UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECTS OF VARIETY, SPACING AND SOIL AMENDMENT ON GROWTH, YIELD AND MILLING QUALITY OF RICE (*Oryza sativa* L.) IN THE GUINEA SAVANNAH ZONE OF GHANA

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JULY, 2024

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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, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN CROP SCIENCE

JULY, 2024

DECLARATION

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

.... 05 – 03 – 2025

SIGNATURE DATE

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

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ABSTRACT

Low soil fertility, lack of high-yielding varieties and poor planting methods hinder rice production in the Northern region of Ghana. It is against this background that research comprising survey and field experiments were conducted in the Sagnarigu and Kumbungu districts of the Northern region of Ghana. The survey was carried out to determine the perception and knowledge of rice value chain actors on the effect of improved practices on yield and milling characteristics of rice in the study area using multi-stage sampling and questionnaire administration. Survey results indicated that rice production is hindered by by the use of poor variety, poor spacing, poor time of transplanting and the incidence of low soil fertility in both low land and irrigated rice ecosystems of the study areas. Three field experiments were conducted. Field experiment I was carried out in the 2021 rainy season to evaluate the effects of time of transplanting and spacing on growth and yield of rice. Field experiment II was a repetition of field experiment I but was conducted under irrigated conditions in Bontanga in the Kumbungu district. Field experiments I and II were a 4 x 5 factorial experiments laid out in a randomized complete block design. The factors include four levels of spacing and five levels of time of transplanting. Data were collected on the growth and yield parameters of Agra rice as well as value cost ratio. Under the rainfed condition, plants from 25 cm x 25 cm plots where seedlings were transplanted at 21 days after planting produced the highest yield with a value of 9194 kg ha^{-1} whereas plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting produced the highest value cost ratio with a value of 1.42. Under the irrigated condition, plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting produced the highest grain yield and value cost ratio with values of 7810 kg ha^{-1} and 1.10

respectively. Field experiment III was carried out in the 2022 cropping season to determine the effect of variety**,** spacing and soil amendments on growth, yield**,** and milling characteristics of rice using a 5 x 2 x 4 factorial experiments laid out in a randomized complete block design (five levels of rice variety, two levels of spacing, and four levels of soil amendment). Results of experiment III indicated that Gbewaa variety transplanted at 25 cm x 25 cm spacing with 37.5 kg/ha N, P and K + 26.25 kg/ha N applied and Agra variety transplanted 20 cm x 20 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied produced highest effective tiller count per plant with values of 20.78 and 18.67 respectively. The post experiment soil analysis showed that soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N maintained total N and increased K, Ca and Mg in the soil. The highest grain yield was obtained from Agra variety transplanted at 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied. Similarly, Gbewaa variety transplanted at 20 cm x 20 cm spacing, on plot where 37.5 kg/ha N, P and K + 26.25 kg/ha N were applied produced high grain yield. Mandii rice variety transplanted at 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied also produced high brown yield, grain length and grain length-width ratio. Mandii rice is a local variety and incorporating it with varieties of good milling characteristics through breeding would make a positive impact in the rice business in the study area. The application of 37.5 kg/ha NPK + 26.25 kg/ha N has the potential to promote plant growth and yield while soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N would improve the soil physical and chemical properties.

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DEDICATION

This work is dedicated to my loving and caring family and friends, whose prayers, love, financial assistance, sacrifices and encouragement have made this work a success.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Rice contributes significantly to the global economy. It plays a vital role in both food security and economic growth of the world. Rice production plays a crucial role in minimizing malnutrition and sustaining livelihood across the globe (Fukagawa and Ziska, 2019).

Rice is an important staple food in Ghana and contributes substantially to Ghana's economy (MoFA-IFPRI MARKET BRIEF 2020). In 2018, agriculture contributed 19.7 % of the nation's GDP, with the crop sector being the largest contributor which accounted for 65 % of that GDP (MoFA 2019).

Rice is grown on approximately 155 million hectares worldwide under different ecologies (USDA, 2023). The rainfed ecology covers the largest area as it accounts for 75 % of the land area use in global cultivation of rice (Ulzen *et al*., 2023). Inland swarms or valley bottoms and irrigated rice ecologies covers 15 % and 10 % of the land area used in cultivating rice respectively (Ulzen *et al* 2023).

Global rice production is witnessing positive trends due to productivity gains as the first and second top producers of rice in the global market are China and India, respectively (USDA, 2023). The global average rice yield is projected to be 6 t ha^{-1}, whereas the projected yield values for upland areas and irrigated areas are 4 t ha^{-1} and 8 t ha^{-1} respectively (Muthayya *et al*., 2014). However, rice yield as high as 22.4 t ha^{-1} was achieved in India using SRI technology in 2011(Gordon, 2013).

Rice production in Africa is experiencing significant increase due to increase in consumption. The increase in production is mainly attributed to increase in farm land (Yuan *et al*., 2024). However, the average yield obtained in Africa is 49 % lower than that of world yield. Africa can only produce to satisfy 60 % of her consumption (Yuan *et al*., 2024).

Majority of the rice produced in Ghana is under lowland rainfed ecologies (Azumah and Adzawla, 2017) with the average yearly yield of 2.96 t ha^{-1} in 2018 (MoFA 2019). When compared to the national average, the Northern region's rice yield was low (with production of 2.6 t ha^{-1}) (MoFA 2019). In the same breadth, no district from the Northern region performed above the national average (MoFA 2019). According to Ministry of Food and Agriculture and Savannah Agricultural Research Institute (SARI) the nation's rice producing area has significant opportunity to reach potentially achievable yield range of 6 to 8 t ha^{-1} (Ragasa *et al*,. 2013).

Northern region has the potential to produce the most rice in the country. For instance, in 2012, the Northern region was the top producer (37 %) of the nation's rice (Ragasa, *et al.*, 2013). Also, Northern region accounts for the largest land used in rice cultivation in Ghana. In 2018, Northern region had 81,165 hectares of land under rice cultivation, followed by the Volta region which had 58,662 hectares of land under rice production (Ghana Rice Mechanization Policy Brief, 2020).

The consumption of rice is greater than the local production of rice in most of the rice producing countries across the globe. For instance, in 2020, 513.7 million tonnes of milled rice were produced globally whilst 697.09 million tonnes of milled rice were consumed (AMIS, 2021).

In 2017, Ghana produced 721,610 tonnes of rice but consumed 1.3 million tonnes of rice (IFPRI, 2020). Ghana has heavily been relying on Thailand, Vietnam and India for rice imports which is costing the government huge sums of money (IFPRI, 2020). The country spent $ 1.2 billion to export rice into the country in 2015 (IFPRI, 2020). In order to achieve food security and self-sufficiency in food production, rice production should be prioritized (Seck *et al*., 2013). The demand for rice is driven by urbanization, changes in consumer behavior as people get wealthier, and an increasing shift in dietary preferences from indigenous staples to rice (Eureka *et al*., 2023).

Climate change, extreme weather conditions, decreasing arable areas, labor shortages, crop diversification, and low availability of resources are the bottlenecks that impede global rice production (Sengupta, 2023).

Africa is still battling with self-sufficiency in rice production due to mainly low production technologies and over reliance on rainfed rice ecologies for rice production (Yuan *et al*., 2024).

Only 20% of the rice land is transplanted, only 13% of the rice field is planted in rows or lines, and half of the rice area is still planted using the broadcasting method, despite the 1990s' intensive promotion of row planting (Ragasa et al., 2013).

Researchers have found that recommended practices and actual practices differ greatly. For example, according to Ragasa et al. (2013), only 43% of transplanted rice plots and 45% of directly sown plots followed the recommended fertilizer delivery schedule in 2012 in Ghana.

Due to insufficient spacing between the rice plants, the higher leaves will inevitably repress the lower leaves, resulting in poor root growth (Thiyagarajan and Gujja, 2013).

The world is currently dealing with the negative consequences of widespread chemical fertilization (Hindersah et al., 2022). Ineffective fertilizer management is the main cause of low fertilizer efficiency. Intensive and high-dose nitrogen fertilizer application may cause nitrogen to leach and volatilize due to the high temperatures in the tropics (Wang et al., 2015; Jadon et al., 2018; Sari et al., 2021).

1.2 Problem statement and justification

Low adoption of modern farm technologies, inadequate accessibility of fertilizers, high-yielding varieties, soil fertility and aging workforce are source of the problems that confront rice production in the Northern region of Ghana (Tanko *et al*., 2016; Ulzen *et al*., 2023).

Research has shown that older rice seedlings when transplanted do not promote maximum plant growth (Liu *et al*., 2015). Reuben *et al*. (2016) research showed that seedlings transplanted when they were 12 days old gave better yield than seedlings transplanted later. Issues that affect varietal quality include genetics, socioeconomic and institutional factors. The unimproved varieties possessed traits with low yielding abilities. Optimal yield from these varieties are still low. Farmers do not also take into consideration the milling quality of the varieties they used in cultivating their fields. Improved varieties have shown to have higher yield potential, resistant to pest and diseases and of higher grain quality (Rahman *et al*., 2022).

Plant growth slows down and grain yield declines when plant density surpasses the optimum level due to intense competition for nutrients and sunlight (Yussif, 2015). More than 50 % of the nation's rice growers plant their crop using traditional techniques (Ragasa *et al*., 2013).

Optimal plant spacing facilitate proper uptake of nutrients from the soil and sunlight which leads to healthy plant growth and development leading to higher yield in rice. Researchers have varied views on recommended spacing for rice plants. Xu *et al*. (2020) recommended 18 cm x 18 cm while Tadesse *et al*. (2019) and proponents System of Rice Intensification (SRI) recommended 25 cm x 25 cm spacing for transplanted rice. Appropriate spacing (20 cm x 20 cm) enhances the performance of each individual hills of the plant rice (Sheriff *et al.*, 2020).

Research indicates that low soil fertility leads to low nutrient release which leads to low nutrient uptake by rice plants which eventually leads to low rice yield (Zhu *et al*., 2022). The average application rate of fertilizer is still lower than the recommended rate in Ghana. Ragasa *et al.* (2013).

Soil amendment plays a vital role in increasing rice yield as it reduces the soil acidity, improving the soil health and releasing adequate nutrients for plant uptake. Research done by Zhu *et al*. (2022) showed that manure amendment impacted net photosynthetic rate, improve plant physiological resistance to unfavourable environmental conditions leading to better rice yield. Also, Dzomeku *et al*. (2016), indicated that applying either the recommended amount of chemical fertilizer or compost had a good return on the rice plots. These authors added that soil amendment with organic matter (compost) increased overall soil fertility than the solely chemical fertilizer amendment.

The interactions of variety and spacing, variety and soil amendment, or spacing and soil amendment have also shown positive results in terms of plant growth and grain yield.

Arianti *et al*. (2022) reported unique response of different varieties to different spacings, of which some of the interactions gave good yields. El-Katony *et al*. (2021) studies showed positive results in rice plant growth and grain yield as a result of combining soil amendment with specific varieties.

Rice has a significant economic impact on both the global and Ghanaian economies. Given that the growth, development, and yield of rice depend greatly on the variety, timing of transplanting, spacing, and soil amendments, it is necessary to examine their combined impact on yield and milling quality in order to provide crucial information to support farmers in their decision-making process and encourage sustainable production of rice. Earlier studies on rice production have failed to examine the combined effects of variety, timing of transplanting, spacing and soil amendment on growth and yield as well as milling characteristics of rice.

1.3 General research objectives

1.3.1 Main objective:

The main objective of the study was to determine the effect of following improved practices: time of transplanting, spacing, variety and soil amendment on growth, yield and milling characteristics of rice.

1.3.2 Specific objectives:

1. To determine the perception and knowledge of rice value chain actors on effect of improved practices on yield and milling characteristics of rice.
2. To determine the effects of time of transplanting on growth and yield of rice under rainfed and irrigated conditions.
3. To determine the effects of spacing on growth, yield and milling characteristics of rice under rainfed and irrigated conditions.

4. To determine the effects of variety on growth, yield and milling characteristics of rice under rainfed conditions.
5. To determine the effects of soil amendment on growth, yield and milling characteristics of rice under rainfed conditions.
6. To determine the effects of the interaction of the factors (time of transplanting, spacing, variety and soil amendment) on growth, yield and milling characteristics of rice under rainfed and irrigated conditions.
7. To assess the cost-effectiveness of the various treatment combinations under both rainfed and irrigated condition

1.4 Hypothesis tested

H_{01} - The perception and knowledge of rice value chain actors on the effect of improved practices has no influence on yield and milling characteristics of rice.

H_{A1} - The perception and knowledge of rice value chain actors on effect of improved practices has influence on yield and milling characteristics of rice.

H_{02} - Time of transplanting has no influence on growth and yield of rice under rainfed and irrigated conditions.

H_{A2} - Time of transplanting has influence on growth and yield of rice under rainfed and irrigated conditions.

H_{03} – Spacing has no influence on growth, yield and milling characteristics of rice under rainfed and irrigated conditions.

H_{A3} – Spacing has influence on growth, yield and milling characteristics of rice under rainfed and irrigated conditions.

H_{04} – Variety has no influence on growth, yield and milling characteristics of rice under rainfed conditions.

H_{A4} – Variety has influence on growth, yield and milling characteristics of rice under rainfed conditions.

H_{05} – Soil amendment has no influence on growth, yield and milling characteristics of rice under rainfed conditions.

H_{A5} – Soil amendment has influence on growth, yield and milling characteristics of rice under rainfed conditions.

H_{06} – The interaction of the factors mentioned above do not influence growth, yield and milling characteristics of rice under rainfed and irrigated conditions.

H_{A6} – The interaction of the factors stated above have influence on growth, yield and milling characteristics of rice under rainfed and irrigated conditions.

H_{07} – The interaction of the factors mentioned above do not influence the profitability of rice production under rainfed and irrigated conditions.

H_{A7} – The interaction of the factors mentioned above influence the profitability of rice production under rainfed and irrigated conditions.

CHAPTER TWO

GENERAL LITERATURE REVIEW

2.1 Rice taxonomy and anatomy

Chauhan *et al*. (2017) reported that the cultivated rice is a member of the tribe Oryzeae, subfamily Bambusoideae, and genus *Oryza*. Four species complexes have been identified within the genus *Oryza*: the *sativa*, *officinales*, *meyeriana*, and *ridley* complexes (Chauhan *et al*., 2017).

The tropics and subtropics are where indicas are grown (Chauhan *et al*., 2017). According to Chauhan *et al*. (2017), traditional indicas are distinguished by their tall stature, weak stem, droopy leaves, strong tillering capability, long grains, and poor responsiveness to high nutrient input conditions.

When ripe (full grains with intact husks), rough rice is made up of a brown kernel encased in a husk (Nawaz, 2018). The most noticeable component of a rough rice grain is the husk, sometimes referred to as the hull (Nawaz, 2018). Although it is inedible, the hull is the outer covering that covers the caryopsis and makes up 20 % to 25 % of the total grain weight (Nawaz, 2018). The hull serves as a defense against invasion and changes in the environment. The hull is made up of sterile lemmas, palea, rachilla, and lemma (Nawaz, 2018). Two-thirds of the seed is covered by the lemma, which forms a tight seal around the remaining third with the margins of the palea (Nawaz, 2018).

The pericarp and seed coat encapsulate the embryo and starchy endosperm within the caryopsis (Hoogenkamp *et al*., 2017). The pericarp (the ovary wall), the seed coat, and the nucleus are three thin layers of differentiated tissues that make up brown rice (Li, 2003). The aleurone layer is the innermost of the seed coat. The connecting portion (mesocotyl), the embryonic primary root (radical), which has been unsheathed by the coleorhizae, and the embryonic leaves (plumule) are all found inside the embryo

(Nawaz, 2018). Starch granules in a protein-rich matrix make up the majority of the rice endosperm, which also contains sugar, lipids, crude fiber, and organic matter (Nawaz, 2018). About 20 % of the total grain weight is the weight of the hull. Some rice grains have palea, lemmas, and richilla in their hulls, while others do not (Nawaz, 2018).

2.2 Economic importance of rice

Over half of the world's population depends on rice for food security (Zhao *et al*., 2020). By 2030, it is expected that worldwide rice production will increase by 58 to 567 million tonnes (t). The amount of calories and vital vitamins, minerals, and other nutritious components in rice are substantial (Zhao *et al*., 2020).

For many nations, rice is now a source of foreign currency and contributes to their economies. India, Thailand, Pakistan, USA, Vietnam, Italy, Uruguay, Brazil, China, and Australia were the top 10 exporting nations in 2014 (Chauhan *et al*., 2017). The Middle East, as well as sub-Saharan and Western Africa, are the major importers (Chauhan *et al*., 2017).

Numerous nations have incorporated rice into their cultural identities, and some of their national holidays are centered around the bumper rice harvest. Examples are Ghana's Amu festival and India's Pongal festival where the first rice grains are offered to gods during these festivals as an act of adoration (Chauhan *et al*., 2017).

Researchers from all over the world are investigating the use of rice crop leftovers in a variety of industries, including the production of compost and manures, animal feed, biogas, textile, and power (Devi *et al*., 2018). Morphology and physiology of rice varieties

2.3.1 Rice varieties

The rice varieties released and registered in Ghana by CSIR include FARO 15, GR 17, GR 18, GR 19, GR 20, GR 21, and TOX 3108. The rest include DIGANG, NERICA 1, NERICA 2, JASMINE 85, NABOGO RICE, KATANGA RICE, OTOOMU, EMO TEAA, Marshall, Wakatsuki, Bodia and Sakai.

According to Ragasa and Chapoto (2017), during the 2012 growing season, 65 % of rice farmers planted improved varieties but not from certified sources. Only 17 % of the rice farmers used improved varieties from certified sources (registered seed dealers, certified seed growers, MoFA projects, or researchers/breeders). 83 % of the farmers used seed from other farmers, recycled seeds, or obtained it from the open grain market.

According to Ragasa and Chapoto (2017), the most widely grown varieties are JASMINE 85 (improved variety), Togo Marshall (unknown), Mandii (local variety), Jet 3 (unknown), Digang (improved variety), and Aromatic Short (local variety). Rice farmers are better off cultivating certified seed as opposed to farmer-saved seed, regardless of the fertilizer regime they use (Dogbe *et al*., 2014). Similarly, according to Dogbe *et al*. (2014), farmers are worse off financially if they don't apply fertilizer or apply 3 tons of Deco compost per hectare with either half or the full recommended rates of fertilizer.

2.3.1.1 The morphological and physiological characteristics of improved rice varieties

2.3.1.1.1 Agra rice

Due to its resistance to rust and lodging, Agra is becoming more and more popular. Approximately 74 % (478 t) of the total 578 t of certified seeds were produced as Agra. Agra is a white, long and slender grain, aromatic, and has strong milling ability. Agra can be cultivated in Guinea Savannah, Coastal savannah, and Forest zones of Ghana. Agra milling yield up to 70.4 % and is noted to contain 16 – 18 % amylose. It has alkaline spreading value of 7.

2.3.1.1.2 Gbewaa rice (jasmine 85)

During the 2012 main season, 27 % of the rice field was planted with Jasmine 85, making it the most widely used variety in Ghana (Ragasa *et al*., 2013). It has long, slender intermediate amylose fragrant grain which Ghanaian consumers value a lot in the Ghanaian rice market in the late 90s (Marco *et al*., 1997). Jasmine 85 rice variety was created by the International Rice Research Institute (IRRI) from the cross IR262-43-8-11/KHAO DAWK MALI 4-2-105 (Marco *et al*., 1997) and released in Ghana in 1998 as Gbewaa by CSIR-Savannah Agricultural Research Institute (CSIR-SARI) (Diako *et al.*, 2010). The maturation period of Jasmine 85 is 110–115 days (Ragasa *et al.*, 2013).

Gbewaa plant has good pest and disease resistance. This variety's milling rate is 62 %. It is cultivated both in lowland and irrigated ecologies.

In Ghana, numerous varieties of Jasmine 85 rice are cultivated (Ragasa and Chapoto, 2017). Jasmine 85 samples were obtained from the CSIR-CRI in Nobewam (denoted

DARTEY), Kumasi (denoted CRI), and SARI in Tamale (denoted GBEWAA and SARI) (Ragasa and Chapoto, 2017).

Along with the reference sample from AfricaRice, Senegal (denoted ARI), samples were also taken from the Kpong Irrigation Project in Asutsuare (denoted KIP), the Prairie Volta Co Ltd. in Aveyime (denoted PV), and the Tono Irrigation Project in Tono (denoted TONO (Ragasa and Chapoto, 2017).

Gbewaa has a 5–6 t production potential and superb cooking quality. According to Ragasa *et al.* (2013), the distinctive traits include aromatic, long grain, good flavor, and consumer preference.

2.3.1.1.3 Digang rice (abirikukuo or aberikukugo)

In 2002, CSIR disclosed and promoted the Digang Source of germplasm, which came from IRRI (Ragasa and Chapoto, 2017). In 115 days, this cultivar reaches maturity. It is non-aromatic and has a long, thin grain (Ragasa and Chapoto, 2017).

The Digang plant has a 4.8 t yield potential. It is particularly adaptable to minimal input systems and may be grown in a variety of ecologies. It is noted for the preparation of dishes such as waakye, Jollof, and omutuo. It has an acceptable cooking quality and a 65 % milling rate (Ragasa and Chapoto, 2016; Ragasa *et al*., 2013). A high level of resilience to common diseases and pests as well as lowland/hydro morphic ecology is its favored type (Ragasa and Chapoto. 2017; Ragasa *et al*., 2013).

Digang stands out for its adaptability to various ecologies, early maturation, suitability for drought-prone locations, and easily breakable grains (Ragasa *et al*., 2013).

2.3.1.2 The morphological and physiological characteristics of local rice varieties

2.3.1.2.1 Mandii

Mandii, which was originally from Sierra Leone and was introduced by MoFA in the 1970s, was the second most widely grown variety (19 % of all rice area and 25 % of the rice area in lowland rainfed, mostly in the north); it is suitable for low-input systems, can withstand long flood periods, and can compete very well with weeds (Ragasa *et al*, 2013).

In the Northern Savannah zone, Mandii and other traditional varieties appear to be effectively competing with newer varieties in terms of yield (Ragasa *et al*, 2013).

2.3.1.2.2 Mr. Harry and Mr. Moore varieties

Mr. Harry and Mr. Moore were the next most prevalent varieties in the upland region (Ragasa *et al*., 2013). Both are thought to be traditional varieties from the south of the nation that were also introduced to the northern part of Ghana and were named after the people who first brought these varieties to the communities (Ragasa *et al*., 2013). Similarly, other rice varieties had their names from those who brought them to the farmers' local communities; these varieties are Moses, Paul, Assemblyman rice varieties.

2.4 Factors influencing rice productivity

2.4.1 Planting methods of rice

Despite extensive promotion of row planting during the 1990s, half of the rice area is still planted using broadcasting method, only 20 % of the rice area is transplanted, and only 13 % of the rice field is planted in rows or lines (Ragasa *et al*., 2013). When rice seedlings are transplanted with the right spacing and using good agronomic procedures grain yield will increase by twofold (Yussif, 2015).

In all rice ecologies, row planting and seed priming are also linked to increased yields. According to Hindersah *et al*. (2022), adopting good planting techniques such as transplanting and organic amendment provide higher yields than fields without these practices.

The use of improved varieties of rice along with other practices such as timely planting, an integrated pest management system, timely harvesting, appropriate harvesting technique, improved parboiling, proper drying and storage enhances rice productivity (Emran *et al*., 2012: Lamptey *et al*., 2022).

Row planting and ideal plant density and spacing are encouraged in rice cultivation. It is advisable to plant rice plants in rows or lines. The recommended planting density for transplanting is 35–45 kilogramgs per hectare (Baloch *et al*., 2006), with two plants per hill with any of the spacing 15 cm x 15 cm, 20 cm x 20 cm or 25 x 25 cm (Reuben *et al*., 2016). Transplanting should be done 21–28 days after seeding (SRI-Rice, 2022).

2.4.2 Timing and rate of fertilizer application

The timing and the rate of fertilizer application is crucial in rice production henceforth, the recommendations made by CSIR and MoFA should be followed. First application or basal application and a second application or top dressing is recommended in Ghana. Farmers should apply fertilizer for the first time one week after transplanting or two to three weeks after direct seeding (Ofoso, 2021). It is advisable to use compound fertilizer NPK for the basal application. According to Kamai *et al* (2020), the second application (top dressing) should be made five to six weeks after planting, seeding, or right before booting in the southern part of Ghana and seven to eight weeks after planting in the northern part of the country. For the second application, urea or sulfate of ammonia (with a higher nitrogen concentration for plant growth) is advisable (Dzomeku *et al*., 2016). According to researchers conducted, real practices diverge significantly from recommended practices. For instance, Ragasa *et al*. (2013), reported that only 43 % of transplanted rice plots and 45 % of directly seeded plots adhered to the suggested schedule of application of fertilizer.

2.4.3 Spacing

Wider spacing practices resulted in a more open plant architecture with larger, more erect leaves, increased light interception and higher leaf chlorophyll content at the ripening stage of the rice plant. Wider spacing resulted in delayed senescence and greater fluorescence efficiency, higher photosynthetic rate**,** and lower transpiration, more grains in each panicle, better-grain-filling panicles, and higher grain yield in rice (Uphoff *et al*., 2011).

The single plant per hill and the wider spacing encouraged root growth while also exposing the plant's leaves for increased sunlight absorption and improved photosynthesis (Thiyagarajan and Gujja, 2013). Closer-spacing and wider-spacing plants had respective smaller and larger leaf area indexes that intercepted 15 % and 67 % of the sun's light, respectively. According to Uphoff *et al*. (2011), the wider spacing with other System of Rice Intensification (SRI) principles led to increases in total chlorophyll and net photosynthetic rates of 30 % and 89 %, respectively.

According to Thakur *et al*. (2010), wider spacing with other SRI principles plants exhibited greater leaf development, function, and tillering, which led to higher productivity. Additionally, an investigation by Thakur *et al*. (2010) showed that rice plants grown under wider spacing intercepted considerably more light energy than rice plants grown under conventional management practices after 60 days of sowing. According to Thiyagarajan and Gujja (2013), at the panicle initiation stage in SRI principles and conventional management practice, the plant canopies intercepted light at a rate of 89 % and 78 %, respectively.

Earlier, Gani (2002) experimented in Indonesia and reported that the radiation intercepted was high in rice plants with wider spacing and lower in narrow-spacing rice plants. Gani (2002) discovered that the lower third of the leaves were blocked and unable to get adequate sunlight for photosynthesis; as a result, instead of helping the plant produce its food, these impoverished leaves depended on the plant's already-produced food, making them parasitic.

Poor root growth is inevitable as a result of the rice plants' inadequate spacing, which causes the higher leaves to repress the lower leaves (Thiyagarajan and Gujja, 2013). There is increased lateral root development when there is less intra-hill competition (Mishra and Salokhe, 2010).

To ensure adequate root growth, rice plants should be spaced farther apart and not be flooded before flowering (Thiyagarajan and Gujja, 2013). According to Barison and Uphoff *et al*. (2011), rice plant grown under SRI have superior root development than those grown under conventional rice cultivation methods.

Vijayakumar *et al*. (2005) also carried out an experiment using 20 cm by 20 cm and 25 cm by 25 cm with the conventional weeding (herbicide and/or + hand weeding) and SRI weeding (hand weeding intermittently at least thrice using the weeder), and they realized a significant yield increase of 9.7 % from 20 x 20cm plant spacing and 11.1 % from 25 x 25cm plant spacing. Wider spacing encourages delayed flowering in plants (Yussif, 2015).

Better nitrogen supply to the plant and better ability of the plants to utilize the nitrogen very well was made possible by rice cultivation practices such as careful transplanting, wider spacing, intermittent irrigation, and the use of chemical fertilizers. These practices promoted better dry biomass in the plants. The wider spacing of 25 cm by 25 cm led to higher chlorophyll levels, which ultimately led to higher photosynthesis in those plants (Yussif, 2015).

The cautious transplantating of the seedlings, transplanting them one at a time, and widely spacing promoted taller plants (Latham, 2012).

Additionally, Yussif (2015) found that rice fields with 25 cm x 25 cm spacing produced higher yields than rice fields with poorly spaced (broadcasted rice seed) fields of the same variety.

According to Larry *et al*. (2012), better crop establishment, closer spacing (which increased intra-competition), and higher plant densities per unit area led to quicker reproductive and maturity phase responses in direct-seeded rice plants, which resulted in early flowering and shorter maturity days. A healthier root system, more productive tillers per unit area, larger panicles, and more grain weight were all observed with wider spacing plants (Uphoff *et al*., 2011).

Also, IRRI (2010) reported greater tillering in rice plants which was associated with the wider spacing of the plants, which gives the plants better sunlight and nutrients to produce a higher number of tillers. According to research published in 2020, farmers should space their rice plants at least 25 cm (SRI-Rice, 2022). As a result of the wider spacing between the plants compared to the broadcasted rice field, Mahamudu Yahaya, a farmer in Golinga, Ghana, noted that these practices helped him in weeding and moving through his rice field (Ghanaweb, 2013).

The right spacing of the rice plants gives the ideal plant population as well as labor input and drudgery are decreased (Kega *et al*. 2015). It is best to choose cultivars that are non-lodging, have rapid canopy development, and have early seedling vigor. Additionally, good seed is needed, and weeds must be effectively controlled using herbicides, cultural methods, or all three (Kega *et al*. 2015).

2.4.4 Transplanting

According to Kega *et al*. (2015), shallow transplantating at 1-2 cm depth and as early as 15 days after planting is recommended. Kega *et al*. (2015) recommended the ideal plant-to-plant planting spacing ranges from 20 x 20 cm to 25 x 25 cm, whereas the ideal plant per hill ranges from 1 to 2. For fields that receive mechanical weeding, 30 cm x 15 cm is recommended whilst 25 cm x 15 cm spacing is recommended for low tillering rice varieties (Kega *et al*. 2015).

Before transplanting, cut off the tops of the seedlings to prevent the transfer of stem borer eggs from the nursery to the main rice field. To manage rice caseworms, avoid transplanting young seedlings and leaving standing water in rice fields (Kega *et al* 2015). Transplanting of rice seedlings should be done in rows (Kega *et al*. 2015).

2.4.5 Soil fertility and amendments

2.4.5.1 Organic and inorganic amendments

Even with the application of recommended quantities of inorganic fertilizers, rice yields from areas that have been continually cultivated have been seen to decrease with time. Low soil fertility, which is partially the result of low levels of soil organic matter (OM), has been blamed for the decrease in yield of rice (Nyalemegbe *et al*., 2010).

There is a need to test for the best fertilizer, application time, technique, and rate. The bodies that have this mandate in Ghana are CRI and SARI. Following numerous on-station and on-farm trials, basal application of compound fertilizer followed by topdressing with sulfate of ammonia or urea is recommended for rice cultivation in Ghana (Ragasa *et al*., 2013).

For the first application, rates of 200–400 kg ha $^{-1}$ of compound fertilizer (NPK 15–15–15) are advised, and depending on crop history, rates of 150 kg ha $^{-1}$ of sulfate of ammonia or 95 kg ha $^{-1}$ of urea are also advised. The first application is advised to be made one week after transplanting and two to three weeks after planting for direct seeding. The second application should be carried out five to six weeks after planting (seven to eight weeks after planting for the northern savannah) (Kamai *et al*., 2020). The soils in the forest zones require total nitrogen between 60 and 80, total phosphorus between 30 and 45, and total potassium of 30 and 45, with 75 kg ha $^{-1}$ of urea application at 49-56 DAP as top dressing (Nyalemegbe *et al*., 2010). Based on Nyalemegbe *et al.'s* (2010) recommendation, 90 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, and 35 kg K_2O ha^{-1}, are applied to Vertisols of the Accra Plains.

According to the findings of Hindersah *et al*. (2022), fertilizer combination enhanced shoot height, root length, shoot and root dry weight (RDW), root-to-shoot ratio (R/S), tiller number, 1,000 grain weight, and yield but did not affect clump number.

2.4.5.2 Liquid or foliar fertilizers

The adverse effects of extensive chemical fertilization are currently posing an issue on the globe (Hindersah *et al*., 2022). Low fertilizer efficiency is primarily the result of ineffective fertilizer management. Because of the high temperatures in the tropics, intensive and high-dose nitrogen fertilizer application might result in leaching and volatilization of nitrogen (Wang *et al*., 2015; Jadon *et al*., 2018; Sari *et al*., 2021). Phosphorus absorption by plants in the tropics is also a problem as unacceptable quantities are usually applied. To provide an acceptable amount of phosphorus for plant uptake, tropical soil must overcome phosphorus adsorption difficulties (Hanyabui *et al*., 2020).

Additionally, the Russia-Ukraine conflict is causing chemical fertilizer costs to rise quickly (Hindersah *et al*., 2022). Farmers prefer less costly liquid organic fertilizers to conventional inorganic and compost fertilizers. Biofertilizers (BF) and organic matter amendment are recommended to reduce the use of chemical fertilizers (Hindersah *et al*., 2022). In general, liquid organic fertilizer provides several benefits**,** including being a complete fertilizer with macronutrients like N, P, K, and Mg and micronutrients like Zn, Mn, Cu, Mo, B, and Fe (Ginting, 2019). In addition, liquid fertilizers can also add acidic substances like amino acids, organic acids, vitamins, and naturally occurring growth regulators like Giberelin/GA3 and Zeatin that act as soil enhancers (Ginting, 2019). Soil enhancers enhance the chemical, physical, and biological properties of the soil, boost the activity of soil microorganisms, and control natural pests (Ginting, 2019).

2.4.6 Rice plant nutrition

2.4.6.1 Nitrogen

According to Yu *et al*. (2020), nitrogen is a vital nutrient for the growth and development of rice plants and is also important for increasing rice yield and quality. The production of more leaves, biomass per plant, and photosynthesis are all attributed to nitrogen and are crucial for the general growth and development of crops (Wang *et al*., 2022a). According to Yu *et al*. (2020), applying and testing nitrogen fertilizer correctly can increase fertilizer utilization and lessen its detrimental effects on the environment. Additionally, nitrogen influences rice's physiological traits, including the plant's ability to withstand environmental stress (Zhang *et al*., 2023). Even at adequate nitrogen levels, some research has shown that plants gradually lose nitrogen as they grow and develop and that this trend eventually affects rice yield (Yu *et al*., 2020). For this reason, controlling plant nutrition status is crucial to achieving consistent yields (Zhang *et al*., 2023).

2.4.6.2 Phosphorus

One of the second-most crucial nutrients for the growth and development of rice plants is phosphorus (Bhatta *et al*., 2022). It is a macronutrient that controls metabolic processes, preserves the overall morphometry of plants, and is a key component of several vital biomolecules involved in reproduction (Bhatta *et al*., 2022). The physicochemical characteristics of the soil influence phosphorus uptake, and decreased phosphorus availability in soils which lowers rice biomass and grain yield (Nishigaki *et al*., 2019). Tissue-specific biomass and phosphorus allocation patterns are associated with rice phosphorus use efficiency (Irfan *et al*., 2020). Under saline-sodic stress, phosphorus has emerged as the primary limiting factor affecting rice growth and yield (Wei *et al*., 2022).

2.4.6.3 Potassium

When it comes to rice plant growth and yield, potassium is important. Potassium plays a role in controlling stomatal opening and closing, which impacts how efficiently a plant uses water (Cakmak, 2005). Potassium plays a role in cell elongation, which is crucial for the growth and development of plants (Cakmak, 2005). Potassium contributes significantly to the metabolic reactions that occur in plants by activating several enzymes (Uddin *et al*., 2013). Fertilization with potassium helps rice plants better metabolize nitrogen, which may result in higher yields (Cakmak, 2005). According to Uddin *et al*. (2013), potassium helps rice plants withstand the damaging effects of abiotic stresses like salinity and drought. The effects of conventuional practices are discussed as follow.

Densely planted and continually flooded rice plants, which farmers believe to boost yield, will rather promote root growth and more root degeneration (Lee *et al*., 2021). According to Uphoff *et al*. (2011), traditional transplanting techniques traumatize seedlings and reduce root development and consequently reduce tillering of the rice plant. Transplanting seedlings which are more than 14 days old leads to more transplanting shock which hinders the growth and eventual yield of the rice crops (Muhammad and Abdullah, 2013). Seedlings are transplanted with extreme caution. The seedling must be handled carefully during transplantating. A ball of earth is formed around the root as the seedling is removed (Laulanié, 2011). When planting, the root of the seedling can also be twisted into a u shape (Laulanié, 2011). These guidelines, which call for transplanting young seedlings, planting one seedling per hill, widening the distance between transplants, and intermittent irrigation of the rice field, were first proposed in 1983 (Sato, 2012).

The phenomenon which is also associated with continuously flooded rice field under irrigation is low nitrogen-use efficiency. The rice plants can only use 20 –35 % of the nitrogen applied (Uphoff *et al*., 2011). This implies that the farmers who practiced continuous flooding are focused more on the supply of nutrients than on plants' demand for them (Uphoff *et al*., 2011).

Better nitrogen supply to the plant and better ability of the plants to utilize the nitrogen very well was made possible by SRI practices like careful transplanting, wider spacing, intermittent irrigation, and the use of chemical fertilizers (Yussif, 2015). This led to better dry biomass in the system of rice intensification (SRI) plants. When rice seedlings are transplanted at the two-leaf stage, transplant shock is significantly decreased or avoided (Yussif, 2015).

Unfortunately, majority of farmers that grow rice are subsistence farmers who flood their fields regularly, grow local varieties, transplant seedlings when they are more than 21 days old. They also sow three to four seedlings in each hole. Poor yield, low water productivity, and ineffective water utilization are the results of the farmers nonadherence to improve practices (Katambara *et al*., 2013).

According to Yussif (2015), 100 kg ha^{-1} of rice seeds are used for broadcasted fields, 30 to 60 kg ha^{-1} of the seeds are used for direct rice field planting, and 4 to 10 kg ha^{-1} are used for SRI nurseries and transplanting. Cost of acquiring certified seeds are drastically reduced.

2.5 Factors that affect milling characteristics of rice

2.5.1 Milling degree

The ability of rice grains to endure the dehulling and polishing process without breaking is known as milling quality (Samantara, 2023).

The amount of bran that remains on milled rice kernels after the milling process is referred to as the rice milling degree, or Degree of Milling (DOM) (Puri *et al*., 2014).

The overall nutritional value, composition, and quality of rice are all greatly impacted by the DOM (Puri *et al*., 2014). Rice nutrients are lost during the milling process, and this loss occurs more quickly at lower DOM levels (0–10 %) than at higher DOM levels (10–14 %) (Liu *et al*., 2021). When cooking rice in excess water, the DOM has an impact on the cooking kinetics, sensory attributes, and energy requirements (Billiris *et al*., 2012). When milling rice lots, laboratory milling systems are used to estimate the milling yield that can be anticipated. For a fair comparison of milling outcomes, measuring the DOM of rice that has been milled in a lab is essential (Kim *et al*., 2020). The nutritional value, cooking qualities, and sensory appeal of rice are all influenced by the milling process, which is an essential stage in the production process (Bodie *et al*., 2019).

2.5.2 Head rice

Head rice is the whole grain that is left over after milling, after bran, husk, and broken rice, among other byproducts are removed or sorted out (Bodie *et al*., 2019). A key component of rice production is the head rice yield (HRY), which is influenced by several variables including grain size, shape, and molecular makeup (Ali *et al*., 2013). By changing the layered structure of starch granules, the amylose synthase gene waxy influences head rice yield and grain fissure resistance (Zhu *et al*., 2022). The head rice yield (HRY) and paddy grain length of indica rice can be measured with the PaddyCheck (Liu *et al*., 2021).

2.5.3 Broken rice

Broken rice is made up of shorter pieces, whereas head rice is made up of milled rice kernels that are at least three-quarters of their original length (Fall, 2012). According to grain length, broken rice is separated into three categories: brewer's rice (< ¼), screenings (¼ - ½), and second heads (½ - ¾) in comparison to whole rice (IRRI, 2010). The reason rice kernels break easily under mechanical impact and thermal stress can be attributed to the structure of the rice grain (Belsnio, 1980).

2.5.4 Milling recovery

The percentage of whole, undamaged kernels that remain after milling is known as the rice milling recovery. To make the rice edible, this process entails removing its outer layers, such as the husk and bran (Roy *et al*., 2011).

Several variables, including the type of rice, level of polishing, drying process, and harvesting period, affect the milling recovery (Thapa *et al*., 2013).

Rough rice can be milled after being stored for up to 10 days, suggesting that the drying technique and when to harvest it during ripening can influence the recovery of the milling process (Xangsayasane *et al*., 2018).

2.6 Value cost ratio / benefit-cost analysis of rice cultivation

A method for assessing the financial viability of employing particular inputs, practices, or technology in crop production is the value-cost ratio (VCR). The value-cost ratio (VCR) can be used in making well-informed decisions in the agriculture sector by providing information for cost-benefit analyses and comparing the value of the additional yield to the cost of the input package (Szott and Motamed, 2023).

A study on the productivity and profitability of rice and pepper production in the Upper region of Ghana found that a Ghana cedi invested in rice production yields forty-three pesewas (GH₵ 0.43) on average as profit (Akolgo, 2021). Several studies have revealed that technologies when properly applied in rice cultivation produce more profit. According to research done in 2021 by SRI-Rice (2022), Ghana's SRI enterprise produces rice more profitably than traditional methods. The highest profit was made using SRI techniques along with the application of recommended chemical fertilizers, followed by the use of SRI techniques along with either the application of compost or the application of top dressing of chemical fertilizer at half the recommended rate along with the application of 13 t ha^{-1} of compost (Yussif, 2015). Similar to this, the benefit-cost analysis suggested that the 100 % NPK was the best in the short run (Denkyirah, 2015). According to studies conducted at Kasena Nankana, farmers who used SRI produced rice at a higher profit than those who used conventional methods (Denkyirah, 2015). Farmers might make 25 % more money using SRI than they would using conventional methods (Denkyirah, 2015).

2.7 Rice value chain actors perceptions

2.7.1 Rice value chain actors perceptions of the use of indigenous practices

Farmers still stick to local varieties due to the better adaptability to the environment. These varieties are drought, disease and pest resistant and respond better to low nutrients level in the soil. The local varieties produce more fodder and less resources or inputs are required in producing them (Choudhury *et al*., 2017). In addition, farmers do not want to part ways with certain local practices because they perceived those practices to be part and parcel of their culture (Choudhury *et al*., 2017). Also File *et al*. (2023) and Acheampong *et al.* (2021) report that farmers in Ghana use indigenous practices due to easy access of indigenous services, lack of complexity, cultural significance and other factors such as land tenure system

In Northern region, the vital factor that influence indigenous rice cultivation practices is the climate change (Guodaar, 2021). Indigenous methods are used in processing rice in the Northern region of Ghana. The processors do not only lack access to modern processing technologies but also accept the traditional practices to be part of their culture (Bissah *et al.*, 2022: Amfo *et al*., 2022). Another challenge facing the rice industry in the Northern region is lack of standardization in measurement of paddy (Donkoh *et al*., 2011).

2.7.2 Rice value chain actors perceptions of the use of improved practices

Improved practices are perceived by farmers to bring more yield and more profit than the local practices. Arsil *et al*. (2022) reported that farmers who adopt improved practices such as SRI got more profit than those who used conventional or local methods in rice production.

In Ghana, varietal qualities preferred by consumers has impact on farmers adoption of improved varieties for rice production. Marketable qualities such as aroma, taste, alongside high yield potential, made some farmers adopt aromatic rice varieties like Jasmine 85 and Togo Marshal I (Addison *et al.*, 2022).

Similarly, in Northern region, factors such as good milling qualities, disease resistance and adaptability of variety facilitate adoption of the improved variety. Azumah *et al.* (2022) and Donkor *et al*. (2018) revealed that the vital factors that influenced adoption of improved practices by farmers in the Northern region were ready market for the rice and the resistant of rice to diseases.

Some of the value chain actors show lukewarm attitude towards innovations or improved practices and still stick to their traditional practices because they believe those practices are part of their culture. For instance, in Ghana some rice processors are still using traditional methods of processing rice in order to preserve their culture. Elsewhere in Nigeria, Indigenous communities, like the Ojibwe and Anishinabeg, have also continued indigenous rice processing methods in other to preserve their culture (Jessica, 2024).

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Location and site characteristics

Field experiments were conducted at Sagnarigu Kukuo and Bontanga in the Sagnarigu and Kumbungu districts of the Northern region respectively from 2021 to 2022 cropping seasons. At Sagnarigu Kukuo, the field experiment was situated at a height of 142 meters above sea level between latitudes 09° 43" N and longitudes 0° 53" W of the equator. At Bontanga, the experimental field was situated at a height of 95 meters above sea level between latitudes 90 36" N and longitude $1^{0}40$" W. The research sites are located in Guinea Savannah Agro-Ecological Zone. Smart GPS Coordinates Locator software was used in collecting the altitude, latitude and longitude of the experimental sites.

Sagnarigu and Kumbungu experience unimodal rainfall, which is distributed from April to November with mean annual rainfall ranging from 1000 mm to 1200 mm. The peak of the rainfall is experienced in September. Temperature distribution is uniform with the average monthly minimum of 21.9 ^{0}C and maximum of 34.1 ^{0}C. The area also experiences relative humidity ranging from a minimum of 46 % to a maximum of 76.8% (SARI Annual Report, 2007). The vegetation of the experimental area is characterized by large areas of grassland interspersed with trees. The area is also characterized by drought-resistance trees such as acasia, mango, baobab, shea nut tree, dawadawa and neem (GSS, 2014). In 2021, between March and November, there was an average annual rainfall of 82.6 mm in the study locations, with the heaviest rain falling in August. Whereas, in 2022, between March and October, there was an average annual rainfall of 109.4 mm in the study locations, with the heaviest rain falling in August. The range of temperatures and relative humidities were between 23.8 C to 34.4 C and 52.5 % to 75 % respectively in 2021 and between 23.4 ^{o}C to 33.0 ^{o}C and 63 % to 81 % respectively in 2022 (SARI, 2022).

The soils pH is near neutral to moderately acidic as it ranges from pH of 5.6 to 6. The soils are pale in color, inadequately and poorly drained sandy loams that range in depth from shallow to moderate. During the wet seasons, they become flooded, and during the dry ones, they dry out. They have virtually little nutritional value. According to Bationo *et al*. (2008), Soils in the experimental sites are used to grow rice, sorghum, millet, beans, groundnuts, and pasture. The soils in the research areas are planosols and belong to the Changnaliyili series (FAO, 2008).

3.2 Soil and compost physiochemical properties

Physical and chemical characteristics of the soil and compost used for the experiment were conducted. Pre- and post-experimental analysis of the soil were conducted. Three soil samples from each plot were collected using a soil auger at a depth of 30 cm for the analyses. Before analysis, the samples from each plot were carefully mixed, air-dried, and analyzed for physiochemical properties. Organic carbon (OC), total nitrogen (N), potassium (K), available phosphorus (P), magnesium (Mg), and calcium (Ca) were all determined at the Soil Science Laboratory of the CSIR Savannah Agricultural Research Institute, Nyankpala

3.3 The research

One survey, three field experiments, and one laboratory study were considered in the present studies.

3.4 Materials for the field experiments

The test crop used in field experiments I and II was certified Agra variety obtained from a certified producer and distributor of certified seeds, Puzuri Agro Seed Dealer, Tamale. The varieties that were used in field Experiment III were also obtained from Puzuri Agro Seed Dealer, Tamale. These varieties were Agra, Gbewaa, and Digang which were improved varieties, and Mandii and Moses which were local varieties. The compost used in Experiment III was Deco Compost obtained from Deco, Tamale. Chemical fertilizers used were YARA NPK (15-15-15) and FALCON sulfate of ammonia whilst foliar fertilizers were from FOLIAR PLUS COMPLETE NPK and UREA which were obtained from Ganorma Agro Chemicals Ltd, Tamale.

3.5 Survey study

Survey was conducted to gather fundamental data on farmers' practices for cultivating, milling, and marketing rice in the Sagnarigu and Kumbungu districts of the Northern region of Ghana. In addition, information was gathered on farmers' perceptions of the practices they undertake in cultivating, processing, and marketing rice in the two districts. These pieces of information are vital in enhancing the adoption of improved practices. Questionnaires were administered to the key actors of rice value chain in the research area. 134 rice farmers, 82 rice processors, and 22 rice marketers were interviewed.

3.5.1 Methodology

The survey was conducted from January to March 2021. The survey's primary goal was to gather fundamental data on farmers' improved practices for cultivating, milling, and marketing rice in the Sagnarigu and Kumbungu districts of the Northern region of Ghana.

In addition, information was gathered on farmers' perceptions of the practices they undertake in cultivating, processing, and marketing rice in the two districts. This information is vital in enhancing the adoption of improved practices. Questionnaires were administered to the key actors of the rice value chain in the research area. Those interviewed were 134 rice farmers, 82 rice processors, and 22 rice marketers.

