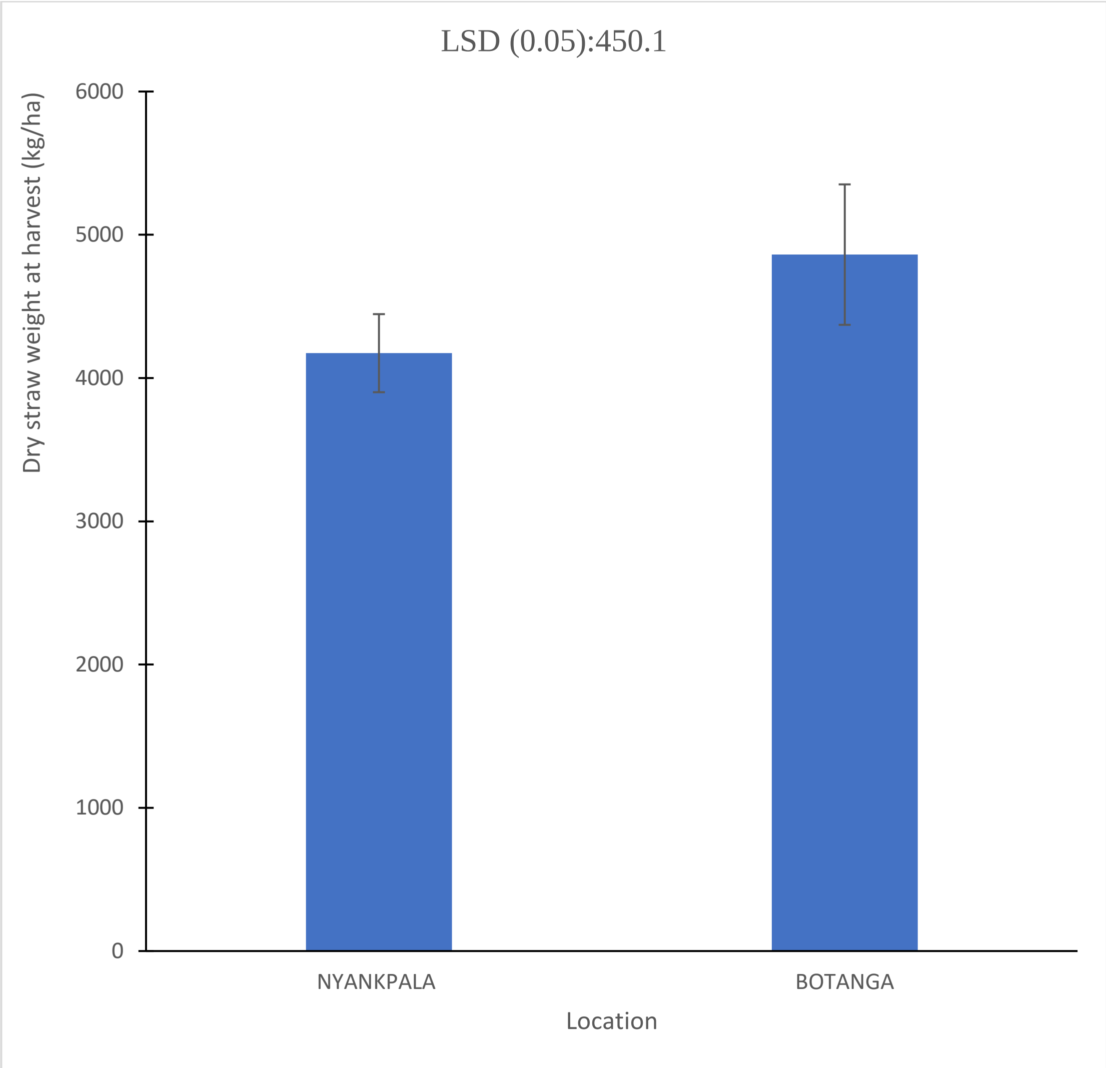

Figure 19. Location effects on dry biomass at harvest under rainfed (Nyankpala) and irrigation (Botanga). Error bars represent SEM.

4.13 1000 seed weight

Location by nutrient (P>0.05) and nutrient (P>0.05) did not have effect on 1000 seed weight, but location (P<0.001) recorded effect. Nyankpala under rainfed recorded the highest 1000 seed weight of 28.31g as compared to Botanga (25.04 g) under irrigation (Figure 20).