3.5.1.1 Sampling techniques and data collection

A multi-stage sampling methodology was used in this study. Sagnarigu Kukuo and Bontanga were chosen for the first stage using the purposive sampling technique because they are the two main rice-producing localities in the study area. In the second stage, stratified sampling was employed to divide the population into three categories: (a) producers, (b) processors, and (c) marketers. Finally, simple random sampling was used in sampling 134 farmers, 22 marketers and 82 processors from the study area. Out of the 134 farmers, 69 of them were selected from rainfed condition and the remaining 65 from irrigated condition. A well-structured questionnaire was used to gather primary data through face-to-face interviews

3.5.1.2 Data analysis

Both qualitative and quantitative data collected from the interview were subjected to descriptive analysis using IBM SPSS software version 17th edition. The differences between means were separated using least significant difference (LSD) at 5 %. Statistical inferences and conclusions were made from the results which were presented in form of simple frequencies and percentages in tables

3.6 Field Experiments I and II

The Field Experiment I was conducted in the rainy season of 2021 under rainfed conditions at Sagnarigu Kukuo in the Sagnarigu municipality of Northern region of Ghana whereas the Field Experiment II was conducted in the dry season of 2022 under irrigated condition at Bontanga in Kumbungu district of Northern of Ghana. Spacing and timing of transplanting were the two factors under investigation. The levels of spacing were four while that of timing of transplanting were five. The five levels of transplanting were transplanting when the seedlings were 14 days old, transplanting when the seedlings were 21 days old, transplanting when the seedlings were 28 days old, transplanting when the seedlings were 35 or 42 days old.

3.6.1 Materials and methods

The Experiments were carried out in the cropping season of 2021 and 2022 under rainfed conditions at Sagnarigu Kukuo in the Sagnarigu district (Experiment I), and it was repeated the following year in Bontanga in the Kumbungu district (Experiment II), but under irrigation. The experiment were 4 x 5 factorial laid in a randomized complete design and replicated three times. The levels of spacing was four (20 cm × 20 cm, 25 cm x 25 cm, 30 cm x 30 cm, and 35 cm x 35 cm), whereas the time of transplanting was five levels (14, 21, 28, 35 and 42 days old).

The experimental site coverfed a total field area of 1,260m^2 (35m x 36m), with each block measuring 105m^2 (35m x 3m) and each treatment plot measuring 21m^2 (7m x 3m). Between adjacent treatment plots in a block and adjacent blocks, were alleys measuring 1 m and 2 m respectively. Each block was replicated three times. Agra variety was the test rice variety. Experimental plots were bunded to prevent water from spilling over from one plot to another. Treatment combinations were replicated three times in factorial experiment using randomize complete block design (RCBD).

3.6.1.1 Data collection

3.6.1.1.1 Plant height

The height of the plants was determined using Issahaku's (2020) approach. Ten randomly selected and pegged plants per plot were used to calculate plant height. Plant height data were collected at 42 and 63 days after planting (DAP). The average of the ten heights was calculated after measuring each plant's height from the soil's surface to its peak with a meter rule.

3.6.1.1.2 Number of tillers per plant

Tillers from selected plants were counted at 63, and 84 DAP, and the average number of tillers for each plant was calculated. This was accomplished by sampling two quadrats from each plot and counted. The procedures used by Yussif (2015) were applied in this circumstance.

3.6.1.1.3 Number of days to 50 % flowering

Sikuku *et al.* (2010) described methods for calculating the number of days to 50 % flowering was employed. Days to 50 % flowering were calculated as a percentage of the flowering plants per plot divided by the total number of plants in the plot. The number of days it took half of the plant population in each plot to flower was visually examined and documented.

3.6.1.1.4 Number of panicles per plant

The protocols described by Sikuku (2010) were followed. Each of the tagged plants in each plot had their panicles counted and recorded. Their mean values were later computed.

3.6.1.1.5 Number of spikleletes and infertile spikeletes per plant

Yussif (2015) discussed the procedures used to determine the number of viable and sterile spikelets in each panicle. If a kernel was present, the grain was considered filled or productive. The total number of viable grains was counted and averaged. A sterile grain or empty grain contains no kernel. Ten panicles were sampled, the empty grains were counted and the means were calculated.

3.6.1.1.6 1000 seed weight

From each sample, 1,000 cleaned, dried seeds were chosen at random, counted using a seed counter and weighed with a digital electric balance while the seeds were still at 14 % moisture content. The mean weight was then expressed in grams. The approach provided by Issahaku (2020) was used in this circumstance.

3.6.1.1.7 Grain and adjusted grain yields

Rice plants were harvested from net plot of 2 m x 6 m manually using sickle from each plot and sundried consecutively for three sunny days. The dried plants were threshed and winnowed manually. The grains obtained were weighed using digital scale to obtain grain yield weight (kg) per plot. The moisture content (MC) of the grains obtained from each plot was measured using Dicky John multi-grain moisture metre and adjusted to 14 % MC and converted to kilogram per hectare (kg ha^{-1}) as reported by Paudel (1995). Grain yield was computed using the formula below:

$$\text{Grain yield (kg/ha) at 14\% MC} = \frac{\left((100-MC)\ X\ net\ plot\ grain\ (kg)\ X\ 1000\ \ (m^2)\right)}{(100-14\ )\ X\ net\ plot\ area\ (m^2)}$$

3.6.1.1.8 Straw yield

The net plot was used to calculate straw yield. Following grain separation, the straw was dried in an oven at 80 ^{0}C for 48 hours (Peng *et al.*, 2011). Then the kg m^{-2} of straw yield was calculated.

3.6.1.1.9 Value cost ratio

To assess the cost-effectiveness of the various treatment combinations and make sound recommendations on the best method for producing rice in the study area, data on production costs, as compared to yield per treatment, was collected and analyzed using the Value Cost Ratio (VCR), which was calculated by adding the costs in the production process. The pricing was computed using Ghana Cedis. Price data for various inputs and outputs (rice) were obtained from the Tamale market. The assessment was based on rice market prices for the December 2021 harvest season. By dividing the total revenue by the total cost incurred by each treatment, the value cost ratio was calculated while by dividing the profit by the total cost incurred by each treatment, the benefit cost ratio was calculated. Thus, Value cost ratio (VCR) and Benefit Cost Ratio were computed using the formulas below:

$$\text{Value cost ratio (VCR)} = \frac{Total\ revenue\ (TR)}{Total\ cost\ (TC)}$$

$$\text{Benefit cost (BC)} = \frac{Profit\ (P)}{Total\ cost\ (TC)}$$

3.6.1.2 Data analysis

Data collected from each field experiment were subjected to analysis of variance (ANOVA) using Genstat software version 18th edition. The differences between means were separated using least significant difference (LSD) at 5% and Duncan's Multiple Range Test (DMRT). Pearson's correlation coefficient was used to study the relationship between grain yield and some growth and yield parameters.

3.7 Field Experiment III

This experiment was conducted in the raining season of 2022 under rainfed condition at Sagnarigu Kukuo in the Sagnarigu municipality of Northern region of Ghana. Variety, spacing and soil amendment were the three factors under investigation. The levels of variety, spacing and soil amendment were 5, 2 and 4 respectively.

3.7.1 Materials and methods

3.7.1.1 Experimental design and treatments

This study was a 5 x 2 x 4 factorial experiment laid out in a randomized complete design replicated three times The factore were varieties at five levels (V1 = Agra, V2 = Gbewaa rice, V3 = Digang, V4 = Mandii and V5 = Moses): Spacing at two levels (S1 = 20 cm x 20 cm and S2 = 25 cm x 25 cm) and soil amendments at four levels (basal application of 37.5 kg ha^{-1} each of NPK (15-15-15); FF = foliar basal application of 18.5 kg ha^{-1}N, 6 kg ha^{-1}P and 6 kg ha^{-1} K (26-12-12) followed by foliar top dressing of 18.5 kg $ha^{-1}$of N (from urea); HRCFOF = initial application of 10 t ha^{-1} Deco compost followed by basal application of 18.75 kg ha^{-1}each of NPK (15-15-15) and top dressing with 13.13 kg ha^{-1} of N (from sulfate of ammonia); and RCF = basal application of 37.5 kg ha^{-1} each of NPK (15-15-15) followed by top dressing with 26.25 kg $ha^{-1}$of N (from sulfate of ammonia) as a top dressing. The experimental field measured 2,520m^2 (36m x 70m), with each block measuring 840m^2 (12m x 70m) and each treatment plot measuring 21m^2 (7m x 3m).

Adjacent treatment plots in a block and adjacent blocks, alleys measuring 1 m and 2 m were used respectively. Experimental plots were bunded to prevent water from spilling over from one plot to another. Deco compost was incorporated into the respective fields 3 weeks before transplanting. To ascertain the nutrient composition, laboratory testing was done on the compost.

3.7.1.2 Determining physical and chemical properties of soil and compost

Laboratory analysis was done on the physical and chemical features of the compost and soil samples. The parameters that were chosen were as follows:

3.7.1.2.1 Organic carbon

Nelson and Sommers' (1982) modified Walkley-Black wet oxidation method was used to calculate organic carbon (OC). Compost and soil samples weighing 100 milligrams (0.10 g) each were placed into a 500 ml conical flask together with 10 ml of a 0.166 M (1.0 N) $K_2Cr_2O_7$ solution and 20 ml of H_2SO_4. The mixture was subjected to 30 minutes of cooling over an asbestos-containing surface. 200 ml of distilled water, 10 ml of H_2PO_4, and 1 ml of the diphenylamine indicator solution were all added. The mixture was titrated with 1.0 M ferrous sulfate solution until the color changed from blue-black to a consistent greenish hue. In every batch of samples analyzed, a blank determination was performed in the same way. The calculation of the percentage of carbon (C) was based on Nelson and Sommers' (1982) methodology.

3.7.1.2.2 Total nitrogen

The Kjeldahl digestion method, as reported by Okalabo, was used to calculate total N. An amount of 2.0 grams each of compost and soil that had been oven-dried and powdered to pass through a 0.5 mm filter was weighed into a Kjeldahl digestion flask. One spatula of catalyst (copper sulfate**,** sodium sulfate, and selenium powder) was then added, followed by 20 ml of concentrated H_2SO_4. Strong heat was applied to the combination to cause the plant matter to break down and turn a permanent clear green color. The digest was cooled, transferred to a volumetric flask measuring 100 ml, and diluted with distilled water to the appropriate level. An amount of 20 ml of a 40 % NaOH solution was added after 10 ml of the digest's liquid was transferred to a Tecator distillation flask. 20 ml of a 40 % NaOH solution was added after 10 ml of the digest's liquid was transferred to a Tecator distillation flask. Steam from the Foss Tecator device was allowed to flow into the flask. The distilled ammonium was collected into a 250 ml flask with 15 ml of 4 % boric acid and mixed with bromocresol green and methyl red indicator. The 0.1 N HCl solution was used to titrate the distillate. As a precaution against nitrogen residues in the utilized reagents and water, blank digestion, distillation, and titration were performed. The percentage of nitrogen was determined using the method described by Okalabo *et al*. (1993).

3.7.1.2.3 Phosphorus, Calcium, Magnesium, Potassium, and Sodium determination in compost

For the analysis of P, Ca, Mg, K, and Na, Olsen *et al*. (1954) methodology was applied. One (1) gram of compost was ashed at 500 ^{0}C for two hours before the determination. A 5 ml aliquot of the supernatant digest of sample was pipetted into a 50 ml volumetric flask for phosphorus analysis. An amount of 5 ml of ammonium molybdate and ammonium vanadate mixture were added into the volumetric flask. Distilled water was used to make the mixture up to the 50 ml level, and it was left undisturbed for 30 minutes to allow the color to develop. A standard curve was created at the same time using P values of 0.0, 10.0, 15.0, and 20.0 mg P kg^{-1}. At a wavelength of 430 mm, the Jenway Colorimeter was used to measure the absorbance of the blank, the control, and the samples (Watanabe and Olsen 1965). The absorbance against concentration (ppm) P was shown on a graph. Reading the unknown and blank standards allowed for the interpolation of the ppm P value, which was then calculated using the Watanabe and Olsen (1965) formulas and the graph displayed from the graph.

For K and Na, 1.908 g and 2.542 g of analytical grade KCl and NaCl, respectively, were dissolved in 200 ml of deionized water after being dried for 4 hours at 105^0C in an oven. The two solutions were combined to create a 1000 ml volume. A composite standard of 1000 ppm was produced. A 200, 400, 600, and 800 ppm calibration curve (standard curve) was created for K. For sodium, a standard curve with concentrations of 20, 40, 60, and 80 ppm was created. The flame photometer was used to take all of the absorbance measurements. On the flame photometer, the sample solution of $HClO_4$ and HNO_3 was measured. The concentrations of K and Na were determined from the standard curve using the specific absorbance reserved for the sample (Mehlich, 1984).

Several reagents were added to determine the levels of calcium and magnesium using an ethylenediaminetetraacetic (EDTA) titration (Mehlich, 1984). From the supernatant digest, 5.0 ml of the calcium sample solution from the sample replica was added to each 100 ml Erlenmeyer flask. Following the addition of 10 ml of 10 % KOH solution, 1 ml of 30 %

triethanolamine (TEA) was added. Three drops of 10 % KCN and a few drops of the indicator solution for ferrochrome black-T (EBT). To make sure the mixture was homogeneous, it was well shaken. According to Mehlich (1984), the combination was titrated with 0.02 N EDTA solution from a red to the blue endpoint.

3.7.1.2.4 Soil pH

A calibrated pH meter comprising two buffer solutions was used to assess soil pH, which quantifies the acidity, neutrality, and alkalinity of the soil (FAO, 2008). For each replicate soil sample, 5 g of oven-dried soil was weighed into a 100 ml beaker along with 50 ml of distilled water. For 20 minutes, the suspension was sporadically stirred with a hand agitator. Before taking a pH reading, the suspension-containing beaker was allowed to stand for 30 minutes. Blanks were used to calibrate the pH meter at pH 7 and pH 4, respectively. The electrode of the pH meter was inserted into the suspension to determine the pH (Nelson and Sommers, 1982). The pH of each sample was determined using the simple pH meter PH29P.

3.7.1.2.5 Effective cation exchange capacity

With a few minor modifications, the technique outlined by Schwertfegr and Hendershot (2009) was used to assess the Effective Cation Exchange Capacity (ECEC). Soil samples were dried in an oven at 80 ^{o}C for six hours. Following rolling-pin crushing, the dried materials were sieved using a 2-mm screen. The sieved sample was weighed at around three grams (3 g), and 30 ml of 0/1 $BaCl_2$ was added. After centrifuging at 3000 rpm for one hour with the resulting soil/solution ratio of 1:10, the supernatants were filtered through Whatman no. 41 filter paper and placed in a plastic bottle to get the 0.2 % final concentration. With 10 % (v/v) HNO_3, 10 ml of the filtered solution was made acidic. K, Na, Ca, and Mg concentrations of extractable bases were measured in the extract using ICP-OES, or inductively coupled plasma optical emission spectroscopy. The ECEC was determined by adding the bases that could be extracted.

3.7.1.3 Plant height

The method used by Issahaku (2020) was employed in determining the height of the plants. Ten randomly chosen and pegged plants per plot were used to calculate the plant height. Data on plant height were collected at 42 and 63 weeks after planting (DAP). The average of the 10 heights was computed after measuring the height of the plant using the meter rule from the soil's surface to its apex.

3.7.1.4 Number of tillers per plant

Tillers were counted at the 63 and 84 DAP and the average number of tillers for each plant was calculated. Two quadrats were sampled from each plot and tillers from the area covered counted as reported by Yussif (2015).

3.7.1.5 Chlorophyll content

A chlorophyll meter (model: Minolta SPAD, Japan) was used to measure the chlorophyll content (nm) of the leaf of 10 sampled plants from each plot on the 63 and 84 DAP. 3 spots on the flag leaf or freshest leaf readings were taken using the SPAD meter and the average of these readings recorded for each of the sampled plants on the plot. The mean chlorophyll (nm) value of the 10 sampled plants from the plot was computed and recorded.

3.7.1.6 Leaf area index

The method described by Gomez and Gomez (1984) was used to measure the leaf area index. A ceptometer was used to measure the leaf area index at 63 DAP. Five (5) hills each were randomly selected from each plot, bearing in mind that each of these selected hills were surrounded by other plant hills for the measurement. The leaf area index value was taken from the ceptometer and recorded.

3.7.1.7 Day to 50 % flowering

The numbers of days taken for half of the plant population in the individual plots to flower were visually observed and recorded as days to 50 % flowering.

3.7.1.8 Dry root weight at harvest

Asagi and Ueno. (2009) method was followed in taking the data for the dry root weight of the rice plants. From each plot, plants were chosen at random at harvest and uprooted and the roots separated from the shoots. Soil particles attached to the roots were removed and the roots dried in a drying oven at 80 ^{0}C. The samples were then taken out and their dry weights recorded.

3.7.1.9 Panicle number

The procedures used by Sikuku (2010) were used. Each of the tagged plants in each plot had its panicles counted and documented.

3.7.1.10 Spiklelete and infertile spiklete per panicle

If a kernel is present, then the grain is regarded as filled or fertile. On the sampled panicles, the total number of fertile grains was counted and then averaged. These filled grains, which were present on each of the sample panicles, were numbered and then averaged. A sterile grain or unfilled grain has no kernel inside. Ten panicles were sampled, and their unfilled grains were counted and their means recorded.

3.7.1.11 Thousand seed weight

From each sample, 1,000 cleaned, dried seeds were randomly selected, counted using a seed counter, and weighed using a digital electric balance when the seeds still had 14 % moisture in them. The mean weight was computed as described by Issahaku (2020).

3.7.1.12 Total grain yield and adjusted grain yields

Rice plants were harvested from net plot of 2 m x 6 m manually using sickle from each plot and sundried consecutively for three sunny days. The dried plants were threshed and winnowed manually. The grains obtained were weighed using digital scale to obtain grain yield weight (kg) per plot. The moisture content (MC) of the grains obtained from each plot was measured using Dicky John multi-grain moisture metre and adjusted to 14 % MC and converted to kilogram per hectare (kg ha^{-1}) as reported by Paudel (1995). Grain yield was computed using the formula below:

$$\text{Grain yield (kg/ha) at 14\% MC} = \frac{\left((100 - MC)\ X\ net\ plot\ grain\ (kg)\ X\ 1000\ \ (m^2)\right)}{(100 - 14\ )\ X\ net\ plot\ area\ (m^2)}$$

3.7.1.13 Straw yield

The net plot was used to calculate the yield of straw. The straw was dried in an oven at 80 ^{0}C for 48 hours after the grains had been separated (Peng *et al*., 2011). Then, the tons ha^{-1} of straw yield was determined.

3.7.1.14 Value cost ratio

To evaluate the cost-effectiveness of the various treatments and provide sound recommendations on best method for producing rice in the Northern region, data on the cost of production as compared to the yield per treatment was gathered and analyzed using the Value Cost Ratio (VCR), which was determined using the combined cost of variety, spacing, and soil amendment. Please refer to section 3.6.1.1.9 for details.

3.7.1.15 Data analysis

Data collected from each field experiment were subjected to analysis of variance (ANOVA) using Genstat software version 18^{th} edition. The differences between means were separated using least significant difference (LSD) at 5% and Duncan's Multiple Range Test (DMRT). Pearson's correlation coefficient was used to study the relationship between grain yield and some growth and yield parameters.

3.8 Experiment IV

Experiment IV was a laboratory experiment conducted in Avnash laboratory in Tamale on samples of rice grains that were collected at harvest from the field Experiment III. Plants from the plots from the various treatments combinations from Experiment III were harvested and grains used for this study. Therefore, the treatment structure of this laboratory study remains the same as that of Experiment III.

Six kilograms (6kg) paddy samples from each of the treatment plots were collected immediately after harvest and shade-dried while measuring the moisture content until 14 % moisture content was achieved. Each 6kg paddy from the treatment plots was straight-milled using a Satake dehusking machine. An electronic scale was used to weigh the husk and brown rice. Using a Satake polishing machine, brown rice was polished. White rice and bran weights were measured and recorded. Head rice and broken rice were separated from the white rice that was transferred to the Satake grading machine. Head rice, brown rice, husk, and broken rice weights were measured, and calculations were made using IRRI (2010) formulas.

3.8.1 Materials and methods

3.8.1.1 Materials and laboratory equipment

The following laboratory equipment and materials were used for the experimental investigation:

Milling machine: The model of the device is THU-35, Satake Hiroshima, Japan with power (kW) consumption of 0.2-0.4 and capacity of milling to be 50-500 g / min This machine was used to mill the paddy samples. Polisher: The model is Satake Tekko with power (kW) consumption of 0.41-0.46 with a capacity of polishing to be 500 g / 5 min. This machine was used to remove the bran layer of the brown rice. Grader: The model of the grader used was Satake Test Rice Grader TRC 0.5 with a capacity of grading 500 g / 3 min. This was used to separate white rice into head and broken grains. Moisture meter: the name of the moisture meter used was Grain Moisture Tester, Riceter J301. The measuring range of the instrument was 9 - 30 %. This was used to measure the moisture contents of the paddy samples before milling.

Electronic scale used was of a model LIBROR EB-32000 with 3120.0 g x 600.00 g capacity. This was used to measure the weight of paddy and milled rice. Vernier calipers and meter rule: they were used in measuring the length and width of the rice grains. Sample mixer / divider: It was used to either mix or divide the paddy for a better sampling of the grains before milling. Grainscope or magnifying lens: It was used for viewing milled or processed grains. This was used in determining the crackness of rice grains and others. Sacks: the type of sacks used were polythene bags with size 23 cm x 16.5 cm. The sacks were used to contain paddy and milled rice during weight measurement.

3.8.1.2 Experimental design and treatments

The field experiment where the rice grains were obtained for the laboratory experiment was conducted in the raining season of 2022 under rainfed condition at Sagnarigu Kukuo in the Sagnarigu municipality of Northern region of Ghana. Variety, spacing and soil amendment were the three factors under investigation. The levels of variety, spacing and soil amendment were 5, 2 and 4 respectively. The five levels of varieties were V1 = Agra, V2 = Gbewaa rice, V3 = Digang, V4 = Mandii and V5 = Moses. The two levels of spacing were S1 = 20 cm x 20 cm and S2 = 25 cm x 25 cm. The 4 levels of soil amendment were BCF = basal application of 37.5 kg ha^{-1} each of NPK (15-15-15); FF = foliar basal application of 18.5 kg ha^{-1}N, 6 kg ha^{-1} P and 6 kg ha^{-1} K (26-12-12) followed by foliar top dressing of 18.5 kg ha^{-1} of N (from urea); HRCFOF = initial application of 10 t ha^{-1} Deco compost followed by basal application of 18.75 kg ha^{-1}each of NPK (15-15-15) and top dressing with 13.13 kg ha^{-1} of N (from sulfate of ammonia); and RCF = basal application of 37.5 kg ha^{-1} each of NPK (15-15-15) followed by top dressing with 26.25 kg ha^{-1} of N (from sulfate of ammonia) as a top dressing. Treatment combination were replicated three times using factorial experiment in randomized complete block design (RCBD).

Six kilogramme paddy samples from each of the experimental treatment plots from chapter 6 were collected immediately after harvest after shade-drying at 14 % moisture content. Foreign matter, admixture and discoloured grains were separated from the sample. The remaining grains were straight-milled using a Satake dehusking machine. An electronic scale was used to weigh the husk and brown rice. Using a Satake polishing machine, brown rice was polished. White rice and bran weights were measured and recorded. Head rice and broken rice were separated from the white rice that was transferred to the Satake grading machine. Weight of rice of the parameters were measured and calculations were made using IRRI (2010) formulas.

3.8.1.3 Data collection

3.8.1.3.1 Foreign matter

The method used by Belsnio (1980) was employed in determining the foreign matter in sample grains. Using the six-kilogram paddy sample, weed seeds were separated using magnifying glasses and sieve. The remaining paddy was passed through a laboratory aspirator twice to separate other impurities such as chaffs, hulls, stones, stalks etc. The impurities including the weed seeds were gathered as foreign matter and weighed. Foreign matter was computed using the formula below

$$Foreign\ matter = \frac{weight\ of\ foreign\ matter\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

3.8.1.3.2 Admixture

The method described by Belsnio (1980) was employed in determining admixture of the grains. Other rice grains apart from the variety were manually separated on the sorting board after the foreign matter was removed. The admixture was weighed using electronic scale and was then calculated using the formula below.

$$Foreign\ matter = \frac{weight\ of\ admixture\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

3.8.1.3.3 Discolour grain

Discolour grains were manually separated on the sorting board after the foreign matter was removed. The weight of the discolour grains was taken using electronic scale which was then used to calculate the percentage of discolour grains in the sample using the formular below.

$$Discoloured\ grains\ = \frac{weight\ of\ discoloured\ grains\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

The method employed by Belsnio (1980) was used in determining the discoloured grains.

3.8.1.3.4 Red grains

The method described by Sampang (1980) was used to measure the red grains.

From the dehulled rough grains from the sample, the red grains were separated using the sorting board and weighed. The weight of the red grains was taken using electronic scale.

This was used to calculate the percentage of red grains in the sample using the expression below.

$$Red\ grains\ = \frac{weight\ of\ red\ grains\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

3.8.1.3.5 Green grains

The procedures used by Sampang (1980) were used. From the dehulled rough grains from the sample, the green grains were separated using the sorting board and weighed. The weight of the green grains was taken using electronic scale. The formula below was used in computing green grains.

$$Green\ grains\ = \frac{weight\ of\ green\ grains\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

3.8.1.3.6 Chalky grains

The procedures used by Sampang (1980) were used. From the dehulled rough grains from the sample, the chalky grains were separated using the sorting board and weighed. The formula below was used in computing chalky grains.

$$Chalky\ grains\ = \frac{weight\ of\ chalky\ grains\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

3.8.1.3.7 Immature grains

From the dehulled rough grains from the sample, the immature grains were separated using the sorting board and weighed. The formula below was used in computing immature grains.

$$Immature\ grains\ = \frac{weight\ of\ immatured\ grains\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

The procedures described by Sampang (1980) was followed in determining the immature grains.

3.8.1.3.8 Combined grains

From six-kilogram paddy sample, the foreign matter was removed using the sieve and aspirator. Sorting out rice seeds with partially removed hulls as combined grains carried out manually by handpicking. The combined grains obtained was weighed and determine using the Fajardo (1980) procedures. The combined grains was calculated using the formula below.

$$Combined\ grains = \frac{weight\ of\ combined\ grains\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

3.8.1.3.9 Crackness of grain

From the dehulled grains from the sample, the cracked grains were separated using the grainscope. The cracked grains were weighed. The formula below was used in computing the crackness of the grains.

$$Crackness\ of\ grains\ = \frac{weight\ of\ cracked\ grains\ (g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

The method used by Sampang (1980) was used in determining the crackness of the grain.

3.8.1.3.10 Brown rice

The sample was milled using Satake dehusking machine. The weight of brown rice was taken using an electronic scale reported by Singh and Prasad (2024). Brown yield was computed using the formula below:

$$Brown\ rice = \frac{weight\ of\ brown\ rice(g)}{weight\ of\ paddy\ (g)} X\ 100\ \%$$

3.8.1.3.11 Husk

The sample was milled using Satake dehusking machine. The weight of husk yield was taken using an electronic scale as reported by Paudel (1995). Husk yield was computed using the formula below:

$$Husk = \frac{weight\ of\ husk\ (g)}{weight\ of\ paddy\ (g)}\ X\ 100\ \%$$

3.8.1.3.12 Broken grain

The procedures used by Mobasher *et al*. (2016) was used in determining broken grains. A laboratory dehusker (Satake Engineering Co., Ltd., Tokyo, Japan) was used to de-husk the paddy samples. Then, laboratory friction-type rice whitener (McGill Miller, Brookshire, TX, USA) was used to polish the brown rice. A rotary indent separator (TRG 058; Satake Engineering Co., Ltd.) was used for separating head and broken kernels. A kernel being less than 75% of the whole kernel was considered to be broken grains. The broken grains were collected and weighed and its percentage was calculated using the expression:

$$Broken\ grains = \frac{(weight\ of\ broken\ grain(g)}{weight\ of\ paddy\ (g)}\ X\ 100\ \%$$

3.8.1.3.13 Milled grain length, width and length-to-width ratio

The methods described by Singh and Prasad (2024) were used in determining length, width, and length to width ratio. Using a digital vernier caliper (Model AD-5765-100), 100 grains from each sample length and width were measured. The mean length and width were determined. The length – to – width ratio was also determined using the formula below.

$$Length\ width\ ratio = \frac{(length\ of\ grain(g)}{width\ of\ grain\ (g)}$$

3.8.1.4 Data analysis

Data were analyzed with GENSTAT, 18th Edition using the general analysis of variance (ANOVA) technique. The differences between means were separated using least significant difference (LSD) at 5% and Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

CHAPTER FOUR

PERCEPTION OF RICE VALUE CHAIN ACTORS ON IMPROVED CULTIVATION AND MILLING PRACTICES IN RICE PRODUCTION

4.1 Introduction

In Africa, rice has become a key component of diets and has become a fulcrum in the fight for food security (IRRI, 2013). Over the continent, rice consumption has surpassed that of other staples due to rising urbanization, rising population rates, and changing culinary preferences. Seck *et al*. (2013) points out that this increase in rice consumption demonstrates the food's growing significance of the crop in African diets.

Local rice production in Africa is unable to keep up with the increasing demand (Seck *et al*., 2013). Although local rice output increased quickly in the wake of the 2007–2008 food crisis, supply still cannot keep up with demand. According to Muthayya *et al.* (2014), only 54 % of the rice consumed in Africa is produced domestically, meaning imports are necessary to make up the difference. The continent still imports substantial amount of rice to meet her needs, even with increased domestic production.

Africa's rice sector faces numerous difficulties that call for all-encompassing assistance in order to increase sustainability and productivity. Strong seed systems, climate-resilient varieties, good agricultural practices (GAP) advocacy, improving quality control throughout the value chain, and critical infrastructure investment are among the important areas that need to be addressed (Muthayya *et al*., 2014). In order to optimize rice production and close the ongoing supply and demand gap, these initiatives are essential.

Ghana presents a promising location for year-round rice cultivation due to its favorable agronomic conditions (Addai *et al*., 2022). Ghana has the potential to greatly increase rice yields due to its large agricultural land and significant irrigation potential (MoFA, 2019).

Regional differences still exist, though, with some districts performing better in terms of yield. Although yields in some areas are impressive, in others they fall short of even the national average.

Numerous obstacles prevent the Northern region of Ghana, which is important for producing rice, from operating at maximum efficiency. The region's agricultural potential is hampered by elements like the restricted use of contemporary agricultural technologies due to misconceptions, poor fertilizer availability, dependence on low-yielding cultivars, and lack of credit facilities (Tanko *et al*., 2016).

Some of the misconceptions the value chain actors (farmers, processors and marketers) hold are not helping in enhancing technology adoption. Value chain actors do not want to part ways with certain local practices because they perceived those practices to be part and parcel of their culture (Choudhury *et al*., 2017). They compromised convenience for quality or higher production due to the simplicity, accessibility, affordability and cultural significance of the indigenous practices (File *et al*., 2023; Acheampong *et al*., 2021).

Provision of well-structured educational and awareness programs with empirical evidence to the value chain actors will help dispel the misconceptions. Malabe *et al.* (2021) and Assaye *et al*. (2023) reported increased in adoption of technologies such as high-yielding rice varieties, row planting, recommended fertilizer rates, and modern processing and marketing of rice associated with farmers and processors who had adequate education or information.

The demographic characteristics of the value chain actors in Northern region do not favour technology adoption. Most of the value chain actors are old, male producers and female processors and marketers and have no formal education. Ismaila and Tanko (2021) indicated that farmers with lower levels of education may have less access to technical information and training, which could result in a slower uptake of current agricultural production technology.

The female producers and male processors and marketers should be empowered as well as provided with mouth-watering starter packages for new entrants to address the problem of gender inequity amongst the producers, processors and marketers. People who are below 25 years old should also be sensitized. These initiatives should focus on building technical and entrepreneurial skills, empowering the targeted gender and age to play a more active role in the rice value chain (Tsado *et al*., 2014).

According to Malabe *et al*. (2021) more educated farmers adopt technologies faster than those with less education. Education enables farmers to better understand the benefits of new technologies and how to use them.

These difficulties highlight how important it is to carry out focused interventions in order to improve the area's agricultural environment and raise rice production.

Despite these obstacles, implementing better practices has the potential to increase rice productivity. However, this expectation needs to be empirically validated. In Ghana's Sagnarigu and Kumbungu districts, this study aims to ascertain how actors in the rice value chain perceive and are aware of the effects of improved practices on rice yield and milling characteristics. This research attempts to understand the subtleties of rice production dynamics and provide guidance for strategic interventions targeted at realizing the rice sector's full potential by exploring the viewpoints of stakeholders.

4.2 Main objective:

The main objective of the study is to determine the perception and knowledge of rice value chain actors on effect of improved practices on yield and milling characteristics of rice.

4.2.1 Specific objectives

1. To assess the improved practices of value chain actors in cultivating, processing, and marketing rice in the Sagnarigu and Kumbungu districts of the Northern region of Ghana
2. To assess value chain actors' perceptions on the practices they undertake in cultivating, processing, and marketing rice in the two districts

4.3 Methodology

Detailed sampling, design and entire methodology of this study is as stated in Chapter Three under section 3.5.

4.4 Results

4.4.1 Gender of respondents

The farmers, processors and marketers who were interviewed were 134, 82, and 22 respectively. The farmers were made of 94 % males and 6 % females, the processors were made of 7.3 % males and 92.7 % females and the marketers were made up of 13.6 % males and 86.4 % females (Table 1). Majority of the farmers were males whist majority of the processors and marketers were females.

Table 1 Gender of farmers, processors, and marketers

	Farmers		Processors		Marketers	
Gender	Frequency	Percent	Frequency	Percent	Frequency	Percent
Male	126	94.0	6	7.3	3	13.6
Female	8	6.0	76	92.7	19	86.4
Total	134	100.0	82	100.0	22	100.0
Mean	1.06		1.93		1.86	
SEM	.021		.029		.075	

4.4.2 Age of respondents

The age range with the highest percentage (36.6 %) of the farmers was within the ages of 36 to 45 years whilst the age range with the least population (11.9 %) of farmers were within 18 to 24 years (Table 2). More than half (52.4 %) of the rice processors in the study area were within the ages of 36 to 45 years whilst the least population (1.2 %) of the processors were within the age range of 18 to 24 years. Half (50.0 %) of the rice marketers in the study area were within the age range of 46 to 70 years whilst the age range with the least population (4.5 %) was from the age range of 18 to 24 years. Majority of the value chain actors in the study area are above 36 years whilst the rice business is unattractive to the population with ages 24 years and below.

Table 2: Age of farmers, processors and marketers

	Farmers		processors		Marketers	
Age	Frequency	Percent	Frequency	Percent	Frequency	Percent
18 – 24	16	11.9	1	1.2	1	4.5
25 – 35	33	24.6	10	12.2	0	0
36 – 45	49	36.6	43	52.4	10	45.5
46– 70	36	26.9	28	34.1	11	50.0
Total	134	100.0	82	100.0	22	100.0
Mean	3.78		4.20		4.45	
SEM	0.084		0.077		0.127	

4.4.3 Education of respondents

Majority (62.7 %) of the farmers had not received formal education whilst 10.4 % of them had received tertiary education (Table 3). Majority (92.7 %) of the processors had not received formal education (Table 3) whilst 1.2 % of the population had received either primary school education or tertiary education. All the marketers had not received formal education (Table 3). The respondents who received the highest tertiary education was the farmers as 10.4 % of them had received tertiary education. This was followed by the processors as 1.2 % of them received tertiary education.

Table 3: Education of farmers, processors and marketers

	Farmers		Processors		Marketers	
Educational level	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
No formal educ.	84	62.7	76	92.7	22	100.0
Primary	11	8.2	1	1.2		
JHS/Middle Sch.	13	9.7	4	4.9		
SSS/SHS	12	9.0				
Tertiary	14	10.4	1	1.2		
Total	134	100.0	82	100.0		
Mean	1.96		1.16		1.00	
SEM	.123		.068		.000	

4.4.4 Source of rice seed for cultivation

Only 8.2 % of the farmers in the study area used certified seed in cultivating rice (Table 4) whilst 54.5 % of the farmers used their own seed in cultivating rice in the 2020 cropping season. Farmers who obtained their rice seeds from other farmers were more than those who obtained theirs from certified sources.

A significant percentage (48.5 %) of the farmers from the study area did not use the certified seed because the certified seeds were costly (Table 4) whilst 15.7 % of the farmers were contended with the yields, they had the previous season and continued with their seed.

Table 4: Source of rice seed for cultivation and reason for the choice of seed source

Seed source	Fre	%	Reasons for choice	Frequency	Percent
Farmer own seed without selection	28	20.9	Cheaper than certified seeds	8	6.0
Seeds from other farmers without selection	7	5.2	Readily available	11	8.2
Farmer own seed with selection	73	54.5	Higher yield obtained from previous season	21	15.7
Seeds from other farmers with selection	15	11.2	Certified seeds are costly	65	48.5
Certified seeds	11	8.2	To supply certified seeds to farmers	4	3.0
			Higher yield	10	7.5
			Own seeds performed well	11	8.2
			High yield obtained from the farmer	4	3.0
Total	134	100.0	Total	134	100.0
Mean	4.04		Mean	4.04	
SEM	.139		Std. Error of Mean	.139	

4.4.5 Variety used by the value chain actors

The variety that was used the most in the 2020 cropping season in the study area was Agra as 37.3 % of the farmers used this variety in the 2020 cropping season (Table 5). This was followed by the variety Moses as 23.9% of the farmers planted this variety. These were followed by Gbewaa, Mandi, Bumbass, Digang, and Salimasaa with the respective percentage of farmers' usage of 11.2 %, 6.7 %, 5.2 %, 4.5 %, and 3.0 %.

Majority (64.6 %) of the rice processors in the study area prefer Agra as paddy for processing (Table 5), 12.2 % of the respondents prefer Gbwewa as paddy for processing while 9.8 % of the respondents prefer Balzogu variety for processing. Also, 4.9 % of the processors prefer Moses, 2.4 % of them prefer Digang or Gomma and 1.2 % of them prefer Mandii, Tops and Anofula as paddy for processing.

Gbewaa was preferred by 27.3 % of the rice marketers in the study area (Table 5) whilst 13.6 % of the marketers preferred Bazolgu. Also, 9.1 % of the respondents preferred either Agra, Moses, or Gomma as their paddy for marketing while 4.5 % of the respondents preferred either Digang, Mandii, Tops, Anofula, Amaru, Faaro or GR18 paddy or milled rice for marketing.

Table 5: Variety cultivated, processed or marketed in 2020 in Sagnarigu and Kumbungu districts of the Northern region of Ghana

	Farmers			processors			Marketers	
Variety	**Fre**	**%**	**Variety**	**Fre**	**%**	**Variety**	**Fre**	**Perce**
Bumbas	7	5.2	Gbewaa	10	12.2	Gbewaa	6	27.3
Moses	32	23.9	Agra	53	64.6	Agra	2	9.1
Digang	6	4.5	Moses	4	4.9	Moses	2	9.1
Mandii	9	6.7	Digang	2	2.4	Digang	1	4.5
Bazolgu	3	2.2	Gomma	2	2.4	Gomma	2	9.1
Salimasaa	4	3.0	Mandee	1	1.2	Mandee	1	4.5
Assemblyman	3	2.2	Tops	1	1.2	Tops	1	4.5
Kuradoo	2	1.5	Anofula	1	1.2	Anofula	1	4.5
Tox	1	.7	Bazolgu	8	9.8	Amaru	1	4.5
Digang	2	1.5				Bazolgu	3	13.6
Agra	50	37.3				Faaro	1	4.5
Gbewaa rice	15	11.2				GR18	1	4.5
Total	134	100.	Total	82	100	Total	22	100.0
Mean	8.19		Mean	3.37		Mean	6.18	
SEM	.453		SEM	.384		SEM	1.086	

4.4.6 Reason for choice of rice variety

Majority (91 %) of the farmers selected varieties based on the yield (Table 6). Unfortunately, very few (0.7 %) of the farmers made their choice of variety for cultivation based on recommendation from MoFA.

Table 6: Reason for choice of rice variety in cultivating during the 2020 cropping season

Reason for choice of variety	Frequency	Percent
Seeds are available	1	0.7
Change of variety	4	3.0
High yielding	122	91.0
Good price for the paddy	4	3.0
Milled grains are of good quality	2	1.5
Recommended by MoFA or other certified institutions	1	0.7
Total	134	100.0
Mean	4.03	
SEM	.044	

4.4.7 Planting method employed by farmers

Majority (54.5 %) of the farmers planted their seeds using the broadcasting method (Table 7). It was observed that majority of these farmers were from lowland rainfed ecology while majority of the farmers under irrigated ecology nursed and transplanted their rice seedlings. Some (28.4 %) of the respondents transplanted seedlings without a definite distance or space between plants and 13.4 % of them practised line transplanting with well-defined spacing. Most of the farmers selected broadcasting because they could not afford the cost involved in transplanting and those who selected transplanting indicated that transplanting gave them better yield (Table 7).

Table 7: Planting method rice farmers used in the 2020 cropping season

Method of planting	Fre	%	Reason for the choice of method	Frequency	Percent
Broadcasting haphazardly	73	54.5	Carrying out cultural practices is easy	5	3.7
Transplanting seedlings without a definite distance or space between plants	38	28.4	Transplanting is costly	6	4.5
Hand drilling in rows without approximate spacing	1	.7	Inadequate tractor services	1	.7
Dibbling without approximate spacing	4	3.0	Transplanting is faster	29	21.6
Line transplanting	18	13.4	Broadcasting is faster	3	2.2
			Less costly	45	33.6
			Higher yield	18	13.4
			Less labour	17	12.7
			No labor available for transplanting	2	1.5
			Right plant population	8	6.0
Total	134	100.0	Total	134	100.0
Mean	2.06			5.83	
SEM	.146			.180	

4.4.8 Timing of transplanting rice seedling

Only 1.5 and 11.2 % of the respondents transplanted when the seedlings were 2 and 3 weeks old respectively. Table 8 revealed that 6 % and 7.5 % of the respondents transplanted when the seedlings were 4 weeks and 5 weeks old respectively. In addition, 10.4 % and 5.2 % of the farmers transplanted when the seedlings were 6 or more weeks old respectively. It is worth noting that 58.2 % of the farmers did not use transplanting in planting their rice.

Table 8: Age of seedling at transplanting

Age of seedling	Frequency	Percent
2 weeks after nursing seeds	2	1.5
3 weeks after nursing seeds	15	11.2
4 weeks after nursing seeds	8	6.0
5 weeks after nursing seeds	10	7.5
6 weeks after nursing seeds	14	10.4
More than 6 weeks after nursing seeds	7	5.2
N/A	78	58.2
Total	134	100.0
Mean	5.63	
SEM	.163	

4.4.9 Rate and type of fertilizer application

The same percentage (44 %) of the farmers applied only the basal application of chemical fertilizer, and chemical fertilizer at the recommended rate (Table 9). Only 1.5 % of the farmers applied both compost and chemical fertilizer. Respondents who applied only the second application of chemical fertilizer, self-prepared organic manure (compost) / farm yard manure, and no fertilizer were 9.0 %, 0.7 %, and 0.7 %, respectively.

More than half of the farmer population choice of type and rate of fertilizer were based on the increase yield the fertilizer would bring on board (Table 9 . Some (6.7 %) of the farmers who could not apply the recommended ratattributed it to their inability to afford it.

Table 9: Rate and types of fertilizer application and reason

Rate/type of fertilizer	Fre	%	Reason	Frequency	Percent
Only basal application of chemical fertilizer	59	44.0	Recommended by MoFA	27	20.1
Only the second application of chemical fertilizer	12	9.0	Cannot afford the recommended rate	5	3.7
Application of self-prepared organic manure (compost) or farm yard manure	1	.7	Can only afford the basal application	9	6.7
No fertilizer application	1	.7	Can only afford a second application	2	1.5
Chemical fertilizer (solid) application at the recommended rate	59	44.0	Higher yield	76	56.7
Both chemical and compost fertilizer applications at recommended rates	2	1.5	Chemical fertilizer application is costly	14	10.4
			Less costly	1	.7
Total	134	100	Total	134	100.0
Mean	2.98		Mean	4.73	
SEM	.170		Std. Error of Mean	.190	

4.4.10 Qualities of paddy rice

A significant percentage (34.1 %) of the rice processors in the study area made their choice of a variety of paddy based on the uniformity of the grains, whilst 26.8 % of them made their choice based on the cooking characteristics (Table 10). Those who made their choice based on the percentage of unbroken grains, moisture content of grains and aromatic characteristics of the grains were 24.4 %, 9.8 % and 4.9 % respectively.

Substantial percentage (22.7 %) of rice marketers in the study area made their choice of variety of paddy based on the cooking characteristics (Table 10), whereas 18.2 % of the rice marketers choice of paddy was based on either long grains or uniformity of grains. Also, 13.6 % of the marketers made their choices based on either broken grains or aromatic grains. Marketers who preferred unbroken grains were 9.1 %. Finally, 4.5 % of the marketers in the study area made their choice based on the moisture content of grains.

Table 10: Qualities that influence the choice of paddy for processing and marketing

Processors			Marketers		
Qualities	**Frequency**	**Percent**	**Qualities**	**Frequency**	**Percent**
Unbroken grains	20	24.4	Unbroken grains	2	9.1
Aromatic grains	4	4.9	Long grains	4	18.2
Uniformity of grains	28	34.1	Broken grains	3	13.6
Cooking characteristics	22	26.8	Aromatic grains	3	13.6
The moisture content of grains	8	9.8	Uniformity of grains	4	18.2
			Cooking characteristics	5	22.7
			The moisture content of grains	1	4.5
Total	82	100.0	Total	22	100.0
Mean	4.90		Mean	4.32	
SEM	.285		Std. Error of Mean	.485	

4.5 Discussion

4.5.1 Gender, age and education of respondents

The male farmers dominated the female farmers, and constituted 94 % of the farmers interviewed (Table 1). This shows that the male folk still dominate rice cultivation in the two districts. This claim is supported by Addison *et al.* (2023) findings, which revealed that male farmers have historically dominated rice production in Northern Ghana. The population of females involved in rice production is low and does not auger well for rice productivity in the study area as females play crucial roles in rice production, processing, and marketing. On the other hand, 92.7 % of the processors from the study area were females (Table 1). This shows that females dominate in rice processing in the study area.

Lelea's (2020) finding is similar as she revealed that one of the most popular processing tasks undertaken by women in Northern Ghana is parboiling of rice.

The female folk dominated rice marketing in the study area as 86.4 % of the marketers interviewed were females (Table 1). This shows that the female folk still dominate rice marketing in the two districts. The population of males involved in rice marketing is low and does not auger well for rice marketing in the study area as the males play crucial roles in rice production. Addison *et al*. (2014) finding is in line with this result as they revealed that women work primarily in post-harvest tasks including threshing, winnowing, and drying.

The age range that has the highest farmer respondents (36.6 %) were between 36 to 45 years whereas the age with the lowest respondents (11.9 %) were between 18 to 24 years (Table 2). According to MoFA (2013), farmers in Ghana are 55 years old on average. This shows that majority of the active youth are into rice cultivation. However, rice production enterprises in the two districts are not attracting the very young ones who are 24 years and below.

Majority of the rice processors (52.4 %) in the study area were 36 to 45 years (Table 2). The age with the least rice processors (1.2 %) were between 18 to 24 years. The average age of the rice processor was 46 years. Frimpong *et al*. (2023) reported 46 years as the average age of rice processors in the Northern region of Ghana. This age is within the agricultural productive age in Ghana. Hence forth, this is good for rice processing in the country.

Half of the rice marketers (50%) in the study area age were above 45 years (Table 2). The average age of the marketer is 51 years. Rice marketing in the study area is not attracting young ones.

Most of the farmers who were interviewed (62.7 %) have no formal education while 10.4 % of them have received tertiary education (Table 3). In contrast, File and Nhamo (2023) reported that 46 % of farmers in the Northern region lacked formal education. This result is not good for technology transmission and subsequently adoption as the majority of them do not have formal education. Tanko and Ismaila and Tanko(2021) supported this assertion by indicating that there is evidence to suggest that farmers with lower level of education may have less access to technical information and training, which could result in a slower uptake of current agricultural production technology.

Greater population of the processors who were interviewed (92.7 %) had no formal education. Only very few of them (1.2 %) had either primary school education or tertiary education (Table 3). This shows that majority of the rice processors in the study area had no formal education and are most unlikely to adopt technologies in rice processing. Adams *et al.* (2019) reported that approximately 85 % of rice processors in Ghana's Northern region lack a formal education. All the respondents had no formal education (Table 3). This happening is not good, not only for rice marketing but also rice production in the area.

4.5.2 Seed source, crop variety and method of planting

Very few (8.2 %) in the study area used certified seed in cultivating rice (Table 4). Ragasa *et al* (2013) corroborated this by indicating that 54.5 % of the farmers from Ghana used their rice seeds in planting while 31.1 % of them sourced their rice seeds for planting from other farmers. The low adoption of certified seed is a recipe for low production, as there is a decline in varietal purity and positive varietal traits such as high yielding associated with the farmers' seeds.

Most of the farmers (48.5 %) from the study area did not use the certified seed because of the high cost involved in procuring it (Table 4). According to Ragasa and Chapoto (2017), one of Ghana's biggest obstacles to rice production is the high cost of hybrid rice seeds.

The variety that was the most cultivated was Agra as 37.3 % of the farmers' fields were planted with Agra in the 2020 cropping season (Table 5). Farmers were still using local seeds a lot in producing rice, as 54.7 % of the farmers used local varieties (Moses, Bumbass, Mandii, Bazolgu, Salimasaa, and Assemblyman) in planting their fields. It was observed that most of the farmers at Bontanga prefer variety Moses because of its ready market when harvested with at least 12 % moisture content in addition to its high-yielding ability.

Most of the rice processors (64.6 %) in the study area prefer Agra for processing (Table 5). Azumah *et al.* (2022) reported similar results as they indicated that farmers in the area have embraced improved rice varieties like Agra, Sakai, Jasmine 85 and Afife. Adams *et al*. (2019) also reported that women in the Northern region primarily engage in parboiling rice, with Jasmine and Agra being the two varieties most frequently used.

The variety that had the highest preference was Gbewaa rice as 27.3 % of the marketers preferred it to others (Table 5). Asante *et al.* (2013) and Adams *et al.* (2019) corroborated this by revealing that Jasmine and Agra are the most processed rice varieties in the Northern region of Ghana. These varieties have qualities such as aroma, grain size, and better cooking characteristics that consumers prefer. Ayeduvor (2018) supported this when he found that the characteristics of local rice in Ghana that influence preference and consumption are grain size, aroma, and cooking quality

The majority of the farmers selected their varieties based on the yield. However, it was observed that most of the farmers at Bontanga selected variety Moses due to its good milling qualities when harvested at 12 % moisture content besides its high-yielding ability. Bissah *et al.* (2022) reported that Ghanaian farmers have a preference for certain rice varieties because of their good taste, aroma and high-yielding potential.

More than half of the farmers (54.5 %) planted their seeds using the broadcasting method (Table 7). The majority of these farmers were from lowland rainfed ecology, while the majority of the farmers under irrigated ecology nursed and transplanted their rice seedlings. However, most of these farmers transplanted without definite spacing. Only 18 % of the repondents practised line transplanting with well-defined spacing. The adoption of line transplanting is still low in the study area. Ragasa *et al* (2013) corroborated that by indicating that most farmers in the Northern region use broadcasting in planting rice.

Most of the farmers selected broadcasting because they could not afford the cost involved in transplanting and those who selected transplanting indicated that transplanting gave them better yield. Hindersah *et al.* (2022) revealed that while transplanting method can yield higher productivity, the broadcasting method is the choice for rice farmers in the Northern region of Ghana because it is simpler, less expensive, and requires less labor as compared to some of the other methods

4.5.3 Age of seedling at transplanting, and rate and type of fertilizer application

Substantial number of farmers (41.8%) who practiced transplanting, transplanted at different ages of the seedlings (Table 8). Majority of the farmers transplanted when the seedlings were at least 4 weeks old. Only 12.7 % of the population transplanted when the seedlings were 2 and 3 weeks old. Studies have shown that early transplanting reduces transplanting shock which leads to better establishments and consequently higher productivity. Koudjega *et al.* (2019) supported this statement by recommending transplanting rice seedlings at any age between 8 and 15 days. Reuben *et al.* (2016) also indicated that earlier transplanting (8-12 days) gives superior crop growth performance.

Farmers who applied only the basal application of fertilizer were at par with those who applied the chemical fertilizer at the recommended rate (Table 9). The adoption of the recommended rate of chemical fertilizer was not the best. The application of compost was the worst. The current study has revealed that on average, a farmer applied 2.34 bags per acre or 5.84 per ha of fertilizer on their rice farm. This data suggests that rice farmers did not use the recommended quantities of fertilizer on their fields, which is consistent with findings from Ragasa *et al*. (2013) regarding low fertilizer usage among farmers in northern Ghana. Tetteh *et al.* (2002) also supported this assertion that the recommended dosages are typically broad and out of date.

The choice of rate of fertilizer application was tied to higher yield. Addison *et al.* (2023) corroborating with this revealed that to increase food security, increase operators' income, and lower the rate of poverty in rural Ghana, the government should offer subsidies to rice farmers so they can engage in modern rice cultivation.

Uniformity of the grains was the most preferred quality as 34.1 % of the respondents selected it (Table 10). The rest were cooking characteristics, unbroken grains, and aromatic grains as 26 %, 24 % and 4.9 % of the processors respectively made their choice of paddy for processing based on these qualities. Processors have these qualities at the back of their minds when purchasing paddy for processing and this should impress on the producers to cultivate the right varieties. Asante *et al.* (2013) reported that rice varieties with excellent grain qualities are the basis for the selection of a variety for rice for cultivation in the Ashanti region of Ghana.

4.6 Conclusion

Results of the survey indicated the following. More than half of the farmers used local varieties which were Moses, Bumbass, Mandii, Bazolgu, Salimasaa, and Assemblyman. Most of the farmers planted their seeds using the broadcasting method, only a few of them practised line transplanting with well-defined spacing. Majority of those who transplanted rice seedlings transplanted when the seedlings were at least 4 weeks old. Less than half of the farmers applied chemical fertilizers at the recommended rate.

The rice processors in the study area ranked uniformity of grains as the first quality of rice grains they look out for when purchasing paddy for processing. The second, and third ranked qualities were cooking characteristics and percentage of unbroken grains respectively.

Rice marketers in the study area first preferred quality of grains was cooking characteristics. The second, third, fourth, fifth, sixth and seventh preferred qualities were long grains, uniformity of grains, broken grains, aromatic grains and unbroken grains respectively.

4.7 Recommendation

Since cost considerations often deter farmers from using certified seeds and adopting modern cultivation technologies, takeholders should help make technologies such as improved varieties, certified seeds, line transplanting and recommended fertilizer application regime more accessible and affordable. Standardization of most of the activities in the rice value chain will help do away unfairness and promote healthy local rice enterprise which can compete well in the international market.

CHAPTER FIVE

TIME OF TRANSPLANTING AND SPACING EFFECTS ON GROWTH AND YIELD OF RICE (*Oryza sativa* L.)

5.1 Introduction

The rice industry is very beneficial to the global economy. It is necessary for food security as well as the growth of the world economy. Rice production is crucial for sustaining livelihoods and lowering malnutrition worldwide (Fukagawa and Ziska, 2019).

Roughly 155 million hectares of rice are cultivated worldwide in a variety of ecologies (USDA, 2023); 75 % of this land is utilized for rainfed ecology (Ulzen *et al.*, 2023). Inland swarms, or valley bottoms, and irrigated rice ecology comprise 15 % and 10 % of the land utilized for rice production, respectively (Ulzen *et al.*, 2023). In a similar vein, the majority of Ghana's rice production comes from lowland rainfed ecologies (Azumah and Adzawla, 2017).

Global rice production is rising as a result of productivity gains. Right now, rice is produced in the greatest quantities in China and India, respectively (USDA, 2023). Similar to this, Africa is producing a great deal more rice due to increased consumption; the majority of this increase can be attributed to an expansion of farmland (Yuan *et al.*, 2024). Africa can only produce enough rice to meet 60 % of its needs; the average yield attained there is 49 % lower than the global yield.

Variations in rice yields are determined by the ecology of rice. The average rice yield predicted for the world is 6 t ha^{-1}, according to Muthayya *et al.* (2014), whereas the yield values for upland and irrigated areas are 4 t $ha^{-1}$and 8 t ha^{-1}, respectively, but a farmer named Sumant Kumar in India was able to produce as much rice as 22.4 t ha^{-1} in 2011 using SRI technology (Gordon, 2013).

In 2018, the average annual production of rice in Ghana was 2.96 t ha^{-1} (MoFA, 2019). In comparison to the national average, the Northern region's rice yield (2.6 t ha^{-1}) was low (MoFA, 2019). According to MoFA (2019), no district in the Northern region performed better than the national average.

However, the Ministry of Food and Agriculture (MoFA) and Savannah Agricultural Research Institute (SARI) stated that the rice-producing area of the nation has a good chance of possibly achieving the yield range of 6 to 8 t ha^{-1} (Ragasa *et al*, 2013). The Northern region may produce the most of the nation's rice. For instance, 37 % of the nation's rice production in 2012 came from the Northern region (Ragasa *et al.*, 2013). Furthermore, greater part of Ghana's land used for rice cultivation is situated in the Northern region. The Volta region and the Northern region are the two that produced most of Ghana's rice. In 2018, 58,662 hectares of land were used to produce rice in the Volta region, and 81,165 hectares were used in the Northern region (Ghana Rice Mechanization Policy Brief, 2020).

Ghana produced 721,610 tonnes of rice in 2017, but only consumed 1.3 million tonnes (IFPRI, 2020). The government of Ghana has suffered large financial losses as a result of the country's heavy importation of rice from Thailand, Vietnam, and India (IFPRI, 2020). As per IFPRI (2020), the country's rice exports were valued at $1.2 billion in 2015. Rice production should be prioritized in order to achieve food security and self-sufficiency (Seck *et al.*, 2013). The primary factors driving the demand for rice are urbanization, behavioral changes brought about by rising wealth, and a growing dietary preference for rice over native staples (Eureka *et al.*, 2023).

Studies have indicated that older rice seedlings do not grow to their full potential and thus perform poorly when transplanted (Liu *et al.*, 2015). Plant growth is slowed and grain yield is decreased when plant density surpasses the ideal threshold because there is intense competition for nutrients below the soil and sunlight above it (Yussif, 2015). Greater percentage of Ghanaian farmers continues to broadcast rice seeds on their fields, which prevents the appropriate number of rice plants per unit area. More than half of rice farmers in the nation use traditional planting techniques (Ragasa *et al.*, 2013).

When plants are spaced appropriately, they can absorb more nutrients from the soil and sunlight, which leads to healthy plant growth and development and an increase in rice yield. An optimal plant spacing of approximately 18 cm was found to maximize rice yield more than any other plant spacing, according to Xu *et al.* (2020). Tadesse *et al.* (2019) discovered that row spacing of 25 cm x 25 cm yielded the highest grain output when planting by drilling.

Although wider spacing enhances the performance of individual hills, low plant density cannot be made up for by improved hill performance alone (Sheriff *et al.,* 2020). Thus, it is advised that farmers plant 20 cm by 20 cm or 25 cm by 25 cm of rice.

The age of rice seedling at transplanting has a positive effect on rice growth and yield. Reuben *et al.* (2016) found that seedlings transplanted at 12 days of age yielded more than seedlings transplanted later.

The rice industry has a big impact on both the global and Ghanaian economies. Researching the combined effects of time of transplanting and spacing on rice growth, development, and yield is necessary to providing crucial information that will support farmers in making decisions and encourage sustainable rice production.

5.2 Main objective

The main objective of the study was to determine the influence of time of transplanting and spacing on growth and yield of rice.

5.2.1 Specific objectives

1. To determine the effects of time of transplanting on growth and yield of rice under rainfed and irrigated rice.
2. To determine the effects of spacing on growth and yield of rice under rainfed and irrigated rice.
3. To determine the interactive effects of time of transplanting and spacing on growth and yield of rice under rainfed and irrigated rice.
4. To assess the benefit-cost of combining time of transplanting and spacing for rice production and the implication for its adoption in the Guinea savannah zone of Ghana.

5.3 Materials and methods

Details on materials and methods of this experiment are captured in Chapter Six under section 3.6.

5.4 Results

5.4.1 Baseline and post-study physicochemical properties of the soils

The acidity of the soil was reduced by the end of the experiment as the pH increased from 5.35 to 5.55 in the course of the experiment in the 2021 cropping season at Sagnarigu Kukuo (Table 11). P, Ca, and Mg ions also increased from 5.58 mg kg^{-1}, 107.07 mg kg^{-1}, and 31.70 mg kg^{-1} values to 6.83 mg kg^{-1}, 129.51 mg kg^{-1}, and 57.08 mg kg^{-1}. respectively. Also, OC and total N on the other hand decreased from 0.62 % and 0.08 % to 0.46 % and 0.06 % respectively.

Table 11: Baseline and post-study physicochemical properties of the soils at Sagnarigu Kukuo used during the 2021 cropping seasons under rainfed

Soil parameter	**Experiment at** Sagnarigu Kukuo	
	Pre-study	**Post-study**
PH (1:2:5)1	5.35	5.55
% Organic carbon (OC)	0.62	0.46
% Nitrogen (N)	0.08	0.06
Extratable bases		
Mg kg^{-1} Phosphorus (P)	5.58	6.83
Mg kg^{-1} Potassium (K)	84.21	70.61
Mg kg^{-1} Calcium (Ca)	107.07	129.51
Mg kg^{-1} Magnesium (Mg)	31.70	57.08
Textural class		
% Sand	61.10	60.90
% Silt	32.07	32.09
% Clay	6.80	6.98

The acidity of the soil was reduced by the end of the experiment as the pH changed from 4.98 to 5.64 in the course of the experiment in the 2022 cropping season at Bontanga (Table 12). P, Ca, and Mg ions also increased from the respective values of 5.91 mg kg^{-1}, 238.70 mg kg^{-1}, and 33.70 mg kg^{-1} to 6.53 mg kg^{-1}, 241.70 mg kg^{-1} and 46.69 mg kg^{-1}. OC and total N on the other hand decreased from 0.57 % and 0.06 % to 0.41 % and 0.04% respectively.

Table 12: Baseline and post-study physicochemical properties of the soils at Bontanga used during the 2022 cropping seasons under irrigation

Soil parameter	Experiment at Bontanga	
	Pre-study	**Post-study**
PH (1:2:5)1	4.98	5.64
% Organic carbon (OC)	0.57	0.41
% Nitrogen (N)	0.06	0.04
Extractable bases		
Mg kg^{-1} Phosphorus (P)	5.91	6.53
Mg kg^{-1} Potassium (K)	91.24	70.64
Mg kg^{-1} Calcium (Ca)	238.70	241.70
Mg kg^{-1} Magnesium (Mg)	33.76	46.69
Textural class		
% Sand	61.10	60.90
% Silt	32.07	32.09
% Clay	6.80	6.98

5.4.2 Plant height

Time of transplanting and spacing had a significant ($P < 0.05$) influence on plant height at 42 and 63 DAP. The mean plant height ranged from 28.4 cm to 46.3 cm. Plants from 35 cm x 35 cm plots where seedlings were transplanted at 28 days after planting (DAP) gave the tallest height value of 46.3 cm (Table 13). The least plant height with a value of 28.4 cm was obtained from 30 cm x 30 cm spacing transplanted at 42 DAP.

The mean height of plants at 63 DAP ranged from 59.8 cm to 109.8 cm. Plants from 35 cm x 35 cm plots where seedlings were transplanted 28 DAP gave the tallest height of 109.8 cm (Table 13). The least plant height with a value of 59.8 cm was obtained from 25 cm x 25 cm transplanted at 28 days after planting.

Table 13: Interaction effects of spacing and time of transplanting on plant height at 42 and 63 DAP at Sagnarigu Kukuo during the 2021 cropping seasons under rainfed

	Plant height at 42 DAP (cm)					Plant height at 63 DAP (cm)				
Spacing	Days After Planting (DAP)					Days After Planting (DAP)				
	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	44.2	40.7	30.2	29.7	29.1	77.3	81	80.2	70.2	70.5
25 cm x 25 cm	41.7	42.3	37.6	31.4	29.3	94.1	95.7	59.8	76	76.6
30 cm x 30 cm	43.6	43.5	33.6	37.8	28.4	90.7	93	83.6	88	70.2
35 cm x 35 cm	43.6	43.3	46.6	34.0	40.7	89.7	84.	109.8	83.2	75.8
LSD (0.05)		5.9					11.4			

At Bontanga (under irrigation), time of transplanting and spacing had a significant (P < 0.05) influence on plant height (Table 14). Plants from 35 cm x 35 cm transplanted 28 DAP produced the tallest height (63.04 cm) whilst plants from 30 cm x 30 cm transplanted 42 DAP produced the least plant height (17.67 cm) Similarly, 35 cm x 35 cm spacing transplanted at 14 DAP produced the tallest heights (99.39 cm) at 63 DAP whilst 20 cm × 20 cm transplanted at 35 DAP produced the least (54.67 cm).

Table 14: Interaction effects of spacing and time of transplanting on plant height at 42 and 63 DAP at Bontanga during the 2022 cropping seasons under irrigation

	Plant height at 42 DAP (cm)					Plant height at 63 DAP (cm)				
	Days After Planting (DAP)					Days After Planting (DAP)				
Spacing	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	48.53	50.67	38.67	32.20	21.00	49.67	77.84	60.33	54.67	56.00
25 cm x 25 cm	48.53	46.33	41.87	35.00	21.33	67.82	73.36	71.87	68.20	63.80
30 cm x 30 cm	49.65	47.67	46.67	36.17	17.67	85.32	79.64	79.64	78.40	62.94
35 cm x 35 cm	59.58	60.40	63.04	45.27	20.00	99.39	90.57	98.80	91.43	72.40
LSD (0.05)	4.72						3.88			

5.4.3 Tiller count

There was no significant (P > 0.05) interactive effect between transplanting and spacing on tiller count per plant at 63 DAP. However, spacing as a main effect had a significant (P

< 0.05) influence on tiller count per plant at 63 DAP. Plants from 35 cm x 35 cm plots produced the highest tiller count per plant with a value of 64.19 which was followed by plants from 30 cm x 30 cm plots with a value of 46.48 (Figure 1). The least tiller count per plant was recorded in plants from 20 cm × 20 cm plots with a value of 25.24.

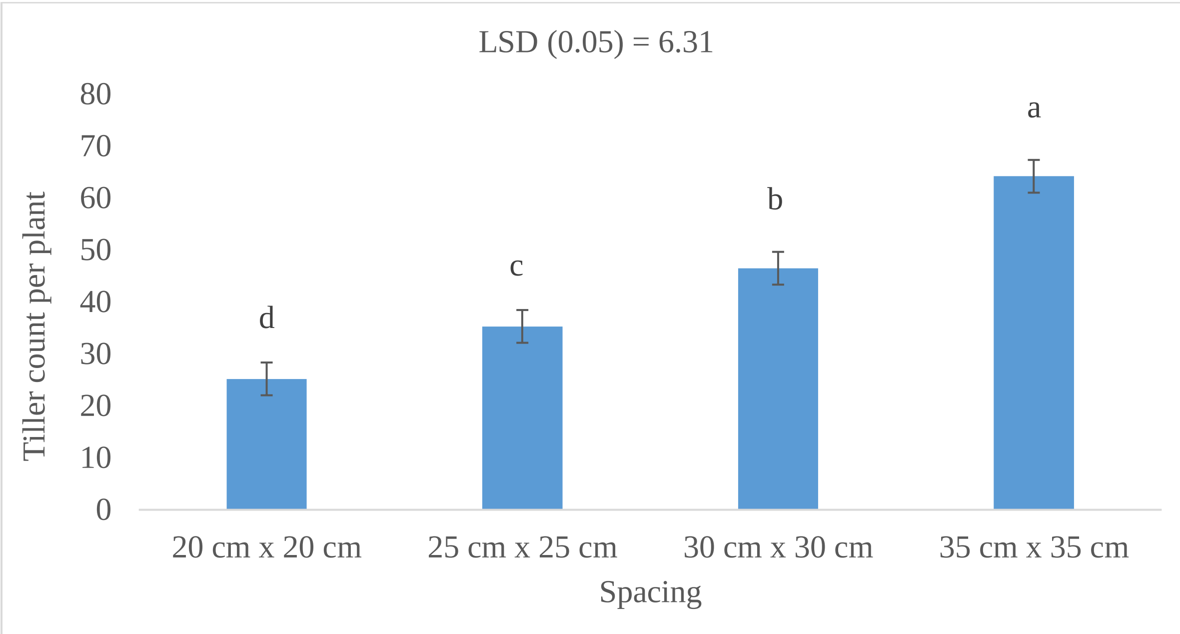

Figure 1: Influence of spacing on tiller count per plant at 63 DAP at Sagnarigu Kukuo during the 2021 cropping season under rainfed. Error bars indicate ± SEM. Means with the same letters are not significantly (P > 0.05) different at 5 % level of significance.

Time of transplanting and spacing had a significant (P < 0.05) influence on tiller count per plant at 84 DAP (Table 15). The mean tiller count per plant ranged from 9.7 to 38.76. Plants from 35 cm x 35 cm plots where seedlings were transplanted at 14 DAP produced the highest tiller count (38.76). The least tiller count (9.7) was recorded in plants from 20 cm × 20 cm plots transplanted at 42 DAP.

Table 15: Interaction effects of spacing and time of transplanting on tiller count per plant at 84 DAP at Sagnarigu Kukuo during the 2021 cropping seasons under rainfed

	Days after transplanting (DAP)				
Spacing	14	21	28	35	42
20 cm × 20 cm	13.59	12.7	12.36	11.72	9.7
25 cm x 25 cm	18.19	20.03	18.29	16.91	16.25
30 cm x 30 cm	23.27	28.24	26.29	21.93	20.66
35 cm x 35 cm	38.76	32.04	34.72	33.47	38.15
LSD (0.05)	6.688				

At Bontanga, Time of transplanting and spacing had a significant (P < 0.05) influence on tiller count (Table 16).. Plants from 35 cm x 35 cm plots where seedlings were transplanted at 28 DAP recorded the highest (59.58) tillers per plant while 20 cm × 20 cm transplanted at 14 DAP recorded the least (26.65). At 84 DAP, plants from 35 cm x 35 cm where seedlings were transplanted at 14 DAP produced the highest (73.80). With a value of 35.00, plants from 20 cm × 20 cm plots transplanted at 42 DAP and 20 cm × 20 cm transplanted 35 DAP produced the least.

Table 16: Interaction effects of spacing and time of transplanting on tiller count per plant at Bontanga during the 2022 cropping seasons under irrigation

	Tiller count at 63 DAP					Tiller count at 84 DAP				
	Days after transplanting (DAP)					Days after transplanting (DAP)				
Spacing	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	26.65	48.30	30.00	28.5	27.17	38.13	50.77	36.33	35.00	35.00
25 cm x 25 cm	38.61	39.78	39.42	33.73	28.78	32.01	50.22	46.93	41.43	43.09
30 cm x 30 cm	42.19	48.44	50.60	41.8	31.53	32.92	53.50	49.87	47.67	39.60
35 cm x 35 cm	54.10	51.04	59.58	47.00	29.00	73.80	40.53	50.00	41.33	36.00
LSD (0.05)	1.293						1.469			

5.4.4 Chlorophyll content (nm).

Time of transplanting and spacing had a significant (P < 0.05) influence on chlorophyll content (nm) (Table 17). Plants from 35 cm x 35 cm transplanted at 14 DAP produced the highest (76.55 nm and 62.47 nm) at 63 and 84 DAP respectively (Table 17). The least chlorophyll of 28.77 nm and 26.30 nm were recorded in 25 cm x 25 cm transplanted at 42 DAP at 63 and 84 DAP respectively.

Table 17: Interaction effects of spacing and time of transplanting on chlorophyll content at Bontanga during the 2022 cropping seasons under irrigation

	Chlorophyll at 63 DAP (nm)					Chlorophyll at 84 DAP (nm)				
	Days after transplanting (DAP)					Days after transplanting (DAP)				
Spacing	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	41.89	51.52	40.54	40.54	29.3	32.915	41.824	36.967	30.7	26.4
25 cm x 25 cm	38.55	47.81	43.76	40.84	28.77	33.93	39.698	38.844	38.4	26.3
30 cm x 30 cm	50.27	45.44	45.61	43.24	37.27	42.63	38.891	40.633	37.678	33.6
35 cm x 35 cm	76.55	58.45	58.15	54.11	44.73	62.466	52.375	50.32	49.48	43.773
LSD (0.05)	1.41						1.2259			

5.4.5 Number of days to 50 % flowering

Time of transplanting and spacing had a significant (P < 0.05) influence on number of days to 50 % flowering. The mean range of number of days to 50 % flowering ranged from 75.60 days to 122.43 days. Plants from 35 cm x 35 cm plots where seedlings were transplanted at 42 DAP took the longest days (122.43) to flower (Table 18). Plants from 20 cm × 20 cm plots transplanted at 14 DAP experienced earlier flowering of 75.60 days.

Table 18: Interaction effects of spacing and time of transplanting on number of days to 50 % flowering at Sagnarigu Kukuo during the 2021 cropping seasons under rainfed

	Days after transplanting (DAP)				
Spacing	14	21	28	35	42
20 cm × 20 cm	75.60	81.90	88.20	92.61	90.09
25 cm x 25 cm	86.33	98.00	98.00	110.25	105.24
30 cm x 30 cm	84.00	98.00	100.33	102.90	115.50
35 cm x 35 cm	86.33	111.30	111.30	109.07	122.43
LSD (0.05)		2.587			

Number of days to 50 % flowering was significantly (P < 0.05) affected by the interaction effect of time of transplanting and spacing. Plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 DAP recorded the earliest days of 77 to flower (Table 19). Plants from 35 cm x 35 cm plots where seedlings were transplanted at 42 days after planting experienced delayed (122 days) flowering.

Table 19: Interaction effects of spacing and time of transplanting on number of days to 50 % flowering at Bontanga used during the 2022 cropping seasons under irrigation

	Days after transplanting (DAP)				
Spacing	14	21	28	35	42
20 cm × 20 cm	78.6	76.5	82.8	93.56	99
25 cm x 25 cm	85	88.32	95.04	92.74	101.76
30 cm x 30 cm	83	94.67	99	100.8	106
35 cm x 35 cm	85	92	108.9	114.34	122.43
LSD (0.05)		1.573			

5.4.6 Straw weight kg m^{-2}

Time of transplanting and spacing had a significant ($P < 0.05$) influence on straw weight kg m^{-2}. Plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting produced the highest straw weight m^{-2} with a value of 2.16 kg m^{-2} (Table 20). The lowest straw weight was recorded in plants from 30 cm x 30 cm plots where seedlings were transplanted at 35 days after planting with a value of 0.460 kg m^{-2}

Table 20: Interaction effects of spacing and time of transplanting on straw weight (kg m^{-2}) at Sagnarigu Kukuo during the 2021 cropping seasons under rainfed

	Days after transplanting (DAP)				
Spacing	14	21	28	35	42
20 cm × 20 cm	2.16	1.70	1.22	0.55	0.60
25 cm x 25 cm	0.90	1.30	0.56	1.27	0.57
30 cm x 30 cm	0.79	1.31	0.63	0.46	0.91
35 cm x 35 cm	0.87	0.66	0.89	0.59	0.72
LSD (0.05)		0.212			

There was a significant ($P < 0.05$) interactive effect on straw weight at harvest by the time of transplanting and spacing. Plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting gave the highest straw weight value of 4.002 kg m^{-2} (Table 21). The least straw weight was recorded in plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting with a value of 1.290 kg m^{-2}.

Table 21`: Interaction effects of spacing and time of transplanting on straw weight at Bontanga used during the 2022 cropping seasons

	Days after transplanting (DAP)				
Spacing	14	21	28	35	42
20 cm × 20 cm	1.29	4.00	2.56	2.46	2.27
25 cm x 25 cm	1.80	2.24	2.16	1.92	1.64
30 cm x 30 cm	2.15	2.11	2.48	2.15	1.63
35 cm x 35 cm	1.73	1.95	2.00	2.12	1.72
LSD (0.05)		0.61			

5.4.7 Number of panicles

Time of transplanting and spacing had a significant ($P < 0.05$) influence on panicle number per plant (Table 22). Plants from 35 cm x 35 cm spacing transplanted at 21 DAP produced the highest panicle number per plant with a value of 28.26 whilst 20 cm × 20 cm transplanted at 42 DAP produced the least (5.74) .

Table 22: Interaction effects of spacing and time of transplanting on panicle number at Sagnarigu Kukuo during the 2021 cropping seasons under rainfed

	Days after transplanting (DAP)				
Spacing	14	21	28	35	42
20 cm × 20 cm	12.22	9.99	9.27	7.57	5.74
25 cm x 25 cm	11.81	16.77	10.58	10.90	9.25
30 cm x 30 cm	8.38	18.35	15.48	13.25	14.12
35 cm x 35 cm	23.89	28.26	20.83	20.58	24.37
LSD (0.05)	*4.21*				

Time of transplanting and spacing had a significant ($P < 0.05$) influence on panicle number per plant. Plants from 35 cm x 35 cm transplanted 14 DAP produced the highest panicle number per plant of 53.24 (Table 23). Plants from 20 cm × 20 cm transplanted at 42 DAP produced the least (21.33).

Table 23: Interaction effects of spacing and time of transplanting on the number of panicles per plant **at Bontanga during the 2022 cropping seasons under irrigation**

	Days after transplanting (DAP)				
Spacing	14	21	28	35	42
20 cm × 20 cm	22.87	45.27	27.67	25.33	21.33
25 cm x 25 cm	39.31	34.07	33.00	29.67	26.67
30 cm x 30 cm	42.88	41.07	41.00	30.67	28.67
35 cm x 35 cm	53.24	41.53	46.33	38.33	33.00
LSD (0.05)		3.06			

5.4.8 Number of spikelet per panicle

Time of transplanting and spacing had a significant ($P < 0.05$) influence on number of spikelet and infertile spikelet per panicle (Table 24). Plants from 35 cm x 35 cm plots transplanted at 21 DAP produced the highest (240.8). The least (123.4) spikelet per panicle was recorded in 20 cm × 20 cm transplanted 35 DAP which was statistically the same as 25 cm x 25 cm transplanted 42 DAP with a value of 144.4.

Plants from 25 cm x 25 cm plots where seedlings were transplanted at 35 DAP produced the highest (43.3) number of infertile spikelets the least (19.2) was recorded in 35 cm x 35 cm transplanted at 42 DAP.

Table 24: Interaction effects of spacing and time of transplanting on the spikelete per panicle and infertile spikelets at Sagnarigu Kukuo during the 2021 cropping seasons under rainfed

	Number of spikelet per panicle					Number of infertile spikelet per panicle				
	Days after transplanting (DAP)					Days after transplanting (DAP)				
Spacing	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	181.0	179.2	158.0	123.4	155.3	23.8	34.8	30.8	23.4	33.6
25 cm x 25 cm	206.0	189.2	179.3	189.4	144.4	30.9	19.5	34.4	43.3	22.8
30 cm x 30 cm	204.0	186.2	170.8	170.9	171.2	25.7	25.4	23.0	32.0	30.3
35 cm x 35 cm	179.0	240.8	190.0	190.1	150.0	25.3	33.0	31.2	39.8	19.2
LSD (0.05)	37.80						10.04			

At Bontanga (under irrigation), time of transplanting and spacing had a significant (P < 0.05) influence on number of spikelet per panicle and infertile spikelet (Table 25). Plants from 35 cm x 35 cm transplanted at 21 DAP produced the highest (317.6) number of spikelet per panicle. The least (161.0) was recorded in 20 cm × 20 cm transplanted 42 DAP. The highest (40.67) number of infertile spikelets was registered in 20 cm × 20 cm plots 21 DAP treatment The least (13.0) number was recorded in 20 cm × 20 cm transplanted 14 DAP.

Table 25: Interaction effects of spacing and time of transplanting on the spiklete per panicle at Bontanga used during the 2022 cropping seasons under irrigation

	Number of spikelet per panicle					Number of infertile spikelet per panicle				
	Days after transplanting (DAP)					Days after transplanting (DAP)				
Spacing	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	190.7	261.2	201.7	171.7	161	13.00	47.30	33.00	25.33	20.67
25 cm x 25 cm	262.1	208.8	214.5	174.7	162.7	27.67	25.67	26.33	25.33	22.67
30 cm x 30 cm	270.7	253.6	249.3	216.3	205.7	28.00	20.17	29.00	26’00	20.00
35 cm x 35 cm	286.3	317.6	289.3	240.3	223.0	40.67	13.77	19.83	23.33	21.93
LSD (0.05)	22.40						11.44			

5.4.9 Thousand seed weight and total grain yield

Time of transplanting and spacing had a significant ($P < 0.05$) influence on thousand seed weight grain yield (Table 26). Plants from 35 cm x 35 cm plots where seedlings were transplanted at 21 DAP gave the heaviest thousand seed weight with a value of 39.69 g. Plants from 20 cm × 20 cm transplanted 42 DAP with a value of 18.42 g produced the lightest.

The mean range of grain yield was from 2530.6 kg ha^{-1} to 9194 kg ha^{-1} (Table 26).

Plants from 25 cm x 25 cm plots where seedlings were transplanted at 21 DAP produced the highest yield with a value of 9194 kg ha^{-1} .The yield value obtained was statistically the same as what was produced by20 cm × 20 cm plots transplanted 14 DAP, 25 cm x 25 cm transplanted 14 DAP, 20 cm × 20 cm transplanted 21 DAP, 30 cm x 30 cm transplanted 21 DAP, and 25 cm x 25 cm transplanted 28 DAP with yield values of 8632 kg ha^{-1}, 7141 kg ha^{-1}, 6597 kg ha^{-1}, 6476 kg ha^{-1} and 6377 kg ha^{-1} respectively. These were followed by plants from 35 cm x 35 cm transplanted at 21 DAP and 20 cm × 20 cm transplanted 28 DAP with values of 6216 kg ha^{-1} and 5824 kg ha^{-1} respectively. Plants from 35 cm x 35 cm transplanted at 35 DAP and plants from 35 cm x 35 cm transplanted at 42 DAP produced the least with values of 2826 kg ha^{-1} and 2530.6 kg ha^{-1} respectively.

Table 26 Interaction effects of spacing and time of transplanting on thousand seed weight and total grain yield at Sagnarigu Kukuo during the 2021 cropping seasons under rainfed

	Thousand seed weight (g)					Total grain yield (kg ha^{-1})				
	Days after transplanting (DAP)					Days after transplanting (DAP)				
Spacing	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	30.12	29.02	25.41	23.18	18.42	8632	6597	5824	3579	3627
25 cm x 25 cm	31.25	31.57	30.50	23.74	19.39	7141	9194	6377	5051	3261
30 cm x 30 cm	28.98	33.12	28.93	26.10	18.62	2865	6476	4873	4234	4296
35 cm x 35 cm	37.50	39.69	36.65	28.66	20.62	3855	6216	4084	2826	2530.6
LSD (0.05)	3.74						2087.0			

At Bontanga (under irrigation), time of transplanting and spacing had a significant ($P < 0.05$) influence on thousand seed weight and grain yield (Table 27). Plants from 35 cm x 35 cm transplanted at 28 DAP produced the highest (34.00.g) thousand seed weight. The least (25.67g) was recorded in 25 cm x 25 cm transplanted 28 DAP.

The mean range of grain yield was from 1632 kg ha^{-1} to 7810 kg ha^{-1} (Table 27). Plants from 20 cm × 20 cm transplanted21 DAP produced the highest (7810 kg ha^{-1}) grain yield. This was followed by plants from 25 cm x 25 cm transplanted 14 DAP with a grain yield of 6455 kg ha^{-1}. plants from 35 cm x 35 cm transplanted42 DAP produced the least with a value of 1632 kg ha^{-1} which was not significantly ($P > 0.05$) different from 25 cm x 25 cm transplanted 42 DAP, 30 cm x 30 cm transplanted 42 DAP, and 35 cm x 35 cm transplanted 35 DAP with values of 2536 kg ha^{-1}, 2501 kg ha^{-1}, and 2274 kg ha^{-1}respectively.

Table 27: Interaction effects of spacing and time of transplanting on thousand seed weight and grain yield at Bontanga during the 2022 cropping seasons under irrigation

	Thousand seed weight (g)					Total grain yield kg ha^{-1}				
	Days after transplanting (DAP)					Days after transplanting (DAP)				
Spacing	14	21	28	35	42	14	21	28	35	42
20 cm × 20 cm	27.89	30.00	27.67	30.67	29.33	2908	7810	4516	3666	2736
25 cm x 25 cm	27.89	32.67	25.67	32.67	28.00	6455	5126	3971	3591	2536
30 cm x 30 cm	29.77	31.00	31.33	29.33	31.00	4873	4881	4421	2656	2501
35 cm x 35 cm	31.96	31.67	34.00	31.00	28.67	3717	3786	3813	2274	1632
LSD (0.05)	3.23						959.80			

5.4.10 Correlation coefficient

Grain yield positively correlated with 1000 seed weight ($r = 0.826^{**}$), panicle number ($r = 0.624^{**}$), and tiller count at 84 DAP ($r = 0.478^{**}$) (Table 28).

Table 28: Spearman's correlation coefficients ® for parameters measured for rice at Sagnarigu Kukuo during the 2021 cropping season

	PH	TC	CHL	STRW	PN	1000S	GY
PH	-						
TC	0.011	-					
50%FL	0. 63**	0.052	-				
STRW	0. 003	0.552**	0.040	-			
PN	0. 065	0.516**	-0.02	0.618**	-		
1000S	0. 599**	0.077	0.599**	0.280*	0.192	-	
GY	0. 261*	0.478**	0.175	0.624**	0.826**	0.826**	-

*PH= Plant height at 63 DAP, TC = Tiller count at 84 DAP, 50 %FL = Days to 50 % flowering, DAP, STRW = Straw, PL=Panicle no. , 1000S = Thousand seed weight, GY=Grain yield. **=significant at P <0.01

Grain yield positively correlated with straw weight (r = 0.808**), panicle number (r = 0.535**), spikelet per panicle (r = 0.526**), and plant height at 84 DAP (r = 0.511**) (Table 29).

Table 29: Spearman's correlation coefficients ® for parameters measured for rice produced at Bontanga in 2022 cropping season

	PH	TC	CHL	50%F	STRW	SP/P	PN	GY
PH	-							
TC	0.885**	-						
CHL	0.924**	0.854**	-					
50%F	-0.025	-0.01	- 0.16	-				
STRW	0. 432**	0.385**	0.417**	0.474**	-			
SP/P	0. 874**	0.830	0.833**	-0.18	0.511	-		
PN	0. 886**	0.910**	0.842**	-0.122	0.491**	0.904**	-	
GY	0.511**	0.443**	0.426**	-0.61**	0.808**	0.526**	0.535**	-

*PH= Plant height at 63 DAP, TC = Tiller count at 84 DAP, CHL = Chlorophyll (nm) at 84 DAP, STRW = Straw, SP/P = Spikelet per panicle, PL=Panicle no. GY=Grain yield. **=significant at P <0.01.

5.4.11 Value cost ratio

When more revenue is generated from a technology profit is realized whilst when more cost is generated loss is realized. Breakeven is realized when revenue and cost is at par. In this study, the cost or prices of inputs, services and materials were critically examined to make sure that they were true reflection of what were on the grounds in the study area. Prices of goods, materials and services from Tamale market were used as benchmark. The total cost was calculated by adding the cost of inputs, labour services, machinery services, land rent, irrigation dues, transportation and packaging or storage materials. Revenue was obtained solely from the sales of rice grains harvested. Thus, output (grain harvested) multiplied by the selling price gives the revenue. When the total cost and total revenue were established, value cost ratio and benefit cost ratio were used to establish the profitability of a practice or technology.

Plants from 20 cm × 20 cm transplanted 14 DAP produced the highest yield (9194 kg ha^{-1}) and henceforth the highest revenue (12980 Ghana cedis) whilst plants from 35 cm x 35 cm transplanted 42 DAP produced the lowest yield (2530.6 kg ha^{-1}) and revenue (2946 Ghana cedis) (Table 30). Similarly, the highest cost (9141.60 Ghana cedis) was generated from plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting while the least cost (5508.50 Ghana cedis) was also generated from plants from 35 cm x 35 cm transplanted 42 DAP. Again, the highest value cost ratio and benefit cost ratio of 1.42 and 0.42 respectively were obtained from plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting whilst the lowest 0.65 and -0.35 respectively were obtained from plants from 35 cm x 35 cm plots where seedlings were transplanted at 42 DAP. Plants from 20 cm × 20 cm transplanted 14 days after planting produced the highest profit of 3838.2 Ghana cedis while plants from 35 cm x 35 cm spaing transplanted 42 DAP recorded a loss of 1935.30 Ghana cedis.

Table 30: Benefit-cost analysis of rice cultivated under different time of transplanting and spacing in Sagnarigu Kukuo in the Guinea Savannah zone of Ghana.

Treatment Combination	Yield kg ha^{-1}	Total Revenue (GH₵ ha^{-1})	Total Cost (GH₵ ha^{-1})	Value cost ratio	Profit (GH₵ ha^{-1})	Benefit cost ratio
S1T1	9194	12979.8	9141.6	1.42	3838.2	0.42
S2T1	8632	12186.4	8777.9	1.39	3408.4	0.39
S3T1	7141	10081.4	7813.1	1.29	2268.3	0.29
S4T1	6597	9313.4	7461.1	1.25	1852.3	0.25
S1T2	6476	9142.6	7382.9	1.24	1759.7	0.24
S2T2	6377	9002.8	7318.8	1.23	1684.0	0.23
S3T2	6216	8775.5	7214.6	1.22	1560.9	0.22
S4T2	5824	8222.1	6961.0	1.18	1261.1	0.18
S1T3	5051	7130.8	6460.8	1.10	670.0	0.10
S2T3	4873	6879.5	6345.6	1.08	533.9	0.08
S3T3	4296	6064.9	5972.3	1.02	92.7	0.02
S4T3	4234	5977.4	5932.1	1.01	45.3	0.01
S1T4	4084	5765.6	5835.1	0.99	-69.4	-0.01
S2T4	3855	5442.4	5686.9	0.96	-244.6	-0.04
S3T4	3627	5120.5	5539.4	0.92	-418.9	-0.08
S4T4	3579	5052.7	5508.3	0.92	-455.6	-0.08
S1T5	3261	4603.8	5302.6	0.87	-698.8	-0.13
S2T5	2865	4044.7	5046.3	0.80	-1001.6	-0.20
S3T5	2826	3989.6	5021.1	0.79	-1031.4	-0.21
S4T5	2087	2946.4	4542.9	0.65	-1596.6	-0.35

S1 = 20 cm × 20 cm plant spacing, S2 = 25 cm × 25 cm, S3 = 30 cm × 30 cm, and S4 = 35 cm × 35 cm. T1 = seedlings transplanted @ 14 DAP, T2 = seedlings transplanted @ 21 DAP, T3 = seedlings transplanted @ 28 DAP, T4 = seedlings transplanted @ 35 DAP, and T5 = seedlings transplanted @ 42 DAP.

At Bontanga (under irrigation), plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting (DAP) produced the highest yield and henceforth the highest revenue of 7810 kg and 18376 Ghana cedis respectively whilst 35 cm x 35 cm transplanted42 DAP produced the lowest yield and revenue with 1632 kg and 3840 Ghana cedis respectively (Table 31). Similarly, the highest cost of 16689 Ghana cedis was generated from 20 cm × 20 cm spacing transplanted 21 DAP while the lowest cost of 9602

Ghana cedis was also generated from plants from 35 cm x 35 cm transplanted 42 DAP (Table 31). Again, the highest value cost ratio and benefit cost ratio of 1.10 and 0.101 respectively were obtained from plants from 20 cm × 20 cm transplanted 21 DAP whilst the lowest 0.40 and -0.600 respectively were obtained from plants from 35 cm x 35 cm transplanted 42 DAP. Plants from 20 cm × 20 cm transplanted at 21 DAP produced the highest profit of 1688 Ghana cedis while plants from 35 cm x 35 cm plots transplanted 42 DAP recorded a loss of 5762 Ghana cedis

Table 31: Benefit-cost analysis of rice cultivated under different time of transplanting and spacing in Bontanga in Guinea Savannah zone of Ghana in 2022 cropping season under irrigation

Treatment Combination	Yield kg ha^{-1}	Total Revenue (GH₵ ha^{-1})	Total Cost (GH₵ ha^{-1})	Value cost ratio	Profit (GH₵ ha^{-1})	Benefit cost ratio
S1T1	2908	6842	11066	0.62	-4223	-0.382
S2T1	6455	15188	15134	1.00	54	0.003
S3T1	4873	11466	13320	0.86	-1854	-0.139
S4T1	3717	8746	11994	0.73	-3248	-0.271
S1T2	7810	18376	16689	1.10	1688	0.101
S2T2	5126	12061	13610	0.89	-1549	-0.114
S3T2	4881	11485	13329	0.86	-1844	-0.138
S4T2	3786	8908	12073	0.74	-3165	-0.262
S1T3	4516	10626	12910	0.82	-2284	-0.177
S2T3	3971	9344	12285	0.76	-2941	-0.239
S3T3	4421	10402	12801	0.81	-2399	-0.187
S4T3	3813	8972	12104	0.74	-3132	-0.259
S1T4	3666	8626	11935	0.72	-3309	-0.277
S2T4	3591	8449	11849	0.71	-3400	-0.287
S3T4	2656	6249	10777	0.58	-4527	-0.420
S4T4	2274	5351	10338	0.52	-4988	-0.482
S1T5	2736	6438	10868	0.59	-4431	-0.408
S2T5	2536	5967	10639	0.56	-4672	-0.439
S3T5	2501	5885	10599	0.56	-4714	-0.445
S4T5	1632	3840	9602	0.40	-5762	-0.600

S1 = 20 cm × 20 cm plant spacing, S2 = 25 cm × 25 cm, S3 = 30 cm × 30 cm, and S4 = 35 cm × 35 cm. T1 = seedlings transplanted @ 14 DAP, T2 = seedlings transplanted @ 21 DAP, T3 = seedlings transplanted @ 28 DAP, T4 = seedlings transplanted @ 35 DAP, and T5 = seedlings transplanted @ 42 DAP.

5.5 Discussion

5.5.1 Soil physio-chemical properties

The activities carried out during the experimentation might have caused the neutralization of hydrogen (H^+) and aluminum (Al^{3+}) ions in the soil hence the variations in the soil pH of at the end of experiment. Enesi *et al*. (2023) supported this assertion by indicating that hydrogen (H^+) and aluminum (Al^{3+}) ions neutralization increases the pH of the soil. Also, P, Ca, and Mg ions recorded in the soils by the end of the experiment were higher than what were measured before the start of the experiment. Under the rainfed condition, P, Ca, and Mg increased by 22 %, 22 %, and 30 % whilst under the irrigated condition P, Ca, and Mg increased by 62 %, 43 %, and 38 % respectively. The increase was probably due to increased organic matter in these soils during experimentation. The decrease in soil acidity might have also led to the increased P, Ca and Mg levels in the soils. The finding of Prasad and Chakraborty (2019) is in line with this assertion. On the other hand, OC levels decreased from 0.62 % and 0.57 % to 0.46 % and 0.41 % whilst N levels decreased from 0.08 % and 0.06 % to 0.06 % and 0.04 % under the rainfed rice and irrigated rice respectively. The decrease was probably due to the higher sand content in these soils. The findings of Zhou *et al.* (2019) that soils with higher sand content generally have lower OC and N compared to those rich in silt and clay supported this assertion.

5.5.2 Plant height, tiller count and chlorophyll content

These results showed that the widest spacing (35 cm x 35 cm) treatments probably received more growth factors such as moisture, nutrients and sunlight as compare with the others. This finding is consistent with Sheriff *et al.* (2020) who were of the view that wider-spacing plants received more moisture, nutrients and sunlight than narrow-spacing plants. Lee *et* *al*. (2021) also supported this assertion by indicating that the initial growth of rice after transplanting is greatly affected by temperature and solar radiation.

At 63 DAP, plants from 35 cm x 35 cm transplanted 28 DAP and 35 cm x 35 cm transplanted 14 DAP produced the tallest plant height values of 109.83 cm and 99.39 cm respectively (Table 13) (Table 14) under the rainfed ecology and irrigated ecology respectively. Plants from 35 cm x 35 cm spacing transplanted 28 DAP and plants from 35 cm x 35 cm plots transplanted14 days after planting had more canopy architecture than the others resulting in competitive growth which promoted better photosynthesis and consequently better vegetative growth. The findings of Sherif *et al.* (2020) and Dzomeku *et al.* (2016) are consistent with this finding. They argued that wider or better spacing of plant and soil amendment results in high plant heights.

Plants from 25 cm x 25 cm spacing transplanted 28 DAP and 20 cm × 20 cm plots transplanted 14 DAP produced the least plant height with values of 59.77 cm and 49.67 cm respectively (Table 13) (Table 14) under the rainfed and irrigated rice respectively. This was probably due to higher competition for sunlight and nutrient created by the narrow spacing of the rice plants. Bissah *et al.* (2022) corroborates this statement by indicating that when rice plants are stressed they grow at reduced height.

Plants from 35 cm x 35 cm plots and plants from 35 cm x 35 cm plots where seedlings were transplanted 28 DAP produced the highest tiller count per plant with values of 64.19 and 59.58 respectively (Figure 1) (Table 16) under the rainfed and irrigated rice respectively. Plant spacing 35 cm x 35 cm received more nutrients, moisture, and sunlight which resulted in better growth and development of the plants resulting in higher tiller production at the maximum tillering stage of the plants. Other studies confirm this assertion. For instance, Ahtisham Tahir *et al.* (2018), and Sanjeewanie Ginigaddara and Ranamukhaarachchi's's (2011) studies are in line with this finding. The least tiller count per plant which was recorded in plant in plots with plant spacing 20 cm × 20 cm with a value of 25.24 was probably due to the greater competition for solar radiation and nutrients amongst plants from 20 cm x 20 cm. Yussif (2015) findings corroborates this finding.