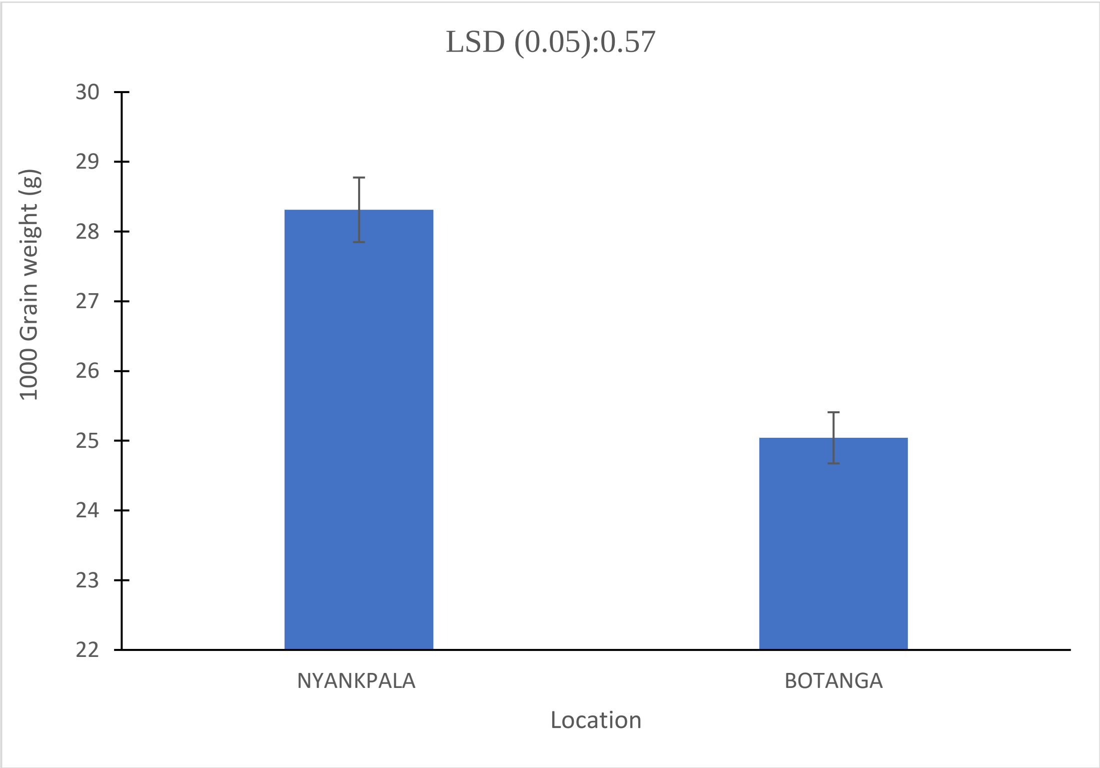

Figure 20. Location effects on 1000 seed weight under rainfed (Nyankpala) and irrigation (Botanga). Error bars represent SEM.

4.14 Paddy Yield

Paddy yield was not influenced by location by nutrient (P>0.05). Location (P<0.01) and nutrient (P<0.01) affected paddy yield. The highest yield was produced by NPK2+P+Zn (4425 kg/ha), but similar to NPK1+Zn+S+Fe, whilst NPK2+P+Zn+Fe produced the least yield of 2600 kg/ha (Figure 21). Botanga under irrigation recorded the highest paddy yield of 3635 kg/ha as compared to Nyankpala under rainfed of 2965 kg/ha (Figure 22).

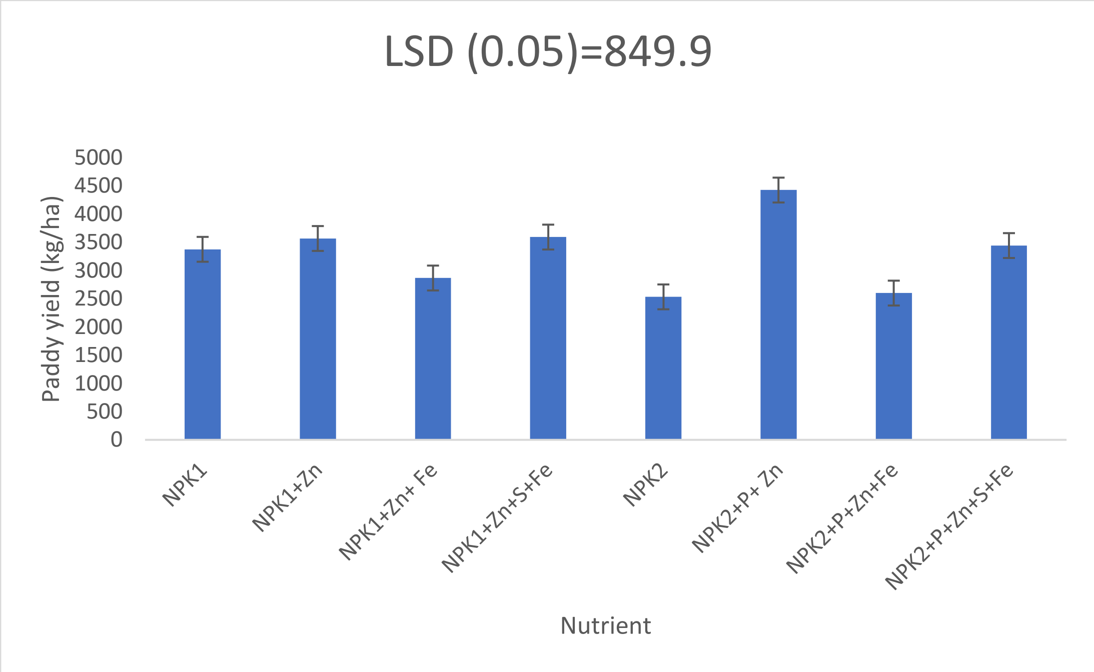

Figure 21. Nutrient Effect on Paddy yield under both irrigated (Botanga) and rainfed (Nyankpala). Bars represent SEM.