The highest effective tiller produced by 35 cm x 35 cm planted 14 DAP may probably due to their better ability to establish well and respond well to resources created by spacing and the nutrients and their accompanying benefits the soil amendment offered. Kshkooll *et al.* (2020), Abdul Halim *et al.* (2018), and Hasanuzzaman *et al.* (2009) studies are in line with this finding.

The least effective tiller count per plant (9.7) recorded in plants from 20 cm × 20 cm transplanted42 DAP probably may be caused by unhealthy competition for space and nutrients and transplanting shock due to transplanting of older seedlings. Yussif (2015) and Lee *et al.* (2021) findings are in line with this finding as they revealed that greater competition for sunlight and nutrients and transplanting shock especially due to delayed transplanting resulted in less tillering of rice plants.

The high chlorophyll (nm) in plants with spacing 35 cm x 35 cm transplanted 14 DAP could be attributed to the space and less competition which exposed more leaves of the rice plants to sunlight. This enhanced the nitrogen, magnesium, iron, and potassium status of the plant which consequently produced more chlorophyll (nm). Abdul-Rahman (2019) supported this assertion by indicating that more spacing of plants lead to less competition among them. It could also be due to early transplanting which resulted in less transplanting shock and better establishment resulting in enhanced production of chlorophyll (nm) in the rice plants. Yang and Lee (2001) studies supported this assertion.

5.5.3 Number of days to 50 % flowering, straw weight, number of panicles and number of spikelets per panicle

The longest days (122.43 and 122.00) to flower recorded in 35 cm x 35 cm spacing transplanted 42 DAP under rainfed and irrigated rice ecology (Table 19) respectively may probably be availability of nutrients, moisture, and sunlight whilst the delayed transplanting, (42) DAP delayed vegetative growth stage of the rice. The findings of Marie-Noel *et al.* (2021), Sherif *et al.* (2020) and Dzomeku *et al.* (2016) confirm this. The combined effect of wider spacing (35 cm x 35) probably promoted more availability of nutrients, moisture, and sunlight, and delayed transplanting (42 DAP), probably promoted the delayed vegetative growth stage of the rice plant. The findings of Yussif (2015) supported this. Transplanting at 42 days after planting on the other hand promoting longer days to flowering could be attributed to a break in the vegetation growth stage of the plant due to transplanting shock which resulted in the longer vegetative stage of the plant. This finding is in contrast with the finding of Yun *et al.* (2023) who revealed that earlier transplanting results in longer days to flowering.

Plants from 20 cm × 20 cm plots transplanted 14 DAP and 20 cm × 20 cm transplanted 21 DAP took the shortest days to flower under rainfed rice and irrigated rice ecology respectively. This was probably due to early establishment and higher competition for nutrient which resulted in shorter vegetative stage of the rice plants. Lee *et al.* (2021) findings supported this as they revealed that transplanting younger seedlings resulted in early heading or flowering compared to transplanting older seedlings.

The highest straw weight produced by 20 cm × 20 cm transplanted14 DAP and 20 cm × 20 cm transplanted 21 DAP could be due to the closer spacing and early transplanting which promoted better straw production per unit area. Ram *et al.* (2014) revealed that closer spacing resulted in around 12.30 % higher yield over wider spacing, indicating a potential impact on straw weight.

The least straw weights m^{-2} (0.4600 kg) and 1.290 kg m^{-2} recorded in plants from 30 cm x 30 cm transplanted 35 DAP under the rainfed rice and 20 cm × 20 cm transplanted 14 DAP under irrigated rice ecology respectively. Plants from 30 cm x 30 cm plots where seedlings were transplanted at 35 days after planting producing least straw could be attributed to the wide spacing and late transplanting which did not enhance plant biomass production per unit area. This resulted in less straw accumulation per unit area and less straw weight. Tadese *et al*. (2019) and Asmamaw (2017) studies supported this finding as they revealed that widely spaced rice plants produced less straw per unit area compared to closely spaced plants.

Under the rainfed rice ecology, plants from 35 cm x 35 cm plots where seedlings were transplanted at 21 days after planting produced the highest panicle numbers per plant whilst under the irrigated ecology, plants from 35 cm x 35 cm plots where seedlings were transplanted at 14 days after planting produced the highest panicle number per plant. This was probably due to transplanting at 14 days after planting and transplanting at 21 days after planting showing better response to the wider spacing 35 cm x 35 cm which ensured better availability of nutrients especially nitrogen which promoted quality nutrition and higher dry matter accumulation. Wang *et al.* (2020) finding supported this assertion.

The least panicle number recorded in 20 cm × 20 cm transplanted 42 DAP may be due to delayed transplanting coupled with narrower spacing which could have resulted in less availability and accessibility of nutrients and solar energy by the plants leading to lesser number of panicles per plant. Li *et al.* (2020) supported this statement by indicating that delayed transplanting can lead to reduced differentiation and degeneration of spikelets and panicles in rice plants, ultimately affecting yield.

Under both rainfed rice ecology and irrigated rice ecology, the 35 cm x 35 cm transplanted 21 DAP recording the highest number of spikelet per panicle. and the highest filled spikelets could be due to appropriate temperature, better nitrogen availability, and less competition from other plants and weeds and better resistant to pest and diseases. Chowdhury *et al.* (2016) supported this finding by stating that less competition ensures adequate availability of nitrogen which leads to better grain filling in rice.

The least number of spikelet per panicle recorded with 20 cm × 20 cm transplanted 35 DAP and 20 cm × 20 cm transplanted 42 DAP under irrigation could be attributed to the delay in transplanting the rice seedlings. This is in agreement with Liu *et al*. (2017) who reported that as the age of seedlings at transplanting increases, the number of effective panicles per square meter and the number of spikelets per panicle decrease, leading to a decline in rice grain yield and sink capacity per tiller.

Infertile spikelet has a negative significant association with yield per hectare (Oladosu *et al.*, 2018). Spikelet per panicle is directly proportional to the yield of crop (Kumar *et al.*, 2021). The least infertile spikelet per panicle was recorded in 20 cm × 20 cm transplanted14 DAP under the irrigated rice.

5.5.4 Thousand seed weight, total grain yield and value cost ratio.

Plants from 35 cm x 35 cm plots where seedlings were transplanted at 14 days after planting (DAP) under the rainfed and 35 cm x 35 cm transplanted 28 DAP under irrigated rice produced the heaviest thousand seed weight.This could be attributed to the conducive environment created by the wider spacing, that is 35 cm x 35 cm. Sanjeewanie Ginigaddara and Ranamukhaarachchi (2011) and Roshan *et al.* (2011) findings supported this statement as they indicated that wider spacing and early transplanting results in vigorous growth of the plant leading to the production of weightier seeds.

Under the rainfed rice ecology, 25 cm x 25 cm transplanted 21 DAP produced the highest yield with a value of 9194 kg ha^{-1}. This was statistically similar to 20 cm × 20 cm transplanted 14 DAP, 25 cm x 25 cm transplanted 14 DAP, 20 cm × 20 cm transplanted 21 DAP, 30 cm x 30 cm transplanted 21 DAP, and 25 cm x 25 cm transplanted 28 DAP with respective values of 8632 kg ha^{-1}, 7141 kg ha^{-1}, 6597 kg ha^{-1}, 6476 kg ha^{-1}and 6377 kg ha^{-1}. Under the irrigated rice ecology, 20 cm × 20 cm transplanted 21 DAP produced the highest grain yield of 7810 kg ha^{-1}, followed by 25 cm x 25 cm transplanted 14 DAP with a grain yield of 6455 kg ha^{-1} which is within the achievable yield range of 6 – 8 t ha$^{-1.}$. The least (1632 kg ha$^{-1)}$ grain yield achieved in 35 cm x 35 cm transplanted 42 DAP reflects the difference in the synergetic effect of the time of transplanting and spacing. This is not in agreement with Sanjeewanie Ginigaddara and Ranamukhaarachchi (2011) and Roshan *et al.* (2011) who indicated that wider spacing and early transplanting results in vigorous growth leading to the production of more and weightier seeds. The space provided by 20 cm x 20 cm and 25 cm x 25 cm plots responded well to the early (14 and 21) transplanting of the rice. . The cost of technology is very crucial in terms of its adoption and sustainability. The value cost ratio and benefit cost analysis were carried out to determine the cost involved in carrying out the various technologies, the returns and the profitability of the technology.

It was noticed that crops from 20 cm × 20 cm transplanted 14 DAP and 20 cm × 20 cm transplanted 21 DAP technologies were more profitable due to the high yields or returns obtained from these practices. This finding is in line with the findings of Hoquea *et al*. (2022) and Lawal *et al.* (2023) who recorded significant increase in profit efficiency of rice technologies with higher productivity. This study suggests the use of 20 cm × 20 cm plots where seedlings were transplanted at 14 DAP and from 20 cm × 20 cm transplanted 21 DAP are more profitable. Lawal *et al*. (2023) finding supports this assertion as they indicated that rice farmers who employed technology had a higher gross margin and net profit.

5.6 Conclusion

The pH of the soil decreased the P, Ca, and Mg ions increased whilst the OC and N levels decreased by the end of the experiment.

Spacing of 20 cm × 20 cm transplanted 14 DAP and 20 cm × 20 cm transplanted 21 DAP maximized rice straw production with weights of 2.1597 4 kg m^{-2} and 4.002 kg m^{-2} under the rainfed and irrigated rice respectively.

Under rainfed, 35 cm x 35 cm transplanted at 21 days after planting optimized panicle production whilst under the irrigated ecology, 35 cm x 35 cm transplanted at 14 DAP produced the highest panicle number per plant.

Crops from 35 cm x 35 cm plots transplanted at 21 DAP showed the highest number of spikelets per panicle under both rainfed and irrigated rice ecology.

Under irrigation, 35 cm by 35 cm transplanted 14 DAP produced the heaviest (37.50 g) thousand seed weights, and under the irrigated rice ecology, the heaviest thousand seed weight was produced by crops from 35 cm x 35 cm transplanted at 28 DAP with a value of 34.00 g.

Crops from 25 cm by 25 cm spacing transplanted 21 DAP produced the highest yield (9194 kg ha^{-1}) whereas 20 cm × 20 cm transplanted 14 DAP produced the best cost ratio (1.42) and benefit cost ratio (0.42) under rainfed. Under the irrigated rice ecology, the highest grain yield of 7810 kg ha^{-1} was produced by crops from 20 cm × 20 cm plots transplanted at 21 DAP, this resulted to the highest value cost ratio and benefit-cost ratio of 1.10 and 0.101, respectively . Crops from 35 cm by 35 cm transplanted 42 DAP produced the least (1632 kg ha^{-1}) yield.

5.7 Recommendation

Transplanting with definite spacing improved the soil characteristics as the acidity of the soil was reduced whilst the P, Ca and Mg ions levels in the soil increased by the end of the experiments.

For higher productivity , farmers are advised to adopt plant spacing of 20 cm × 20 cm or 25 cm x 25 cm and transplanting of 14 DAP or 21 DAP in the study area and beyond. Further research could be conducted by nursing the seedlings on different days and transplanting them at the same time.

CHAPTER 6

INFLUENCE OF VARIETY, SPACING AND SOIL AMENDMENT ON GROWTH AND YIELD OF RICE (*Oryza sativa* L.)

6.1 Introduction

The world economy benefits greatly from the rice industry. Rice is essential to both global economic expansion and food security. Globally, rice production is essential for reducing malnutrition and maintaining livelihoods (Fukagawa and Ziska, 2019). As a staple food, rice has a great impact on Ghana's economy (MoFA-IFPRI MARKET BRIEF 2020). Ghana's agricultural sector accounted for 19.7 % of the country's GDP in 2018, with the crop sector accounting for the majority of that amount at 65 % (MoFA 2019).

Approximately 155 million hectares of rice are grown in various ecologies across the world (USDA, 2023). Since 75 % of the land used for rice cultivation worldwide is used for this purpose, the rainfed ecology has the greatest area (Ulzen *et al.*, 2023). A total of 15 % and 10 % of the land used for rice cultivation, respectively, is made up of irrigated rice ecologies and inland swarms (Ulzen *et al.*, 2023). In a similar vein, lowland rainfed ecologies are used to grow most of the rice produced in Ghana (Azumah and Adzawla 2017).

China and India are currently the world's two largest producers of rice, respectively (USDA,2023). Rising consumption of rice is driving up rice production throughout Africa. The expansion of farmland is primarily responsible for the increase in production (Yuan *et al.*, 2024). However, Africa can only produce to meet 60 % of its consumption due to its average yield being 49 % lower than the global yield (Yuan *et al.*, 2024).

The rice ecology determines variations in rice yields. According to Muthayya (2014), the average rice yield worldwide is predicted to be 6 t ha^{-1}, while the yield values for irrigated and upland regions are 4 t $ha^{-1}$and 8 t ha^{-1}, respectively. However, in 2011 (Gordon 2013), rice yields as high as 22.4 t ha^{-1}were achieved in India using SRI technology. According to MoFA (2019), Ghana's average annual rice yield in 2018 was 2.96 t ha^{-1}. The rice yield in the Northern region was low (2.6 t/ha) compared to the national average (MoFA 2019). No district from the Northern region outperformed the national average in the same breadth (MoFA 2019).

However, the nation's rice-producing region has a significant opportunity to reach potentially achievable yield range of 6 to 8 t ha^{-1}, according to Ministry of Food and Agriculture and Savannah Agricultural Research Institute (SARI) (Ragasa *et al*,. 2013). The country's largest rice production could come from the Northern region. For example, according to Raggasa *et al.* (2013), the Northern region was the country's top producer of rice in 2012. Additionally, the majority of Ghana's rice-growing land is located in the Northern region. The Volta region produced rice on 58,662 hectares of land in 2018, while the Northern region produced rice on 81,165 hectares of land (Ghana Rice Mechanization Policy Brief, 2020).

In 2015, the nation exported rice worth $1.2 billion, according to IFPRI (2020). Prioritizing rice production can help achieve food security and self-sufficiency in food production (Seck *et al.,* 2013). Urbanization, behavioral shifts brought about by rising wealth, and a growing dietary preference for rice over native staples are the main factors driving the demand for rice (Eureka *et al.,* 2023).

The obstacles impeding global rice production are climate change, extreme weather, shrinking arable areas, labor shortages, crop diversification, and low resource availability

(Sengupta, 2023). Due to low production technologies and an excessive dependence on rainfed rice ecologies, Africa continues to struggle with being self-sufficient in rice production (Yuan *et al.,* 2024).

The unimproved varieties possessed traits with low yielding abilities. Optimal yield from these varieties are still low. Studies have shown that adoption of new variety alone does not always lead to higher rice yield (Zhang *et al,* 2019). Improved varieties are usually costly and resource intensive which disadvantages the farmers leading to none adoption or poor adoption (Zhang *et al,* 2019). Using improved variety without timely application of input alongside good agronomic practices results in low yield.

Improved varieties have shown to have higher yield potential, resistant to pest and diseases and of higher grain quality (Rahman *et al.*, 2022).

Plant growth slows down and grain yield declines when plant density surpasses the optimum level due to intense competition for nutrients and sunlight (Yussif, 2015). The appropriate rice plant density per unit area is not heeded to by farmers in Ghana as majority of them still broadcast their field with rice seeds. More than 50 % of the nation's rice growers plant their crop using traditional techniques (Ragasa *et al.*, 2013). Optimal plant spacing facilitate proper uptake of nutrients from the soil and sunlight which leads to healthy plant growth and development leading to higher yield in rice. According to Tadesse *et al.* (2019), row spacing of 25 cm x 25 cm resulted in the highest grain output (3.3 t ha^{-1}) when compared to planting by drilling.

Research indicates that low soil fertility leads to low nutrient release which leads to low nutrient uptake by rice plants which will eventually leads to low rice yield (Zhu *et al.*, 2022). The average application rate of fertilizer is still lower than the recommended rate in

Ghana. Ragasa *et al*. (2013) research indicated that majority of the local rice farmers did not adhere to the recommended rate of fertilizer application in the 2012 growing season. Soil amendment plays a vital role in increasing rice yield as it reduces the soil acidity, improving the soil health and releasing adequate nutrients for plant uptake. Research done by Zhu *et al.* (2022) showed that manure amendment impacted net photosynthetic rate, improve plant physiological resistant to unfavorable environmental conditions leading to better rice yield. Also, Dzomeku *et al.* (2016), indicated that applying either the recommended amount of chemical fertilizer or compost had a good return on the rice plots. These authors added that soil amendment with organic matter (compost) increased overall soil fertility than the solely chemical fertilizer amendment.

The interactions of variety and spacing, variety and soil amendment, or spacing and soil amendment have also shown positive results in terms of plant growth and grain yield.

Arianti *et al.(*2022) reported unique response of different varieties to different spacings, of which some of the interactions giving good yields. El-Katony *et al*. (2021) studies showed positive results in rice plant growth and grain yield as a result of combining soil amendment with specific varieties.

The use of suitable variety, spacing and soil amendment is crucial in ensuring proper growth of rice plants which will eventually lead to higher yield and quality milled rice. Higher yields and quality milled rice obtained could contribute greatly to the country's economy and improved livelihood of rice value chain actors.

6.2 Main objective:

The main objective of the study was to determine the main or interactive effect of variety**,** spacing and soil amendment on growth and yield of rice.

6.2.1 Specific objectives.

1. To determine the effects of variety on growth and yield of rice under rainfed rice.
2. To determine the effects of spacing on growth and yield of rice under rainfed rice.
3. To determine the effects of **soil** amendment on growth and yield of rice under rainfed rice.
4. To determine the effects of the interaction of the factors on growth and yield of rice
5. To assess the main and interactive effects of the factors on soil properties in the low land soils in the study area.
6. To assess the benefit-cost of combining variety, spacing and soil amendment for rice production

6.3 Materials and methods

For detailed materials and methods for this experiment, refer to section 3.7 under Chapter Three.

6.4 Results

6.4.1 Physical and chemical characteristics of soil, chemical fertilizers, compost, and foliar fertilizers

pH increased from 5.55 to 5.73, thus soil acidity was reduced at the end of the experiment in the 2022 cropping season at Sagnarigu Kukuo. Organic carbon increased from 0.46 % to 0.61 % while N decreased from 0.06 % to 0.05 %. Extractable bases Ca, K, and Mg also increased from 129.51 mg kg^{-1}, 70.61 mg kg^{-1} and 57.08 mg kg^{-1} to 156.46 mg kg^{-1}, 84.05 mg kg^{-1}, and 58.61 mg kg^{-1} respectively whereas P content decreased from 6.83 mg kg^{-1} to 6.18 mg kg^{-1} (Table 32).

Table 32: Physio-chemical properties of chemical fertilizers, compost, and foliar fertilizers used in the study at Sagnarigu Kukuo in 2022 cropping seasons

Treatments	Soil Baseline	Compost	Foliar NPK	Foliar Urea
PH (1:2:5)1	5.55	7.7	1.51SG	1.51SG
% Organic carbon (OC)	0.46	12.05 %	-	-
% Nitrogen (N)	0.06	0.85 %	6 %	18.5 %
Mg kg^{-1} Phosphorus (P)	6.83	6 %	-	-
Phosphorus (as P_2O_5)	-	0.56 %	-	-
Mg kg^{-1} Potassium (K)	70.61	1.39 %	6 %	-
Mg kg^{-1} Calcium (Ca)	129.51	1.71 %	-	-
Mg kg^{-1} Magnesium (Mg)	57.08	0.27 %	1.5 %	1.5 %
% Sand	60.90	-	-	-
% Silt	32.09	-	-	-
% Clay	6.98	-	-	-

Plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N, plots that received 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied, and plots that received 37.5 kg/ha N, P, and K plots' pH changed from 5.55 to 5.84, 5.84, and 5.73 respectively. Thus, these treatments reduced the acidity of the soil on their treatment plots. On the other hand, the plots that received 37.5 kg/ha N, P, and K + 26.25 kg/ha N amendment decreased pH from 5.55 to 5.47. Plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N amendment maintained total N at 0.06 %, the rest of the soil amendment treatments recorded a reduction in total nitrogen. Plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N soil amendment also increased K, Ca, and Mg more than any other treatment. Plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N increased K, Ca, and Mg by 41 %, 26 %, and 56 % respectively with values of 99.77 mg kg^{-1}, 162.66 mg kg^{-1}, and 189.15 mg kg^{-1} (Table 33).

Table 33: Post-study physicochemical properties of treatment soils at Sagnarigu Kukuo in 2022 cropping seasons

Treatments	**PH (1:2:5)**	**% OC**	**% N**	Mg kg^{-1} **P**	Mg kg^{-1} **K**	Mg kg^{-1} **Ca**	Mg kg^{-1} **Mg**
37.5 kg/ha N, P, and K	5.79	0.58	0.043	6.05	74.93	144.45	33.96
18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	5.84	0.60	0.037	5.12	57.21	162.27	60.87
10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	5.84	0.70	0.058	6.78	99.77	162.66	89.15
37.5 kg/ha N, P, and K + 26.25 kg/ha N	5.47	0.56	0.051	6.77	104.30	156.47	50.47
Soil – post study	5.73	0.61	0.05	6.18	84.05	156.46	58.61
Soil texture		% Sand = 60.57		% Silt = 30.95		% Clay = 6.72	

6.4.2 Plant height

There was no significant interaction between variety, spacing and soil amendment on plant height at 42 and 63 DAP. However, variety significantly ($P < 0.05$) influenced plant height at 42 DAP with Mandii recording the tallest plant height of 60.04 cm (Figure 2). This was followed by Digang, Gbewaa, and Moses with the respective values of 48.61 cm, 46.50 cm, and 46.14 cm. The least plant height was recorded in Agra with a value of 43.89 cm. Similarly, spacing significantly ($P < 0.05$) influenced plant height at 42 DAP with 25 cm x 25 cm recording the tallest plant height of 50.49 cm (Figure 2). The lowest plant height was recorded in 20 cm x 20 cm with a value of 47.58 cm (Figure 2). Soil amendment significantly ($P < 0.05$) influenced plant height at 42 DAP. Plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied produced the tallest plant with a value of 53.81 cm while plots where 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N 0were foliar applied produced the lowest plant height value of 46.11 cm.

At 63 DAP, variety significantly ($P < 0.05$) influenced plant height. Mandii gave the highest value of 97.5 cm (Figure 2). This was followed by Digang which gave a height value of 82.95 cm. The least plant height was recorded in Gbewaa, Moses and Agra with the respective values of 75.5 cm, 71.11 cm, and 70.65 cm. Also, 25 cm x 25 cm spacing gave the highest height value of 82.27 cm (Figure 2) whilst the lowest plant height was recorded in 20 cm x 20 cm with the value of 76.81cm. Plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied gave the highest height value of 86 cm (Figure 2). This was followed by plots where 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied and plots where 37.5 kg/ha NPK was applied which gave height values of 80 cm and 78.48 cm respectively. The least plant height was recorded in plots where 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N were foliar applied with the value of 73.51 cm.

a. Plant height at 42 DAP

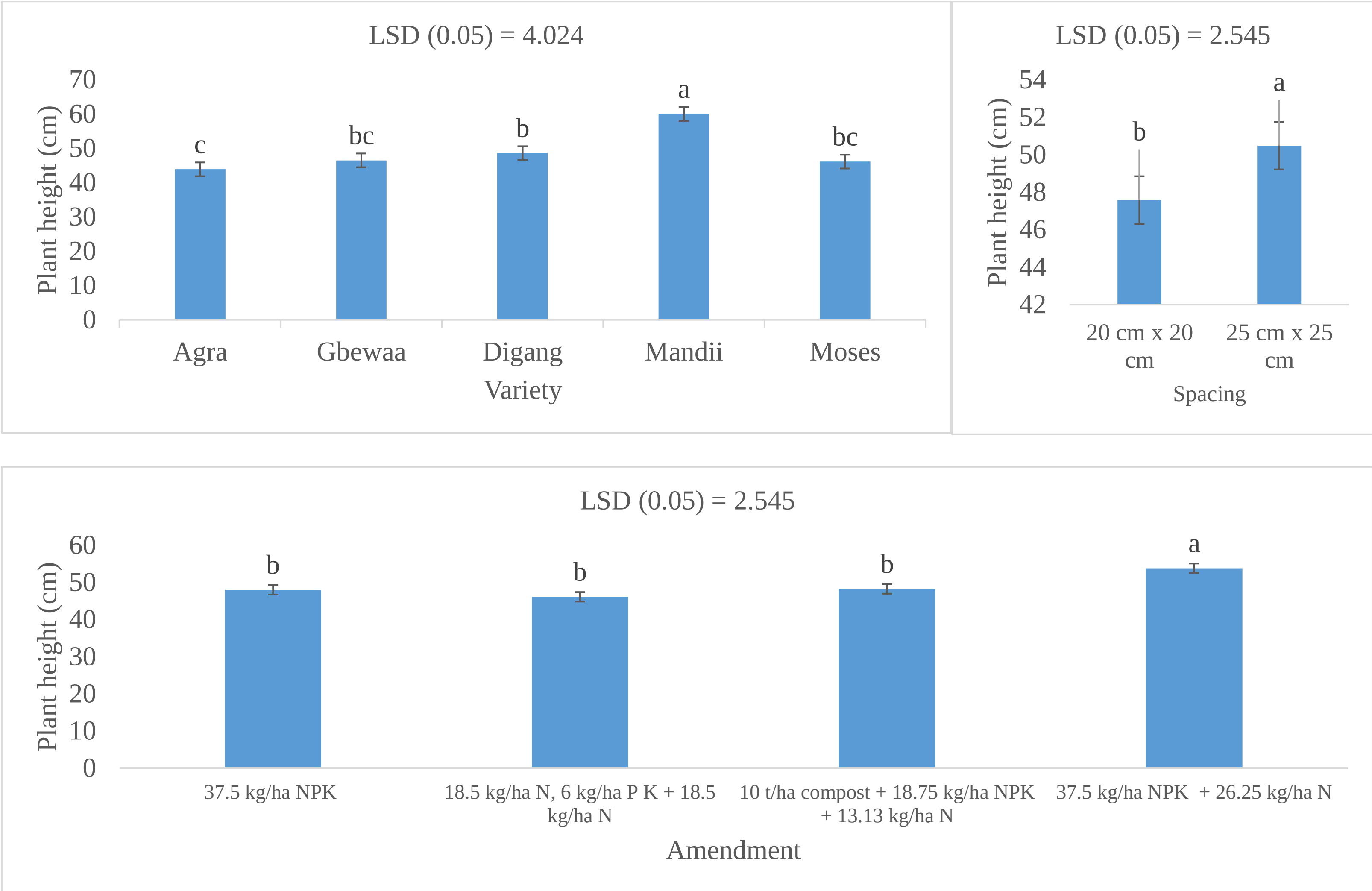

Figure: 2a: Effect of variety or spacing or soil amendment on plant height at 42 DAP. Error bars indicate ± SEM. Means with the same letters are not significantly (P > 0.05) different at 5 % level of significance.

b.Plant height at 63 DAP

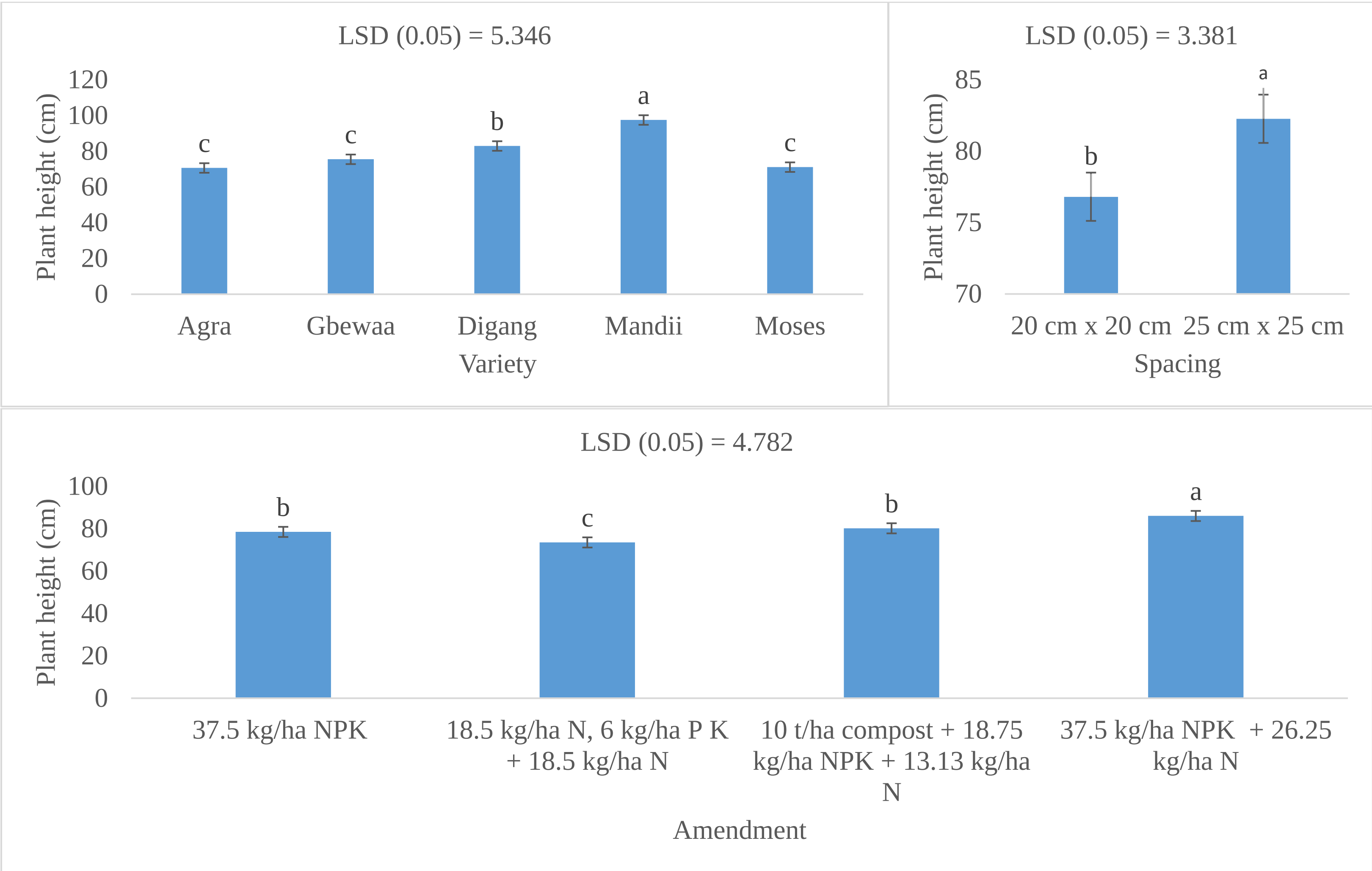

Figure: 2b: Effect of variety or spacing or soil amendment on plant height at 63 DAP. Error bars indicate ± SEM. Means with the same letters are not significantly (P > 0.05) different at 5 % level of significance.

6.4.3 Tiller count

The combined effect of variety, spacing, and soil amendment had a significant (P < 0.05) influence on tiller count at 63 and 84 DAP (Table 34). At 63 DAP, Moses variety transplanted 25 cm x 25 cm with 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N produced the highest (118.80) tiller count. This was followed by Moses transplanted 25 cm x 25 cm with 37.5 kg/ha each of N, P, and K and Agra transplanted 25 cm x 25 cm with 37.5 kg/ha N, P, and K + 26.25 kg/ha N.

At 84 DAP, Gbewaa transplanted 25 cm x 25 cm with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied. recorded the highest (83.1) tiller count per plant whereas the least (19.2) tiller count was recorded in Digang transplanted 25 cm x 25 cm with 37.5 kg/ha N, P, and K + 26.25 kg/ha N (Table 34).

Table 34: Combined effect of variety, spacing and soil amendment on tiller count at 63 (a) and 84 (b) DAP

		Tiller count at 63 DAP				Tiller count at 84 DA			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N
Agra	20 cm x 20cm	34.2	54.4	49.0	78.7	40.0	40.8	41.3	74.7
	25 cm x 20 cm	51.4	70.2	74.0	82.8	28.4	53.7	58.7	62.6
Gbewaa	20 cm x 20cm	31.0	24.7	51.7	36.4	24.0	28.0	50.2	61.3
	25 cm x 20 cm	61.5	28.5	38.5	77.5	59.4	40.0	36.7	83.1
Digang	20 cm x 20cm	40.5	30.0	51.0	60.0	38.4	20.5	36.6	40.2
	25 cm x 20 cm	43.2	50.4	67.2	43.8	39.1	22.9	34.4	19.2
Mandii	20 cm x 20cm	51.7	40.9	64.3	51.7	31.0	24.5	48.0	34.0
	25 cm x 20 cm	61.2	33.0	68.4	78.0	63.8	37.6	44.9	51.5
Moses	20 cm x 20cm	56.2	22.9	49.9	38.7	45.6	24.4	52.0	24.0
	25 cm x 20 cm	83.7	59.4	118.8	67.2	29.7	53.5	36.2	44.0
LSD (0.05)			24.6				16.43		

6.4.4 Plant Chlorophyll

There was no significant interaction between spacing, variety and soil amendment. However, variety had a significant ($P < 0.05$) influence on chlorophyll at 63 and 84 DAP. Mandii, Gbewaa and Agra produced highest chlorophyll with values of 40.56 nm, 39.99 nm, and 39.1 nm respectively, while Moses produced the least chlorophyll content with a value of 37.78 nm (Figure 3).

Spacing at 25 cm x 25 cm produced the highest (46.09 (nm)) chlorophyll while 20 cm x 20 cm produced the least value of 37.77 nm (Figure 3). Soil amendment with 37.5 kg/ha NPK + 26.25 kg/ha N, 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N, and 37.5 kg/ha NPK produced higher chlorophyll with respective values of 44.21 nm, 43.06 nm, and 42.93 nm. The least (37.53 nm)) was produced by 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N (Figure 3).

At 84 DAP, variety significantly ($P < 0.05$) affected chlorophyll content with Mandii producing the highest (40.56 nm) and Digang least (34.92 nm). The spacing of 25 cm x 25 cm produced higher chlorophyll of 43.43 nm while 20 cm x 20 cm produced the least value of 33.51 nm (Figure 3). Plant on plots where 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and 37.5 kg/ha NPK + 26.25 kg/ha N produced higher chlorophyll of 40.54 nm and 39.65 nm respectively. The least was produced by 37.5 kg/ha NPK and 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar applied with values of 37.15 nm and 36.54 nm respectively (Figure 3).

a. Chlorophyll at 63 DAP

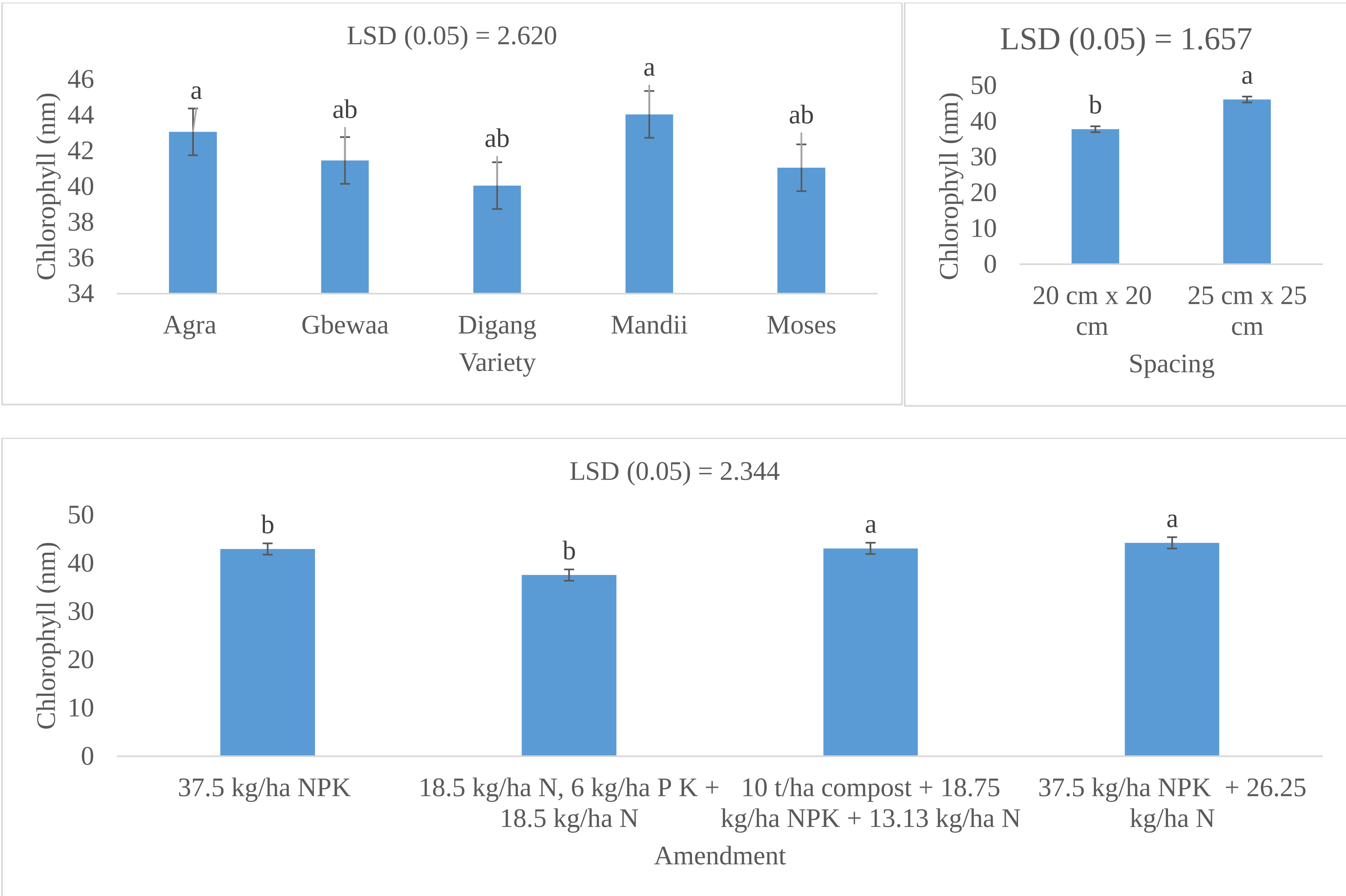

Figure 3a: Effect of variety or spacing or soil amendment on chlorophyll content (nm) at 63 DAP. Error bars indicate ± SEM. Means with the same letters are not significantly ($P > 0.05$) different at 5 % level of significance.

b. Chlorophyll at 84 DAP

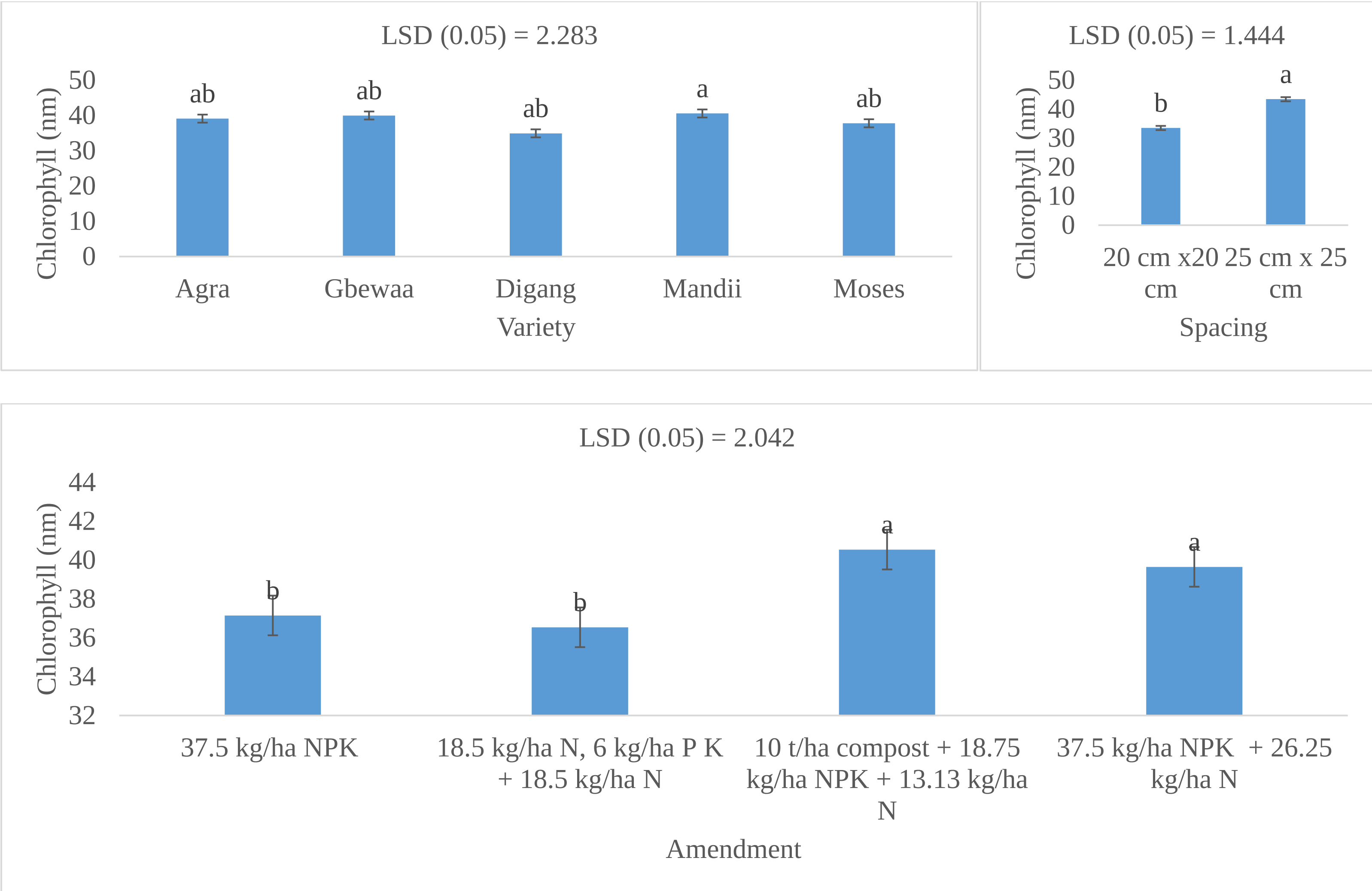

Figure 3b: Effect of variety or spacing or soil amendment on chlorophyll content (nm) at 84 DAP. Error bars indicate ± SEM. Means with the same letters are not significantly (P > 0.05) different at 5 % level of significance.

6.4.5 Leaf area index

At 63 and 84 DAP, the leaf area index was significantly ($P < 0.05$) affected by the interaction of variety, soil amendment, and spacing. Agra variety transplanted 25 cm x 25 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied and Mandii transplanted 25 cm x 25 cm spacing, with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied produced the highest leaf area index with values of 5.929 and 5.852 respectively (Table 35). Moses variety transplanted 20 cm x 20 cm spacing with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied produced the least (3.06).

At 84 DAP, Agra transplanted 25 cm x 25 cm spacing with37.5 kg/ha N, P, and K + 26.25 kg/ha N applied and Mandii transplanted 25 cm x 25 cm spacing with37.5 kg/ha N, P, and K + 26.25 kg/ha N applied produced the highest LAI with respective values of 6.5219 and 6.4372 (Table 35). Moses transplanted 20 cm x 20 cm spacing where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied produced the least (3.3943)., 3.3858, and 3.3689.

Table 35: Combined effect of variety, spacing, and soil amendment on leaf area index at 63 and 84 DAP

		Leaf area index at 63 DAP				Leaf area index at 84 DAP			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N
Agra	20 cm x 20cm	3.59	3.47	4.47	4.56	3.94	3.82	4.91	5.02
	25 cm x 20 cm	4.47	4.37	5.70	5.93	4.92	4.81	6.27	6.52
Gbewaa	20 cm x 20cm	3.49	3.41	4.39	4.52	3.55	3.44	4.42	4.52
	25 cm x 20 cm	4.49	4.26	5.60	5.71	4.94	4.69	6.19	6.28
Digang	20 cm x 20cm	3.17	3.09	3.95	4.03	3.49	3.39	4.35	4.43
	25 cm x 20 cm	3.81	3.96	4.85	5.31	4.19	4.36	5.34	5.84
Mandii	20 cm x 20cm	3.65	3.50	4.52	4.55	4.01	3.85	4.97	5.00
	25 cm x 20 cm	4.70	4.61	5.80	5.85	5.17	5.07	6.38	6.44
Moses	20 cm x 20cm	3.08	3.06	3.89	4.00	3.39	3.37	4.28	4.40
	25 cm x 20 cm	3.82	3.66	4.76	4.86	4.20	4.03	5.24	5.35
LSD (0.05)				0.13				0.14	

6.4.6 Days to 50 % flowering

Days to 50 % flowering were not significantly (P > 0.05) affected by the interaction of variety, spacing, and soil amendment. However, variety and spacing significantly (P < 0.05) influenced it. Days to 50 % flowering ranged from 76 to 107 days. Plants of Digang variety transplanted at 20 cm x 20 cm recorded the earliest (76) days whilst Mandii transplanted at 25 cm x 25 cm experienced delayed flowering and recorded 107 (Table 36). Similarly, the interaction of variety and soil amendment significantly (P < 0.05) affected days to 50 % flowering. The mean days taken to flower ranged from 78 to 107 days (Table 36). Mandii with 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N applied and Mandii with 37.5 kg/ha NPK + 26.25 kg/ha N applied took the longest(107) days to flower. Plants of Digang with 37.5 kg/ha NPK applied and Digang with 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar applied took the shortest (78) days to flower.

Table 36: Effect of Variety and spacing or variety and soil amendment on days to 50% flowering

	Spacing		Soil amendment			
Variety	20 cm x 20 cm	25 cm x 25 cm	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N
Agra	89.5	94.69	89.01	87.96	95.71	95.71
Gbewaa	89.25	95.85	88.65	90.08	95.77	95.71
Digang	75.5	81.5	77.98	77.62	78.66	79.73
Mandii	98	106.82	98.25	97.42	107.01	106.96
Moses	89.58	99.69	94.04	91.18	95.83	97.49
LSD (0.05)	1.85		2.617			

6.4.7 Root weight

Root weight was not significantly (P > 0.05) affected by the interaction of variety, spacing, and soil amendment. However, variety and spacing significantly (P < 0.05) influenced root weight per plant. Mandii transplanted with 25 cm x 25 cm spacing recorded the highest (14.14 g) root weight (Table 37) whilst Moses transplanted 20 cm x 20 cm produced the least (5.29 g).

Similarly, root weight per plant was significantly (P < 0.05) affected by the interaction of variety and soil amendment. Mandii transplanted with 37.5 kg/ha NPK + 26.25 kg/ha N applied and Mandii with10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N applied recorded the highest values of 17.087 g and 16.359 g respectively (Table 37). Digang with 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar applied produced the least (4.437 g).

In addition, root weight per plant was significantly (P < 0.05) affected by the interaction of spacing and soil amendment. Plants transplanted 25 cm x 25 cm with 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N applied and 25 cm x 25 cm with 37.5 kg/ha NPK + 26.25 kg/ha N applied recorded the highest values of 15.226 g and 14.936 g respectively (Table 37). Plants with 20 cm x 20 cm transplanted with 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N applied produced the least root weight of 5.047 g.