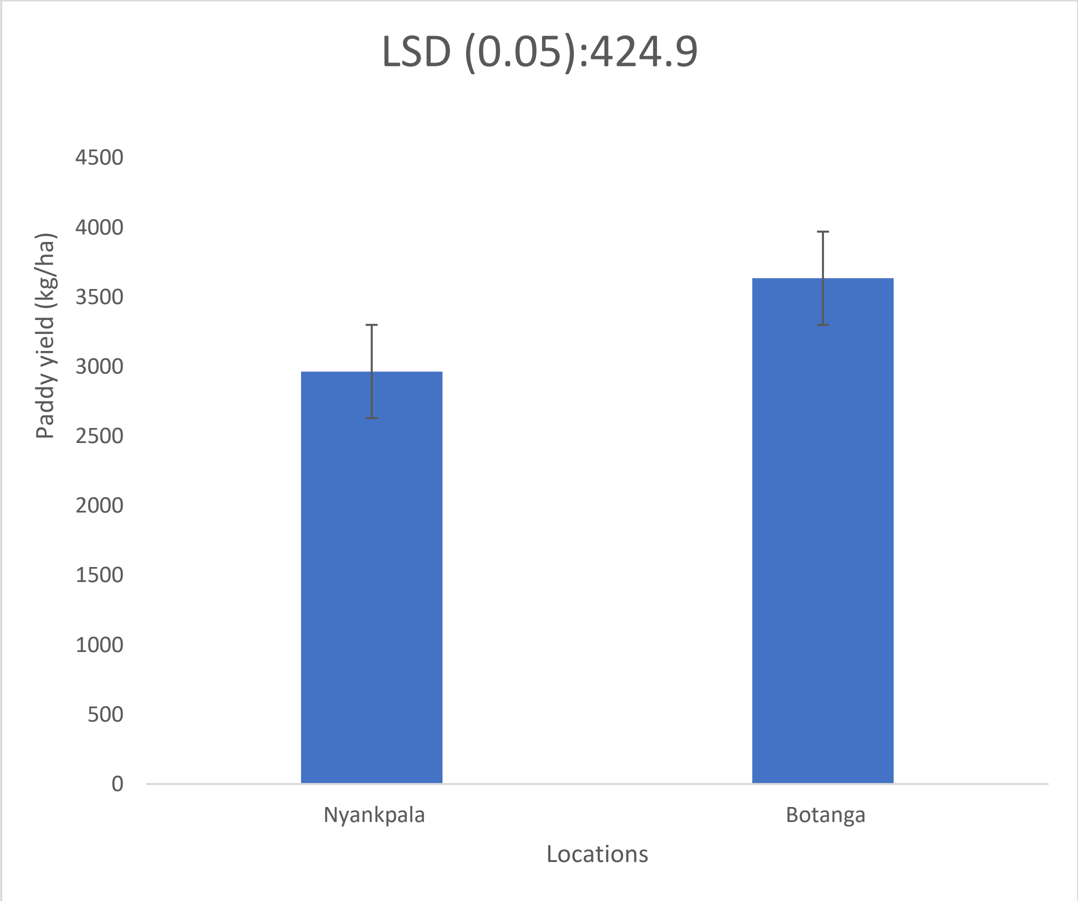

Figure 22. Location effect on paddy yield under rainfed and irrigation
Error bars represent SEM.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Combined effects of foliar application of P, S and micronutrient Zn and Fe on growth parameters

5.1.1 Plant height

The height of rice plants is an essential growth and development indicator. Plant height is the main contributor to the rice straw biomass weight (Ranawake et al., 2014). The influence of foliar application of P, S and micronutrients of Zn and Fe on plant height exhibited significant differences at 2, 4, and 6 WAT on plant height. At 6 WAT, location by nutrient effect showed NPK1+Zn supported the tallest plant height of 68.38 cm at Nyankpala under rainfed conditions and, at Botanga NPK1+Zn+S+Fe was the best, but producing similar result with that of Nyankpala. However, similar plant heights to the maximum were obtained at Nyankpala with NPK1+Zn+S+Fe, NPK1+Zn+Fe, NPK1 and NPK2+P+Zn. Botanga under irrigation, with a plant height of 104.56 cm, did better than Nyankpala under rainfed, with a height of 91.94 cm, at 8 WAT.

Cakmak & Dell (2018), revealed that foliar Zn application is more successful in plant growth compared to direct soil applications. Although foliar Zn treatment is good for plant growth its efficacy may be influenced by a number of circumstances such as the timing of application is very important (Boonchuay et al., 2013). foliar applied Fe caused greater increases in rice Fe concentration. Moreover, the time of foliar application may differentially influence grain Fe concentration. It is well established that foliar Fe application after the flowering stage more distinctly increases the grain Fe concentration (Wei et al., 2012). One nutrient, Sulphur, may had caused a substantial effect on rice plant height. According to (Kumar Singh et al., 2012) During all phonological phases, the amount of Sulphur was not the same for each level, and it increased as growth progressed. A sufficient amount of P is essential for good plant growth, particularly during the early stages of plant development (Amaral et al., 2013). It was discovered that combining micronutrients with macronutrients boosted plant height more than applying macronutrients separately (Islam et al., 2018) and this agrees with the current study

5.2 Tiller count

Tillering in grains is influenced by mineral nutrition. Tillering determines the plant architecture and canopy growth for primary production by capturing incident light. Tillering is an important morphological feature in cereals because it influences the quantity of panicles or ears produced in the final stand (Opio, 2019).

The influence of foliar application of P, S, and micronutrients of Zn and Fe on tiller count revealed significant differences among nutrients at 2, 4 and 6 WAT. At 2 WAT nutrient effect recorded 8.50 tillers per hill for NPK1 under both irrigation and rainfed. However, Nyankpala location which is under rainfed conditions performed better with 7.37 tillers per hill compared to 6.40 tillers per hill for Botanga under irrigation. At 4 WAT, nutrient effect gave the highest tiller count of 15.17 tillers per hill for NPK1 under both irrigation and rainfed conditions, although NPK1+Zn+Fe, NPK1+Zn+S+Fe and NPK1+Zn gave similar tiller count. Nyankpala under rainfed did better with 13.26 tillers per hill, than Botanga under irrigation, with 12.28 tillers per hill. Nutrient effect at 6 WAT gave NPK1+Zn had the highest tiller count of 21.60 tillers per hill, while NPK1+Zn+S+Fe, NPK1, and NPK1+Zn+Fe had similar tiller counts per hill. Nyankpala under rainfed performed better under rainfed conditions, with 19.40 tillers per hill, than Botanga under irrigation, with 18.42 tillers per hill, at 6 WAT.