Table 37: Root weight g per plant affected by the variety, spacing and Soil amendment

	Spacing			Soil amendment			
Variety	20 cm x 20 cm	25 cm x 25 cm	Variety	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N
Agra	8.78	11.26	Agra	6.32	6.09	14.22	13.46
Gbewaa	10.12	12.66	Gbewaa	7.78	7.55	15.35	14.86
Digang	7.26	9.98	Digang	6.41	4.44	10.56	13.08
Mandii	9.98	14.14	Mandii	8.83	5.98	16.36	17.09
Moses	5.29	8.94	Moses	5.86	6.4	8.31	7.9
LSD (0.05)	0.86			0.86			

	Soil amendment			
Spacing	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N
20 cm x 20 cm	5.79	5.05	10.69	11.62
25 cm x 25 cm	8.29	7.14	15.23	14.94
LSD (0.05)	0.7657			

6.4.8 Straw weight

Straw weight was not significantly (P > 0.05) affected by the interaction of variety, spacing, and soil amendment. Variety significantly (P < 0.05) affected the straw weight with Mandii recording the highest value of 2.338 kg (Figure 4). The least was recorded in Gbewaa and Digang with respective values of 1.433 kg and 1.338 kg. The soil amendment had a significant (P < 0.05) influence on straw weight at harvest. Plants on plots where 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied and 37.5 kg/ha NPK + 26.25 kg/ha N applied gave the highest weight of 1.969 kg and 1.811 kg (Figure 4). The least straw weight at harvest was recorded in plants on 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar applied with 1.444 kg.

a. Variety **b. Soil amendment**

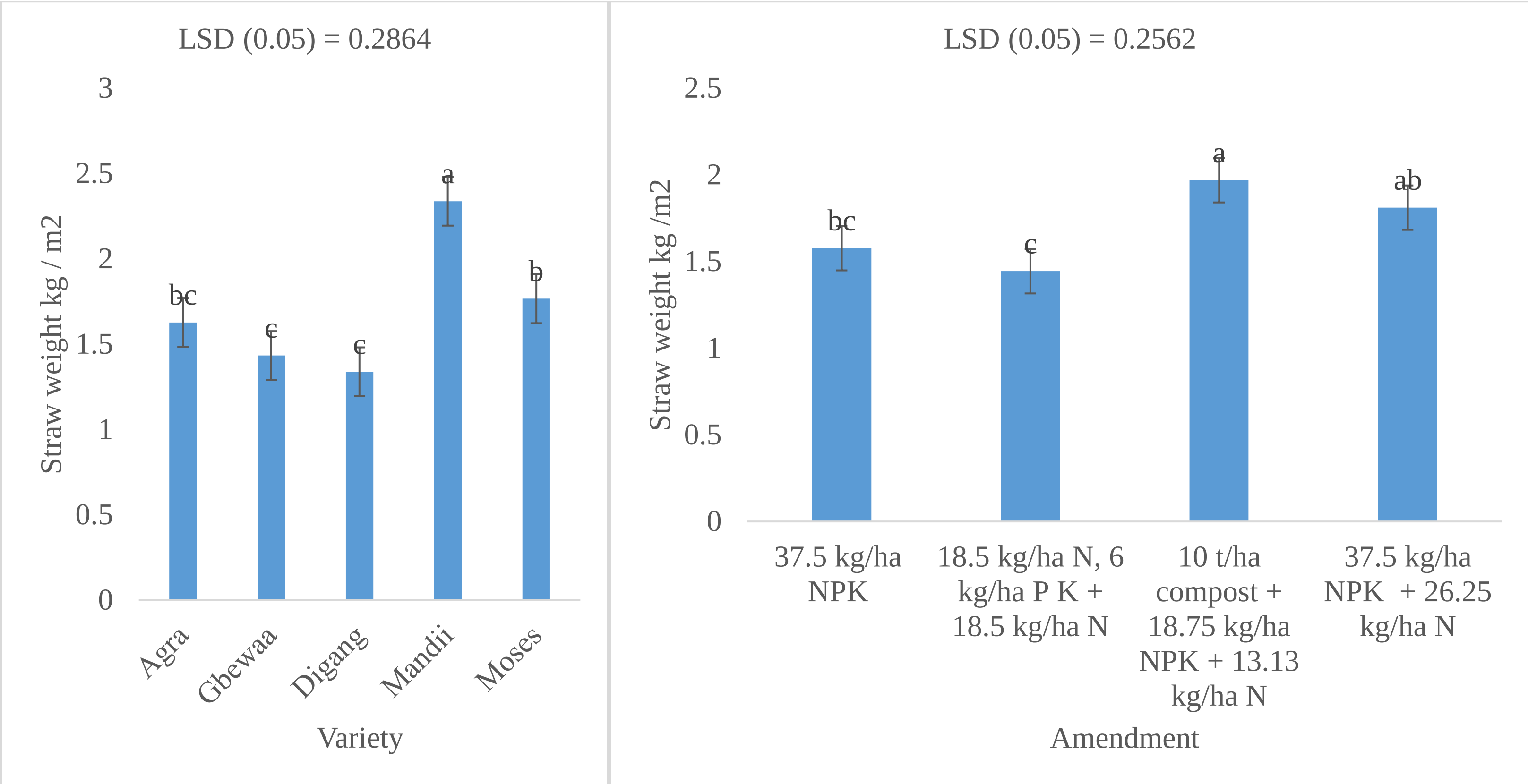

Figure: 4 Effect of (a) variety or (b) soil amendment on straw weight kg m^{-2}. Error bars indicate ± SEM. Means with the same letters are not significantly (P > 0.05) different at 5 % level of significance.

6.4.9 Panicle number

The interaction of variety, spacing, and soil amendment had a significant (P < 0.05) influence on panicle number. Moses variety transplanted 20 cm x 20 cm spacing with10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N applied produced the highest panicle number of 35.96 (Table 38). The least (7.6) was recorded in Moses variety transplanted 20 cm x 20 cm spacing with18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied.

Table 38: Effect of variety, spacing and soil amendment on panicle number

		Soil amendments			
Variety	Spacing	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N
Agra	20 cm x 20cm	10.43	16.80	20.50	16.43
	25 cm x 20 cm	16.09	26.16	18.18	27.37
Gbewaa	20 cm x 20cm	11.55	10.95	15.22	10.24
	25 cm x 20 cm	16.70	16.58	23.69	16.93
Digang	20 cm x 20cm	15.63	22.44	19.43	16.85
	25 cm x 20 cm	13.29	13.20	23.62	30.41
Mandii	20 cm x 20cm	17.26	8.07	13.63	17.57
	25 cm x 20 cm	17.05	17.69	17.50	16.89
Moses	20 cm x 20cm	12.79	7.36	35.96	17.66
	25 cm x 20 cm	21.98	10.87	22.56	16.74
LSD (0.05)		7.968			

6.4.10 Number of spikelet per panicle

Number of spikelet per panicle was significantly (P < 0.05) affected by the interaction of variety, soil amendment, and spacing. Mandii transplanted 25 cm x 25 cm spacing with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliarapplied produced the highest (257) number of spikelet per panicles (Table 39). Moses transplanted 20 cm x 20 cm spacing on plot with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied produced the least (60.5).

Variety x soil amendment significantly (P < 0.05) affected the number of infertile spikelet. Mandii with 37.5 kg/ha NPK applied produced the highest infertile spikelet with a value of 30.44 (Table 39). Digang variety with 37.5 kg/ha NPK + 26.25 kg/ha N applied produced the lowest (3.06).

Table 39: Interactive effect of variety, spacing and soil amendment on spikelet

Variety	Spacing	Soil amendment				Soil amendment			
		37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ N, P, and + 26.25 kg/ha N
Agra	20 cm x 20cm	117.7	81.9	109.7	118.6	9.39	18.56	16.67	10.83
	25 cm x 20 cm	124	107	206.2	178.5				
Gbewaa	20 cm x 20cm	109.1	100	88.9	184.4	17.94	4.28	5.94	9.17
	25 cm x 20 cm	142.7	146.5	152.7	218.7				
Digang	20 cm x 20cm	66	112.7	109.2	84.3	7.00	3.56	4.39	3.06
	25 cm x 20 cm	109	100	124.8	91.2				
Mandii	20 cm x 20cm	145.1	121.1	126.1	110.4	30.44	15.83	13.5	11.61
	25 cm x 20 cm	162.7	257	205	223.2				
Moses	20 cm x 20cm	60.5	104.7	142.8	132.2	9.77	4.19	7.00	8.50
	25 cm x 20 cm	122.5	130	119.5	153.5				
LSD (0.05)			44.01				9.411		

6.4.11 Thousand seed weight

Thousand seed weight was not significantly (P > 0.05) affected by variety x soil amendment x spacing. However, the main effect of variety significantly (P < 0.05) influenced thousand seed weight with Mandii reording the highest (29.36) and Agra the least (25.33). Similarly, 25 cm x 25 cm produced higher thousand seed weight of 28.52 g whilst 20 cm x 20 cm produced lower with a value of 25.86 g (Figure 5). Finally, plants with 37.5 kg/ha NPK + 26.25 kg/ha N applied, and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N applied produced higher thousand seed weight with values of 29.1 g and 28.3 g respectively (Figure 5). Application of37.5 kg/ha NPK was and 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar applied produced lower thousand seed weight with values of 26.33 g and 25.05 g respectivel

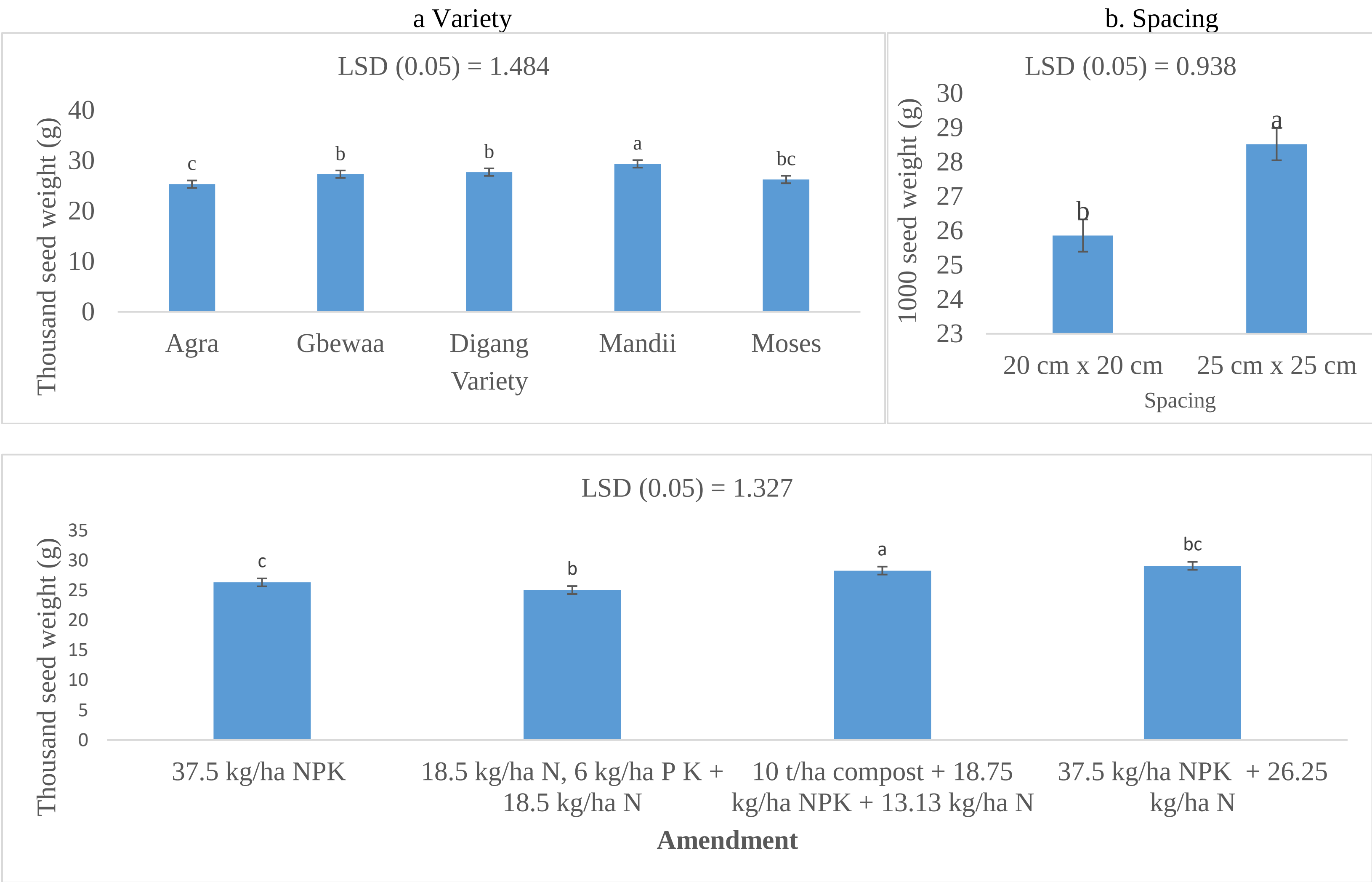

Figure 5: Figure 5: Effect of (a) variety, (b) spacing, (c) soil amendment on thousand seed weight. Bars represent SEM. Means with the same letters are not significantly (P > 0.05) different at 5 % level of significance.

6.4.12 Grain yield

The grain yield of rice was affected significantly (P < 0.05) by the interactive effect of variety, spacing and soil amendment. The mean yield ranged from 1252 kg ha^{-1} to 8169 kg ha^{-1}. The highest yield (8169k kg ha^{-1}) was recorded in Mandii transplanted 20 cm x 20 cm spacingwith 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied whilst the least yield (1252 kg ha^{-1}) was recorded in Agra transplanted 25 cm x 25 cm spacing with 37.5 kg/ha each of N, P, and K applied (Table 40).

Table 40: Interactive effect of variety, spacing and soil amendment on yield kg ha^{1}

		Soil amendment			
Variety	Spacing	37.5 kg/ha N, P, and K	18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N	37.5 kg/ha N, P, and K + 26.25 kg/ha N
Agra	20 cm x 20cm	2916	5231	4439	5002
	25 cm x 20 cm	1252	1513	2839	7172
Gbewaa	20 cm x 20cm	5781	4298	6210	6003
	25 cm x 20 cm	4101	3667	5058	3894
Digang	20 cm x 20cm	4291	3522	5343	4289
	25 cm x 20 cm	2178	2396	3801	2782
Mandii	20 cm x 20cm	4588	3167	5902	8169
	25 cm x 20 cm	2288	1302	2720	2095
Moses	20 cm x 20cm	3772	3082	3875	3849
	25 cm x 20 cm	2470	2176	3179	3335
LSD (0.05)			4368.6		

6.4.13 Correlation coefficient

Grain yield positively correlated with root weight (r = 0.68**), leaf area index (r = 0. 0.50**), panicle number (r = 0.50**), and straw weight (r = 0.45**) (Table 41). This implies that, the higher the root weight, leaf area index, panicle number and straw weight the higher the grain weight or yield.

Table 41: Spearman's correlation coefficients ® for parameters measured for rice in 2022

	PH	TC	LAI	50%F	RTW	STRW	PN	GY
PH	-							
TC	0.66	-						
LAI	0.041**	0.38**	-					
50%F	0.461**	0.36**	0.59**	-				
RTW	0.450**	0.46**	0.82**	0.51**	-			
STRW	0. 059	0.23**	-0.02	-0.07	0.29**	-		
PN	0.471**	0.30**	0.69**	0.51**	0.67**	0.07	-	
GY	0.395**	0.30**	0.50**	0.27**	0.68**	0.45**	0.50**	-

*PH= Plant height at 63 DAP, TC = Tiller count at 84 DAP, LAI = Leaf are index at 84 DAP, 50 %F = 50 % flowering, RTW = Root weight, STRW = Straw weight, PL=Panicle number, GY=Grain yield. **=significant at P <0.01

6.4.14 Value cost ratio

Plants of Agra plants transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest benefit-cost ratio and value cost ratio with values of 1.514 and 2.51 respectively while plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied produced the lowest benefit-cost ratio and value cost ratio with values of 0.52 and -0.483 respectively (Table 42).

Table 42: Benefit and cost assessment of rice production based on variety, spacing and soil amendment at Sagnarigu Kukuo in the Guinea Savanna zone of Ghana

Treatment Combination	**Yield kg ha $^{-1}$**	**Total Revenue** (GH₵ ha^{-1})	**Total Cost** (GH₵ ha^{-1})	**Value cost ratio**	**Benefit cost ratio**	**Profit** (GH₵ ha^{-1})
V1S1BCF	2918	12014	11887	1.01	0.011	127
V1S2BCF	1253	5158	9977	0.52	-0.483	-4819
V2S1BCF	5784	23818	15175	1.57	0.570	8643
V2S2BCF	4103	16896	13247	1.28	0.275	3649
V3S1BCF	4293	17679	13465	1.31	0.313	4214
V3S2BCF	2179	8973	11040	0.81	-0.187	-2066
V4S1BCF	4591	18903	13806	1.37	0.369	5097
V4S2BCF	2289	9427	11166	0.84	-0.156	-1739
V5S1BCF	3774	15541	12869	1.21	0.208	2671
V5S2BCF	2471	10176	11375	0.89	-0.105	-1198
V1S1FF	5234	21552	8572	2.51	1.514	12980
V1S2FF	1514	6234	5880	1.06	0.060	353
V2S1FF	4300	17708	7897	2.24	1.242	9811
V2S2FF	3669	15108	7440	2.03	1.031	7668
V3S1FF	3524	14511	7335	1.98	0.978	7176
V3S2FF	2397	9872	6520	1.51	0.514	3352
V4S1FF	3169	13048	7078	1.84	0.843	5970
V4S2FF	1303	5364	5728	0.94	-0.063	-363
V5S1FF	3084	12698	7016	1.81	0.810	5682
V5S2FF	2177	8965	6360	1.41	0.410	2605
V1S1HRCFOF	4442	18289	13497	1.35	0.355	4791
V1S2HRCFOF	2841	11697	11661	1.00	0.003	36
VSS1HRCFOF	6214	25585	15530	1.65	0.647	10055
V2S2HRCFOF	5061	20839	14208	1.47	0.467	6631
V3S1HRCFOF	5346	22013	14535	1.51	0.514	7478
V3S2HRCFOF	3803	15660	12765	1.23	0.227	2895
V4S1HRCFOF	5905	24316	15176	1.60	0.602	9140
V4S2HRCFOF	2722	11206	11524	0.97	-0.028	-318
V5S1HRCFOF	3877	15965	12850	1.24	0.242	3115
V5S2HRCFOF	3181	13097	12051	1.09	0.087	1046
V1S1RCF	5005	20608	13531	1.52	0.523	7077
V1S2RCF	7176	29549	16021	1.84	0.844	13527
VSS1RCF	6006	24732	14680	1.68	0.685	10053
V2S2RCF	3896	16043	12259	1.31	0.309	3784
V3S1RCF	4291	17671	12713	1.39	0.390	4958
V3S2RCF	2784	11462	10983	1.04	0.044	479
V4S1RCF	8174	33656	17166	1.96	0.961	16491
V4S2RCF	2096	8631	10194	0.85	-0.153	-1563
V5S1RCF	3851	15858	12208	1.30	0.299	3650
V5S2RCF	3337	13740	11618	1.18	0.183	2123

V1 = Agra, V2 = Gbewaa, V3 = Digang, V4 = Mandii and V5 = Moses. S1 = 20 cm x 20 cm and S2 = 25 cm x 25 cm BCF = 37.5 kg ha^{-1} each of NPK (15-15-15); FF = 18.5 kg ha^{-1}N, 6 kg ha^{-1}P and 6 kg ha^{-1} K (26-12-12) + 18.5 kg ha^{-1}of N (from urea); HRCFOF = 10 t ha^{-1} Deco compost + 18.75 kg ha^{-1}each of NPK (15-15-15) + 13.13 kg ha^{-1} of N; and RCF = 37.5 kg ha^{-1} each of NPK (15-15-15) + 26.25 kg ha^{-1}of N.

6.5 Discussion

6.5.1 Physical and chemical characteristics of soil

The analysis of the soil and soil amendment used revealed that general soil nutrient levels were low for enhanced rice production under the low-land rice ecology. Buri *et al*. (2010) found out that soils that are good for rice cultivation should have these levels of nutrients or properties in them; N (0.88 g kg^{-1}), carbon (9.1 g kg^{-1}), magnesium (2.5 mg kg^{-1}), phosphorus (3.2 mg kg^{-1}), potassium (0.3 kg–¹), calcium (4.8 kg^{-1}) and pH of 5.2. Therefore, the soil in the study area has low nutrient content and needs proper soil amendment for productive and sustainable rice production. Analysis of the textural classes of the soil in the experimental field at Sagnarigu Kukuo indicated that 60.57 % of the particle size was sandy, 31.95 % of the particle size was silt, and 6.72 % of the soil particles were clay. This result is consistent with the results of Joseph and Issahaku (2015) who revealed that soils from the Northern regions of Ghana are sandy. The soil acidity was reduced at the end of the experiment whilst Organic matter increased and N decreased. The reduction in N was probably due to the assertion made by Baanante *et al.* (1992) that about two-thirds of the N applied to cereals is gathered in the grain and is removed from the field during harvest. The N left would be stored in the Stover and would not necessarily be cycled back to the soil (Issahaku, 2020). Extractable bases Ca, K, and Mg in the soil increased whilst P content in the soil decreased.

Plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N, plots that received 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied, and plots that received 37.5 kg/ha N, P, and K reduced acidity. This was probably due to the compost containing negatively charged sites that neutralized excess H+ ions in the soils reducing the acidity of the soil. McCauley *et al.* (2017) corroborates with this assertion by indicating that organic matter contains negatively charged sites that can bind to and neutralize excess H+ ions in acidic soils, increasing the pH of the soil. On the other hand, the plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied recorded decreased pH. The nitrification process associated with the sulfate of ammonia applied might have released more hydrogen ions which resulted in lowering the pH of the soil. Bell and Mathesius (2019) confirm this assertion by revealing that ammonium-based fertilizers like urea, ammonium sulfate, and ammonium nitrate have the greatest potential in acidify soil as they release more hydrogen ions in the process of nitrification.

Plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N maintained total N at 0.06 % whilst the rest of the soil amendment treatments recorded a reduction in total nitrogen. The mineralization associated with the decomposition of the mineral fertilizers might have released more nitrogen into the soil which resulted in the increased acidity. Wibowo and Kasno (2021) finding is in line with this finding as they indicated that increasing soil organic matter content is positively correlated with increasing total nitrogen in the soil. Plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N also increased K, Ca, and Mg than any other treatment.

6.5.2 Vegetative growth

The performance of Mandii could be attributed to it having superior varietal traits in utilizing nutrients in the soil which promoted better and robust plant growth in its early stages. The local varieties in the Guinea savannah zone of Ghana are noted to grow taller than the improved varieties.Plants transplanted 25 cm x 25 cm spacing producing the tallest plants could be attributed to the more moisture, nutrients and sunlight they received. This finding is consistent with Sheriff *et al.,* (2020) who were of the view that wider-spacing plants received more moisture, nutrients, and sunlight than narrow-spacing plants.

Plants on plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied producing the highest plant height was probably due to better release of nutrients at different times which were readily accessible by the plants. The plants on this treatment plots had better access to nitrogen which resulted in higher vegetative growth and plant height. Buri and Issaka (2016) supported this assertion and indicated that the interaction of nitrogen levels in rice varieties had a significant effect on plant height. The interactive effect of variety and chemical fertilizer application did not affect plant height at 42 DAP, however, Atakora *et al*. (2019) reported the otherwise that variety and chemical fertilizer interaction influences plant height.

Similarly, as observed in 42 DAP, plants of Mandii probably had better utilization of soil amendment applied and soil moisture as they produced the tallest plants. Sherif *et al.*, (2020) and Dzomeku *et al.* (2016) confirm this statement by indicating that moisture, spacing and fertilizer are factors that influence plant height in the Guinea Savannah agroecological zone of Ghana.

The organic fertilizers that were foliar applied were not as effective as chemical fertilizers applied either solely or with compost in determining plant height. This was probably due to either poor uptake of the nutrients from the plant foliage or low quantities of nutrients especially nitrogen supplied to plants from the foliar fertilizers.

Moses variety spaced 25 cm x 25 cm with 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were superior in producing tillers at the maximum tillering stage of the plants. Other studies such as Kshkooll *et al.* (2020), Abdul Halim *et al.* (2018), and

Hasanuzzaman *et al.* (2009) are in line with this finding. Surprisingly, Moses and Gbewaa rice responded poorly to spacing 20 cm x 20 cm and soil amendment 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar applied producing few tillers. . This could be as a result of more competition created by 20 cm x 20 cm and lower nutrients released by 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar fertilizers applied.

Chlorophyll is very important in plant growth and development as it is an essential component of photosynthesis. Zheng *et al.* (2012) reported that when better conditions in terms of spacing and nutrient availability are created to enhance photosynthesis or chlorophyll fluorescence it will lead to a 10 % increase in yield.

Plants transplanted with spacing 25 cm x 25 cm producing the higher chlorophyll could be attributed to the space 25 cm x 25 cm created which exposed 2/3 lower leaves of the rice plants to sunlight which enhanced the nitrogen status of the plant as well and less competition was created among the plants in the wider spacing.

The sole chemical fertilizers or compost were superior in influencing the chlorophyll of the plants. This could be attributed to a better release of nutrients for plant uptake and or maintaining soil health and fertility for the proper functioning of the plants for the soil amendment provided. Leaf chlorophyll concentration could also be due to moderate potassium deficiency in rice, as Hou *et al.* (2020) confirm.

The combined effect of chemical fertilizers and organic fertilizers has been reported by Khan, (2018), Ali *et al.* (2020), Esfahani *et al*. (2019), and Gholizadeh *et al.* (2017) to positively impacted chlorophyll formation in plants.

Plants of Mandii, Gbewaa and Agra producing more chlorophyll could be that they better tolerated the soil and made good use of the resources the soil provided. In contrast, Junfei *et al.* (2017) reported that reduced chlorophyll content exhibits higher photosynthetic rate and efficiency, improved canopy light distribution, and greater yields than normally pigmented plants. This indicates plants with lower chlorophyll can still do well in terms of grain yield.

Plants of Agra and Mandii varietal traits continued with their positive responses to the combined effect of 25 cm x 25 cm spacing and 37.5 kg/ha NPK + 26.25 kg/ha N amendment. This could be attributed to the better varietal characteristics, more available nutrients, water, and light as well as the continuous flooding of the fields experienced when the rice plants were 63 DAP. Other studies that are in line with this finding include Haque and Haque (2016), Mahajan *et al.* (2012), Maftukhah *et al*. (2019), Begum (2014) and Venkatesh (2023).

Plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied, plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, plants of Moses transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied, and plants of Moses transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the least leaf area index. The poor quantity and arrangement of leaves in plants of Digang and Moses responded poorly to the combined effect of solely basal application of chemical fertilizers or foliar organic fertilizers which probably released low nutrients and narrow spacing which resulted in the high competition of plants for nutrients which led to low leaf area index in these treaments.

Plants of Agra and Mandii showed better genetic characteristics in terms of quantity and arrangement of leaves, number of stems, and ears in both the vegetative and reproductive stages of the rice plants. Spacing 25 cm x 25 cm and 37.5 kg/ha NPK + 26.25 kg/ha N amendment also responded better than the others in terms of release and availability of nutrients from the vegetative to the reproductive stage of the plant. Several studies are in line with this finding. For instance, Yu *et al.* (2020) reported that as the amount of nitrogen applied increases, the leaf area index, biomass, and other indicators related to nitrogen uptake in rice plants also increase

Plants of Digang transplanted with 20 cm x 20 cm taking shorter days to flower could be attributed to shorter maturity varietal traits which were triggered by less nutrients, moisture, sunlight, and photoperiod but with increased temperature for plant growth.

Plants of Mandii transplanted with spacing 25 cm x 25 cm experiencing delayed flowering could be attributed to the enhanced innate ability of Mandii to respond to a better continuous supply of factors that facilitate the vegetative growth of the plant. Findings that are related to this finding include Ezin *et al.* (2022) who reported interaction of wider spacing and temperature resulted in the prolonged vegetative stage of rice plants, Vergara *et al*. (1985) indicated delayed production of carbohydrates by the plants which delayed flowering of the rice plants.

6.5.3 Root weight and shoot biomass accumulation

Variety and spacing influenced root weight per plant. Ighere *et al.* (2019) finding is in line with this finding as they conducted a study on plant spacing and rice variety which showed a significant effect on root growth and rice performance. The combined effect of plants of Mandii and spacing 25 cm x 25 cm producing the highest root weight could be attributed to the better innate ability of Mandii which responded well to the 25 cm x 25 cm spacing created which consequently resulted in better root formation and development.

Plants of Mandii had consistently shown its ability to give up its maximum under adequate nutrients released from the most effective amendments 37.5 kg/ha NPK + 26.25 kg/ha N, and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N of the study.

Spacing 25 cm x 25 cm offered more space, water, and nutrients which was boosted by 37.5 kg/ha NPK + 26.25 kg/ha N, and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N which manifested in higher root weight. A study conducted by Kaysar *et al.* (2023) confirms this as they found that the interaction between water and nutrients had a considerable and advantageous impact on growth indices of the rice plant (Kaysar *et al.*, 2023). Another study by Wang *et al*. (2022a) supported the assertion above by stating that water use efficiency and N uptake efficiency were both positively associated with the increased rate of root volume density, root dry weight, and root weight density.

The differences between soil amendment treatments may probably due to differences in nitrogen received Wang *et al*. (2022a) and Phung *et al.* (2020) findings are in line with this finding.

6.5.4 Grain yield and components of yield

The combined effect of variety, spacing and soil amendment affected panicle number. Moses variety transplanted 20 cm x 20 cm spacing on with10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N applied and Digang variety transplanted 25 cm x 25 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied produced the highest panicle number of 35.96 and 30.41 (Table 38). This was probably due to plants of Moses and Digang showing better response to the spacing and soil amendment which promoted quality nutrition and higher dry matter accumulation. The least panicle number was recorded in Moses variety transplanted 20 cm x 20 cm spacing with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied. Surprisingly, Moses variety response was low due to the 20 cm x 20 cm spacing and the low supply of nutrients from 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar fertilizers which led to low dry matter accumulation. Wang *et al.* (2020) finding supported this assertion.

Abookheili and Mobasser (2021) are in support of 20 cm x 20 cm as they indicated that the number of panicles per square meter increased when planting density was increased while Roshan *et al.* (2011) found out that when plant density decreased, a higher number of panicles were obtained.

The interaction of variety, spacing and soil amendment influenced spikelet formation in the rice plants. Plants of Mandii transplanted using 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, plants of Mandii transplanted using 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied., and plants of Gbewaa rice transplanted using 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest spikelet per panicle with values of 257, 223.2, and 218.7 respectively (Table 39). This could be attributed to plants of Mandii and Gbewaa possessing superior varietal traits in producing more spikelet when interacted with wider spacing 25 cm x 25 cm which contained better nutrients and sunlight and the soil amendment applied especially 37.5 kg/ha NPK + 26.25 kg/ha N amendment which has shown to be more effective in supplying nutrients to the plants. The findings of Rebecca *et al*. (2004), Gunasekaran *et al.* (2023), Reuben *et al.* (2016) and Iqbal *et al*. (2022) supported this assertion. In contrast, Buri *et al.* (2016) and Pokharel *et al.* (2018) rather found narrow spacing to be more effective in producing higher spikelets per panicle than wider spacing.

Plants of Mandii transplanted on plots where 37.5 kg/ha NPK was applied produced the highest number of infertile spikelet. This was probably due to inadequate supply and utilization of nitrogen. Chowdhury *et al.* (2016) finding is in line with this finding.

The interaction of variety, spacing and soil amendment did not influence thousand seed weight. However, variety influenced thousand seed weight. The finding of Venkatesan *et al*. (2023) is in line with this finding. This was probably due to superior genetic makeup which promoted long grain length, width, or thickness or bigger grain shape and higher amylose content in plants of Mandii as compared with the others. The findings of Chen *et al.* (2021) and Venkatesan *et al.* (2023) supported this assertion.

Spacing significantly influenced thousand seed weight. Plant spacing 25 cm x 25 cm produced a higher thousand seed weight whilst 20 cm x 20 cm spacing produced a lower thousand seed weight. Zuo *et al.* (2021) finding is in line with this finding. Plant spacing 25 cm x 25 cm producing the highest seed weight could be attributed to the conducive environment created by the wider spacing which resulted in vigorous growth of the plant, resulting in bigger and weightier seeds. Roshan *et al.* (2011) findings supporedt this statement.

Soil amendment affected thousand seed weight. Soil amendments 37.5 kg/ha NPK + 26.25 kg/ha N and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N produced higher thousand seed weights as compared with the others. The use of sole chemical fertilizer or with compost gave the highest seed weight and this could be due to adequate nutrients supplied by them which resulted in better grain filling and consequently higher seed weight. The findings of Abdul Halim *et al*. (2018) and El-Katony *et al*. (2021) confirm this assertion.

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest grain yield of 8169 kg ha^{-1}, followed by plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, and plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied. with yield values of 7172 kg ha^{-1}, 6210 kg ha^{-1}, and 6003 kg ha^{-1} respectively which were all statistically the same (Table 40). They had a yield within the achievable yield range of 6 – 8 t ha^{-1}. The lowest grain yield was achieved in plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied with a yield value of 1252 kg ha^{-1}. The difference in yield reflects the difference in the synergetic effect of variety, spacing and soil amendment. The highest yield obtained from Mandii x 20 cm x 20 cm x 37.5 kg/ha N, P, and K + 26.25 kg/ha N could be due to the varietal traits of plants of Mandii responding well to the environment created by the spacing 20 cm x 20 cm and the nutrients released from 37.5 kg/ha N, P, and K + 26.25 kg/ha N amendment. Similarly, the higher yield obtained from plants of Agra x 25 cm x 25 cm x 37.5 kg/ha N, P, and K + 26.25 kg/ha N could be due to plants of Agra varietal trait responding well to the wider spacing 25 cm x 25 cm with nutrients released from the 37.5 kg/ha N, P, and K + 26.25 kg/ha N amendment. Whereas in plants of Gbewaa x 20 cm x 20 cm x 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N and Gbewaa x 20 cm x 20 cm x 37.5

kg/ha N, P, and K + 26.25 kg/ha N could be due to varietal traits of plants of Gbewaa responding well to both spacing with nutrients made available from 37.5 kg/ha N, P, and K + 26.25 kg/ha N and 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N amendment.

Plants of Agra and Gbewaa were improved varieties, hence improved varieties give higher yields. Wang *et al*. (2022a) confirm this by revealing that improved varieties improved yield from 6.57 t ha^{-1} to 9.49 t ha^{-1} In addition, Stokstad, (2023) recorded an increase in yield by 40 % when improved variety was used. In contrast, plants of Mandii which is a local variety, has superior agronomic traits which resulted in higher yield as compare with the improved varieties. Wang *et al*. (2022a) confirm this assertion.

In adopting a technology, the cost involved is crucial, henceforth, value cost ratio (VCR) was used in determining how profiting each of the technology was. The total cost involved in carrying out each technology and the total revenue obtained from the sales of each output were calculated. Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied., plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, and plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied. produced higher profits. This was due to the higher yield obtained from these practices. Rahman and Connor (2022) corroborate this assertion by indicating that farmers who adopted good technologies recorded 35% increase in rice yield, which also translated into a 73% increase in the income obtained from the farm as compared to non-adopting farmers. Plants of Agra plants transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied., plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, and plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest value cost ratio with values of 2.51, 2.24, and 2.03. The cost of foliar fertilizers (18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N foliar) were very low as compare to the others which resulted in the higher B/C values. This might be the cause of the low adoption of fertilizer technology in the study area as farmers cannot afford the right and adequate rate of fertilizers for production. Adzogah, (2023) corroborates this finding by indicating that the rising cost of fertilizers drastically affected crop production and profitability of farmers.

Root weight, 50 % flowering, and panicle number highly correlated with grain yield (r=0.68), (r=0.50 and (r=0.50) respectively confirming the strong relationship of the parameters measured with grain yield (Table 41).

6.6 Conclusion

Results of the third field experiment indicated that rice plant growth, yield parameters, and grain yield were promoted by the combined effects of variety, spacing and soil amendment. Soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N affected soil physiochemical properties and promoted the growth of rice plant and yield factors.

Variety influenced the onset of flowering as plants of Digang took 79 days to flower while plants of Mandii experienced delayed flowering and took 102 days to flower. Mandii variety transplanted 20 cm x 20 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied produced the highest grain yield of 8169 kg ha^{-1}. Straw biomass higher with 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied and 37.5 kg/ha NPK + 26.25 kg/ha N aplied with 1.969 kg m^{-2} and 1.811 kg m^{-2}. Plants of Agra transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, and plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest value cost ratio with values of 2.51, 2.24, and 2.03 respectively.

6.7 Recommendation

Variety, spacing and emendment influenced rice yield and benefit cost ratio. Soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N improved soil physiochemical properties and promoted the growth of rice plant and yield factors.

Farmers are advised to adopt Mandii x 20 cm x 20 cm spacing x 37.5 kg/ha N, P, and K + 26.25 kg/ha N, or Agra x 25 cm x 25 cm x 37.5 kg/ha N, P, and K + 26.25 kg/ha N, or Gbewaa x 20 cm x 20 cm x 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N, or Gbewaa x 20 cm x 20 cm x 37.5 kg/ha N, P, and K + 26.25 kg/ha N in the study area and beyond for higher productivity.

Agra x 20 cm x 20 cm x 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar or Gbewaa x 20 cm x 20 cm x 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar, or Gbewaa x 25 cm x 25 cm spacing x 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar should be ,adopted for better profitability in the farming enterprise.

Further research is needed under different ecological systems as this research was carried out under low land rainfed ecology. The efficiency of 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N and foliar applied soil amendments and their absorption can also be an important area of research under both rainfed and irrigated conditions.

CHAPTER SEVEN

MILLING CHARACTERISTICS OF RICE (*Oryza sativa* L.) AS AFFECTED BY VARIETY, SPACING AND SOIL AMENDMENT

7.1 Introduction

Prioritizing rice production can help achieve food security and self-sufficiency in food production (Seck *et al*., 2013). Urbanization, behavioral shifts brought about by rising wealth, and a growing dietary preference for rice over native staples are the main factors driving the demand for rice (Eureka *et al*., 2023).

The northern region of Ghana faces several challenges in rice production, including low adoption of modern farm technologies, limited availability of fertilizers, high-yielding varieties and credit, poor soil fertility, and an aging labor force (Ulzen *et al.*, 2023).

Research has indicated that implementing novel varieties may not consistently result in increased rice yield (Zhang *et al.*, 2019). Because improved varieties are typically more expensive and resource-intensive, farmers are less likely to adopt those (Zhang *et al*., 2019). Low yield is the result of using improved variety without timely application of input in conjunction with sound agronomic practices. Farmers generally do not also consider the quality of the milling of the varieties they used.

When plant density exceeds the optimal level, there is fierce competition for nutrients below the soil and sunlight above it, which slows down plant growth and reduces grain yield (Yussif, 2015). The majority of Ghanaian farmers still broadcast rice seeds across their fields, so they are not leading to the proper density of rice plants per unit area. Traditional planting methods are used by more than half of the country's rice farmers (Ragasa *et al.*, 2013).

Low soil fertility, according to research, causes low nutrient release, which in turn causes low nutrient uptake by rice plants, which ultimately results in low rice yield (Zhu *et al.*, 2022). In Ghana, the average rate of fertilizer application remains below the recommended rate of 5 bags of 50 kg NPK (37.5 kg/ha N, P and K) as basal application and 2.5 bags of either sulfate of ammonia (26.25 kg/ha N) or urea as topdressing for a hectare. The majority of the local rice farmers did not apply fertilizer at the recommended rate during the 2012 growing season, according to research by Ragasa *et al*. (2013).

According to Rahman and Connor (2022) improved varieties have demonstrated increased yield potential, resistance to pests and diseases, and improved grain milling quality. Around the world, improved varieties are created to better fit into ecologies and intensive production systems, encouraging higher grain yields, higher profits, and better consumer nutrition.

The right amount of space between plants allows for the maximum uptake of nutrients from the soil and sunlight, promoting healthy plant growth and development and an increase in rice yield. According to Xu *et al.* (2020), rice yield was maximized by an ideal plant spacing of about 18 cm more than by any other plant spacing. When comparing planting by drilling to row spacing of 25 cm x 25 cm, Tadesse *et al*. (2019) found that the latter produced the highest grain output. Consequently, it is recommended that farmers plant rice 20 × 20 cm or 25 cm x 25 cm.

Because soil amendments improve soil health, lower soil acidity, and release sufficient nutrients for plant uptake, they are essential for raising rice yields. Zhu *et al.'s* research in 2022 demonstrated how the addition of manure affected net photosynthetic rate and enhanced plant physiological resistance to adverse environmental conditions, which improved rice yield. Furthermore, Dzomeku *et al.* (2016) found that rice plots yielded good results when the recommended amount of chemical fertilizer or compost was applied. According to Dzomeku *et al.* (2016), adding compost to the soil improved its overall fertility more than adding just chemical fertilizers.

In terms of plant growth and grain yield, the combinations of variety and spacing variety and soil amendment, or spacing and soil amendment have also demonstrated beneficial outcomes.

According to Arianti *et al.* (2022), each variety has a distinct reaction to varying spacings, and some of these interactions produced high yields. The combination of specific varieties with soil amendment yielded positive results in rice plant growth and grain yield, according to studies conducted by El-Katony *et al.* (2021).

The world and Ghanaian economies are significantly impacted by rice. In order to provide vital information that will assist farmers in making decisions and promote sustainable rice production, it is necessary to investigate the combined effects of variety, spacing and soil amendments on growth, development, and yield of rice.

Earlier studies on rice production have failed to examine the combined effects of variety, spacing and soil amendment on milling characteristics of rice.

The purpose of this study is to ascertain how soil amendments, spacing and variety affect rice milling characteristics.

7.2 Main objective:

The main objective of the study was to determine the effect of variety**,** spacing and soil amendment on milling characteristics of rice.

7.2.1 Specific objectives

1. To determine the main effects of variety on milling characteristics of rice.
2. To determine the main effects of spacing on milling characteristics of rice.
3. To determine the main effects of soil amendment on milling characteristics of rice.
4. To determine the effects of the interaction of any two of the factors or interaction of the three factors on milling characteristics of rice.

7.3 Materials and methods

Detailed materials and methods of this experiment are captured in Chapter Three on the section 3.9.

7.4 Results of experiment

7.4.1 Foreign matter and admixture

Variety, spacing and soil amendment influenced significantly ($P < 0.05$) the foreign matter and admixture in the grains. Agra variety transplanted 20 cm x 20 cm spacing with 37.5 kg/ha each of N, P, and K was applied recorded the highest foreign matter with a value of 40.90 %. The least value was recorded in Agra transplanted 20 cm x 20 cm spacing with37.5 kg/ha N, P, and K + 26.25 kg/ha N applied.

Digang variety transplanted 35 cm x 35 cm spacing with37.5 kg/ha each of N, P, and K recorded the highest admixture with a value of 4.20 % (Table 43). Most of the treatment combination had no admixture, hence they recorded a value of 0.00 % (Table 43).

Table 43: Three-way interaction for: (a) foreign matter and (b) admixture

		Foreign matter				Admixture			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/h NPK + 26.25 kg/ha N
Agra	20cm x 20 cm	40.9	33.3	15.3	6.1	1.3	1.3	1	0.6
	25 cm x 25 cm	16.4	20.6	7.8	4.2	1.2	2.6	1.2	0.2
Gbewaa	20cm x 20 cm	8.1	11.9	2.7	6.1	1.2	1.4	1	0.6
	25 cm x 25 cm	8.2	13.8	5.2	3.4	1.4	1.2	1.2	1
Digang	20cm x 20 cm	17.7	32.9	9.2	14.4	4.2	2.3	0.8	1.2
	25 cm x 25 cm	16.6	23.6	8.3	3.2	1.2	1.6	1	0
Mandii	20cm x 20 cm	5.6	15.4	2.6	5.1	2.1	1.2	0	0
	25 cm x 25 cm	5.7	21.6	5.1	2.8	1.2	1.7	0	0
Moses	20cm x 20 cm	21.8	11.6	8.4	8.4	2.1	2.4	2	1.4
	25 cm x 25 cm	13.1	13.1	7.9	2.6	2	2.1	1.2	1.2
LSD (0.05)				0.7939				0.007033	

7.4.2 Discolored grain and red grains

Variety, spacing and soil amendment also influenced significantly ($P < 0.05$) the discolored grains and red grains in the grains. Gbewaa transplanted 20 cm x 20 cm spacing with 37.5 kg/ha each of N, P, and K applied recorded the highest discolored grain with a value of 55.40 % (Table 44). The least discolored grain was recorded in Agra transplanted 25 cm x 25 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied with a value of 0.50 %. The highest red grain was recorded in Digang transplanted 20 cm x 20 cm spacing with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied with a value of 46.2 % (Table 44). The least (1.1%) red grain was recorded inGbewaa transplanted25 cm x 25 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied

Table 44: Interactive effect of variety, spacing and soil amendment on: (a) discolored grain and (b) red grains

		Discolored grains				**Red grains**			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N
Agra	20cm x 20 cm	8.6	4.8	1.1	4.2	4.2	5	3	2.5
	25 cm x 25 cm	7.5	3.5	1.2	0.5	6	5.7	2.2	1.7
Gbewaa	20cm x 20 cm	55.4	47.1	0.5	3.8	2	3.4	1.2	1.5
	25 cm x 25 cm	48.1	10.9	3.8	2	7.2	6.8	1.2	1.1
Digang	20cm x 20 cm	4.2	2.8	2.1	2.2	24.3	46.2	13.5	11.2
	25 cm x 25 cm	2.2	5.5	1.3	0.7	16.9	35.2	7.9	8.9
Mandii	20cm x 20 cm	10	24.5	1.4	3.8	20.4	9.7	5.2	5.3
	25 cm x 25 cm	32.4	6.8	4.7	2.5	7.9	9.7	4.6	0.8
Moses	20cm x 20 cm	2.1	2.5	2	1	18.4	22.8	12.7	13
	25 cm x 25 cm	1.3	1.9	1.3	1.9	22.8	17.8	13	5.2
LSD (0.05)				1.3218				0.8708	

7.4.3 Green grains and chalky grains

Variety, spacing and soil amendment also influenced significantly ($p < 0.05$) the green grains and chalky grains in the grains. Digang transplanted 20 cm x 20 cm spacing with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied recorded the highest (46.2%) green grain (Table 45). Mandii transplanted 25 cm x 25 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied produced the least (0.8%) green grain. The highest chalky grain was produced by Agra transplanted 20 cm x 20 cm spacing with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied with a value of 23.30 % (Table 45). The least chalky grain was recorded in Gbewaa transplanted 25 cm x 25 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied with a value of 2 %.

Table 45: Interactive effect of variety, spacing and soil amendment on (a) green grain and (b) chalky grains

		Green grains				Chalky grains			
		Soil mendment				Soil amendment			
Variety	Spacing	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N
Agra	20cm x 20 cm	4.2	5	3	2.5	15.3	23.3	2.8	2.1
	25 cm x 25 cm	6	5.7	2.2	1.7	4.5	9.6	9	2.8
Gbewaa	20cm x 20 cm	2	3.4	1.2	1.5	8.5	21.3	4.6	4.8
	25 cm x 25 cm	7.2	6.8	1.2	1.1	6.1	5.6	5	2
Digang	20cm x 20 cm	24.3	46.2	13.5	11.2	11.7	12.6	2.4	2.8
	25 cm x 25 cm	16.9	35.2	7.9	8.9	8.7	3.4	2.3	2.1
Mandii	20cm x 20 cm	20.4	9.7	5.2	5.3	17.4	7.2	4.8	4.6
	25 cm x 25 cm	7.9	9.7	4.6	0.8	13.5	16.8	5.3	2.2
Moses	20cm x 20 cm	18.4	22.8	12.7	13	4.8	4.3	3.7	3.4
	25 cm x 25 cm	22.8	17.8	13	5.2	15.3	3.9	3.4	2.1
LSD (0.05)				0.8708				0.5087	

7.4.4 Immature grains and combined grains

Variety, spacing and soil amendment influenced significantly (P < 0.05) the immature grains and combined grains in the grains. Mandii transplanted with 25 cm x 25 cm spacing with 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar applied produced the highest immature grains with a value of 10.20 % (Table 46). Plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied, plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Moses transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Agra transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Agra transplanted with spacing 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied produced the least immature grain, all with a value of 1.00 % (Table 46).

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest combined grain with a value of 11.40 % (Table 46).

The least combined grains were produced in plants of Agra transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, Plants of

Agra transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, Plants of Agra transplanted with spacing 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, and plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied all with a value of 0.10 %, and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied, V Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied all with a value of 0.00 % (Table 46).

Table 46: interactive effect of variety, spacing and soil amendment on (a) immature grains and (b) combined grains

		Immature grains				Combined grains			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N
Agra	20cm x 20 cm	3.8	3.8	1	1	1	1.1	0.1	0.1
	25 cm x 25 cm	7.5	1.8	1.3	1	1	1	0.1	0.1
Gbewaa	20cm x 20 cm	7.3	6.5	1.1	1	1.1	1.2	1	0.8
	25 cm x 25 cm	1.4	2.4	1.1	1	1	3.1	0.8	1
Digang	20cm x 20 cm	6.6	7.1	1	1.6	1.2	1.1	0.6	1
	25 cm x 25 cm	2.8	8.5	2.2	1	0.8	1	0.2	0.6
Mandii	20cm x 20 cm	5.5	7.1	2.5	1.9	0	11.4	0	0
	25 cm x 25 cm	6.5	10.2	2.1	1.1	0.7	1.1	0	1
Moses	20cm x 20 cm	1.3	3.4	1.1	1.1	1.4	1	1.1	1
	25 cm x 25 cm	1.2	1.3	1.1	1	1.1	10	0.7	0.4
LSD (0.05)				0.2231				0.2418	

7.4.5 Crackness of grain and broken grains

Variety, spacing and soil amendment influenced significantly ($P < 0.05$) the cracks in the grains and broken grains.

Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest crackness with a value of 100 %. The least cracks was recorded in plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied and plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied with values of 2.00 %, 2.00 % and 1.80 % respectively (Table 47).

Plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest broken grain with a value of 58.60 %. Plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the least broken grain with values of 2.90 % and 2.80 % respectively which was not significantly different from plants of Agra transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied with values of 4.30 % and 3.60 % respectively (Table 47).

Table 47: Combined effect of variety, spacing and soil amendment on (a) crackness of grain and (b) broken grains

		Crackness of grains				**Broken grains**			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N
Agra	20cm x 20 cm	53	52.3	3.6	3	38.6	55.6	5.4	4.3
	25 cm x 25 cm	5.9	41.6	5.9	1.8	38.2	58.6	8	2.9
Gbewaa	20cm x 20 cm	13.6	40.4	10.7	10.7	17.8	40.7	6.1	5
	25 cm x 25 cm	13.3	39.4	2	4.1	7.8	39.1	5	4.8
Digang	20cm x 20 cm	15.2	43.8	2	13.3	21.1	49.2	11.7	6.5
	25 cm x 25 cm	14	39.5	8.9	5	23.3	35.3	3.6	2.8
Mandii	20cm x 20 cm	36.9	100	6	8.8	29.7	48.1	10.6	9.9
	25 cm x 25 cm	47.9	74	25	6	26	32.3	6.4	6.3
Moses	20cm x 20 cm	67.1	81.4	37.9	28.5	36.9	38.8	18.3	19.6
	25 cm x 25 cm	42	52.5	8.1	14.7	24	25.3	14.4	9.8
LSD (0.05)				2.321				1.479	

7.4.6 Brown yield and husk yield

Variety, spacing and soil amendment influenced significantly (P < 0.05) the brown yield and husk yield of the grains. The mean range of brown yield was from 64.90 % to 77.40 %. The treatments that produced the highest brown yield werea;

- plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Moses transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied;
- plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied;
- plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied;
- plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied;

- plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Agra transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied;
- plants of Moses transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied;
- plants of Moses transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied and
- plants of Moses transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied (Table 48).

The least brown yield was produced in Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied with a value of 64.90 %,

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest husk yield with a percentage value of 35.10. Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied. Plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the lowest husk yield with percentage values of 22.70 and 22.60 respectively (Table 48).

Table 48: Interactive effect of variety, spacing and soil amendment on (a) brown yield and (b) husk yield.

		Brown yield				Husk yield			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ NPK + 26 kg/ha N
Agra	20cm x 20 cm	74.5	74.1	75.3	76.2	25.5	25.9	24.7	23.8
	25 cm x 25 cm	74.5	74.8	75.6	76.2	25.5	25.2	24.4	23.8
Gbewaa	20cm x 20 cm	73	72	75.5	76.4	27	28	24.5	23.6
	25 cm x 25 cm	73.4	72.4	77	77.2	26.6	27.6	23	22.8
Digang	20cm x 20 cm	75	74.5	76.5	76.6	25	25.5	23.5	23.4
	25 cm x 25 cm	74.5	74.5	76.8	77.3	25.5	25.5	23.2	22.7
Mandii	20cm x 20 cm	71.2	64.9	72.7	75.4	28.8	35.1	27.3	24.6
	25 cm x 25 cm	72.2	71.5	76.5	77.4	27.8	28.5	23.5	22.6
Moses	20cm x 20 cm	74.1	74.3	75.9	75.9	25.9	25.7	24.1	24.1
	25 cm x 25 cm	74.2	74.1	76.1	77.1	25.8	25.9	23.9	22.9
LSD (0.05)				1.4107				0.5407	

7.4.7 Length and width of grain

Variety, spacing and soil amendment influenced significantly (P < 0.05) the length of the grains and width of the grains. The mean range of length of grain was from 6.15 mm to 7.39 mm Plants of Mandii transplanted using 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied., plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the longest grain length with values of 7.39 mm, 7.32 mm, 7.32 mm and 7.30 mm The least grain. length was recorded in plants of Moses transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied with a value of 6.15 mm (Table 49).

Plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied., and plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied recorded the grain width with the values of

2.45 mm, 2.45 mm, 2.45 mm, 2.42 mm, 2.41 mm, and 2.41 mm respectively. Plants of Moses transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the least grain width with a value of 2.21 mm Length width ratio of grain (Table 49).

Table 49: Interactive effect of variety, spacing and soil amendment on (a) length of grain and (b) width of grain.

		Length of grains				Width of grains			
		Soil amendment				Soil amendment			
Variety	Spacing	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N	37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/h NPK + 26.25 kg/h N
Agra	20cm x 20 cm	6.67	6.55	6.78	7.2	2.28	2.26	2.34	2.38
	25 cm x 25 cm	6.73	6.6	6.88	7.32	2.31	2.28	2.41	2.41
Gbewaa	20cm x 20 cm	6.78	6.39	6.8	6.8	2.26	2.26	2.26	2.42
	25 cm x 25 cm	6.78	6.68	6.8	6.84	2.26	2.26	2.34	2.4
Digang	20cm x 20 cm	6.69	6.32	7.06	7.04	2.32	2.38	2.36	2.38
	25 cm x 25 cm	6.83	6.69	7.2	7.23	2.34	2.28	2.45	2.45
Mandii	20cm x 20 cm	6.8	6.49	7.18	7.3	2.3	2.26	2.28	2.28
	25 cm x 25 cm	6.84	6.65	7.32	7.39	2.28	2.4	2.28	2.45
Moses	20cm x 20 cm	6.81	6.15	6.86	6.86	2.26	2.21	2.26	2.36
	25 cm x 25 cm	6.8	6.8	6.95	7	2.26	2.26	2.36	2.35
LSD (0.05)		0.13344				0.04319			

7.4.8 Length – width ratio

Variety, spacing and soil amendment influenced significantly (P < 0.05) the grain length-width ratio. The mean range of grain length width ratio was from 2.655 to 3.211. Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied produced the highest grain length width ratio with the values of 3.211, 3.202, and 3.149 respectively. The least grain length width ratio was recorded in plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied with a value of 2.655 (Table 50).

Table 50: Interactive effect of variety, spacing and soil amendment on length-width ratio of grain

Variety	Spacing	Soil amendment 37.5 kg/ha NPK	18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N	10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N	37.5 kg/ha NPK + 26.25 kg/ha N
Agra	20cm x 20 cm	2.9254	2.8982	2.8974	3.0252
	25 cm x 25 cm	2.9134	2.8947	2.8548	3.0373
Gbewaa	20cm x 20 cm	3	2.8274	3.0088	2.8099
	25 cm x 25 cm	3	2.9558	2.906	2.85
Digang	20cm x 20 cm	2.8836	2.6555	2.9915	2.958
	25 cm x 25 cm	2.9188	2.9342	2.9388	2.951
Mandii	20cm x 20 cm	2.9565	2.8717	3.1491	3.2018
	25 cm x 25 cm	3	2.7708	3.2105	3.0163
Moses	20cm x 20 cm	3.0133	2.7828	3.0354	2.9068
	25 cm x 25 cm	3.0088	3.0088	2.9449	2.9787
LSD (0.05)			0.05855		

7.5 Discussion

7.5.1 Foreign matter, admixture and discoloured grains

Foreign matter is all materials other than paddy or rice kernels, including soil, stones, weed seeds, fragments of rice stalk, dust, husk, and dead insects. Plants of Agra transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied recording the highest foreign matter could be attributed to poor farm sanitation and post-harvest handling of the grains obtained in this treatment field. Lantin (1999) finding is in line with this finding as he revealed that in the course of sun drying, paddy rice may be contaminated with impurities such as sand, soil, stones and animal excreta. On the other hand, all the samples from treatments that had no foreign matter were from plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied. This could be that plants on plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied or 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied supported vegetative growth of the plants of Mandii, Agra and Digang which consequently resulted in the suppression of weeds which led to less or no weeds on these treatment fields. It could also be that, grains from these fields were handled well in the course of drying or packaging of the paddy. The finding of Abera *et al.* (2021) confirms this assertion. They stated that paddy quality is affected by factors such as genetic factors (variety), weather conditions during crop production, crop agronomic practices, soil conditions, harvesting, and postharvest practices.

Plants of Agra transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied producing the highest admixture was probably due to poor farm sanitation, poor harvesting, and post-harvest handling of the paddy. Abera *et al*. (2021)

supported this assertion by revealing that poor harvesting and postharvest practices affect the quality of paddy rice. Meanwhile, it was also observed that all the samples from treatments that had less admixture were from plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied. Plants on plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied might have drastically suppressed stray rice growth thereby reducing other rice grains or under developed rice grains in the paddy after harvest.

Plants of Gbewaa rice transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied recorded the highest discolor grain with a value of 55.40 % could be due to improper drying which resulted in a fungal attack on grains. This assertion is in line with Amini and Asoodar (2015) study who revealed that rice grain discoloration is a disease condition caused by a range of microorganisms such as fungal agents which include Alternaria sp., Curvularia sp., Cladosporium spp., Bipolaris spp.

7.5.2 Green, red, chalky and immature grains

Variety, spacing and soil amendment influenced significantly ($P < 0.05$) the green grain in the grains (Table 45). The highest green grain was recorded in plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied. with a value of 17.50 % which was probably due to early harvesting which resulted in harvesting immature grains. The finding of Chao *et al*. (2022) supported this assertion by stating that green grains of rice are harvested before maturity. Interestingly, green grain is reported by Sugg (2023) to have higher nutritional value as it contains protein, riboflavin, and other nutrients. From this research, plants of

Mandii transplanted on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied took longer days to flower (Table 36) which implies a longer maturity period.

On the contrary, wider spacing is reported by Vergara *et al.* (1985) to have supported longer maturity days, and longer maturity means more green grains but, in this case, 20 cm x 20 cm rather promoted a higher quantity of green grains of rice.

Plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied recorded the highest discolored grain. Gbewaa and37.5 kg/ha each of N, P, and K interaction recording the highest discoloured grains could be due low supply of nitrogen which affected proper growth and functioning of high input demand variety Gbewaa which resulted in the production of discoloured grains. Several findings are in line with this finding. Ighere *et al.*. (2019) indicated that variety and spacing interaction affect the quality of rice. While Hindersah *et al*. (2022) also indicated grain quality is determined by soil amendment and planting methods interaction, Kakar *et al.* (2020) also reported that grain quality is affected by chemical fertilizer and organic fertilizer interaction.

Plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied recording the highest red grain which was followed by plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied was probably due to a higher accumulation of carotenoids in Digang and 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N interactions. Mbanjo *et al.* (2020) confirm this statement by indicating that red and black rice grains occur when varieties accumulate high amount of carotenoids, while white rice accumulates very little. The high moisture content of the grain could have also resulted in the production of red grains as Brinkhoff *et al.* (2023) reported that rice grains at harvest is an important factor in determining the quality of rice.

The highest chalky grain produced by plants of Agra plants transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied with a value of 23.30 % was probably due to less nitrogen availability to the plant especially at the grain filling stage and the exposure of the grains to higher temperatures during and after harvesting. Cheng *et al.* (2019) supported this assertion by indicating that among the abiotic factors, the temperature has a major influence on grain chalkiness.

It was observed that plot where 37.5 kg/ha NPK + 26.25 kg/ha N were applied producing less chalky grains was probably due to adequate nitrogen provided which resulted in promotig the production of acceptable levels of starch granules and protein, consequently resulting in less chalky grain production. Zhao *et al.* (2020) supported this assertion by revealing that nitrogen fertilizer application, for example, can significantly reduce the chalky kernel rate of rice. However, excessive nitrogen application could also lead to higher chalky kernel production.

Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied producing the highest immature grains was probably due to early harvesting of the rice with a moisture content of around 22 % which resulted in partially chalky kernels. This assertion is in line with Chao *et al.* (2022) who indicate that green grains are harvested before their actual maturity. Green grain is noted to have higher nutritional value than matured brown rice. However, immature rice kernels are very slender and chalky and are easily broken, which can reduce milling recovery and head rice yields (IRRI, 2010).

7.5.3 Crackness, broken and brown yield

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied producing the highest crackness was probably due to over-drying of the grains leading to lower moisture content of the grains of the treatment. Owusu *et al.* (2020) supported this assertion as they indicated that rice cracking begins at moisture content below 14.2 % and 18.3 % for crack-resistant and crack-susceptible varieties, respectively. Besides, crackness could be due to varietal traits and the time and type of fertilizer applied. Odoom *et al*. (2021) supported this assertion by stating that the crackness of paddy could be reduced through the identification of the best varieties and time or type of application of inputs.

Plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied producing the highest broken grains was probably due to genetic or poor weather conditions. This is in line with the assertion of Jiang *et al* (2019). The genetic make-up of some varieties such as long and brittle grain can easily break. Jiang *et al.* (2019) supported this assertion by indicating that some rice varieties have more brittle grains, leading to higher breakage rates, for instance, African rice (*Oryza glaberrima*) has more brittle grains and higher breakage compared to Asian rice (*Oryza sativa*). Jiang *et al.* (2019) supported this assertion. Aromatic rice is also noted to have a higher tendency of breakage and cracking than nonaromatic rice. Anjna *et al.* (2019) supported this assertion by stating that aromatic rice varieties are liable to breakage than nonaromatic rice varieties. Besides, the higher moisture content during harvesting of the grains could make rice susceptible to breakage. Zareiforoush *et al.* (2010) supported this assertion by stating that very low or high moisture content of rice grain has the higher tendency of causing the grain breakage.

On the contrary, plants transplanted with 25 cm x 25 cm recorded the highest broken rice as compared with plants transplanted with 20 cm x 20 cm. This is in contrast to what Komalawati *et al.* (2023) reported that narrow plant spacing increases plant competition for the use of nutrients, air, and light, resulting in shading conditions, grain loss, and an increase in broken grains

Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied producing the highest brown yield was probably due to good grain yield from the best-performing treatments as grain yield has a positive correlation with brown yield. The findings of Xu *et al*. (2020) supported this assertion by indicating that grain yield has a significant positive correlation with the brown rice and head rice ratios, and a significant negative correlation with chalky rice and immature kernels.

Spacing 25 cm x 25 cm relatively performed better which could be due to less competition among the plants for nutrients, air, and solar energy which resulted in better plant growth and consequently higher grain and brown yield. Aklilu (2020) supported this assertion as he indicated that closer spacing can lead to more competition among plants for nutrients and light, which can result in weaker and thinner plants and less filled kernels, and reduced grain yield.

Plants on plot where 37.5 kg/ha NPK + 26.25 kg/ha N were applied and plants on plots where 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied were superior in producing brown grain and this could be attributed to better modes and rates of fertilizer applied resulting in better rice yield and quality. Liu *et al.* (2021) findings supported this assertion.

Also, plants on plot where 37.5 kg/ha NPK + 26.25 kg/ha N were applied and plants on plots where 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N were applied superiority could be due to a better supply of nitrogen at the later part of the plant life which resulted in higher brown yield dimensions. Dou *et al.* (2024) supported this assertion.

7.5.4 Husk yield, grain length, grain width, and grain length – width ratio

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied producing the highest husk yield could be due to Mandii having better varietal traits in producing larger husk which resulted in the higher husk yield. Katsura and Nakaide (2011) supported this assertion by indicating that husk size is an important factor that determines grain weight in rice under high-yielding aerobic culture. This could also be due to inadequate nitrogen supply from plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied coupled with 20 cm x 20 cm environment created which led to less grain filling and inferior grain production and rather trigger varietal traits of Mandii that promoted more husk production. Abera *et al*. (2021) also supported this assertion by indicating that growing location had a significant effect on rice quality attributes. This assertion is in contrast to the finding of Zhao *et al.* (2022) who indicated that excessive nitrogen application can lead to lower rice yield and grain quality by inhibiting the grain filling and end up by producing inferior grains.

Variety, spacing and soil amendment influenced significantly ($P < 0.05$) the length of the grains. Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the longest grain length. This could be due to Mandii and Agra having better varietal traits especially quantitative trait loci (QTLs) which promote longer grains in rice. This assertion confirms Zhang *et al*. (2018) findings which indicated that grain size and shape are important components determining rice grain yield, and they are controlled by quantitative trait loci (QTLs).

Also, this could be probably due to plant spacing 25 cm x 25 cm providing the plants with adequate nutrients and solar energy which resulted in vigorous plant growth and better grain filling leading to longer grain length. Marie-Noel *et al.* (2021) supported this assertion by indicating that optimal plant spacing allows the plant to grow properly with their above-ground and underground parts using more solar radiation and soil nutrients.

Plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25

kg/ha N were applied, plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied recorded the highest grain weight. This was probably due to suitable genetic, environmental, and nutrients such as nitrogen factors which promoted the growth and development of rice grains, especially in weight. Randy *et al.* (2017) supported this assertion by revealing that maximum nitrogen uptake by rice plants indirectly affects the width of rice grains.

Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied produced the highest grain length to width ratio. This was probably due to better varietal traits which responded well to the interaction of any of the spacing and nutrients especially nitrogen supplied by 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and 37.5 kg/ha NPK + 26.25 kg/ha N resulting in superior yield parameters and grain length-to-width ratio as well. The findings of Reuben *et al.* (2016) and Zhao *et al.* (2022) supported this assertion. Potcho *et al.* (2022) also supported this assertion by stating that the application of nitrogen fertilizer increased the grain length and length-width ratio. It could also be probably due to the appropriate temperature interacting well with the nitrogen, phosphorus, and potassium supplied. Xu *et al.* (2022) supported this assertion. El-Katony *et al.* (2021) supported this assertion by indicating that the soil amendment improved the width/length ratio of rice grain.

7.6 Conclusion

Grain development and yield influenced the milling characteristics of the grains. The highest grain yield which was obtained from plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied also produced the best brown yield when milled. Plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied also produced the longest grain length and the highest length-width ratio, respectively.

- Poor grain yield also influenced the poor milling characteristics of grains. For instance
- Mandii X 20 cm x 20 cm X 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N produced poor yield + highest green grains
- Digang X 20 cm x 20 cm X 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N and Digang X 25 cm x 25 cm X 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N both produced poor yield + highest red grains.
- Mandii X 25 cm x 25 cm X 37.5 kg/ha N, P, and K + 26.25 kg/ha N, Digang X 25 cm x 25 cm X 37.5 kg/ha N, P, and K + 26.25 kg/ha N and Moses X 25 cm x 25

cm X 37.5 kg/ha N, P, and K + 26.25 kg/ha N all produced poor yield + highest chalky grains.

- Mandii X 20 cm x 20 cm X 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N produced low yield + highest crackness of the grains.

Surprisingly plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied which produced the highest grain yield also produced higher foreign matter as well as highest admixture along side plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied.

7.7 Recommendation

Farmers are advised to adoptAgra transplanted 25 cm x 25 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N, Gbewaa transplanted 20 cm x 20 cm spacingwith 37.5 kg/ha N, P, and K + 26.25 kg/ha N and Mandii transplanted 20 cm x 20 cm spacing with 37.5 kg/ha N, P, and K + 26.25 kg/ha N for higher yield and quality grains. Further research is needed under different ecological systems as this research was carried out under low land rainfed ecology. Moreover, post-harvest handling factors such as drying and storage before milling should be looked at.

CHAPTER EIGHT

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

8.1 Discussion

8.1.1 Perception of rice value chain actors about improved cultivation and milling practices in rice production

The indicators of low technology adoption included gender inequity, unattractive nature of the rice business to the young folk in the study area, and low educational level of rice value chain actors.

The male folk dominates rice cultivation while the female folk has less access to rice farm land. Meanwhile women are actively involved in almost all the activities involved in rice cultivation, processing, and marketing. This discrimination in terms of allocation of resources for farming affects rice production in Ghana. Africa Rice (2020) and Asante *et al*. (2023) corroborated this assertion by stating that men were found to have greater access to and control over resources like land, inputs, and equipment for rice production which hindered rice productivity in Ghana. On the other hand, few males are actively involved in rice processing and marketing. This means that the male folk who are actively involved in rice cultivation have limited influence in rice processing and marketing which affects rice business in the country. In their choice of varieties for cultivation, they pay less attention in selecting market-driven varieties and do not observe proper harvesting, post-harvest practices, and farm sanitation. Lamptey *et al.* (2022) studies confirmed this as they stated that rice farmers in the Northern region have benefited from the dissemination of high-yielding rice varieties. In fact, rice farmers pay much attention to the high yielding varieties than the varieties with marketable traits such as aromatic and long grains because of the farmers less participation in the processing and marketing of rice. In addition, the male folk has more technical skills across the rice value chain who could make crucial impact in processing and marketing of rice. The findings of Medagbe *et al*. (2020) was consistent with this finding as they stated that women have limited access to technical knowledge and resources compared to men in the rice value chain.

The young ones are not given the opportunity to own or start a rice processing business in the study area. Similarly, the old folk dominate the rice processing and marketing in the study area, as the age range with the least population who are into rice marketing was from 25 to 35 years. The young ones are more likely to adopt technology than the old one. Awotide *et al.,* (2016) and Abdulai *et al.* (2018) findings are consistent with this finding as they revealed that older farmers are less receptive to new ideas and less willing to take risks associated with the adoption of new innovations as compared to the younger ones.

The adoption of modern methods of production, processing and marketing of rice is very difficult if not impossible due to the high illiteracy rate of rice producers, processors and marketers. Henceforth, these producers, processors and marketers are still stuck to the traditional methods of rice production, processing and marketing. Male rice farmers who doubled as rice marketers would select the best rice variety and rice cultivation methods to obtain the best price for paddy and could use modern technologies in marketing the rice as well if he or she is literate. Literacy improves the technical efficiency of rice producers, processors and marketers which goes a long way to enhance technology adoption among these value chain actors. Abdulai *et al.* (2018) findings confirmed this assertion as they indicated that adopters of improved rice technologies have about 10% higher technical efficiency compared to non-adopters.

Few farmers using certified seeds for cultivation could be one of the reasons farmers obtained low yields in the study area. Akanbi *et al.* (2022) report is consistent with this assertion as they reported that the farmers who used certified seed achieved 61% higher yields compared to non-users. Majority of the farmers from the study area did not use the certified seed because they indicated that certified seeds were costly. Setiani *et al.* (2023) confirmed this finding by stating that farmers considered certified seeds to be expensive compared to their own saved seeds from previous harvests and eventually fell for the latter. In addition, Ragasa and Chapoto (2017), revealed that one of Ghana's biggest obstacles to rice production is the high cost of hybrid rice seeds.

The varieties which were used the most in the 2020 cropping season in the study area were Agra, Moses, Gbewaa rice, Mandii, Bumbass, Digang, and Salimasaa. Some of these varieties belong to those that are currently promoted by CSIR as Joshua Asaah of Tono radio reported that varieties that were released and promoted by CSIR were Togo Marshall, Agra, IR 841, and Legon Rice, Gbewaa, Malimali and Savanna. Azumah *et al.* (2022) reported similar results as they indicated that farmers in Northern part of Ghana have embraced improved rice varieties like Agra, Sakai, Jasmine 85 and Afife.

Most of the rice processors in the study area prefer Agra, Gbwewa rice, Bazolgu, Moses, Digang or Gomma as Paddy for processing. The finding of Adams *et al.* (2019) is in line with this finding as they reported that women in the Northern region primarily engage in parboiling rice with Jasmine and Agra being the two most frequently used varieties. The rice processors in the study area made their choice of variety of paddy base on the uniformity of the grains, cooking characteristics and the percentage of unbroken grains, moisture content of grains and aromatic characteristics of the grains.

The finding of Ayeduvor (2018) is consistent with this assertion as they revealed that cleanliness and low levels of debris/impurities, uniform grain size and shape, low percentage of broken grains, and appropriate moisture content were the paddy qualities processors and marketers looked for when buying the paddy.

Farmers in the study area employed poor planting methods in cultivating rice. Most of the farmers selected broadcasting because they could not afford the cost involved in transplanting even though farmers were aware of how their rice yield would be tremendously improved when they used line transplanting. However, the cost and their convenience will not allow them to adopt it. Hindersah *et al*. (2022) had similar result as they revealed that farmers in the Northern region of Ghana chose broadcasting method of planting because it is simpler, less expensive, and requires less labor as compared to transplanting. The few farmers who selected transplanting method indicated that transplanting gave them better yield. This finding in line with the finding of Ehsanullah *et al.* (2000) as they stated that transplanted rice gave 30% more yield than direct-seeded broadcast rice.

Those who chose to transplant, transplanted when the seedlings were at least 4 weeks old. These might have caused the low yield rice farmers obtained in the study area. Early transplanting of rice plant could give better yield. Baloch *et al.* (2006) corroborated this by indicating transplanting rice at early date gave the highest paddy yield as compared with delayed transplanting.

Most of the farmers did not use the recommended rate of fertilizing on their rice fields, that is applying 37.5 kg/ha of N, P, and K as basal application (5 bags (50 kg) of NPK) and top dressing with 26.25 kg/ha N (2.5 bags (50 kg) of sulfate of ammonia. Ragasa *et al.*

(2013) finding was similar as they reported that rice farmers in Ghana obtained low yields because they did not apply the recommended rates of fertilizer. Farmers in this current study area knew soil amendment using chemical fertilizer increases rice yield, therefore making these fertilizers affordable will register greater percentage of adoption.

Rice marketers in the study area preferred Gbewaa rice, Bazolgu, Agra, Gomma, Digang, Mandii, Tops rice, Anofula rice, Amaru rice, Faaro rice or GR18 as paddy for marketing. Asante *et al.* (2013) and AGRA (2024) findings are in line with this as they stated Agra, Jasmine 85 (Gbewaa rice), CRI-Dartey, CRI-Mpuntuo, and CRI-Kantinka were the locally produced rice marketers preferred. The rice marketers in the study area made their choice of a variety of paddy based on the cooking characteristics, long grains or uniformity of grains, the variety of the paddy, the price, combined threshing/harvesting or discolor of the milled rice, the weight of the bag or moisture content of the grain or percentage broken or foreign matter or immature grains or Aroma of the paddy before buying. The finding of MoFA-IFPRI Market Brief (2020) corroborated this finding as it stated that local rice which were typically considered to be high-quality were aromatic long grain varieties which competed favorably with imported rice brands in terms of price and quality.

8.1.2 Influence of time of transplanting and spacing on growth and yield of rice (*Oryza sativa* L.)

8.1.2.1 Soil physio-chemical properties

The differences in the soil pH at the end of the experiment could have been caused by the transplanting time and plant spacing which neutralized the aluminum (Al^{3+}) and hydrogen (H^{+}) ions in the soil. This claim was corroborated by Enesi *et al*. (2023), who showed that the soil's pH rises as a result of the neutralization of aluminum ($Al3^{+)}$ and hydrogen (H^{+}) ions. Furthermore, at the end of the experiment, P, Ca, and Mg ion levels in the soils were higher than baseline levels. During the experimentation, these soils probably contained more organic matter, which is why there was an increase. Besides, the higher levels of P, Ca, and Mg in the soils could potentially be attributed to the decrease in soil acidity. This claim is supported by Prasad and Chakraborty's (2019) finding, which showed that plant nutrients like P increase as soil acidity decreases. On the other hand, the levels of nitrogen and organic matter dropped. The soils' higher sand content was most likely the cause of the decline. This claim was bolstered by Zhou *et al.'s* (2019) discovery that soils richer in silt and clay tend to have higher nitrogen and organic matter contents than soils with higher sand content.

8.1.2.2 Plant height, tiller count and chlorophyll content

These results showed that the widest spacing (35 cm x 35 cm) treatments probably received more growth factors such as moisture, nutrients and sunlight as compare with the others. This result is in line with the findings of Sheriff *et al.* (2020), who believed that plants with wider spacing absorb more sunlight, moisture, and nutrients than those with smaller spacing. According to Lee *et al.* (2021), temperature and solar radiation have a significant impact on rice initial growth, which lends further credence to this claim.

The plants that stood taller at 63 DAP were produced by plants from 35 cm x 35 cm plots where seedlings were transplanted at 14 days after planting and plants from 35 cm x 35 cm plots where seedlings were transplanted at 28 days after planting under the irrigated ecology and rainfed ecology, respectively. The plants probably had more canopy architecture than the others. The architecture of these plants promoted better photosynthesis and, as a result, better vegetative growth. This result is in line with the findings of Sherif *et al*. (2020) and Dzomeku *et al.* (2016). They contended that taller plants are the result of wider spacing or better soil amendment.

The least amount of plant height was produced by plants from 25 cm x 25 cm plots where seedlings were transplanted 28 days after planting, and plants from 20 cm × 20 cm plots where seedlings were transplanted 14 days after planting grown under rainfed and irrigated rice, respectively. This could be attributed to the rice plants' close proximity to one another, which increased competition for nutrients and sunlight. This assertion is supported by Bissah *et al.* (2022), who showed that stressed rice plants grow shorter.

The highest tiller count per plant was produced by plants from 35 cm x 35 cm plots (Figure 1) and plants from 35 cm x 35 cm plots where seedlings were transplanted at 28 days after planting (Table 16). These plants were grown under rainfed and irrigated rice, respectively. Plants spacing 35 cm x 35 cm might have provided more sunlight, moisture, and nutrients, which improved plant growth and development and increased the amount of tillers produced when the plants reached their maximum tillering stage. This claim is supported by other research studies by Sanjeewanie Ginigaddara and Ranamukhaarachchi (2011) and Ahtisham Tahir *et al.* (2018). The lowest number of tillers per plant observed in plots with plant spacing 20 cm × 20 cm was likely caused by increased competition among plants planted with 20 cm x 20 cm spacing for nutrients and solar radiation. This finding is supported by Yussif's (2015) findings who reported that the competition from closer plants led to fewer number of tillers produced.

At DAP 84, the highest effective tiller count was produced by plants from 35 cm x 35 cm plots where seedlings were transplanted at 14 days after planting under the rainfed and irrigated rice ecology, respectively (Tables 15 and 16). The differences in tillering were most likely caused by their improved capacity to establish and usage of growth resources produced by spacing and soil amendment. This conclusion is supported by studies by Kshkooll *et al.* (2020), Abdul Halim *et al.* (2018), and Hasanuzzaman *et al.* (2009) who stated that plant ability to establish well and utilize nutrients and solar radiation determined how well it tillers.

Data on chlorophyll were only collected on irrigated rice. Plants with the highest chlorophyll at 63 DAP came from 35 cm x 35 cm plots where seedlings were transplanted 14 days after planting. The space and reduced competition created by the 35 cm x 35 cm plant spacing which exposed more of the rice plants' leaves to sunlight, may be the cause of the high chlorophyll in these plants. Abdul-Rahman (2019) agreed with this statement by indicating that wider spacing improved the plant's absorption of nitrogen, magnesium, iron, and potassium which enhanced chlorophyll production. It might also be because the rice plants were transplanted early, which reduced transplant shock and improved establishment, leading to higher levels of chlorophyll production. Studies by Yang and Lee (2001) backed up this claim.

8.1.2.3 Number of days to 50 % flowering, straw weight, number of panicles and number of spikelets per panicle

Under rainfed ecology (Table 18) and irrigated rice ecology (Table 19), the plants from 35 cm x 35 cm plots where seedlings were transplanted at 42 days after planting took the longest days (122.43 days and 122 days), respectively, to flower. The larger spacing of 35 cm by 35 cm might have encouraged greater nutrient, moisture, and sunlight availability, while the late transplanting that is 42 days after planting promoted longer period of the rice vegetative growth stage. This is supported by the research conducted by Marie-Noel (2021) who reported that longer vegetative growth of rice led to delayed flowering of the rice plants. In rainfed rice ecology, the shortest flowering days were observed in plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting. This was most likely caused by the rice plants' early establishment and increased competition for nutrients, which led to a shorter vegetative stage. This was corroborated by Lee *et al.'s* (2021) findings, which showed that transplanting younger seedlings produced earlier heading or flowering than transplanting older seedlings.

The highest straw weight was produced by plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting and by plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting, respectively, under the rainfed rice ecology and irrigated rice ecology. The higher straw production per unit area observed these plants might have resulted from the earlier transplanting and closer spacing. According to Ram *et al.* (2014), closer spacing produced a yield that was approximately 12.30 % higher than wider spacing where grain yield was positively correlated with straw yield.

Plants from 30 cm x 30 cm plots where seedlings were transplanted 35 days after planting produced the least amount of straw. This could be that the interaction of wide spacing and delayed transplanting did not promote plant biomass production per unit area. As a result, there was less straw weight and less straw accumulation per unit area. This conclusion was corroborated by studies by Tadese *et al.* (2019) and Asmamaw (2017), which showed that closely spaced rice plants produced more straw per unit area than widely spaced plants.

The plants with the highest panicle numbers per plant under the rainfed rice ecology were those planted with 35 cm x 35 cm spacing where seedlings were transplanted 21 days after planting. Under the irrigated ecology, the highest panicle numbers per plant were those planted with the spacing 35 cm x 35 cm where seedlings were transplanted 14 days after planting. The early transplanting might have enhanced the ability of the plants to make better use of the nutrients and solar radiation offered by the wider spacing. The results of Wang *et al.* (2020) lend credence to this claim by stating that wider spacing of plants ensured better nutrient availability, particularly nitrogen, which promoted higher dry matter accumulation and quality nutrition of the plants.

Under rainfed ecology, plants from 20 cm × 20 cm plots, where seedlings were transplanted 42 days after planting, had the lowest panicle number. There may have been fewer panicles per plant as a result of the delayed transplanting and closer spacing which may have reduced the plants' ability to access the limited nutrients and solar energy offered by the narrow space. Li *et al.* (2020) provided evidence to bolster this claim by showing that delayed transplanting resulted in decreased differentiation of panicle and spikelet degeneration in rice plants, which can ultimately impact yield negatively.

The highest filled spikelets were produced by plants from 35 cm x 35 cm plots where seedlings were transplanted 21 days after planting. This could be because of the right temperature, better nitrogen availability, less competition from weeds and other plants, and greater resistance to pests and diseases by these plants. According to Chowdhury *et al.* (2016), less competition guarantees sufficient nitrogen availability, which improves rice grain filling.

The least number of spikelets per panicle was observed in plants with 20 cm × 20 cm spacing plots where seedlings were transplanted 35 days after planting and from 20 cm × 20 cm plots where seedlings were transplanted at 42 days after planting under rainfed and irrigated rice, respectively. The reason for this could be the delayed transplanting of the seedlings. According to Liu *et al.* (2017), there is a decrease in rice grain yield and sink capacity per tiller as the age of seedlings at transplanting increases due to a decrease in the number of effective panicles per square meter and the number of spikelets per panicle. According to Kumar *et al.*. (2021), the number of spikelets per panicle is directly correlated with crop yield. Therefore, the number of infertile spikelets negatively correlates with grain yield. The current study's results confirmed this assertion as the highest yield, which came from plants planted with 20 cm by 20 cm on plots where seedlings were transplanted at 14 days after planting produced the least infertile spikelets.

8.1.2.4 Thousand seed weight, total grain yield and value cost ratio

The highest thousand seed weight was produced by plants planted with 35 cm x 35 cm spacing on plots under rainfed conditions where seedlings were transplanted at 14 days after planting and plants planted with 35 cm x 35 cm spacing on plots under irrigated rice where seedlings were transplanted at 28 days after planting. The wider spacing, that is 35 cm by 35 cm may have contributed to the higher thousand seed weight by creating a favorable environment. This assertion is supported by research carried out by Roshan *et al.* (2011) and Sanjeewanie Ginigaddara and Ranamukhaarachchi (2011), which showed that earlier transplanting and wider spacing caused plants to grow vigorously and produced heavier seeds.

Plants planted with 25 cm by 25 cm spacing on plots where seedlings were transplanted 21 days after planting produced the highest yield under the rainfed rice ecology, with yield value of 9194 kg ha^{-1}. This yield was followed by 8632 kg ha^{-1}, 7141 kg ha^{-1}, and 6597 kg ha^{-1} which were statistically apar with the highest yield which were obtained from plants planted with 20 cm × 20 cm spacing on plots where seedlings were transplanted at 14 days after planting, plants from 25 cm x 25 cm plots where seedlings were transplanted at 14 days after planting, and plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting, plants from 30 cm x 30 cm plots where seedlings were transplanted at 21 days after planting. Under the irrigated rice ecology, the highest grain yield of 7810 kg ha^{-1} was produced by plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting. These plants were followed by plants from 25 cm x 25 cm plots where seedlings were transplanted at 14 days after planting, yielding 6455 kg $ha^{-1,}$ which was within the achievable yield range of 6 to 8 t ha^{-1}. Plants from 35 cm by 35 cm plots, where seedlings were transplanted 42 days after planting, produced the least amount of grain (1632 kg ha^{-1}). The variation in yield is a reflection of the variations in the synergistic impact of transplanting time and spacing. The early rice transplanting (14 days after planting and 21 days after planting) was well received by the space made available by plants from 20 cm x 20 cm plots and plants from 25 cm x 25 cm plots. Plants transplanted at 21 days after planting fared better in plots with 20 cm x 20 cm spacing, while plants transplanted at 14 days after planting fared better in plots with 25 cm x 25 cm spacing. producing a higher yield. The plants grew quickly as a result of the aforementioned interactions, producing more seeds per unit area. This assertion is supported by research by Sanjeewanie Ginigaddara and Ranamukhaarachchi (2011) and Roshan *et al*. (2011), which showed that earlier transplanting and wider spacing cause the plant to grow vigorously, producing more and heavier seeds.

When it comes to technology adoption and sustainability, cost is a major factor. To ascertain the costs associated with implementing the various technologies, as well as the returns and profitability of the technology, the value cost ratio and benefit cost analysis were performed. Due to the high yields or returns from these practices, it was observed that plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting and plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting were more profitable. The results of Hoquea *et al*. (2022) and Lawal *et al.* (2023), who observed a notable rise in the profit efficiency of rice technologies with increased productivity, are consistent with this finding. Given that they are more profitable, this study recommends using 20 cm × 20 cm plots for plants where seedlings were transplanted at 14 days after planting and 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting for rice production in the study area. This claim was corroborated by Lawal *et al.'s* (2023) findings, which showed that rice farmers who used technology saw increases in their net profit and gross margin.

8.1.3 Effects of variety, spacing and soil amendment on growth and yield of rice

8.1.3.1 Soil physio-chemical properties

In general, the soil nutrient levels were low for enhanced rice production under the low-land rice ecology, according to the analysis of the soil and soil amendment used. According to research by Buri *et al.* (2010), these nutrient levels or soil properties are ideal for rice cultivation: N (0.88 g kg^{-1}), carbon (9.1 g kg^{-1}), magnesium (2.5 mg kg^{-1}), phosphorus (3.2 mg kg^{-1}), potassium (0.3 kg^{-1}), calcium (4.8 kg^{-1}), and pH of 5.2. This implies that study area's soil is deficient in nutrients and requires appropriate soil amendment for both profitable and sustainable rice production. From the analysis of the soil, the soil's textural classes in the experimental field at Sagnarigu Kukuo were clay which made up 6.72%, silt which made up 31.95%, and sand which made up 50.57% of the soil particles. This finding is in line with those of Joseph and Issahaku (2015), who found that the northern regions of

Ghana have sandy soils. At the end of the experiment, organic matter had increased, nitrogen had decreased, and the acidity of the soil had decreased. The claim by Baanante *et al.* (1992) that roughly two-thirds of the nitrogen applied to cereals is gathered in the grain and removed from the field during harvest is most likely what caused the decrease in nitrogen. The remaining nitrogen would not always be cycled back into the soil; instead, it would be stored in the Stover as indicated by Issahaku (2020). The soil's extractable bases (Ca, K, and Mg) rose while its P content dropped.

The acidity of the soil was decreased on the treatment plots where 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N were applied, and plots where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, and 3 plots where 7.5 kg/ha N, P, and K was applied. This was most likely brought on by the compost's negatively charged sites, which balance out excess H^+ ions in the soil and lessen the acidity of the soil. This claim is supported by McCauley *et al*. (2017), who showed that organic matter has negatively charged sites that could bind to excess H^+ ions in acidic soils and neutralize them, raising the pH of the soil. In contrast, lower pH was observed in the plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied. The soil's pH may have dropped as a result of increased hydrogen ion release during the nitrification process linked to the applied sulfate of ammonia. Bell and Mathesius (2019) corroborated this claim by showing that ammonium fertilizers such as urea, ammonium sulfate, and ammonium nitrate, had the most potential acidifying the soil because their nitrification process releases more hydrogen ions.

While the remaining soil amendment treatments showed a decrease in total nitrogen, the plots that received 10 t/ha compost + 18.75 kg/ha N, P, and K + 13.13 kg/ha N were able to maintain total nitrogen. The increased acidity in the soil could have been caused by the release of additional nitrogen into the soil during the mineralization process that occurs when mineral fertilizers break down. This conclusion is supported by Wibowo and Kasno's (2021) finding, which showed a positive correlation between rising soil organic matter content and rising soil total nitrogen. More K, Ca, and Mg were observed in plots treated with 10 t/ha compost plus 18.75 kg/ha N, P, and K plus 13.13 kg/ha N than in any other treatment.

8.1.3.2 Vegetative growth

The Mandii plants' superior varietal traits in utilizing soil nutrients may have contributed to the observation of their superior growth in the early stages of plant development. It is observed that the indigenous varieties in Guinea savannah zone of Ghana grow taller than the improved varieties. The tallest plants were produced from plants which were transplanted with spacing of 25 cm x 25 cm. This could be that these plants received more moisture, nutrients, and sunlight. This result is in line with the findings of Sheriff *et al*. (2020), who reported that plants with wider spacing absorbed more sunlight, moisture, and nutrients than those with smaller spacing. The highest plant height was produced by plants on plots where 37.5 kg/ha NPK + 26.25 kg/ha N were applied. This could be attributed to better release of nutrients at different times in a more accessible form from these plots. Because the plants in these treatment plots had easier access to nitrogen, their vegetative growth and height increased. This claim was corroborated by Buri and Issaka (2016), who showed that plant height was significantly impacted by increased nitrogen levels in rice plants. At 42 DAP, the interaction of chemical fertilizer application and variety had no effect on plant height; however, Atakora *et al.* (2019) found that the interaction of chemical fertilizer and variety has an impact on plant height. Similar to what was seen in 42 DAP, Mandii plants probably made better use of the soil moisture and soil amendment applied because they produced the tallest plants. This assertion is supported by Sherif *et al.* (2020) and Dzomeku *et al.* (2016), who showed that plant height was influenced by moisture, spacing and fertilizer application. Plants transplanted with 25 cm × 25 cm spacing probably had wider canopy than plants transplanted with 20 cm × 20 cm spacing which meant that more sunlight was absorbed, improving photosynthesis and, ultimately, vegetative growth. Plants on plots where foliar applications of organic fertilizers were carried out produced the shortest plant height. This could be attributed to either inadequate nutrient uptake from plant foliage or insufficient amounts of nutrients, nitrogen in particular supplied to plants from the foliar fertilizers.

Plants of Moses varietal traits competed better for the nutrients, moisture, and sunlight provided by spacing 25 cm x 25 cm and soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and were superior in producing tillers at the maximum tillering stage of the plants. Other studies such as Kshkooll *et al.* (2020), Abdul Halim *et al*. (2018), and Hasanuzzaman *et al.* (2009) are in line with this finding. Surprisingly, Moses and Gbewaa plants did not respond well to 20 cm × 20 cm spacing and foliar application of 18.5 kg/ha N, 6 kg/ha P K, and 18.5 kg/ha N soil amendment, which resulted in a few tillers at the maximum tillering of the rice plants.

Since chlorophyll is a necessary component of photosynthesis, it plays a significant role in the growth and development of plants. According to Zheng *et al*. (2012), improved spacing and nutrient availability will boost photosynthesis or chlorophyll fluorescence and result in a 10% increase in yield. The reason why plants transplanted with a 25 cm x 25 cm spacing produced more chlorophyll could be because this spacing exposed two thirds of the rice plants' lower leaves to sunlight, improving the nitrogen status of the plant and reducing competition between the plants. Compost in combination with chemical fertilizers or basal and top dressing of sole chemical fertilizers were better at enhancing the plants' chlorophyll content. This may be explained by these fertilizers better release of nutrient for plant uptake or better preservation of soil fertility and health for the plants' healthy growth. The studies of Khan (2018), Ali *et al.* (2020), Esfahani *et al.* (2019), and Gholizadeh *et al.* (2017) are consistent with this assertion as they explained that the effect of chemical and organic fertilizers positively impacted the formation of chlorophyll in plants. This could also be attributed to improved supply of potassium to the plants by these soil amendments. Hou *et al.* (2020) confirmed this by indicating that moderate potassium deficiency in rice may also be the cause of leaf chlorophyll concentration. The reason why Mandii, Gbewaa, and Agra plants produce more chlorophyll may be because they are more adapted to the soil and efficiently utilized its resources. Junfei *et al*. (2017), on the other hand, found that plants with lower chlorophyll content rather had higher photosynthetic rate and yields than plants with normal pigmentation. This suggests that higher grain yield can be achieved by plants with reduced chlorophyll.

At 63 DAP, plants of Agra and Mandii planted with 25 cm x 25 cm spacing on plots where 37.5 kg/ha N, P and K + 26.25 kg/ha N were applied produced the greatest leaf area index. This was probably due to better varietal traits from the two varieties which responded well to the better supply of nutrient, water, and light from the spacing and the soil amendment. Haque and Haque (2016), Mahajan *et al.* (2012), Maftukhah *et al.* (2019), Begum (2014), and Venkatesh (2013) are among the other studies that supported this assertion.

Digang plants that were transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha of N, P, and K were applied, Moses plants that were transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha of N, P, and K was applied, and Moses plants that were transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied yielded the lowest leaf area index. This might be that the less nutrient supplied from only the basal application of chemical fertilizers or foliar organic fertilizers and narrow spacing led to poor leaf quantity and arrangement in Digang and Moses plants.

In both the vegetative and reproductive stages of the rice plants, plants from Agra and Mandii displayed superior genetic traits in terms of the quantity and arrangement of leaves, the number of stems, and the number of ears. This result is consistent with several investigations. For example, Yu *et al.* (2020) found that the leaf area index and biomass in rice plants increase with increasing amounts of nitrogen applied.

Digang plants transplanted with 20 cm x 20 cm spacing taking fewer days to flower, was possibly due to shorter maturity varietal traits induced by higher temperatures and less nutrients, moisture and sunlight.

The reason behind the delayed flowering of Mandii plants transplanted with 25 cm × 25 cm spacing could be the innate ability of Mandii to react to continuous and better supply of factors that facilitate vegetative growth of the plant. Related findings include those of Ezin *et al.* (2022), who found that a combination of temperature and wider spacing caused rice plants to remain in longer vegetative stage. This could also be that the interaction the Mandii variety and 25 cm x 25 cm resulted in long production of carbohydrates in the plants which resulted in longer vegetative stage of the plants. Vergara *et al.* (1985) who found that delayed plant production of carbohydrates delayed rice plant flowering confirmed this assertion.

The study found that Mandii plants were able to support a longer vegetative growth stage in rice crops when they were provided with sufficient and prolonged nutrients from the most effective soil amendments (37.5 kg/ha NPK + 26.25 kg/ha N, and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N). The nutrients provided by 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and NPK + 26.25 kg/ha N unearthed the varietal characteristics of Mandii plants.

8.1.3.3 Root weight and shoot biomass accumulation

Root weight per plant was influenced by the interactive effect of variety and spacing. Ighere *et al.* (2019) who studied plant spacing and rice variety and found that these factors had a major impact on root growth and rice performance, are consistent with this finding. Mandii plants transplanted with spacing 25 cm x 25 cm producing the higher root weight could be attributed to Mandii plants' better innate ability to adapt to the environment created by 25 cm 25 cm spacing which resulted in better root formation and development. Mandii plants have continuously demonstrated higher performance when optimum quantity of nitrogen was provided from the most effective soil amendments in the study, that is 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N, and 37.5 kg/ha NPK + 26.25 kg/ha N. Mandii plants on these plots produced higher root weight as a result of better space, and more water and nutrients made available. This is supported by a study by Kaysar *et al.* (2023), which discovered that the interaction of nutrients and water had a significant and positive effect on the rice plant's growth indices. The above claim is supported by a different study by Wang *et al.* (2022b), which found a positive correlation between the increased rate of root volume density, root dry weight, and root weight density and both water use efficiency and nitrogen uptake efficiency.

The plants with the highest plant biomass were found on plots treated with either 37.5 kg/ha NPK + 26.25 kg/ha N or 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N. This could be due to rice plants from plots where chemical fertilizers alone or both chemical and compost fertilizers were applied received better nutrition than the others. This resulted in better dry matter accumulation and shoot production in these rice plants. The results of Wang *et al*. (2022a) supported this conclusion as they indicated that plants which received better nutrients especially nitrogen produced higher shoot or vegetation.

Plots that received foliar applications of 18.5 kg/ha N, 6 kg/ha P K, and 18.5 kg/ha N probably released low levels of nitrogen, which in turn caused low shoot production which resulted in decreased straw weight in the plants. Phung *et al.* (2020) finding is consistent with this assertion as they reported that low levels of nitrogen in the soil led to low shoot production in plants.