The number of tillers increased when Fe and Zn were applied to the leaves. This could be attributed to improved photosynthetic processes, chlorophyll production, protein synthesis, and nitrogen fixation as a result of Zn and Fe administration. Kadam et al. (2018) also found that applying zinc and iron to the soil boosted the number of tillers. After nitrogen (N), phosphorus, and potassium, sulfur (S), is progressively becoming recognized as the fourth most important protein-forming ingredient for plant growth (Jamal et al., 2010). This study agrees with (Islam et al., 2018) who posited micronutrients had a favorable influence on the number of tillers, and had a positive impact on the quantity of rice tillers.

5.3 Chlorophyll Content

The photosynthetic rate, which is influenced by chlorophyll content, determines the response of the growth and yield parameters. In the current study, the combined impacts of micronutrients and macronutrients resulted in a considerable increase in chlorophyll content. Location by nutrient at 4 WAT at Nyankpala under rainfed, revealed NPK1+Zn recorded the highest SPAD values of 38.35 but NPK1, NPK1+Zn+Fe, NPK1+Zn+S+Fe, NPK2+P+Zn+S+Fe and NPK2+P+Zn gave similar

SPAD value and at Botanga NPK1+Zn+S+Fe was the best (37.15), but producing similar result with that of Nyankpala. Nutrient effect at 6 WAT, revealed NPK1+Zn+S+Fe recorded the highest SPAD value of 41.63 but NPK1+Zn+Fe gave similar SPAD value under both irrigation and rainfed conditions. Location effect at 8 WAT revealed Botanga under irrigation performed better with SPAD value of 47.18 as compared to Nyankpala under rainfed with SPAD value of The improvement in chlorophyll content could be attributed to Zn application because of the enhanced photosynthetic and metabolic activity, which mighty have led to an increase in various plant metabolic pathways responsible for cell division and elongation (Hatwar et al., 2003). In this study, chlorophyll content was also improved by treatment containing ions, probably because Das (2014) stated that chlorophyll is formed with the help of irons. In plant cells, iron is essential for the production of chlorophyll. (Lohry, 2007). As such, the findings of this study agreed with earlier report that the application iron has a considerable favorable impact on leaf metrics (Kumar et al., 2017).

5.4 Days to 50% flowering

Foliar applications of P and S and micronutrients of Zn and Fe enhanced days to 50% flowering with location effect. Botanga under irrigation did better than Nyankpala under rainfed conditions, with 84.08 days to 50% flowering compared to 79.08 for Nyankpala. Zinc increased auxin synthesis, and iron is thought to play a function in the synthesis of flowering molecules (Nehete et al., 2011). The combined influence of many micronutrients might have played a critical part in the improvement of physiological activities that led to the early onset of blooming (Nehete et al., 2011).

5.5 Days to 50% maturity

Nutrient effect supported NPK2 had the maximum days to 50% maturity, with a value of 112.67, although NPK1 and NPK2+P+Zn+S+Fe had equal maturity. Botanga under irrigation took 111.29 days to reach 50% maturity, compared to 106.46 days for Nyankpala under rainfed conditions. The effect of zine and iron in the synthesis of flowering molecules is the same as enhancing days to 50% maturity.

Phosphorus is a significant nutrient that aids in the stimulation of early blooming and has good effects on plant growth (Atakora et al., 2015). Under equal environmental conditions, medium grains typically take five to seven days longer to achieve harvest maturity than long grains (Alifah, 2021).

5.6 Number of panicles per plant

According to Chauhan et al. (2017), when rice receives the ideal amount of fertilizer N, half of the total N is absorbed before half of the entire dry matter is produced. The remaining 30–50% of total N intake occurs after the commencement of panicle initiation. The rice panicle holds 60–70% of the above-ground nitrogen when mature. It is critical to remember that the number of panicles per unit area is the most important factor in rice yield, accounting for 89 percent of grain yield. (Opio, 2019). Location effect showed Nyankpala under rainfed conditions produced 10.03 panicles per plant compared to 6.40 panicles per plant in Botanga under irrigation. Because of the addition of micronutrients and macronutrients and the modification in spacing, the number of panicles per plant increased significantly. The application of S and Zn to rice has been shown to have a considerable impact on the number of panicles (Islam et al., 2018). The commencement of the panicle initiation/booting stage produces nearly half of the total dry matter, and as a result, this stage accounts for half of the total N uptake. The results support the findings of Khan et al., (2007) who found that an appropriate supply of Zn results in an increase in the number of panicles plant^{-1}

5.7 Panicle weight

Location effect showed Botanga had the maximum panicle weight of 35.98 g compared to Nyankpala under rainfed had a panicle weight of 24.93 g. Dry matter transition from store parts to sink parts mighty be boosted by foliar application of micronutrients. (Zayed et al., 2011).

5.8 Leaf Area

The effects of location by nutrient at 2 WAT on foliar applications of P, S, and micronutrients of Zn and Fe on leaf area revealed under rainfed conditions, NPK2+P+Zn had the maximum leaf area of 34.26 cm^2, but NPK1 and NPK2+P+Zn+Fe had similar leaf areas, whilst NPK1+Zn+S+Fe had the highest leaf area of 30.96 cm^2 under irrigation. However, Nyankpala performed better under rainfed conditions, with a leaf area of 27.96 cm^2, compared to Botanga under irrigation, which had a leaf area of 24.75 cm^2. At 4 WAT nutrient effect revealed NPK2+P+Zn had the largest leaf area of 30.87 cm^2 although NPK1 and NPK1+Zn+S+Fe had equal leaf areas. At 6 WAT location by nutrient reported NPK1+Zn+S+Fe had the largest leaf area of 47.07cm^2 under rainfed conditions, whilst NPK2 had the highest leaf area of 50.11cm^2 at Botanga under irrigation conditions. However, location effect showed Botanga performed better under irrigation with a leaf area of 47.46 cm^2 than Nyankpala under rainfed conditions with a leaf area of 38.29 cm^2.

Because of the position of nitrogen in the chemical structure of chlorophylls and other micronutrients such as Zn, it appears that foliar application of Fe plays a significant role in improvement of leaf area. It promotes plant hormonal activity, which results in an increase in leaf area. When compared to the control, micronutrient leaf treatment appears to have significantly boosted rice yield and has a significant impact on cluster formation and seed production. These findings are consistent with those of a study done by Lahijani et al. (2020).

5.9 Fresh straw weight at harvest

Nutrient effect showed NPK2+P+Zn had the highest yield of 8096 kg/ha, whereas NPK1+Zn, NPK1+Zn+S+Fe, and NPK1 had similar yields of fresh straw at harvest. Location impacts revealed that Botanga under irrigation yielded 7182 kg/ha fresh straw at harvest compared to Nyankpala under rainfed yielding 6155 kg/ha fresh straw. In this regard, it has been shown that micronutrient can be used as an effective nutritional solution for improving rice production and morphological trait indicators (Lahijani et al., 2020). (Change to 5.10)

5.10 Sun dry Straw weight

The nutrient effects of foliar applications of P, S, and micronutrients of Zn and Fe on rice straw weight showed that, NPK1+Zn+S+Fe had the maximum straw weight of 3252 kg/ha, while NPK2+P+Zn, NPK1+Zn, and NPK1 had similar results. The crop's dry matter explains the true growth dynamics of arable crops (Haruna, 2019). This finding is similar to that of Nesgea et al. (2012), who found that the increase was due to a higher number of tillers per meter square, and notably longer panicle length, according to the authors.

5.11 1000 seed weight

Location effect reported Nyankpala had the highest 1000 seed weight of 28.31 g under rainfed conditions, compared to Botanga (25.04 g) under irrigation. Foliar nutrient was found to be beneficial in boosting rice growth and, as a result, primary yield components such as 1000-grain weight (Zayed et al., 2011). The results showed that one foliar application of essential micronutrients would have a significant influence on 1000 grain weight of rice.

5.12 Paddy Yield

Effect of foliar application of P, S, and micronutrients of Zn and Fe demonstrated highly significant difference in paddy production among nutrient and locations. The results of the treatment on micronutrients revealed a significant increase in paddy productivity. NPK2+P+Zn had the maximum production of 4425 kg/ha, which was equal to NPK1+Zn+S+Fe. In both experiments, foliar nutrient with Zn, S, and Fe enhanced yield components and rice grain yield. Botanga had the maximum paddy production of 3635 kg/ha under irrigation, while Nyankpala had the lowest paddy output of 2965 kg/ha under rainfed conditions.

The use of micronutrients Zn and Fe in combination with N, P, and K has been shown to boost N, P, K, Zn, and Fe uptake. Improving plant nutrition may help to raise Zn and Fe concentrations in grain by changing the quantities of Zn or Fe-chelating nitrogenous compounds necessary for Zn and Fe transport inside plants, resulting in an increase in Zn and Fe transporters required for uptake by root and phloem loading (Maurya et al., 2020) . Other research has found that phosphorus treatment to rice boosted P accumulation but did not consistently increase rice yields due to floods, which reduced soil P sorption and increased P diffusion (Atakora et al., 2015). However, the results of this experiment show that adding P to lowland rice may not only boost P accumulation but also greatly increase grain production.

Furthermore, foliar micronutrient applications have been demonstrated to be more successful than soil applications due to their rapid overcoming of deficiencies, convenience of administration, reduced toxicity caused by accumulation, and prevention of element stabilization in the soil (Mousavi, 2011) .

There is growing evidence that applying zinc fertilizers foliarly or in a combined soil foliar application under field circumstances is a highly effective and practical strategy to increase zinc uptake and accumulation in plants (Mousavi, 2011) .

The crucial role of Sulphur in protein and methionine synthesis could explain the increase in rice yield caused by Sulphur treatment (Lar et al., 2007). Zinc and iron have a substantial impact on fundamental plant life activities such nitrogen metabolism, nitrogen intake, protein quality, photosynthesis, and chlorophyll synthesis (Mousavi, 2011) Others process include carbon anhydrase activity, resistance to abiotic biotic stresses, and protection against oxidative damage, according to plant professional research (Mousavi, 2011). It is reported that micronutrients applied alone or together with macronutrients have significant effect on crop yield and is also well established that application of Zn increases rice yield (M. Siddika et al., 2016). Because of the high cost of fertilizers containing Zn, their use for addressing its deficiency is limited. Among the various methods for increasing crop productivity, foliar spraying with zinc is an effective one. Zn foliar application after flowering may be effective in increasing zinc in rice grains. As earlier reported Foliar application of Zn, S and Fe increased yield components and paddy yield (Chhabra & Kumar, 2018).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study was a 2 x 8 factorial experiment laid out in randomized complete block design with three replications. The locations were Nyankpala and Bontanga under rainfed lowland and irrigation conditions respectively, and the nutrient formulations included: NPK1, NPK1+Zn+S+Fe, NPK1+Zn+Fe, NPK1+Zn, NPK2, NPK2+P+Zn+S+Fe, NPK2+P+Zn+Fe and NPK2+P+Zn. AGRA rice variety, which has a maturity period of 125 to 130 days was tested under both irrigated and rainfed lowland rice growing conditions. The results of this study demonstrated that foliar treatment of the key micronutrients evaluated (Fe and Zinc) and increased rice output in both rainfed and irrigated fields. Micronutrients might be extremely important as adequate supply could help to ensure higher grain yield and improved economics of production. In addition, application of micronutrients in conjunction with macronutrients could further improved grain yield, with the NPK_2+P+Zn nutrient providing the best option. NPK_1+Zn+S+Fe foliar nutrient resulted in the largest straw biomass, while NPK_1+Zn+S+Fe and NPK_1+Zn resulted in the highest fresh straw weight. NPK_1+Zn+S+Fe, NPK_1+Zn, NPK_2+P+Zn, NPK_2+P+Zn+S+Fe, NPK_1+Zn+Fe and NPK_2 promoted germination percentage, days to 50% flowering and days to 50% maturity, chlorophyll content, straw biomass, number of panicles per plant, panicle weight and leaf area at both rain-fed and irrigation locations which supported higher response in rice production.