8.1.3.4 Grain yield and components of yield

The number of panicles was impacted by the interactive effects of variety, spacing and soil amendment. The highest panicle numbers were produced by Moses transplanted with 20 cm x 20 cm spacing on plot treated with 10 t/ha compost, 18.75 kg/ha of N, P, and K, and 13.13 kg/ha of N, and Digang rice transplanted with 25 cm x 25 cm spacing on plot treated with 37.5 kg/ha of N, P, and K, and 26.25 kg/ha of N. The reason for this could be that the plants of Moses and Digang responded more favorably to spacing of 20 cm x 20 cm and 25 cm x 25 cm respectively, when given nutrients, particularly nitrogen from soil amendments of 10. t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and 37.5 kg/ha

NPK + 26.25 kg/ha N respectively, which encouraged higher dry matter accumulation and quality nutrition. Moses plants that were transplanted with 20 cm × 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied had the lowest panicle number. This could be that Moses plants' response was low because of the narrow spacing and the inadequate supply of nutrients from foliar fertilizers, that is 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K plus 18.5 kg/ha N. This resulted in a low accumulation of dry matter. The findings of Wang *et al*. (2020) corroborate this claim. Roshan *et al.* (2011) discovered that a higher number of panicles was obtained when plant density decreased, whereas Abookheili and Mobasser (2021) showed that the number of panicles per square meter increased when planting density was increased. These findings lend support to narrow spacing, that is 20 cm x 20 cm.

The interaction of variety, spacing and soil amendment influenced spikelet formation in the rice plants. Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied., plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and Gbewaa plants transplanted with a 25 cm x 25 cm spacing on the plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest spikelet per panicle. This might be that Mandii and Gbewaa plants' superior varietal traits resulted in production of more spikelets when they interacted with a wider spacing of 25 cm x 25 cm, which contained better nutrients and sunlight. This claim is supported by the research of Rebecca *et al.* (2004), Gunasekaran *et al*. (2023), Reuben *et al.* (2016), and Iqbal *et al.* (2022) who indicated that variety interaction with wider spacing promoted more spikelet production. On the other hand, the studies of Buri *et al*. (2016) and Pokharel *et al*.

(2018) found out that narrow spacing was more effective than wider spacing in producing more spikelets per unit area.

Mandii plants on plots treated with 37.5 kg/ha of NPK yielded the greatest number of infertile spikelets. This could be due to insufficient nitrogen supply from the soil amendment applied. The result of Chowdhury *et al*. (2016) is consistent with this result as they indicated that low supply of nitrogen to plants resulted in less grain filling which facilitated infertile spikelet production.

Thousand seed weight was not influenced by the interactive effect of variety, spacing and soil amendment. The main effect of variety influenced thousand seed weight. This finding is consistent with the findings of Venkatesan *et al.* (2023) who reported that seed weight differed depending on rice variety. This was probably due to Mandii's superior genetic makeup, which encouraged longer, wider, or thicker grains, as well as larger grain shapes and higher amylose content which accounted for its highest thousand seed weight. This claim is corroborated by the research conducted by Chen *et al*. (2021) and Venkatesan *et al.* (2023) who argued that heavy seeds are produced by rice varieties that have larger and thicker seeds which contain higher amylose.

Thousand seed weight was greatly influenced by spacing. Plant spacing 25 cm x 25 produced higher thousand seed weight. The results of Zuo *et al*. (2021) concurred with this conclusion as they stated the wider the spacing of rice plants the higher the seed weight. The reason why plants spaced 25 cm x 25 cm produced the largest seed weight could be because the wider spacing created more favorable environment for the plant to grow vigorously, which led to the production of larger and heavier seeds. The results of Roshan *et al.* (2011) lend credence to this claim by arguing that when favourable conditions are provided to rice plants it results in the production of heavier seeds.

Thousand seed weight was impacted by the soil amendments supplied. Higher thousand seed weights were obtained in plots where 37.5 kg/ha NPK + 26.25 kg/ha N, and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N soil amendments were applied. This could be because these soil amendments provided enough nutrients, which improved grain filling and increased seed weight. This claim is supported by the research conducted by El-Katony *et al.* (2021) and Abdul Halim *et al.* (2018) who revealed that fertilizers that ensured adequate supply of nutrients helped plants to produce weightier seeds.

The highest grain yield of 8169 kg ha^{-1} was produced by Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied. This was followed by Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and Gbewaa plants transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost, 18.75 kg/ha N, P, and K, and 13.13 kg/ha N were applied. The respective yield values obtained were 7172 kg ha^{-1}, 6210 kg ha^{-1}, and 6003 kg ha^{-1}, which were statistically same as the highest yield. Their yield fell between 6 and 8 t ha^{-1}, which is within the achievable yield range. The synergistic effects of variety, spacing and soil amendment reflected in the yield variations. Mandii plants that were transplanted with 20 cm x 20 cm spacing produced the highest yield on the plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied. This could be attributed to the Mandii plants' varietal traits adapting well to the environment created by the 20 cm x 20 cm spacing and the nutrients released from the 37.5 kg/ha N, P, and K + 26.25 kg/ha N soil amendment. The higher yield from Agra plants transplanted with 25 cm × 25 cm spacing on plot treated with 37.5 kg/ha N, P, and K plus 26.25 kg/ha N was also observed. This may be because Agra varietal trait plants respond well to wider spacing of 25 cm by 25 cm, releasing nutrients from the 37.5 kg/ha N, P, and K + 26.25 kg/ha N. The varietal traits of the Gbewaa plants responded well to both spacings, with nutrients made available from 37.5 kg/ha N, P, and K + 26.25 kg/ha N and 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N soil amendment. Agra and Gbewaa plants were improved varieties, and the improved varieties are associated with higher yields.. This is corroborated by Wang *et al.* (2022a) studies, which reported that improved varieties used increased yield from 6.57 t ha^{-1} to 9.49 t $ha^{-.1}$. Furthermore, Stokstad (2023) found that using an improved variety increased yield by 40%. On the other hand, when compared to the improved varieties, the local variety Mandii produced higher yield due to its superior agronomic traits. Wang *et al*. (2022a) corroborated this claim by stating that rice cultivars with greater agronomic traits produced higher grain yield.

Since the cost of implementing a technology is important, the value cost ratio (VCR) was used to assess each technology's profitability. Each technology's total cost of operation as well as the total revenue from sales of each output were computed. Plants of Gbewaa which were transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied; plants of Mandii which were transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied; and plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied. generated larger earnings. This resulted from the increased yield that these methods produced. Rahman and Connor

(2022) supported this claim by showing that adopting farmers varieties experienced 35% increase in rice yield and 73% increase in farm income.

The highest value cost ratio of 2.51, 2.24, and 2.03 was produced by Agra rice plants transplanted with 20 cm x 20 cm spacing on a plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied; Gbewaa transplanted with 20 cm x 20 cm spacing on a plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied; and Gbewaa transplanted with 25 cm x 25 cm spacing on a plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied. Foliar fertilizers (18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N) were significantly less expensive than other fertilizers, which is why the B/C values were higher. Because farmers cannot afford to apply fertilizers at the proper and sufficient rate for production, this may be the reason for the low adoption of fertilizer technology in the study area. Adzogah, (2023) support this conclusion by showing that farmers' profitability and crop yield were significantly impacted by the rising cost of fertilizers.

The parameters measured with grain yield showed strong correlation (r = 0.68, r = 0.50, and r = 0.50) with root weight, 50% flowering, and panicle number, respectively (Table 41).

8.1.4 Milling characteristics of rice (*Oryza sativa* L.) as affected by variety, spacing and soil amendment

8.1.4.1 Foreign matter, admixture and discoloured grains

All materials other than rice paddy, such as dirt, stones, weed seeds, broken pieces of rice stalk, dust, husk, and dead insects, are referred to as foreign matter. Poor farm sanitation and post-harvest handling of the grains obtained in this treatment field could be the reason for the highest amount of foreign matter found in Agra transplanted 20 cm apart on a plot where 37.5 kg/ha of N, P, and K was applied. This finding is supported by Lantin's (1999) discovery, which showed that paddy rice may become contaminated with sand, soil, stones, and animal feces during the sun-drying process. On the other hand, all the samples from treatments with no foreign matter came from plots that received applications of 37.5 kg/ha NPK + 26.25 kg/ha N and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N. This may have happened because plants on plots treated with 37.5 kg/ha NPK + 26.25 kg/ha N or 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N supported the vegetative growth of Mandii, Agra, and Digang plants. This, in turn, suppressed weeds, resulting in less or no weeds on these treatment fields. Another possibility is that the grains from these fields were treated carefully during the paddy's drying or packing process. This claim is supported by the results of Abera *et al.* (2021). They claimed that a number of factors, including soil conditions, crop agronomic practices, harvesting and postharvest procedures, weather during crop production, and genetic factors (variety), all have an impact on paddy quality. Poor farm sanitation, improper harvesting techniques, and improper handling of the paddy after harvest are likely to be blamed for the highest admixture levels observed in Agra transplanted 20 cm apart on plot that received 37.5 kg/ha of N, P, and K. soil amendment. This claim is supported by Abera *et al.* (2021) which showed that subpar postharvest and harvesting techniques have an impact on paddy rice quality. Additionally, it was noted that all of the samples from treatments with lower admixture came from plots that received fertilizers containing either 10.t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N, or 37.5 kg/ha NPK + 26.25 kg/ha N. It is possible that plants on plots treated with 37.5 kg/ha NPK + 26.25 kg/ha N and 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13

kg/ha N significantly inhibited the growth of stray rice, which reduced the amount of other rice grains or underdeveloped rice grains in the paddy after harvest.

Gbewaa plants that were transplanted with 20 cm × 20 cm spacing on plot where 37.5 kg/ha of N, P, and K were applied produced the highest percentage of discolored grain. This could have been caused by inadequate drying, which led to fungal attack on the grains. This claim is consistent with the findings of Amini and Asoodar (2015), who reported that fungal agents such as Alternaria sp., Curvularia sp., Cladosporium spp., and Bipolaris spp. are among the microorganisms that cause rice grain discoloration.

8.1.4.2 Green, red, chalky and immature grains

Number of green grains in the grains was significantly ($P < 0.05$) influenced by variety, spacing and soil amendment. Mandii plants that were transplanted with 20 cm × 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied had the highest green grain. This was probably due to early harvesting the rice plants on these treatment plots. This claim is supported by the discovery made by Chao *et al.* (2022), which showed that green rice grains were associated with rice grains that were harvested before their maturity. They suggested that green grains are harvested prior to reaching their true maturity. It's been observed that green grains are more nutritious than brown rice that has matured. Surprisingly, Sugg (2023) claimed that because green grains contain protein, riboflavin, and other nutrients, they were considered to be of higher nutritional value and should be of good quality rather than a defect. Mandii plants transplanted on plot where foliar applications of 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K were made took longer period to flower, which led to longer maturity period which might have caused the high production of green grains. Surprisingly, Vergara *et al.* (1985)

reported that wider spacing supported longer maturity days, and longer maturity should give more green grains. However, in this current study 20 cm x 20 cm, which was narrower than 25 cm x 25 cm promoted higher production of green grains in the rice.

Highest percentage of discolored grain was found in Gbewaa plants transplanted 20 cm apart on plot treated with 37.5 kg/ha of N, P, and K. This could be attributed to low nitrogen supply that hindered the healthy growth and operation of the high input demand variety Gbewaa, which in turn produced the discolored grains. This conclusion is supported by Ighere *et al.* (2019) findings which indicated that the quality of rice was impacted by the interaction between variety and spacing. Hindersah *et al.* (2022) also mentioned that the interaction between planting techniques and soil amendments determined grain quality. According to Kakar *et al.* (2020), the combination of chemical and organic fertilizers has an impact on grain quality.

The highest red grain was found in Digang transplanted with 20 cm × 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied. These plants were followed by Digang transplanted with 25 cm × 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied. This was likely because of higher accumulation of carotenoids in Digang on plots where 18.5 kg/ha N, 6 kg/ha P K, and 18.5 kg/ha N were applied. Mbanjo *et al.* (2020) confirmed this assertion by indicating that red and black rice grains were produced when rice variety accumulated high concentration of carotenoids, whereas white rice accumulated very little of these compounds. Given that moisture content of rice grains at harvest play significant role in determining the quality of rice, Brinkhoff *et al.* (2023) reported that the high moisture content of the grain may have also contributed to the production of red grains.

Agra plants that were transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest amount of chalky grain. This was likely caused by the plant having less nitrogen available, particularly during the grain filling stage. It could also be due to the exposure of the grains to higher temperatures during and after harvest. This claim is supported by Cheng *et al.* (2019), who showed that temperature was one of the main abiotic factors influencing grain chalkiness. It was noted that the plot where 37.5 kg/ha NPK + 26.25 kg/ha N were applied produced fewer chalky grains. This was likely because there was enough nitrogen present, which encouraged the production of acceptable amounts of protein and starch granules and, as a result, produced fewer chalky grains. This claim is corroborated by Zhao *et al.* (2020), who showed that applying nitrogen fertilizer, for instance, can drastically lower the rate of chalky kernels in rice. On the other hand, an overabundance of nitrogen may also result in an increased production of chalky kernels.

Mandii transplanted with 25 cm x 25 cm spacing produced the highest number of immature grains on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied. This was likely because the rice was harvested early, which led to partially chalky kernels. On the other hand, head rice yields and milling recovery may be negatively impacted by immature rice kernels because they are extremely thin, chalky, and easily broken. IRRI (2010) supported this assertion by stating that immature grains reduces the head rice yield as they are easily broken..

8.1.4.3 Crackness, broken and brown yield

Mandii plants transplanted with 20 cm × 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest crackiness.

This could be that there was over-drying of the grains obtained from plants on this treatment plot which decreased grain moisture content leading to the crackness of crucial number of grains. This claim is supported by the study Owusu *et al.* (2020) carried out, which found that rice crackiness started when moisture content of grain was less than 14.2% or 18.3% for varieties that were less susceptible or susceptible to cracking respectively. In addition, varietal characteristics, fertilizer type and timing of application may all contribute to crackiness of grain. Odoom *et al*. (2021) findings are in line with this assertion as they stated that paddy crackness decreased when appropriate varieties and timing or kind of input application were employed in the rice production.

The reason for the highest number of broken grains among Agra plants transplanted with 25 cm x 25 cm spacing on plot treated with 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar was probably due to genetic or unfavorable environmental factors. This supported the claim made by Jiang *et al.* (2019) that certain varieties, like long, brittle grain, are prone to breaking due to their genetic makeup. For instance, African rice (*Oryza glaberrima*) breaks more easily than Asian rice (*Oryza sativa*). It has also been observed that aromatic rice is more likely to break and crack than nonaromatic rice. Anjna *et al*. (2019) shared similar view as they stated that aromatic rice grains break more easily than the others. In addition, rice may be more prone to breaking due to the increased moisture content during grain harvesting. Zareiforoush *et al.* (2010) reported that greater percentage of rice grains broke when the grains moisture contents were either too high or too low.

Rice plants transplanted with 25 cm x 25 cm recorded the highest broken rice than those that were transplanted with 20 cm x 20 cm. The plants that received bigger spacing produced higher broken grains. Contrary to this is the findings of Komalawati *et al*. (2023)

which reported that plants compete more with one another for light, air, and nutrients when spaced closely apart, which causes shadowing, grain loss, and a rise in broken grains.

Mandii plants ransplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and Gbewaa plants transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied produced the highest brown yield. The highest brown yield obtained was probably due to the good grain yield from the best-performing treatments, as grain yield and brown yield have a positive correlation. This claim is supported by the results of Xu *et al*. (2020), which showed that grain yield had significant positive correlation with the brown rice. Plants transplanted with 25 cm x 25 cm did better than those transplanted with 20 cm x 20 cm, which may have been because there was less competition between the plants for nutrients, air, and solar energy, which led to better plant growth and an increase in grain and brown yield. This claim was corroborated by Aklilu (2020), who showed that closer spacing can increase competition between plants for light and nutrients, resulting in weaker, thinner plants, less full kernels, and a decrease in grain yield.

Brown grain production was higher in plants on plots treated with either 37.5 kg/ha NPK + 26.25 kg/ha N or 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N. This might be that the improved fertilizer type and rate application led to higher rice yield and quality. The results of Liu *et al.* (2021) corroborated this claim as it explained that recommended fertilizer type and rate application on rice fields produced higher yield and quality grains.

Additionally, the superiority of the plants on the plots treated with 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and the plants on the plots treated with 37.5 kg/ha NPK + 26.25 kg/ha N may have resulted from a better supply of nitrogen during the later stages of the plant's life, which raised the dimensions of the brown yield. Dou *et al*. (2024) lend credence to this assertion as they indicated that when there is adequate supply of nitrogen brown yield is high.

8.1.4.4 Husk yield, grain length, grain width, and grain length – width ratio

The highest husk yield was produced by Mandii plants transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar were applied. This could be because Mandii had superior varietal traits in producing larger husks. In support of this claim, Katsura and Nakaide (2011) showed that under high-yielding aerobic culture, rice grain weight is significantly influenced by the size of the husk. This could also be the result of an inadequate supply of nitrogen from the 18.5 kg/ha N, 6 kg/ha P, and 6 kg/ha K + 18.5 kg/ha N foliar fertilizer applied in conjunction with the plant spacing 20 cm x 20 cm environment created, which reduced grain filling and decreased grain production which led to the higher production of husks. This claim is further supported by Abera *et al.* (2021), who show that rice quality attributes were significantly influenced by the growing location. This claim is at odds with the findings of Zhao *et al.* (2022), who found that an overabundance of nitrogen can inhibit grain filling and ultimately result in lower rice yield and grain quality.

Variety, spacing and soil amendment influenced significantly ($P < 0.05$) the length of the grains. The longest grain length was produced by Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied; Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied; Mandii transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied; and Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied. This might be because rice from Mandii and Agra have superior varietal traits, particularly those related to quantitative trait loci (QTLs), which encouraged longer grains. This claim supported the findings of Zhang *et al.* (2018), which showed that quantitative trait loci (QTLs) regulate grain size and shape, two crucial factors in determining rice grain yield. Additionally, the 25 cm × 25 cm plant spacing may have contributed to this by giving the plants enough nutrients and solar radiation, resulting in strong plant growth and improved grain filling that led to longer grain length. In support of this assertion, Marie-Noel *et al.* (2021), stated that the best plant spacing enabled plants to develop correctly using more solar radiation and soil nutrients for both its above-ground and underground portions.

The highest grain width was obtained from Digang plants transplanted with 25 cm x 25 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, Digang plants transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, Mandii plants transplanted with 25 cm x 25 cm spacing on plot treated with 37.5 kg/ha N, P, and K + 26.25 kg/ha N; Gbewaa plants transplanted with 20 cm x 20 cm spacing on plot treated with 37.5 kg/ha N, P, and K + 26.25 kg/ha N; Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied; and Agra rice transplanted with 25 cm x 25 cm spacing on plot treated with 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N. This was most likely caused by the right combination of genetic, environmental, and nutritional factors that encouraged the growth and development of rice grains, particularly with regard to grain width. It could also be the influence of nitrogen on the plants. The study of Randy *et al.* (2017) is in line with this assertion as it revealed that the widest rice grain and weight were indirectly influenced by the maximum amount of nitrogen that rice plants absorbed. The finding by Ma *et al.* (2018) that there is a positive correlation between grain weight and grain width lends further credence to this claim.

Mandii plants transplanted with 25 cm × 25 cm spacing on plot treated with 10 t/ha compost, 18.75 kg/ha of N, P, and K, and 13.13 kg/ha of N. produced the highest grain length to width ratio. This was statistically same as what was found in Mandii plants transplanted with 20 cm × 20 cm spacing on plot treated with 37.5 kg/ha N, P, and K + 26.25 kg/ha N, and Mandii plants transplanted with 20 cm × 20 cm spacing on plot treated with 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N. The superior yield parameters and grain length-to-width ratio were likely the result of better varietal traits that responded well to the interaction of any spacing and nutrients, especially nitrogen supplied by 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and 37.5 kg/ha NPK + 26.25 kg/ha N. This claim is supported by the researches conducted by Zhao *et al.* (2022) and Reuben *et al.* (2016) which revealed that varietal traits, plant density and plant nutrition contribute to grain development indices. Besides, this claim is also supported by El-Katony *et al.* (2021) studies, which showed that soil amendment enhanced the width/length ratio of the rice grain. This claim is further supported by Potcho *et al.* (2022), who reported that the application of nitrogen fertilizer resulted in an increase in grain length and length-width ratio. It might also be the result of the right temperature which is facilitated by the supply of potassium, phosphorus, and nitrogen.

8.1.5 Conclusions

The rice farmers, processors and marketers are still using the indigenous techniques for producing, processing and selling rice. This was due to gender inequity, illiteracy and ageing population of the value chain actors. Majority of farmers knew the impact of using certain technology adoption was expensive. This led to partial or inappriopriate adoption of technologies.

The results from the study showed that early transplanting (transplanting when seedlings were 14 to 28 DAP) were superior in terms of the plant growth and yield parameters as well as the grain yield. Widely spaced plants performed better vegetatively which was translated into most of the yield parameters. Under rainfed conditions, plants planted with 35 cm x 35 cm spacing determined tiller count at maximum tillering and effective tillering stage of the plant. However narrow spacing out-performed the wider spacing in terms of per unit area. Plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting produced the highest straw per unit area. In addition, and most importantly, narrow spacing produced the highest grain yield (kg ha^{-1}). For instance, plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 and 14 days after planting highest grain yield and VCR respectively ; hence was the most profitable venture farmers must adopt.

On the other hand, under the irrigated conditions, plants from 25 cm × 25 cm plots where seedlings were transplanted at 14 days after planting produced the highest yield and VCR ; hence the most profitable venture.

Mandii or Agra or Gbewaa varieties, 37.5 kg/ha NPK + 26.25 kg/ha N or 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N, 18.5 kg/ha N, 6 kg/ha P K + 18.5 kg/ha N, and 37.5 kg/ha NPK soil amendments , and 20 cm x 20 cm and 25 cm x 25 cm plant spacing have shown superior performance in influencing most of the growth parameters and yield parameters as well as grain yield. They influenced growth and yield parameters, either individually or in combination with other factors. For instance.

Plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest leaf area index alongside. Plants of Mandii transplanted with spacing 25 cm x 25 cm where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied.

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied., plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where either 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N or 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest grain yield. Plants of Agra rice plants transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied and plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest profit and the highest value cost ratio. The aforementioned treatments that produced the highest grain yield also produced relatively high VCRs.

Plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied

The least chalky grain was recorded in plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied with a value of 2 %. Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest immature grains with a value of 10.20 % whilst plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the least immature grain, with a value of 1.00 %.

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest crackness with a value of 100 % whilst the least crackness was recorded in plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied with a value of 1.80 %, respectively (Table 47). The highest broken grain with a value of 58.60 % was obtained from plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied whilst the least broken grains were obtained from plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied with values of 2.90 % and 2.80 % respectively.

Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Agra transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the longest grain length with values of 7.39 mm, 7.32 mm and 7.30 mm respectively. Plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, recorded the highest grain width with the values of 2.42 mm and 2.41 mm respectively.

Grain development and yield influenced the milling characteristics of the grains. The highest grain yield which was obtained from plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied also produced the best brown yield when milled. Plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied also produced the longest grain length and the highest length-width ratio respectively.

Poor grain yield also influenced the poor milling characteristics of grains. Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied which produced poor yield produced the highest green grains whereas plants of Digang transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied and plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied, both produced the highest red grains. Plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Digang transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and Moses x

25 cm x 25 cm x 37.5 kg/ha N, P, and K + 26.25 kg/ha N with poor yield produced the highest chalky grains. Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied also with low yield produced the highest crackness of the grains.

8.1.6 Recommendation

Rice production, processing, and marketing are mainly characterized by indigenous practices which have contributed to making the local rice business unattractive in Ghana. Some of the misconceptions the value chain actors held were not helping in enhancing technology adoption in the study area. Value chain actors compromised convenience for quality or higher production. Others went back to their indigenous ways due to the unaffordability of the technology. To boost the adoption of improved practices along the rice value chain, certain misconceptions concerning the practices should be known and tackled diligently.

Stakeholders of the rice sector in the country should engage farmers, processors, and marketers by providing targeted education and awareness programs to dispel the misconceptions while facilitating acceptance of improved practices or technologies.

Demographic factors such as gender, educational level, and age of the farmers, processors, and marketers were not at the best in promoting technology adoption. The population of females involved in rice production is low and does not auger well for rice productivity in the study area as females play crucial roles in rice production, processing, and marketing. On the other hand, most of the rice processors and marketers were females. The rice production, processing and marketing enterprise in the two districts are not attracting the very young ones who are 24 years and below. Most of the farmers, processors and marketers have no formal education.

To address these disparities, stakeholders should prioritize training and empowerment programs targeted at female farmers, and of course male processors and marketers and people who are below 25 years old in the study area. These initiatives should focus on building technical and entrepreneurial skills, empowering the targeted gender and age to play a more active role in the rice value chain.

There was low adoption of improved practices or technologies in the study area. Majority of the farmers from the study area did not use the certified seed because the certified seeds were costly. Majority of the farmers selected local varieties and had the belief that the local varieties produce high yield. Most of the farmers selected broadcasting because they could not afford the cost involved in transplanting. This present study revealed that cost considerations often deter farmers from using certified seeds and adopting modern cultivation technologies. Stakeholders should help make technologies such as improved varieties, certified seeds, line transplanting and recommended fertilizer application regime more accessible and affordable. Standardization of most of the activities in the rice value chain will help do away unfairness and promote healthy local rice enterprise which can compete well in the international market.

The study aimed at evaluating the effect of the time of transplanting and spacing on rice growth and yield. Partial adoption of technology is not helping rice production in Ghana. Rice producers who transplant employed indigenous ways of transplanting which involves delay in transplanting and transplanting without definite spacing. These have contributed to the low yield obtained by rice farmers in the study area.

Transplanting with definite spacing improved the soil characteristics as the acidity of the soil was reduced whilst the P, Ca and Mg ions levels in the soil increased by the end of the experiments. The performance of the plants with the widest spacing (35 cm and 35 cm) which were transplanted earliest (14 DAP) were superior in the individual plant growth and panicle production. Plants from 35 cm x 35 cm plots where seedlings were transplanted at 14 days after planting optimized plant height, effective tiller count and chlorophyll production. These plants also maximized panicle production at individual plant level.

Plants from plot with spacing 20 cm x 20 cm or 25 cm x 25 cm which were transplanted early (14 DAP or 21 DAP) performed very well in terms of per unit area. Plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting optimized rice straw production per unit area. Plants from 20 cm × 20 cm plots where seedlings were transplanted at 14 days after planting, plants from 20 cm × 20 cm plots where seedlings were transplanted at 21 days after planting, plants from 25 cm x 25 cm plots where seedlings were transplanted at 14 days after planting and plants from 25 cm x 25 cm plots where seedlings were transplanted at 21 days after planting optimized grain yield.

Therefore, farmers are advised to adopt plant spacing 20 cm × 20 cm or 25 cm x 25 cm when they are transplanting their rice seedlings which should be transplanted at 14 DAP or 21 DAP in the study area and beyond for higher productivity. Further research could be conducted by nursing the seedlings on different days and transplanting them at the same time.

Rice production, processing, and marketing are mainly characterized by indigenous practices which has contributed to making the local rice business unattractive in Ghana. To boost the adoption of improved practices along the rice value chain, certain misconceptions or perceptions concerning the practices should be known and tackled diligently. Other variables or indicators of the adoption of technologies should be tackled head-on. Gender, educational level, and age of the farmers, processors, and marketers were not at the best in promoting technology adoption. The population of females involved in rice production is low and does not auger well for rice productivity in the study area as females play crucial roles in rice production, processing, and marketing. The rice production enterprise in the two districts is not attracting the very young ones who are 24 years and below. Almost 63 % (62.7 %) of the farmers have no formal education. The processors were made up of only 13.6 % males. The least age bracket of the processors was 25 – 35 which formed 4.5 % of the sample population.

Some of the perceptions they held unto were not also helping in enhancing technology adoption. Value chain actors compromised their convenience for quality or higher production. Others went back to their indigenous ways due to the unaffordability of the technology. The majority of the farmers (54.5 %) from the study area did not use the certified seed because the certified seeds were costly. The majority (91 %) of the farmers selected varieties based on their yield. Most of the farmers selected broadcasting because they could not afford the cost involved in transplanting. The stakeholders in agriculture have crucial role in solving the challenges head on. Fertilizer subsidy, effective extension, farmer training and booster packages for rice value chain actors should be encouraged in order to enhance rice business in the Sagnarigu and Kumbungu districts of Ghana.

Transplanting the seedlings when they are younger especially when they are 14 – 21 days after planting optimized plant height and tiller count of the plant. Early transplanting with appropriate spacing (in this case 20 cm x 20 cm and 25 cm x 25 cm) maximized straw weight, and yield per plant as well as the number of panicles and number of effective tillers per unit area.

Further research could be conducted by nursing the seedlings on different days and transplanting them at the same time. Early transplanting coupled with suitable spacing could improve the yield of rice which will consequently translate into improved living standards of the farmer and the family.

Variety, spacing and soil amendment is a promising resources of conservation technology for sustainable rice production, through reduction in the cost of production while improving soil heath and without compromising yields of rice crops. For farmers with a poor resource base, variety, spacing and soil amendment can be a viable option and need to be evaluated further under different rice ecologies. Further research is needed under different ecological systems as this research was carried out under low land rainfed ecology. Significant scope exists to evaluate the environmental impact of variety, spacing and soil amendment in the rice cropping system. Moreover, long-term changes in variety, spacing and soil amendment, and their dynamics under different practices also need to be worked out. Improving the local variety by crossing with varieties of poor milling characteristics followed by selection of desirable crosses would make a serious impact on the value chain actors in the study area. The efficiency of soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N and foliar applied soil amendments and their absorption can also be an important area of research under both rainfed and irrigated conditions.

Technology package involving the use of the right variety, plant spacing and soil amendment will lead to sustainable rice production, through reduction in the cost of production while improving soil heath and without compromising yields of rice crops.

Soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N improved soil physiochemical properties and promoted the growth of rice plant and yield factors. This soil amendment maintained total N and increased K, Ca, and Mg ions in the soil.

Plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N applied, plants of Agra rice transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Mandii transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha each of N, P, and K was applied, plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, and plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced higher effective tiller counts per plant

Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest grain yield of 8169 kg ha^{-1}. This was followed by plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N were applied, and plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied with yield values of 7172 kg ha^{-1}, 6210 kg ha^{-1}, and 6003 kg ha^{-1} respectively which were all statistically the same.

Plants of Agra rice plants transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied., plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha

K + 18.5 kg/ha N foliar were applied, and plants of Gbewaa transplanted with 25 cm x 25 cm spacing on plot where 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar were applied produced the highest value cost ratio with values of 2.51, 2.24, and 2.03 respectively.

Therefore, farmers are advised to adopt Mandii x 20 cm x 20 cm spacing x 37.5 kg/ha N, P, and K + 26.25 kg/ha N, or Agra x 25 cm x 25 cm x 37.5 kg/ha N, P, and K + 26.25 kg/ha N, or Gbewaa x 20 cm x 20 cm x 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N, or Gbewaa x 20 cm x 20 cm x 37.5 kg/ha N, P, and K + 26.25 kg/ha N in the study area and beyond for higher productivity.

Soil amendment 10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N should be adopted by farmers to improve the soil properties and health.

Agra x 20 cm x 20 cm x 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar or Gbewaa x 20 cm x 20 cm x 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar, or Gbewaa x 25 cm x 25 cm spacing x 18.5 kg/ha N, 6 kg/ha P and 6 kg/ha K + 18.5 kg/ha N foliar should be adopted for better profitability in the farming enterprise.

Further research is needed under different ecological systems as this research was carried out under low land rainfed ecology. The efficiency of 10 t/ha compost + 18.75 kg/ha each of N, P, and K + 13.13 kg/ha N and foliar applied soil amendments and their absorption can also be an important area of research under both rainfed and irrigated conditions.

Good varietal traits, spacing and soil amendment lead to proper growth of the rice plant and quality development of grains which translates into higher yield and quality milling characteristics of the rice.

Plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied were superior in performance in both grain yield and milling qualities. Plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest brown yield, longest grain and widest grain width. It also produced the least foreign matter, admixture, discoloured grains, combined grains, crackness of grain and broken grains. Plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the highest brown yield, longest grain and width whilst producing the least immature grains. Plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied produced the longest grain and highest length width ratio whilst recording the least admixture and combined grain.

Therefore, farmers are advised to adopt plants of Agra rice transplanted with 25 cm x 25 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied, Plants of Gbewaa transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied and plants of Mandii transplanted with 20 cm x 20 cm spacing on plot where 37.5 kg/ha N, P, and K + 26.25 kg/ha N were applied for higher yield and quality grains. Further research is needed under different ecological systems as this research was carried out under low land rainfed ecology. Moreover, post-harvest handling factors such as drying and storage before milling should be looked at. Mandii which is a local variety performed very well in terms of plant growth and yield and should be considered in a breeding program alongside varieties consumers prefer the most. Agra and Gbewaa could be used in improving Mandii through breeding.

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APPENDICES

Appendix A1: Effect of time of transplanting and spacing on growth and yield of rice under rainfed conditions in the Guinea Savannah zone of Ghana

A.1.1: Plant height at 42 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	9.08	4.54	0.41	
REPS.*Units* stratum					
SPACING	3	71.04	23.68	2.11	0.114
TRANSPLANTING	4	795.75	198.94	17.76	<.001
SPACING.TRANSPLANTING	12	714.06	59.50	5.31	<.001
Residual	38	425.58	11.20		
Total	59	2015.50			

A1.2: Plant height at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	12.85	6.43	0.51	
REPS.*Units* stratum					
SPACING	3	375.97	125.32	9.87	<.001
TRANSPLANTING	4	1297.57	324.39	25.55	<.001
SPACING.TRANSPLANTING	12	505.46	42.12	3.32	0.002
Residual	38	482.49	12.70		
Total	59	2674.35			

A1.3: Tiller count at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	3701.	1850.	0.55	
REPS.*Units* stratum					
SPACING	3	97981.	32660.	9.75	<.001
TRANSPLANTING	4	61357.	15339.	4.58	0.004
SPACING.TRANSPLANTING	12	89108.	7426.	2.22	0.031
Residual	38	127283.	3350.		
Total	59	379428.			

A1.4: Tiller count at 84 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	20481.	10241.	0.55	
REPS.*Units* stratum					
SPACING	3	928983.	309661.	16.61	<.001
TRANSPLANTING	4	331823.	82956.	4.45	0.005
SPACING.TRANSPLANTING	12	236325.	19694.	1.06	0.421
Residual	38	708260.	18638.		
Total	59	2225873.			

A1.5: Days to 50 % flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	4.900	2.450	1.00	
REPS.*Units* stratum					
SPACING	3	3900.714	1300.238	530.71	<.001
TRANSPLANTING	4	4366.909	1091.727	445.60	<.001
SPACING.TRANSPLANTING	12	808.879	67.407	27.51	<.001
Residual	38	93.100	2.450		
Total	59	9174.502			

A1.6: Straw weight (kg m^{-2})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	0.01283	0.00641	0.39	
REPS.*Units* stratum					
SPACING	3	2.17262	0.72421	43.97	<.001
TRANSPLANTING	4	3.23808	0.80952	49.15	<.001
SPACING.TRANSPLANTING	12	5.58805	0.46567	28.27	<.001
Residual	38	0.62587	0.01647		
Total	59	11.63744			

A1.7: Panicle number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	4024.	2012.	0.85	
REPS.*Units* stratum					
SPACING	3	125016.	41672.	17.59	<.001
TRANSPLANTING	4	97285.	24321.	10.26	<.001
SPACING.TRANSPLANTING	12	112289.	9357.	3.95	<.001
Residual	38	90046.	2370.		
Total	59	428661.			

A1.8: Spikelet /panicle

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	662.5	331.3	0.63	
REPS.*Units* stratum					
SPACING	3	7657.4	2552.5	4.88	0.006
TRANSPLANTING	4	15187.0	3796.8	7.26	<.001
SPACING.TRANSPLANTING	12	13106.9	1092.2	2.09	0.042
Residual	38	19868.8	522.9		
Total	59	56482.6			

A1.9: Infertile spikelet /panicle

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	15.71	7.85	0.21	
REPS.*Units* stratum					
SPACING	3	73.63	24.54	0.67	0.578
TRANSPLANTING	4	549.80	137.45	3.73	0.012
SPACING.TRANSPLANTING	12	1778.71	148.23	4.02	<.001
Residual	38	1401.63	36.89		
Total	59	3819.47			

A1.10: Thousand seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	7.439	3.720	0.73	
REPS.*Units* stratum Correlation coefficient 10.557			2.06	0.045	
Residual	38	194.912	5.129		
Total 59 2378.876					

A1.11: Grain yield (kg ha^{-1})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1758147.	879074.	0.38	
REPS.*Units* stratum					
SPACING	3	52136684.	17378895.	7.41	<.001
TRANSPLANTING	4	107335383.	26833846.	11.45	<.001
SPACING.TRANSPLANTING	12	56629950.	4719162.	2.01	0.050
Residual	38	89067623.	2343885.		
Total	59	306927787.			

Appendix A2: Effect of time of transplanting and spacing on growth and yield of rice under irrigated conditions in the Guinea Savannah zone of Ghana

A.2.1: Plant height at 42 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	259.333	129.666	15.90	
REPS.*Units* stratum					
SPACING	3	1341.565	447.188	54.84	<.001
TRANSPLANTING	4	8576.838	2144.209	262.93	<.001
SPACING.TRANSPLANTING	12	649.067	54.089	6.63	<.001
Residual	38	309.893	8.155		
Total 59 11136.695					

A.2.2: Plant height at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	348.407	174.204	31.48	
REPS.*Units* stratum					
SPACING	3	7684.323	2561.441	462.91	<.001
TRANSPLANTING	4	1933.269	483.317	87.35	<.001
SPACING.TRANSPLANTING	12	1920.058	160.005	28.92	<.001
Residual	38	210.267	5.533		
Total	59	12096.324			

A2.3: Tiller count at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	162.1266	81.0633	132.48	
REPS.*Units* stratum					
SPACING	3	2283.0822	761.0274	1243.74	<.001
TRANSPLANTING	4	2338.2283	584.5571	955.33	<.001
SPACING.TRANSPLANTING	12	1223.6625	101.9719	166.65	<.001
Residual	38	23.2517	0.6119		
Total	59	6030.3513			

A2.4: Tiller count at 84 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	157.8532	78.9266	99.89	
REPS.*Units* stratum					
SPACING	3	675.9600	225.3200	285.15	<.001
TRANSPLANTING	4	762.1192	190.5298	241.12	<.001
SPACING.TRANSPLANTING	12	3917.5229	326.4602	413.15	<.001
Residual	38	30.0266	0.7902		
Total	59	5543.4818			

A2.5: Chlorophyll content at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	224.8262	112.4131	154.47	
REPS.*Units* stratum					
SPACING	3	3305.3105	1101.7702	1513.98	<.001
TRANSPLANTING	4	2162.5819	540.6455	742.92	<.001
SPACING.TRANSPLANTING	12	1066.4923	88.8744	122.12	<.001
Residual	38	27.6538	0.7277		
Total	59	6786.8647			

A2.6: Chlorophyll content at 84 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	199.4562	99.7281	181.30	
REPS.*Units* stratum					
SPACING	3	2968.9885	989.6628	1799.10	<.001
TRANSPLANTING	4	945.4059	236.3515	429.66	<.001
SPACING.TRANSPLANTING	12	543.0854	45.2571	82.27	<.001
Residual	38	20.9033	0.5501		
Total	59	4677.8393			

A2.7: Days to 50 % flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	2.6963	1.3482	1.49	
REPS.*Units* stratum					
SPACING	3	2685.7494	895.2498	988.07	<.001
TRANSPLANTING	4	4550.7120	1137.6780	1255.63	<.001
SPACING.TRANSPLANTING	12	915.0347	76.2529	84.16	<.001
Residual	38	34.4303	0.9061		
Total	59	8188.6228			

A2.8: Straw weight (kg m^{-2})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	13.1873	6.5936	49.22	
REPS.*Units* stratum					
SPACING	3	3.4744	1.1581	8.65	<.001
TRANSPLANTING	4	5.7383	1.4346	10.71	<.001
SPACING.TRANSPLANTING	12	7.8262	0.6522	4.87	<.001
Residual	38	5.0905	0.1340		
Total	59	35.3167			

A2.9: Number of panicles

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	268.645	134.322	39.24	
REPS.*Units* stratum					
SPACING	3	1617.924	539.308	157.53	<.001
TRANSPLANTING	4	1541.477	385.369	112.57	<.001
SPACING.TRANSPLANTING	12	1102.121	91.843	26.83	<.001
Residual	38	130.093	3.424		
Total	59	4660.260			

A2.10: Spikelet /panicle

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	18604.0	9302.0	50.83	
REPS.*Units* stratum					
SPACING	3	52414.2	17471.4	95.46	<.001
TRANSPLANTING	4	49084.5	12271.1	67.05	<.001
SPACING.TRANSPLANTING	12	14290.2	1190.8	6.51	<.001
Residual	38	6954.7	183.0		
Total	59	141347.5			

A2.11: Infertile spikelet /panicle

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	2827.94	1413.97	29.52	
REPS.*Units* stratum					
SPACING	3	132.89	44.30	0.92	0.438
TRANSPLANTING	4	299.85	74.96	1.56	0.203
SPACING.TRANSPLANTING	12	3225.06	268.75	5.61	<.001
Residual	38	1820.39	47.91		
Total	59	8306.12			

A2.12: Thousand seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	42.498	21.249	5.57	
REPS.*Units* stratum					
SPACING	3	52.444	17.481	4.58	0.008
TRANSPLANTING	4	43.483	10.871	2.85	0.037
SPACING.TRANSPLANTING	12	149.187	12.432	3.26	0.003
Residual	38	145.047	3.817		
Total	59	432.659			

A2.13: Grain yield kg ha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	21832879.	10916440.	32.38	
REPS.*Units* stratum					
SPACING	3	33594233.	11198078.	33.21	<.001
TRANSPLANTING	4	114097040.	28524260.	84.60	<.001
SPACING.TRANSPLANTING	12	112239345.	9353279.	27.74	<.001
Residual	38	12812432.	337169.		
Total	59	294575930.			