Results showed foliar P increased rice growth and yield responses compared to soil applied P; whilst irrigation ecology enhanced terminal parameters more than rainfed. Although the latter enhanced growth probably due to the initial overflooding at the irrigation site. Rice yield increased with application of S and micronutrients Zn and Fe, whereas foliar P application compensated for lower soil applied P. Grain yield was improved by combination of micro- and macro-nutrients.

6.2 RECOMMENDATIONS

Overall, in rainfed and irrigation ecologies higher responses in rice production would be best supported by four treatments: NPK_2+P+Zn, NPK_1+Zn+S+Fe, NPK_1+Zn, and NPK_1+Zn+Fe. As such, farmers could improve rice production with the inclusion of foliar application of Zn, S, and Fe in their fertilization programme.

Irrigation farmers should ensure adequate drainage system to avoid flowing of farms at wrong growth stages of rice.

Since the study was carried out in a year, it is recommended that the experiment should be repeated under different locations under both rainfed and irrigation to confirm the findings of the study.

Research should be conducted to examine the effects foliar applications of other secondary micro and macro nutrients on the performance of rice.

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APPENDICES

Appendix 1: Analysis of variance for plant height at 2 WATP (cm)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	34.614	17.307	4.71	
Replication. *Units* stratum					
Nutrient	7	60.699	8.671	2.36	0.048
Location	1	96.503	96.503	26.28	<.001
Nutrient. Location	7	91.070	13.010	3.54	0.007
Residual	30	110.161	3.672		
Total	47	393.047			

Appendix 2: Analysis of variance for plant height at 4WATP(cm)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	34.216	17.108	5.96	
Replication.*Units* stratum					
Nutrient	7	162.106	23.158	8.07	<.001
Location	1	96.503	96.503	33.62	<.001
Nutrient. Location	7	91.070	13.010	4.53	0.002
Residual	30	86.108	2.870		
Total	47	470.003			

Appendix 3: Analysis of variance for plant height at 6 WAT (cm)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	9.916	4.958	0.93	
Replication. *Units* stratum					
Nutrient	7	532.537	76.077	14.22	<.001
Location	1	82.625	82.625	15.44	<.001
Nutrient. Location	7	93.814	13.402	2.50	0.037
Residual	30	160.506	5.350		
Total	47	879.397			

Appendix 4: Analysis of variance for plant height at 8WATP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	111.29	55.65	1.57	
Replication. *Units* stratum					
Treatment	7	301.77	43.11	1.22	0.323
Location	1	1911.43	1911.43	54.10	<.001
Treatment. Location	7	362.82	51.83	1.47	0.217
Residual	30	1059.95	35.33		
Total	47	3747.26			

Appendix 5: Analysis of variance for tiller count at 2WATP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	1.2350	0.6175	0.83	
Replication. *Units* stratum					
Treatment	7	31.1058	4.4437	5.99	<.001
Location	1	11.4075	11.4075	15.38	<.001
Treatment. Location	7	3.9858	0.5694	0.77	0.619
Residual	30	22.2583	0.7419		
Total	47	69.9925			

Appendix 6: Analysis of variance for tiller count at 4WATP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	7.562	3.781	1.45	
Replication. *Units* stratum					
Treatment	7	188.739	26.963	10.32	<.001
Location	1	11.408	11.408	4.37	0.045
Treatment. Location	7	3.986	0.569	0.22	0.978
Residual	30	78.385	2.613		
Total	47	290.079			

Appendix 7: Analysis of variance for tiller count at 6WATP

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	141.155	70.577	28.46	
Replication. *Units* stratum					
Treatment	7	246.733	35.248	14.21	<.001
Location	1	11.407	11.407	4.60	0.040
Treatment. Location	7	3.986	0.569	0.23	0.975
Residual	30	74.392	2.480		
Total	47	477.673			

Appendix 8: Analysis of variance for chlorophyll at 4WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	18.015	9.008	1.32	
Replication. *Units* stratum					
Treatment	7	129.816	18.545	2.72	0.026
Location	1	8.755	8.755	1.28	0.266
Treatment. Location	7	117.704	16.815	2.47	0.040
Residual	30	204.632	6.821		
Total	47	478.923			

Appendix 9: Analysis of variance for chlorophyll at 6WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	9.359	4.679	0.52	
Replication. *Units* stratum					
Treatment	7	222.448	31.778	3.50	0.007
Location	1	8.755	8.755	0.96	0.334
Treatment. Location	7	117.704	16.815	1.85	0.114
Residual	30	272.454	9.082		
Total	47	630.720			

Appendix 10: Analysis of variance for chlorophyll at flag leaf

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	65.00	32.50	1.03	
Replication. *Units* stratum					
Treatment	7	261.71	37.39	1.18	0.343
Location	1	2136.53	2136.53	67.49	<.001
Treatment. Location	7	216.87	30.98	0.98	0.465
Residual	30	949.74	31.66		
Total	47	3629.86			

Appendix 11: Analysis of variance for day to 50% maturity

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	73.500	36.750	5.05	
Replication. *Units* stratum					
Treatment	7	118.917	16.988	2.33	0.050
Location	1	176.333	176.333	24.21	<.001
Treatment. Location	7	88.000	12.571	1.73	0.141
Residual	30	218.500	7.283		
Total	47	675.250			

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

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	9.04	4.52	0.32	
Replication. *Units* stratum					
Treatment	7	48.00	6.86	0.48	0.843
Location	1	300.00	300.00	20.92	<.001
Treatment. Location	7	116.33	16.62	1.16	0.355
Residual	30	430.29	14.34		
Total	47	903.67			

Appendix 13: Analysis of variance for germination percentage

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	11.167	5.583	1.10	
Replication. *Units* stratum					
Treatment	7	59.812	8.545	1.68	0.151
Location	1	20.021	20.021	3.95	0.056
Treatment. Location	7	55.813	7.973	1.57	0.182
Residual	30	152.167	5.072		
Total	47	298.979			

Appendix 14: Analysis of variance for leaf area at 2 WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	11.913	5.957	0.73	
Replication.*Units* stratum					
Treatment	7	227.242	32.463	4.00	0.003
Location	1	123.571	123.571	15.24	<.001
Treatment. Location	7	242.690	34.670	4.28	0.002
Residual	30	243.254	8.108		
Total	47	848.670			

Appendix 15: Analysis of variance for leaf area at 4WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	74.77	37.39	2.09	
Replication. *Units* stratum					
Treatment	7	435.71	62.24	3.48	0.008
Location	1	16.31	16.31	0.91	0.347
Treatment. Location	7	55.29	7.90	0.44	0.868
Residual	30	536.85	17.89		
Total	47	1118.92			

Appendix 16: Analysis of variance for leaf area at 6WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	8.46	4.23	0.13	
Replication.*Units* stratum					
Treatment	7	224.69	32.10	1.02	0.438
Location	1	1009.29	1009.29	32.06	<.001
Treatment. Location	7	555.58	79.37	2.52	0.036
Residual	30	944.55	31.48		
Total	47	2742.58			

Appendix 17: Analysis of variance for NO of leaves at 2WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	28.202	14.101	1.62	
Replication. *Units* stratum					
Treatment	7	86.913	12.416	1.42	0.232
Location	1	1058.441	1058.441	121.41	<.001
Treatment. Location	7	81.233	11.605	1.33	0.270
Residual	30	261.532	8.718		
Total	47	1516.319			

Appendix 18: Analysis of variance for NO of leaves at 2WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	28.202	14.101	1.62	
Replication. *Units* stratum					
Treatment	7	86.913	12.416	1.42	0.232
Location	1	1058.441	1058.441	121.41	<.001
Treatment. Location	7	81.233	11.605	1.33	0.270
Residual	30	261.532	8.718		
Total	47	1516.319			

Appendix 19: Analysis of variance for NO of leaves at 4WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	2.73	1.37	0.08	
Replication. *Units* stratum					
Treatment	7	774.88	110.70	6.21	<.001
Location	1	1058.44	1058.44	59.35	<.001
Treatment. LOCATION	7	81.23	11.60	0.65	0.711
Residual	30	535.03	17.83		
Total	47	2452.31			

Appendix 20: Analysis of variance for NO of leaves at 6WAT

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	397.55	198.78	2.43	
Replication. *Units* stratum					
Treatment	7	2575.45	367.92	4.51	0.002
Location	1	1058.44	1058.44	12.96	0.001
Treatment. Location	7	81.23	11.60	0.14	0.994
Residual	30	2449.89	81.66		
Total	47	6562.56			

Appendix 21: Analysis of variance for number of panicles per plant

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	2.332	1.166	0.67	
Replication. *Units* stratum					
Treatment	7	20.387	2.912	1.67	0.156
Location	1	158.413	158.413	90.62	<.001
Treatment. Location	7	15.533	2.219	1.27	0.298
Residual	30	52.442	1.748		
Total	47	249.107			

Appendix 22: Analysis of variance for paddy Yield (kg/ha)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	1655000.	827500.	6.37	
Replication. *Units* stratum					
Treatment	7	4069583.	581369.	4.48	0.002
Location	1	1350052.	1350052.	10.40	0.003
Treatment. Location	7	1586615.	226659.	1.75	0.136
Residual	30	3896250.	129875.		
Total	47	12557500.			

Appendix 23: Analysis of variance for panicle weight(g)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	4.80	2.40	0.08	
Replication. *Units* stratum					
Treatment	7	360.63	51.52	1.69	0.150
Location	1	1467.44	1467.44	48.02	<.001
Treatment. Location	7	27.56	3.94	0.13	0.995
Residual	30	916.83	30.56		
Total	47	2777.26			

Appendix 24: Analysis of variance for straw weight(kg/ha)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	801428.	400714.	1.53	
Replication. *Units* stratum					
Treatment	7	5845458.	835065.	3.19	0.012
Location	1	87692376.	87692376.	335.10	<.001
Treatment. Location	7	5842101.	834586.	3.19	0.012
Residual	30	7850769.	261692.		
Total	47	108032133.			

Appendix 25: Analysis of variance for biomass of straw at harvest (kg/ha)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	1041728.	520864.	0.81	
Replication.*Units* stratum					
Treatment	7	5415952.	773707.	1.21	0.330
Location	1	1383802.	1383802.	2.16	0.152
Treatment. Location	7	5466585.	780941.	1.22	0.324
Residual	30	19252578.	641753.		
Total	47	32560645.			

Appendix 28: Analysis of variance for dry straw at harvest(kg)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	13957064.	6978532.	11.97	
Replication. *Units* stratum					
Treatment	7	25267511.	3609644.	6.19	<.001
Location	1	5679440.	5679440.	9.74	0.004
Treatment. Location	7	7040986.	1005855.	1.73	0.141
Residual	30	17488286.	582943.		
Total	47	69433286.			

Appendix 30: Analysis of variance for fresh straw at harvest (kg)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	15118230.	7559115.	5.73	
Replication. *Units* stratum					
Treatment	7	37729672.	5389953.	4.08	0.003
Location	1	12670103.	12670103.	9.60	0.004
Treatment. Location	7	12786668.	1826667.	1.38	0.248
Residual	30	39598734.	1319958.		
Total	47	117903406.			

Appendix 31: Analysis of variance for thousand seed weight(g)

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Replication stratum	2	11.0513	5.5256	6.02	
Replication. *Units* stratum					
Treatment	7	12.2600	1.7514	1.91	0.103
Location	1	128.0533	128.0533	139.45	<.001
Treatment. Location	7	11.0767	1.5824	1.72	0.141
Residual	30	27.5488	0.9183		
Total	47	189.9900			

Plate 2: NYANKPALA UNDER RAINFED

Plate 3: NYANKPALA UNDER RAINFED

Plate 4: NYANKPALA UNDER RAINFED

Plate 5: NYANKPALA UNDER RAINFED

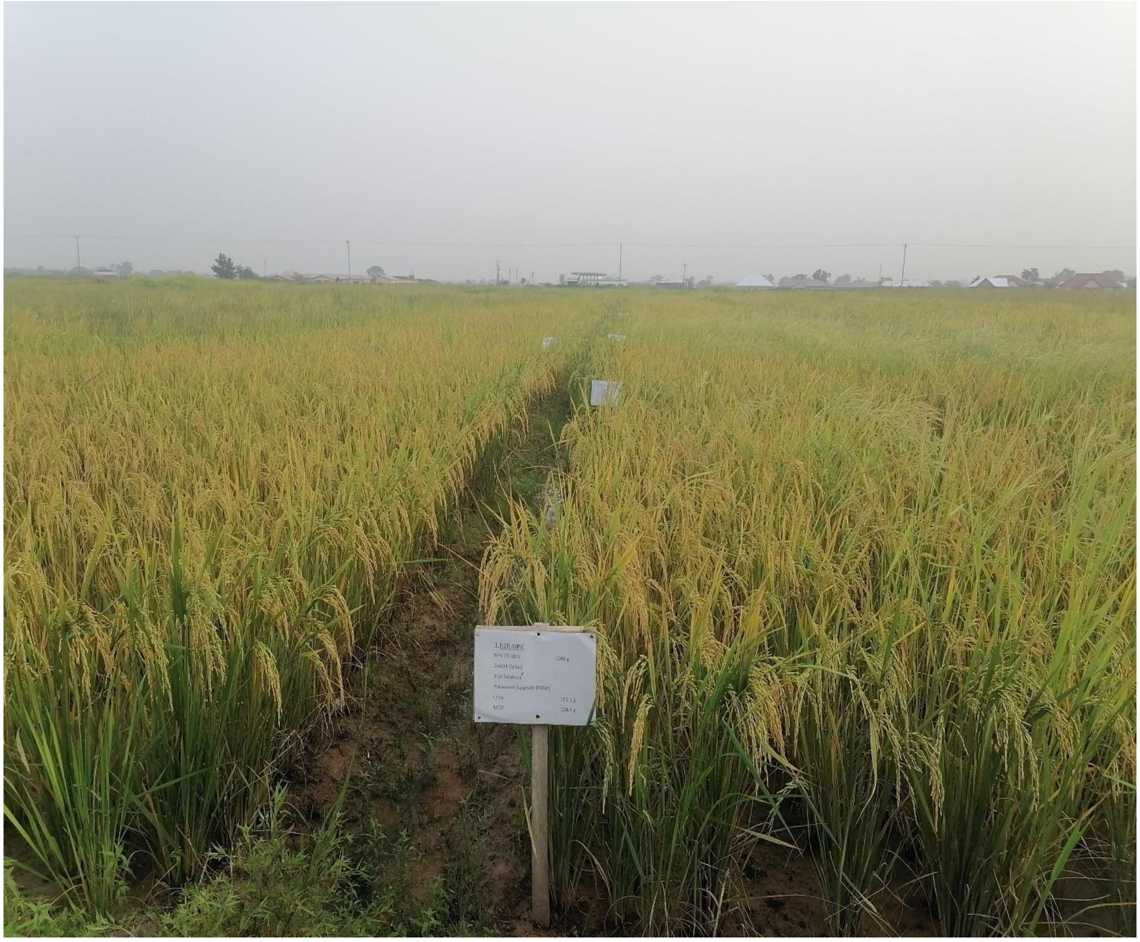

Plate 6: ***NYANKPALA UNDER RAINFED***

Plate 7: BOTANGA UNDER IRRIGATION

Plate 8: BOTANGA UNDER IRRIGATION

Plate 9: BOTANGA UNDER IRRIGATION

FOLIAR APPLICATION OF PHOSPHORUS, SULPHUR AND MICRONUTRIENTS OF ZINC AND IRON ON GROWTH AND YIELD OF RICE (Oryza sativa L.) UNDER RAINFED AND IRRIGATION IN THE GUINEA SAVANNA ECOLOGY OF GHANA

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