Appendix B: Analysis of variance: Effects of variety, spacing and amendment on growth, yield, and post-harvest qualities of rice in the Guinea Savannah zone of Ghana

B1: Plant height at 42 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	374.67	187.33	3.82	
REPS.*Units* stratum					
VARIETY	4	3902.94	975.74	19.90	<.001
SPACING	1	255.21	255.21	5.21	0.025
AMENDMENTS	3	992.92	330.97	6.75	<.001
VARIETY.SPACING	4	318.54	79.63	1.62	0.177
VARIETY.AMENDMENTS	12	855.11	71.26	1.45	0.161
SPACING.AMENDMENTS	3	163.03	54.34	1.11	0.351
VARIETY.SPACING.AMENDMENTS					
	12	610.36	50.86	1.04	0.424
Residual	78	3824.44	49.03		
Total	119	11297.21			

B2: Plant height at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	621.89	310.94	3.59	
REPS.*Units* stratum					
VARIETY	4	12018.05	3004.51	34.72	<.001
SPACING	1	893.00	893.00	10.32	0.002
AMENDMENTS	3	2388.70	796.23	9.20	<.001
VARIETY.SPACING	4	374.71	93.68	1.08	0.371
VARIETY.AMENDMENTS	12	1994.63	166.22	1.92	0.044
SPACING.AMENDMENTS	3	139.11	46.37	0.54	0.659
VARIETY.SPACING.AMENDMENTS					
	12	1000.56	83.38	0.96	0.490
Residual	78	6749.67	86.53		
Total	119	26180.31			

B3: Tiller count at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	2197.3	1098.7	10.76	
REPS.*Units* stratum					
VARIETY	4	2874.2	718.5	7.04	<.001
SPACING	1	3856.1	3856.1	37.77	<.001
AMENDMENTS	3	4073.7	1357.9	13.30	<.001
VARIETY.SPACING	4	2015.7	503.9	4.94	0.001
VARIETY.AMENDMENTS	12	4092.7	341.1	3.34	<.001
SPACING.AMENDMENTS	3	71.0	23.7	0.23	0.874
VARIETY.SPACING.AMENDMENTS					
	12	3008.2	250.7	2.46	0.009
Residual	78	7963.7	102.1		
Total	119	30152.7			

B4: Tiller count at 84 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	3149.0	1574.5	7.55	
REPS.*Units* stratum					
VARIETY	4	5323.8	1331.0	6.38	<.001
SPACING	1	1073.8	1073.8	5.15	0.026
AMENDMENTS	3	3552.4	1184.1	5.68	0.001
VARIETY.SPACING	4	1732.2	433.1	2.08	0.092
VARIETY.AMENDMENTS	12	7465.0	622.1	2.98	0.002
SPACING.AMENDMENTS	3	1184.8	394.9	1.89	0.138
VARIETY.SPACING.AMENDMENTS	12	5860.4	488.4	2.34	0.013
Residual	78	16272.2	208.6		
Total	119	45613.6			

B5: Chlorophyll at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	81.37	40.69	1.96	
REPS.*Units* stratum					
VARIETY	4	245.64	61.41	2.95	0.025
SPACING	1	2074.36	2074.36	99.79	<.001
AMENDMENTS	3	805.20	268.40	12.91	<.001
VARIETY.SPACING	4	143.52	35.88	1.73	0.153
VARIETY.AMENDMENTS	12	432.97	36.08	1.74	0.075
SPACING.AMENDMENTS	3	101.76	33.92	1.63	0.189
VARIETY.SPACING.AMENDMENTS	12	414.11	34.51	1.66	0.092
Residual	78	1621.47	20.79		
Total	119	5920.39			

B6: Chlorophyll at 84 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	91.68	45.84	2.90	
REPS.*Units* stratum					
VARIETY	4	484.03	121.01	7.67	<.001
SPACING	1	2952.03	2952.03	187.01	<.001
AMENDMENTS	3	333.48	111.16	7.04	<.001
VARIETY.SPACING	4	25.55	6.39	0.40	0.805
VARIETY.AMENDMENTS	12	245.84	20.49	1.30	0.237
SPACING.AMENDMENTS	3	64.32	21.44	1.36	0.262
VARIETY.SPACING.AMENDMENTS	12	218.85	18.24	1.16	0.330
Residual	78	1231.27	15.79		
Total	119	5647.07			

B7: Leaf area index at 63 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.245510	0.622755	101.26	
REPS.*Units* stratum					
VARIETY	4	11.273695	2.818424	458.26	<.001
SPACING	1	30.423199	30.423199	4946.65	<.001
AMENDMENTS	3	35.399353	11.799784	1918.58	<.001
VARIETY.SPACING	4	0.635518	0.158880	25.83	<.001
VARIETY.AMENDMENTS	12	0.322799	0.026900	4.37	<.001
SPACING.AMENDMENTS	3	0.643343	0.214448	34.87	<.001
VARIETY.SPACING.AMENDMENTS					
	12	0.209924	0.017494	2.84	0.003
Residual	78	0.479721	0.006150		
Total	119	80.633063			

B8: Leaf area index at 84 DAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.391799	0.695899	97.20	
REPS.*Units* stratum					
VARIETY	4	12.720420	3.180105	444.18	<.001
SPACING	1	41.864439	41.864439	5847.42	<.001
AMENDMENTS	3	41.874562	13.958187	1949.61	<.001
VARIETY.SPACING	4	1.682377	0.420594	58.75	<.001
VARIETY.AMENDMENTS	12	0.369068	0.030756	4.30	<.001
SPACING.AMENDMENTS	3	0.918076	0.306025	42.74	<.001
VARIETY.SPACING.AMENDMENTS					
	12	0.251789	0.020982	2.93	0.002
Residual	78	0.558439	0.007159		
Total 119 101.630969					

B9: Days to 50 % flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	4.525	2.262	0.44	
REPS.*Units* stratum					
VARIETY	4	7149.894	1787.473	344.91	<.001
SPACING	1	1618.397	1618.397	312.28	<.001
AMENDMENTS	3	964.973	321.658	62.07	<.001
VARIETY.SPACING	4	100.698	25.174	4.86	0.001
VARIETY.AMENDMENTS	12	251.519	20.960	4.04	<.001
SPACING.AMENDMENTS	3	9.321	3.107	0.60	0.617
VARIETY.SPACING.AMENDMENTS					
	12	93.480	7.790	1.50	0.141
Residual	78	404.233	5.182		
Total	119	10597.039			

B10: Straw weight (kg m^{-2})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.277	0.639	0.26	
REPS.*Units* stratum					
VARIETY	4	22.408	5.602	2.28	0.068
SPACING	1	8.036	8.036	3.27	0.074
AMENDMENTS	3	22.578	7.526	3.06	0.033
VARIETY.SPACING	4	21.362	5.340	2.17	0.080
VARIETY.AMENDMENTS	12	99.198	8.266	3.37	<.001
SPACING.AMENDMENTS	3	22.446	7.482	3.05	0.034
VARIETY.SPACING.AMENDMENTS					
	12	95.012	7.918	3.22	<.001
Residual	78	191.599	2.456		
Total	119	483.916			

B11: Panicle number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	910.20	455.10	18.94	
REPS.*Units* stratum					
VARIETY	4	350.50	87.62	3.65	0.009
SPACING	1	334.18	334.18	13.91	<.001
AMENDMENTS	3	751.29	250.43	10.42	<.001
VARIETY.SPACING	4	202.78	50.70	2.11	0.088
VARIETY.AMENDMENTS	12	1287.38	107.28	4.46	<.001
SPACING.AMENDMENTS	3	127.04	42.35	1.76	0.161
VARIETY.SPACING.AMENDMENTS					
	12	981.39	81.78	3.40	<.001
Residual	78	1874.40	24.03		
Total	119	6819.16			

B12: Spikelet per panicle

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	30736.1	15368.1	20.97	
REPS.*Units* stratum					
VARIETY	4	63588.4	15897.1	21.69	<.001
SPACING	1	54080.6	54080.6	73.79	<.001
AMENDMENTS	3	19228.9	6409.6	8.75	<.001
VARIETY.SPACING	4	19473.8	4868.5	6.64	<.001
VARIETY.AMENDMENTS	12	39715.1	3309.6	4.52	<.001
SPACING.AMENDMENTS	3	1027.9	342.6	0.47	0.706
VARIETY.SPACING.AMENDMENTS					
	12	26807.8	2234.0	3.05	0.001
Residual	78	57163.9	732.9		
Total	119	311822.6			

B13: Infertile spikelet /panicle

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	192.35	96.17	1.43	
REPS.*Units* stratum					
VARIETY	4	2698.40	674.60	10.06	<.001
SPACING	1	12.31	12.31	0.18	0.669
AMENDMENTS	3	761.30	253.77	3.79	0.014
VARIETY.SPACING	4	170.67	42.67	0.64	0.638
VARIETY.AMENDMENTS	12	1742.60	145.22	2.17	0.022
SPACING.AMENDMENTS	3	281.32	93.77	1.40	0.249
VARIETY.SPACING.AMENDMENTS					
	12	504.76	42.06	0.63	0.813
Residual	78	5229.12	67.04		
Total	119	11592.81			

B14: Thousand seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	31.759	15.880	2.38	
REPS.*Units* stratum					
VARIETY	4	224.509	56.127	8.42	<.001
SPACING	1	212.235	212.235	31.85	<.001
AMENDMENTS	3	306.204	102.068	15.32	<.001
VARIETY.SPACING	4	25.879	6.470	0.97	0.428
VARIETY.AMENDMENTS	12	138.639	11.553	1.73	0.075
SPACING.AMENDMENTS	3	14.360	4.787	0.72	0.544
VARIETY.SPACING.AMENDMENTS					
	12	120.481	10.040	1.51	0.140
Residual	78	519.743	6.663		
Total 119 1593.809					

B15: Grain yield kg ha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	2.090E+07	1.045E+07	1.45	
REPS.*Units* stratum					
VARIETY	4	7.409E+07	1.852E+07	2.56	0.045
SPACING	1	3.575E+07	3.575E+07	4.95	0.029
AMENDMENTS	3	1.412E+08	4.707E+07	6.52	<.001
VARIETY.SPACING	4	8.034E+07	2.008E+07	2.78	0.032
VARIETY.AMENDMENTS	12	2.716E+08	2.264E+07	3.13	0.001
SPACING.AMENDMENTS	3	3.329E+07	1.110E+07	1.54	0.212
VARIETY.SPACING.AMENDMENTS	12	2.847E+08	2.372E+07	3.28	<.001
Residual	78	5.634E+08	7.223E+06		
Total	119	1.505E+09			

B16: Dry root weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	232.943	116.471	104.98	
REPS.*Units* stratum					
VARIETY	4	390.677	97.669	88.03	<.001
SPACING	1	289.964	289.964	261.35	<.001
AMENDMENTS	3	1303.489	434.496	391.62	<.001
VARIETY.SPACING	4	13.611	3.403	3.07	0.021
VARIETY.AMENDMENTS	12	229.359	19.113	17.23	<.001
SPACING.AMENDMENTS	3	26.135	8.712	7.85	<.001
VARIETY.SPACING.AMENDMENTS	12	23.239	1.937	1.75	0.073
Residual	78	86.541	1.109		
Total	119	2595.957			

Appendix C: Analysis of variance – Milling characteristics of rice – Effects of variety, spacing and amendment on milling qualities of rice in the Guinea Savannah zone of Ghana

C1: Foreign matter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	30.7516	15.3758	64.47	
REPS.*Units* stratum					
VARIETY	4	2140.7445	535.1861	2243.89	<.001
SPACING	1	414.0367	414.0367	1735.94	<.001
AMENDMENTS	3	4058.8402	1352.9467	5672.53	<.001
VARIETY.SPACING	4	675.5445	168.8861	708.09	<.001
VARIETY.AMENDMENTS	12	1557.4335	129.7861	544.16	<.001
SPACING.AMENDMENTS	3	156.8602	52.2867	219.22	<.001
VARIETY.SPACING.AMENDMENTS	12	575.0535	47.9211	200.92	<.001
Residual	78	18.6037	0.2385		
Total	119	9627.8685			

C2: Admixture

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	0.345291	0.172646	92.23	
REPS.*Units* stratum					
VARIETY	4	15.042000	3.760500	2009.00	<.001
SPACING	1	1.800750	1.800750	962.03	<.001
AMENDMENTS	3	31.838250	10.612750	5669.73	<.001
VARIETY.SPACING	4	7.788000	1.947000	1040.16	<.001
VARIETY.AMENDMENTS	12	11.148000	0.929000	496.31	<.001
SPACING.AMENDMENTS	3	3.470250	1.156750	617.98	<.001
VARIETY.SPACING.AMENDMENTS					
	12	9.426000	0.785500	419.64	<.001
Residual	78	0.146003	0.001872		
Total 119 81.004544					

C3: Discoloured grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	15.4732	7.7366	11.70	
REPS.*Units* stratum					
VARIETY	4	6552.9630	1638.2408	2477.78	<.001
SPACING	1	145.8607	145.8607	220.61	<.001
AMENDMENTS	3	4892.4742	1630.8247	2466.56	<.001
VARIETY.SPACING	4	547.4730	136.8682	207.01	<.001
VARIETY.AMENDMENTS	12	6953.8770	579.4898	876.46	<.001
SPACING.AMENDMENTS	3	762.1942	254.0647	384.26	<.001
VARIETY.SPACING.AMENDMENTS					
	12	1902.3270	158.5273	239.77	<.001
Residual	78	51.5715	0.6612		
Total	119	21824.2139			

C4: Green grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	5.45676	2.72838	46.89	
REPS.*Units* stratum					
VARIETY	4	322.64550	80.66138	1386.26	<.001
SPACING	1	46.87500	46.87500	805.60	<.001
AMENDMENTS	3	1115.53800	371.84600	6390.59	<.001
VARIETY.SPACING	4	80.18250	20.04563	344.51	<.001
VARIETY.AMENDMENTS	12	117.81450	9.81788	168.73	<.001
SPACING.AMENDMENTS	3	8.49900	2.83300	48.69	<.001
VARIETY.SPACING.AMENDMENTS					
	12	261.19350	21.76613	374.08	<.001
Residual	78	4.53854	0.05819		
Total	119	1962.74330			

C5: Red grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	22.1009	11.0504	38.51	
REPS.*Units* stratum					
VARIETY	4	5616.9705	1404.2426	4893.42	<.001
SPACING	1	138.0307	138.0307	481.00	<.001
AMENDMENTS	3	2523.7762	841.2587	2931.57	<.001
VARIETY.SPACING	4	287.6355	71.9089	250.58	<.001
VARIETY.AMENDMENTS	12	2315.0475	192.9206	672.28	<.001
SPACING.AMENDMENTS	3	14.4863	4.8288	16.83	<.001
VARIETY.SPACING.AMENDMENTS					
	12	367.3425	30.6119	106.67	<.001
Residual	78	22.3833	0.2870		
Total	119	11307.7734			

C6: Chalky grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	10.35472	5.17736	52.86	
REPS.*Units* stratum					
VARIETY	4	457.15950	114.28987	1166.84	<.001
SPACING	1	187.50000	187.50000	1914.27	<.001
AMENDMENTS	3	1333.35000	444.45000	4537.60	<.001
VARIETY.SPACING	4	157.77750	39.44437	402.71	<.001
VARIETY.AMENDMENTS	12	551.81250	45.98437	469.48	<.001
SPACING.AMENDMENTS	3	227.74200	75.91400	775.04	<.001
VARIETY.SPACING.AMENDMENTS					
	12	647.17050	53.93088	550.61	<.001
Residual	78	7.63997	0.09795		
Total	119	3580.5066			

C7: Immature grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.95636	0.97818	51.95	
REPS.*Units* stratum					
VARIETY	4	142.72950	35.68238	1895.07	<.001
SPACING	1	6.34800	6.34800	337.14	<.001
AMENDMENTS	3	376.66500	125.55500	6668.16	<.001
VARIETY.SPACING	4	39.00450	9.75113	517.88	<.001
VARIETY.AMENDMENTS	12	148.40250	12.36688	656.80	<.001
SPACING.AMENDMENTS	3	6.60000	2.20000	116.84	<.001
VARIETY.SPACING.AMENDMENTS					
	12	103.20750	8.60063	456.77	<.001
Residual	78	1.46867	0.01883		
Total	119	826.38203			

C8: Combined grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	0.43997	0.21999	9.95	
REPS.*Units* stratum					
VARIETY	4	39.11550	9.77888	442.08	<.001
SPACING	1	0.01875	0.01875	0.85	0.360
AMENDMENTS	3	148.27425	49.42475	2234.37	<.001
VARIETY.SPACING	4	51.80250	12.95063	585.47	<.001
VARIETY.AMENDMENTS	12	120.09450	10.00788	452.43	<.001
SPACING.AMENDMENTS	3	0.34425	0.11475	5.19	0.003
VARIETY.SPACING.AMENDMENTS					
	12	237.91950	19.82663	896.31	<.001
Residual	78	1.72538	0.02212		
Total	119	599.73460			

C9: Crackness of grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	160.814	80.407	39.44	
REPS.*Units* stratum					
VARIETY	4	13483.250	3370.812	1653.54	<.001
SPACING	1	2339.067	2339.067	1147.42	<.001
AMENDMENTS	3	43307.409	14435.803	7081.41	<.001
VARIETY.SPACING	4	2560.405	640.101	314.00	<.001
VARIETY.AMENDMENTS	12	6629.128	552.427	270.99	<.001
SPACING.AMENDMENTS	3	700.977	233.659	114.62	<.001
VARIETY.SPACING.AMENDMENTS					
	12	3858.461	321.538	157.73	<.001
Residual	78	159.007	2.039		
Total	119	73198.518			

C10: Broken grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	96.8563	48.4282	58.50	
REPS.*Units* stratum					
VARIETY	4	1576.6620	394.1655	476.14	<.001
SPACING	1	750.0000	750.0000	905.98	<.001
AMENDMENTS	3	24539.1630	8179.7210	9880.92	<.001
VARIETY.SPACING	4	407.4000	101.8500	123.03	<.001
VARIETY.AMENDMENTS	12	3550.0320	295.8360	357.36	<.001
SPACING.AMENDMENTS	3	128.4180	42.8060	51.71	<.001
VARIETY.SPACING.AMENDMENTS					
	12	443.5020	36.9585	44.65	<.001
Residual	78	64.5708	0.8278		
Total	119	31556.6041			

C11: Brown yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1235.6318	617.8159	820.29	
REPS.*Units* stratum					
VARIETY	4	129.5295	32.3824	42.99	<.001
SPACING	1	27.9367	27.9367	37.09	<.001
AMENDMENTS	3	291.7642	97.2547	129.13	<.001
VARIETY.SPACING	4	44.1045	11.0261	14.64	<.001
VARIETY.AMENDMENTS	12	99.2745	8.2729	10.98	<.001
SPACING.AMENDMENTS	3	7.0282	2.3427	3.11	0.031
VARIETY.SPACING.AMENDMENTS					
	12	24.6555	2.0546	2.73	0.004
Residual	78	58.7472	0.7532		
Total 119 1918.6723					

C12: Husk yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	142.3702	71.1851	643.47	
REPS.*Units* stratum					
VARIETY	4	129.5295	32.3824	292.72	<.001
SPACING	1	27.9368	27.9368	252.53	<.001
AMENDMENTS	3	291.7643	97.2548	879.13	<.001
VARIETY.SPACING	4	44.1045	11.0261	99.67	<.001
VARIETY.AMENDMENTS	12	99.2745	8.2729	74.78	<.001
SPACING.AMENDMENTS	3	7.0283	2.3428	21.18	<.001
VARIETY.SPACING.AMENDMENTS					
	12	24.6555	2.0546	18.57	<.001
Residual	78	8.6289	0.1106		
Total	119	775.2923			

C13: Average length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	10.405700	5.202850	772.04	
REPS.*Units* stratum					
VARIETY	4	0.985230	0.246308	36.55	<.001
SPACING	1	0.588000	0.588000	87.25	<.001
AMENDMENTS	3	5.585910	1.861970	276.29	<.001
VARIETY.SPACING	4	0.111450	0.027863	4.13	0.004
VARIETY.AMENDMENTS	12	1.211190	0.100932	14.98	<.001
SPACING.AMENDMENTS	3	0.288180	0.096060	14.25	<.001
VARIETY.SPACING.AMENDMENTS					
	12	0.262770	0.021898	3.25	<.001
Residual	78	0.525648	0.006739		
Total 119 19.964079					

C14: Average width

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.1943658	0.5971829	846.01	
REPS.*Units* stratum					
VARIETY	4	0.0887550	0.0221887	31.43	<.001
SPACING	1	0.0388800	0.0388800	55.08	<.001
AMENDMENTS	3	0.2125500	0.0708500	100.37	<.001
VARIETY.SPACING	4	0.0121950	0.0030487	4.32	0.003
VARIETY.AMENDMENTS	12	0.0614250	0.0051187	7.25	<.001
SPACING.AMENDMENTS	3	0.0169800	0.0056600	8.02	<.001
VARIETY.SPACING.AMENDMENTS					
	12	0.0801450	0.0066788	9.46	<.001
Residual	78	0.0550589	0.0007059		
Total	119	1.7603546			

C15: Length width ratio

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.932304	0.966152	744.59	
REPS.*Units* stratum					
VARIETY	4	0.208001	0.052000	40.08	<.001
SPACING	1	0.006544	0.006544	5.04	0.028
AMENDMENTS	3	0.320393	0.106798	82.31	<.001
VARIETY.SPACING	4	0.047901	0.011975	9.23	<.001
VARIETY.AMENDMENTS	12	0.471308	0.039276	30.27	<.001
SPACING.AMENDMENTS	3	0.095400	0.031800	24.51	<.001
VARIETY.SPACING.AMENDMENTS					
	12	0.191015	0.015918	12.27	<.001
Residual	78	0.101210	0.001298		
Total	119	3.374078			

Appendix D1: Value cost ratio for Field Experiment I

Benefit-cost analysis of rice cultivated under different time of transplanting and spacing in Sagnarigu Kukuo in the Guinea Savannah zone of Ghana.

Item	Qty	Ha	S1T1	S2T1	S3T1	S4T1	S1T2	S2T2	S3T2	S4T2	S1T3	S2T3
Inputs trnspt	3	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5
Seeds	1	150	150	150	150	150	150	150	150	150	150	150
NPK	2	900	900	900	900	900	900	900	900	900	900	900
Ammonia	1	375	375	375	375	375	375	375	375	375	375	375
Glyphosate	1	50	50	50	50	50	50	50	50	50	50	50
Stomp	1	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
Select herbici	1	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
Sacks	1	2704.1	2704.1	2538.8	2100.3	1940.3	1904.7	1875.6	1828.2	1712.9	1485.6	1433.2
Land clearing	1	500	500	500	500	500	500	500	500	500	500	500
Ploughing	1	200	200	200	200	200	200	200	200	200	200	200
Harrowing	1	100	100	100	100	100	100	100	100	100	100	100
Nursery mgt	1	50	50	50	50	50	50	50	50	50	50	50
Transplanting	1	250	250	250	250	250	250	250	250	250	250	250
Ch. fert appln	2	50	50	50	50	50	50	50	50	50	50	50
Herbicid appln	3	75	75	75	75	75	75	75	75	75	75	75
Harvesting	1	500	500	500	500	500	500	500	500	500	500	500
Winnowing	1	270.41	270.41	253.88	210.03	194.03	190.47	187.56	182.82	171.29	148.56	143.32
Drying	1	540.82	540.82	507.76	420.06	388.06	380.94	375.12	365.65	342.59	297.12	286.65
Bagging	1	540.82	540.82	507.76	420.06	388.06	380.94	375.12	365.65	342.59	297.12	286.65
Yield trnsprt	1	1352.06	1352.06	1269.41	1050.15	970.15	952.35	937.79	914.12	856.47	742.79	716.62
Storage	1	540.82	540.82	507.76	420.06	388.06	380.94	375.12	365.65	342.59	297.12	286.65
TOTAL COST		9391.53	9391.53	9027.87	8063.16	7711.16	7632.84	7568.81	7464.59	7210.93	6710.81	6595.59
REVENUE		12979.8	12979.8	12186.4	10081.4	9313.41	9142.59	9002.82	8775.53	8222.12	7130.82	6879.53
VCR		1.38	1.38	1.35	1.25	1.21	1.20	1.19	1.18	1.14	1.06	1.04
PROFIT/LOSS		3588.23	3588.23	3158.48	2018.25	1602.25	1509.75	1434.01	1310.94	1011.19	420.01	283.94
BCR												

Trnspt = transport, Ammonia = sulfate of ammonia, herbicid selec = herbicide (Selective), mgt = management, Ch. fert appln = chemical fertilizer application, Herbicid appln = herbicide application.

Appendix D1: Value cost ratio for Field Experiment I (Contd)
Benefit-cost analysis of rice cultivated under different time of transplanting and spacing in Sagnarigu Kukuo in the Gunea Savannah zone of Ghana.

Item	Qty	Ha	S3T3	S4T3	S1T4	S2T4	S3T4	S4T4	S1T5	S2T5	S3T5	S4T5
Inputs trnspt	3	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5
Seeds	1	150	150	150	150	150	150	150	150	150	150	150
NPK	2	900	900	900	900	900	900	900	900	900	900	900
Ammonia	1	375	375	375	375	375	375	375	375	375	375	375
Glyphosate	1	50	50	50	50	50	50	50	50	50	50	50
Stomp	1	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
herbicid selec	1	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
Sacks	1	2704.1	1263.5	1245.3	1201.2	1133.8	1066.8	1052.6	959.1	842.6	831.2	613.8
Ploughing	1	200	200	200	200	200	200	200	200	200	200	200
Harrowing	1	100	100	100	100	100	100	100	100	100	100	100
Nursery mgt	1	50	50	50	50	50	50	50	50	50	50	50
Transplanting	1	250	250	250	250	250	250	250	250	250	250	250
Ch. fert appln	2	50	50	50	50	50	50	50	50	50	50	50
Herbicid appln	3	75	75	75	75	75	75	75	75	75	75	75
Harvesting	1	500	500	500	500	500	500	500	500	500	500	500
Winnowing	1	270.41	126.35	124.53	120.12	113.38	106.68	105.26	95.91	84.26	83.12	61.38
Drying	1	540.82	252.71	249.06	240.24	226.76	213.35	210.53	191.82	168.53	166.24	122.76
Bagging	1	540.82	252.71	249.06	240.24	226.76	213.35	210.53	191.82	168.53	166.24	122.76
Yield trnsprt	1	1352.06	631.76	622.65	600.59	566.91	533.38	526.32	479.56	421.32	415.59	306.91
Storage	1	540.82	252.71	249.06	240.24	226.76	213.35	210.53	191.82	168.53	166.24	122.76
TOT COST		8891.53	5722.24	5682.16	5585.13	5436.87	5289.41	5258.27	5052.53	4796.27	4771.13	4542.9
REVENUE		12979.8	6064.94	5977.41	5765.65	5442.35	5120.47	5052.71	4603.76	4044.71	3989.65	2946.35
VCR		1.46	1.06	1.05	1.03	1.00	0.97	0.96	0.91	0.84	0.84	0.65
PROFIT/ LOSS		4088.3	342.7	295.25	180.52	5.48	-168.94	-205.56	-448.77	-751.56	-781.48	-1596.6
BCR		0.46	0.06	0.05	0.03	0.00	-0.03	-0.04	-0.09	-0.16	-0.16	-0.35

Trnspt = transport, Ammonia = sulfate of ammonia, herbicid selec = herbicide (Selective), mgt = management, Ch. fert appln = chemical fertilizer application, Herbicid appln = herbicide application.

Appendix D2: Value cost ratio for Field Experiment II

Benefit-cost analysis of rice cultivated under different time of transplanting and spacing in Bontanga in Guinea Savannah zone of Ghana

Item	Qty	Ha	S1T1	S2T1	S3T1	S4T1	S1T2	S2T2	S3T2	S4T2	S1T3	S2T3
Land rent	1	105	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0
Water dues	3	750	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
Inputs trnsprt	1	150	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0
Seeds	2	2000	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
NPK	1	750	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0
Ammonia	1	50	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0
Glyphosate	1	62.5	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Stomp	1	112.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
herbicide selec	1	25	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
Sacks	1	250	1282.9	2847.8	2149.9	1639.9	3445.6	2261.5	2153.4	1670.3	1992.4	1751.9
Harrowing	1	375	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0
Motivation	1	100	375.0	375.0	375.0	375.0	375.0	375.0	375.0	375.0	375.0	375.0
Nursery mgt	1	400	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Transplanting	2	100	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0
Ch fert applin	3	150	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Herbicide appln	1	500	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
Guarding	1	875	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0
Harvesting	1	7.5	875.0	875.0	875.0	875.0	875.0	875.0	875.0	875.0	875.0	875.0
Winnowing	1	10	256.6	569.6	430.0	328.0	689.1	452.3	430.7	334.1	398.5	350.4
Drying	1	7.5	342.1	759.4	573.3	437.3	918.8	603.1	574.2	445.4	531.3	467.2
Bagging	1	25	256.6	569.6	430.0	328.0	689.1	452.3	430.7	334.1	398.5	350.4
Transportation	1	10	855.3	1898.5	1433.2	1093.2	2297.1	1507.6	1435.6	1113.5	1328.2	1167.9
Storage			342.1	759.4	573.3	437.3	918.8	603.1	574.2	445.4	531.3	467.2
TOTAL COST			11066	15134	13320	11993	16689	13610	13329	12073	12910	12285
REVENUE			6842.4	15188	11466	8746	18377	12061	11485	8908	10626	9344
VCR			0.62	1.00	0.86	0.73	1.10	0.89	0.86	0.74	0.82	0.62
PROFIT/LOSS			-4223	54	-1854	-3248	1688	-1549	-1844	-3165	-2284	-2941
BCR			-0.382	0.004	-0.139	-0.271	0.101	-0.114	-0.138	-0.262	-0.177	-0.239

Trnspt = transport, Ammonia = sulfate of ammonia, herbicid selec = herbicide (Selective), mgt = management, Ch. fert appln = chemical fertilizer application, Herbicid appln = herbicide application,

Appendix D2: Value cost ratio for Field Experiment II (Contd)

Benefit-cost analysis of rice cultivated under different time of transplanting and spacing in Sagnarigu Kukuo in Guinea Savannah zone of Ghana

Item	Qty	Ha	S3T3	S4T3	S1T4	S2T4	S3T4	S4T4	S1T5	S2T5	S3T5	S4T5
Service	1	750	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0
Land rent	1	105	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
Water dues	3	750	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0
Inputs trnsprt	1	150	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
Seeds	2	2000	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0
NPK	1	750	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0	750.0
Ammonia	1	50	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Glyphosate	1	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
Stomp	1	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
herbicid selec	1	25	1950.4	1682.2	1617.4	1584.3	1171.8	1003.2	1207.1	1118.8	1103.4	720.0
Sacks	1	250	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0	250.0
Harrowing	1	375	375.0	375.0	375.0	375.0	375.0	375.0	375.0	375.0	375.0	375.0
Motivation	1	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Nursery mgt	1	400	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0	400.0
Transplanting	2	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Ch fert applin	3	150	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
Herbicid appln	1	500	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0
Guarding	1	875	875.0	875.0	875.0	875.0	875.0	875.0	875.0	875.0	875.0	875.0
Harvesting	1	7.5	390.1	336.4	323.5	316.9	234.4	200.6	241.4	223.8	220.7	144.0
Winnowing	1	10	520.1	448.6	431.3	422.5	312.5	267.5	321.9	298.4	294.2	192.0
Drying	1	7.5	390.1	336.4	323.5	316.9	234.4	200.6	241.4	223.8	220.7	144.0
Bagging	1	25	1300.3	1121.5	1078.2	1056.2	781.2	668.8	804.7	745.9	735.6	480.0
Transportation	1	10	520.1	448.6	431.3	422.5	312.5	267.5	321.9	298.4	294.2	192.0
Storage			12801	12104	11935	11849	10777	10338	10868	10639	10599	9602
TOTAL COST			12801	12104	11935	11849	10777	10338	10868	10639	10599	9602
REVENUE			10402	8972	8626	8449	6249	5351	6438	5967	5885	3840
VCR			0.81	0.74	0.72	0.71	0.58	0.52	0.59	0.56	0.56	0.40
PROFIT/ LOSS			-2398.8	-3132.0	-3309.2	-3399.7	-4527.2	-4987.8	-4430.7	-4671.9	-4714.1	-5762.0
BCR			-0.19	-0.26	-0.28	-0.29	-0.42	-0.48	-0.41	-0.44	-0.44	-0.60

AppendixD3: Value cost ratio for Experiment III - Effects of variety, spacing and amendment on growth and yield of rice in the Guinea Savannah zone of Ghana

D3.1: Basal + top dressing application of chemical fertilizers (37.5 kg/ha NPK + 26.25 kg/ha N) **treatments plot**

ITEM	Qty	Cost Cost	V1S1RCF Cost	V1S2RCF Cost	V2S1RCF Cost	V2S2RCF Cost	V3S1RCF Cost	V3S2RCF Cost	V4S1RCF Cost	V4S2RCF Cost	V5S1RCF Cost	V5S2RCF Cost
Land charge	1	750	750	750	750	750	750	750	750	750	750	750
Input trnspt.	3	75	75	75	75	75	75	75	75	75	75	75
Seeds	1	150	150	150	150	150	150	150	150	150	150	150
Glyphosate	1	115	115	115	115	115	115	115	115	115	115	115
Stomp	1	125	125	125	125	125	125	125	125	125	125	125
herbici selec	1	125	125	125	125	125	125	125	125	125	125	125
sacks	1	37.5	2208.0	3165.9	2649.9	1718.9	1893.3	1228.1	3606.0	924.8	1699.1	1472.2
Ploughing	1	200	200	200	200	200	200	200	200	200	200	200
Harrowing	1	250	250	250	250	250	250	250	250	250	250	250
Rotovation	1	375	375	375	375	375	375	375	375	375	375	375
Nursery mgt	1	100	100	100	100	100	100	100	100	100	100	100
Transplanting	1	400	400	400	400	400	400	400	400	400	400	400
Herbicid apln	3	150	150	150	150	150	150	150	150	150	150	150
Harvesting	1	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
Bagging	1	7.5	441.6	633.2	530.0	343.8	378.7	245.6	721.2	185.0	339.8	294.4
Grain trnsprt	1	250	1472.0	2110.6	1766.6	1145.9	1262.2	818.7	2404.0	616.5	1132.7	981.4
Storage	1	10.0	588.8	844.2	706.6	458.4	504.9	327.5	961.6	246.6	453.1	392.6
Winnowing	1	7.5	441.6	633.2	530.0	343.8	378.7	245.6	721.2	185.0	339.8	294.4
Drying	1	10.0	588.8	844.2	706.6	458.4	504.9	327.5	961.6	246.6	453.1	392.6
NPK	2	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Sulphate of a	1	750	750	750	750	750	750	750	750	750	750	750
Ch fert appln	2	100	100	100	100	100	100	100	100	100	100	100
TOTAL COST			12780.8	15271.3	13929.7	11509.2	11962.7	10233	16415.6	9444.5	11457.6	10867.6
REVENUE			20608.24	29548.64	24732.36	16043.28	17670.68	11461.84	33656.28	8631.4	15857.88	13740.2
VCR			1.78	1.39	1.48	1.12	2.05	0.91	1.38	1.26	1.38	1.26
PROFIT/ LOSS			7827.44	14277.34	10802.66	4534.08	5707.98	1228.84	17240.68	-813.1	4400.28	2872.6
			0.61	0.93	0.78	0.39	0.48	0.12	1.05	-0.09	0.38	0.26

Trnspt = transport, Ammonia = sulfate of ammonia, herbicid selec = herbicide (Selective), mgt = management, Ch. fert appln = chemical fertilizer application, Herbicid appln = herbicide application.

D3.2: Compost and chemical fertilizers (10 t/ha Deco compost + 18.75 kg/ha NPK + 13.13 kg/ha N) treatments plot

Item	Qty	Cost / Ha	V1S1HRC FOF Cost	V1S2HRC FOF Cost	VSS1HR CFOF Cost	V2S2HR CFOF Cost	V3S1HRC FOF Cost	V3S2HRC FOF Cost	V4S1HRC FOF Cost	V4S2HR CFOF Cost	V5S1HR CFOF Cost	V5S2HRC FOF Cost
Land charg	1	750	750	750	750	750	750	750	750	750	750	750
Inputs trnsprt	9.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5	237.5
Seeds	1	150	150	150	150	150	150	150	150	150	150	150
Glyphosate	1	115	115	115	115	115	115	115	115	115	115	115
Stomp	1	125	125	125	125	125	125	125	125	125	125	125
Herbicide selectiv	1	125	125	125	125	125	125	125	125	125	125	125
Sacks	1	1950	1960	1253	2741	2233	2359	1678	2605	1201	1711	1403
Ploughing	1	200	200	200	200	200	200	200	200	200	200	200
Harrowing	1	250	250	250	250	250	250	250	250	250	250	250
Nursery mgt	1	100	100	100	100	100	100	100	100	100	100	100
Transplanting	1	400	400	400	400	400	400	400	400	400	400	400
Herbicide appln	3	150	150	150	150	150	150	150	150	150	150	150
Harvesting	1	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
Bagging	1	390.00	391.90	250.64	548.25	446.55	471.71	335.57	521.06	240.14	342.11	280.66
Transportation	1	1300.0	1306.33	835.48	1827.51	1488.50	1572.37	1118.58	1736.87	800.46	1140.36	935.53
Storage	1	520.00	522.53	334.19	731.01	595.40	628.95	447.43	694.75	320.18	456.14	374.21
Winnowing	1	390.00	391.90	250.64	548.25	446.55	471.71	335.57	521.06	240.14	342.11	280.66
Drying	1	520.00	522.53	334.19	731.01	595.40	628.95	447.43	694.75	320.18	456.14	374.21
NPK	half	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Sulfate of ammo.	half	375	375	375	375	375	375	375	375	375	375	375
Compost	8	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Compost appln	1	200	200	200	200	200	200	200	200	200	200	200
Chem ferti applin	2	100	100	100	100	100	100	100	100	100	100	100
TOTAL COST			11747.69	9910.64	13779.5	12457.9	12785.19	11015.08	13425.99	9774.6	11100.4	10300.77
VCR			18288.7	11696.7	25585.2	20839	22013.2	15660.1	24316.2	11206.4	15965	13097.48
Benefit-cost ratio			1.56	1.18	1.86	1.67	1.72	1.42	1.81	1.15	1.44	1.27
Profit/loss			6541.01	1786.06	11805.7	8381.1	9228.01	4645.02	10890.21	1431.8	4864.64	2796.71
BCR			0.56	0.18	0.86	0.67	0.72	0.42	0.81	0.15	0.44	0.27

Trnspt = transport, Ammonia = sulfate of ammonia, herbicid selec = herbicide (Selective), mgt = management, application = appln, Ch. fert appln = chemical fertilizer application, Herbicid appln = herbicide application.

D3.3: Basal application of NPK (37.5 kg/ha N, P and K) **treatments plot**

V1S1BCF Service	Qty	Ha Cost	V1S1BCF Cost	V1S2BCF Cost	V2S1BCF Cost	V2S2BCF Cost	V3S1BCF Cost	V3S2BCF Cost	V4S1BCF Cost	V4S2BCF Cost	V5S1BCF Cost	V5S2BCF Cost
Land charge	1	750	750	750	750	750	750	750	750	750	750	750
Inputs trnspt	3	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Seeds	1	150	150	150	150	150	150	150	150	150	150	150
Glyphosate	1	115	115	115	115	115	115	115	115	115	115	115
Stomp	1	125	125	125	125	125	125	125	125	125	125	125
Herbicide selec	1	125	125	125	125	125	125	125	125	125	125	125
Sack	1	1275	1287	553	2552	1810	1894	961	2025	1010	1665	1090
Ploughing	1	200	200	200	200	200	200	200	200	200	200	200
Harrowing	1	250	250	250	250	250	250	250	250	250	250	250
Nursery mgt	1	100	100	100	100	100	100	100	100	100	100	100
Transplanting	1	400	400	400	400	400	400	400	400	400	400	400
Herbicide appln	3	150	150	150	150	150	150	150	150	150	150	150
Harvesting	1	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
Bagging	1	255	257	111	510	362	379	192	405	202	333	218
Grain transport	1	850	858	368	1701	1207	1263	641	1350	673	1110	727
Storage	1	340	343	147	681	483	505	256	540	269	444	291
Winnowing	1	255	257	111	510	362	379	192	405	202	333	218
Drying	1	340	343	147	681	483	505	256	540	269	444	291
NPK	2	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Ch. fert appln	1	50	50	50	50	50	50	50	50	50	50	50
TOTAL COST			11135	9227	14425	12497	12715	10288	13055	10415	12119	10625
REVENUE			12013.92	5158.24	23817.72	16896.12	17678.92	8973.36	18902.56	9426.56	15540.64	10176.4
VCR			1.08	0.56	1.65	1.35	1.39	0.87	1.45	0.91	1.28	0.96
PROFIT/LOSS			878.92	-4068.8	9392.72	4399.12	4963.92	-1314.64	5847.56	-988.44	3421.64	-448.6
BCR			0.08	-0.44	0.65	0.35	0.39	-0.13	0.45	-0.09	0.28	-0.04

Trnspt = transport, Ammonia = sulfate of ammonia, herbicid selec = herbicide (Selective), mgt = management, Ch. fert appln = chemical fertilizer application, Herbicid appln = herbicide application.

D3.4: Foliar fertilizers (37.5 kg/ha NPK + 26.25 kg/ha N) **treatments plot**

Service	Qty	Ha Cost	V1S1FF Cost	V1S2FF Cost	V2S1FF Cost	V2S2FF Cost	V3S1FF Cost	V3S2FF Cost	V4S1FF Cost	V4S2FF Cost	V5S1FF Cost	V5S2FF Cost
Land charge	1	750	750	750	750	750	750	750	750	750	750	750
Input transport	2	25	25	25	25	25	25	25	25	25	25	25
Seeds	1	150	150	150	150	150	150	150	150	150	150	150
Glyphosate	1	115	115	115	115	115	115	115	115	115	115	115
Stomp	1	125	125	125	125	125	125	125	125	125	125	125
Herbicid selecti	1	125	125	125	125	125	125	125	125	125	125	125
Sacks	1	37.5	2309.1	667.9	1897.3	1618.7	1554.7	1057.7	1398.0	574.7	1360.5	960.5
Ploughing	1	200	200	200	200	200	200	200	200	200	200	200
Harrowing	1	250	250	250	250	250	250	250	250	250	250	250
Nursery mgt	1	100	100	100	100	100	100	100	100	100	100	100
Transplanting	1	400	400	400	400	400	400	400	400	400	400	400
Herbicid applin	3	150	150	150	150	150	150	150	150	150	150	150
Harvesting	1	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
Winnowing	1	7.5	184.7	53.4	151.8	129.5	124.4	84.6	111.8	46.0	108.8	76.8
Drying	1	10.0	246.3	71.2	202.4	172.7	165.8	112.8	149.1	61.3	145.1	102.5
Bagging	1	7.5	184.7	53.4	151.8	129.5	124.4	84.6	111.8	46.0	108.8	76.8
Yield trnsprt	1	25.0	615.8	178.1	505.9	431.7	414.6	282.0	372.8	153.3	362.8	256.1
Storage	1	10.0	246.3	71.2	202.4	172.7	165.8	112.8	149.1	61.3	145.1	102.5
NPK foliar	1	70	70	70	70	70	70	70	70	70	70	70
Urea foliar	1	100	100	100	100	100	100	100	100	100	100	100
Foli fert applin	2	200	100	100	100	100	100	100	100	100	100	100
TOTAL COST			7821.9	5130.2	7146.6	6689.8	6584.7	5769.5	6327.6	4977.6	6266.1	5610.2
REVENUE			21551.72	6233.56	17707.76	15108.04	14510.64	9871.52	13048.04	5364.24	12697.84	8965.12
VCR			2.76	1.22	2.48	2.26	2.20	1.71	2.06	1.08	2.03	1.60
PROFIT/LOSS			13729.82	1103.36	10561.16	8418.24	7925.94	4102.02	6720.44	386.64	6431.74	3354.92
BCR			1.76	0.22	1.48	1.26	1.20	0.71	1.06	0.08	1.03	0.60

Trnspt = transport, Ammonia = sulfate of ammonia, herbicid selec = herbicide (Selective), mgt = management, Ch. fert appln = chemical fertilizer application, Herbicid appln = herbicide application, Foli fert applin = foliar fertilizer application.

Appendix E: Improved and farmer practices effects questionnaire for farmers, processors and marketers of rice

E1: Famers quistionaire

Age: [ ] Below 18 [ ] 18 – 24 [ ] 25 – 35 [ ] 36 – 45 [ ] Above 45
Community …………………………
Educational level: [ ] No formal education [ ] Primary [ ]JHS/Middle School [ ]SSS/SHS [ ] Tertiary
Contact ………………………………………………
Gender [ ] Male [ ] Female

Farmer practices (FPs) and improved practices (IPs)

1.1 Indicate agro-ecological system that you use in cultivating rice. [ ] lowland ecology [ ] Irrigated ecology [ ]Upland ecology [ ] Other [ ](specify)………………………………………………..Number of acres ………

1.2 Tick all the practices of farming you use in cultivating rice. (you can tick more than one)

[ ] FPs: They are relatively unimproved or older farmers' practices OR locally modified improved or recommended practices.

[ ] IPs: They are recommended practices by research institutions within Ghana (MoFA, CSIR-SARI, CSIR-SRI, CSIR-WRI, etc.) or outside Ghana (FAO, IRRI etc.).

1.3 Fill in the table below concerning 2020/2021 rice production activities.

Farmers' Practices (FPs) Tick the farmers' practice(s) you carried out.	**Improved Practices (IPs)** Tick the improved practice(s) you carried out.	**Qty**	**Unit Cost**
1. Source of seed for direct sowing or nursing			
[ ] Ordinary seed from previous year without any selection	[ ] Buying certified seeds		
[ ] Ordinary seeds from other farmers without any selection			
[ ] Ordinary seed from previous year with selection			
[ ] Ordinary seeds from other farmers with selection			
[ ] Other	[ ] Other		
2. Reason for choice of source of seed			
3.			
4. for planting			
………………………………………………………………………………………………			
5. Variety of rice used in cultivating in 2020 cropping season			
[ ] "Bumbas"	[ ] Agra		
[ ] "Moses"	[ ] Gbewaa rice		

[ ] Mandii [ ] Digang
[ ] other [ ] Other

6. Reason for the choice of the variety used in cultivating in 2020 season

[ ] Seeds are available	[ ] High yielding
[ ] Other farmers are cultivating it	[ ] Good price for the paddy
	[ ] Milled grains are of good quality
	[ ] Recommended by MoFA or other institutions
[ ] Other	[ ] Other

Type of planting employed in planting the rice field

[ ] Broadcasting haphazardly	[ ] Use of planter
[ ] Transplanting seedlings without a definite distance or space between plants	[ ] Line transplanting
[ ] [ ] Hand drilling in rows without approximate spacing	[ ] using mechanical drills
[ ] [ ] Dibbling without approximate spacing	[ ] Dibbling (hill planting)method with recommended spacing or using mechanical dibbler
	[ ] Using mechanical transplanter
[ ] Other	[ ] Other
[ ] Did not use any of FPs	[ ] Did not use any of IPs

7. Reason for the choice the method for planting

………

8. Did you transplant?

[ ] Yes [ ] No

9. If Yes, when did you transplant?

[ ] 4 weeks after nursing seeds	[ ] 2 weeks after nursing seeds
[ ] 5 weeks after nursing seeds	[ ] 3 weeks after nursing seeds
[ ] 6 weeks after nursing seeds	
[ ] more than 6 weeks after nursing seeds	
[ ] Other	[ ] Other

10. Plant spacing used in transplanting the rice seedlings

[ ] Transplanting seedlings without a definite distance or space between plants	[ ] Spacing of 20 x20cm
	[ ] Spacing of 25 x25cm
	[ ] Spacing of 30 x30cm
	[ ] Spacing of 35 x35cm

[ ] Other	[ ] Other

11. Reason for the choice of spacing used for the transplanting

……………………………………………………………………………………………
…………

12. Type(s) and rate(s) of fertilizer(s) used

[ ] Only basal application of chemical fertilizer	[ ] Chemical fertilizer (solid) application at the recommended rate
[ ] Only second application of chemical fertilizer	[ ] Chemical fertilizer (liquid) application at the recommended rate
[ ] Application of self-prepared organic manure (compost) or farm yard manure	[ ] Both chemical and compost fertilizer application at recommended rates
[ ] Other	[ ] Other

13. Reason for the choice type and rate of fertilizer used on the field

……………………………………………………………………………………
…………………

Appendix E2: Rice processors quistionaire

To determine the milling characteristics of rice produced and processed in the Sagnarigu and Kumbungu districts, Ghana.

A. Name of respondent: …………………………

B. Age :
   1 [ ] Below 18
   2[ ] 18 – 24
   3 [ ] 25 – 35
   4[ ] 36 – 45
   5 [ ] Above 45

C. Community ……………………………………………..

D. Educational level:
   1[ ] No formal education
   2 [ ] Primary
   3[ ]JHS/Middle School
   4[ ]SSS/SHS
   5[ ] Tertiary

E. Contact ………………………………………..

F. Gender
   1[ ] Male
   2[ ] Female

G. General information

1. Variety(ies) used in processing in order of importance
   ……………………………………………………………………………

2. Reason for the choice of variety for processing
   1[ ] Suitable for straight milling
   2[ ] Tolerate adverse weather condition
   3[ ] It is more affordable
   4[ ]High milling yield
   5[ ] Consumers preference
   6[ ] Paddy usually available
   7[ ] Milled rice has good price
   8[ ] Large grain size

3. Quality that influenced your choice of paddy for processing
   1[ ] Unbroken grains
   2[ ] Long grains
   3[ ] Broken grains
   4[ ] Aromatic grains
   5[ ] Uniformity of grains
   6[ ] Shape of grains
   7[ ] Cooking characteristics
   8[ ] Chalkiness of grains
   9[ ] Moisture content of grains

AppendixE3: Rice marketers quistionare

To determine the milling characteristics of rice produced and processed in the Sagnarigu and Kumbungu districts, Ghana.

A. Name of respondent: …………………………
B. Age :
   1 [ ] Below 18
   2[ ] 18 – 24
   3 [ ] 25 – 35
   4[ ] 36 – 45
   5 [ ] Above 45
C. Community …………………………

D. Educational level:
   1[ ] No formal education
   2 [ ] Primary
   3[ ]JHS/Middle School
   4[ ]SSS/SHS
   5[ ] Tertiary
E. Contact ………………………………………..
F. Gender
   1[ ] Male
   2[ ] Female

G. General information

1. Variety(ies) used in marketing in order of importance

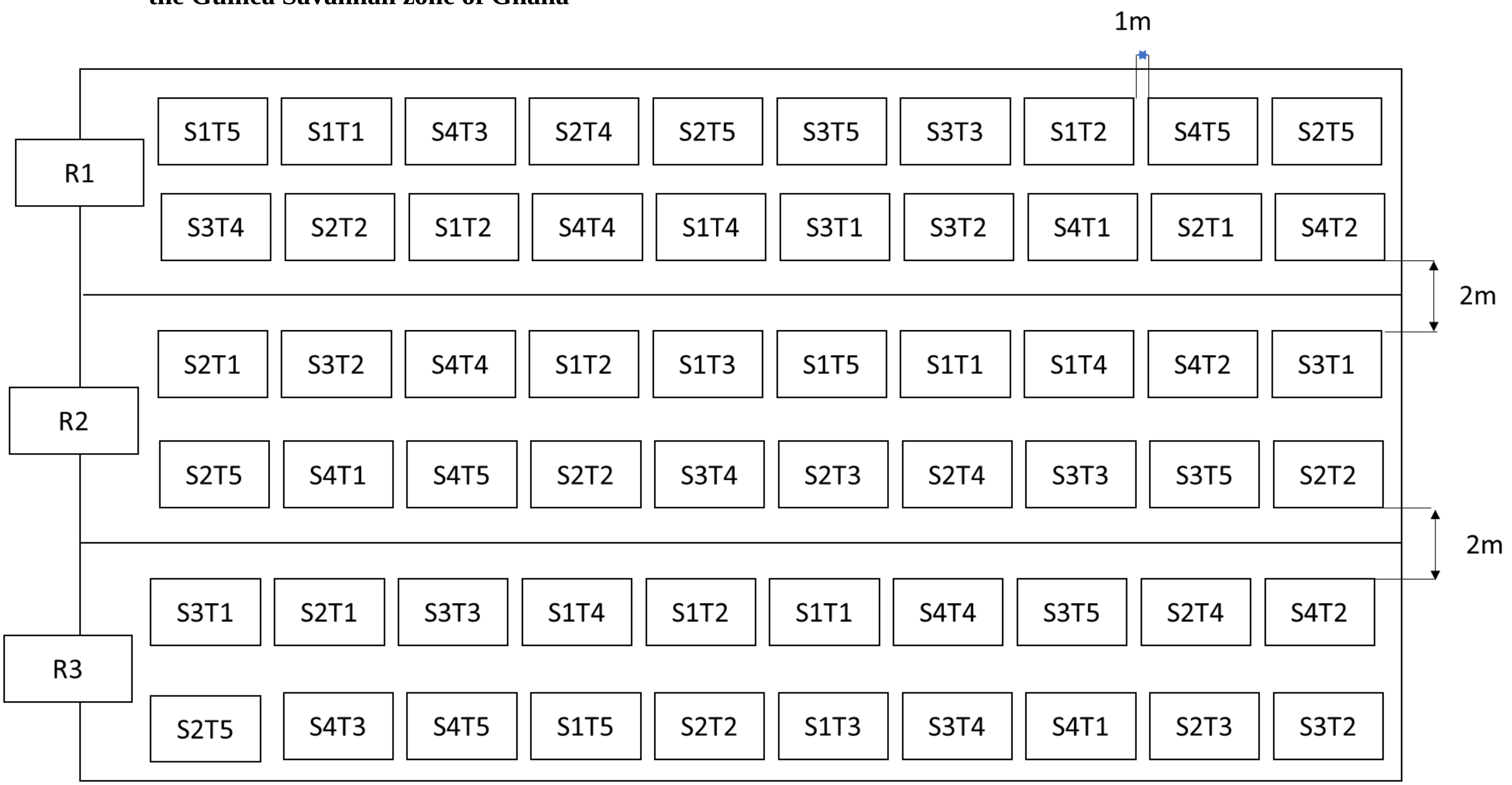
1[ ] Gbewaa rice
2[ ] Agra rice
3[ ] Moses
4 [ ] Digang
5 [ ] Bumbas
6 [ ] Gomma
7[ ] Mandee
8[ ] Tops
9[ ] Anofula
10[ ] Dambala
11 [ ] Salimasaa
12 [ ] Amaru
13[ ] Bazolgu
14 [ ] Faaro

2. Reason for the choice of variety for marketing
1[ ] Suitable for straight milling
2[ ] Tolerate adverse weather conditions
3[ ] It is more affordable
4[ ]High milling yield
5[ ] Consumers preference
6[ ] Paddy usually available
7[ ] Milled rice has a good price
8[ ] Large grain size

3. Qualities that influenced your choice of paddy for marketing
1[ ] Unbroken grains
2[ ] Long grains
3[ ] Broken grains
4[ ] Aromatic grains
5[ ] Uniformity of grains
6[ ] Shape of grains
7[ ] Cooking characteristics
8[ ] Chalkiness of grains
9[ ] Moisture content of grains
10[ ] Unregulated activities of small millers and buyers

Appendix F: Field layouts

Appendix F1.1: Field layout of experimental plots - Time of transplanting and spacing on growth and yield of rice in the Guinea Savannah zone of Ghana



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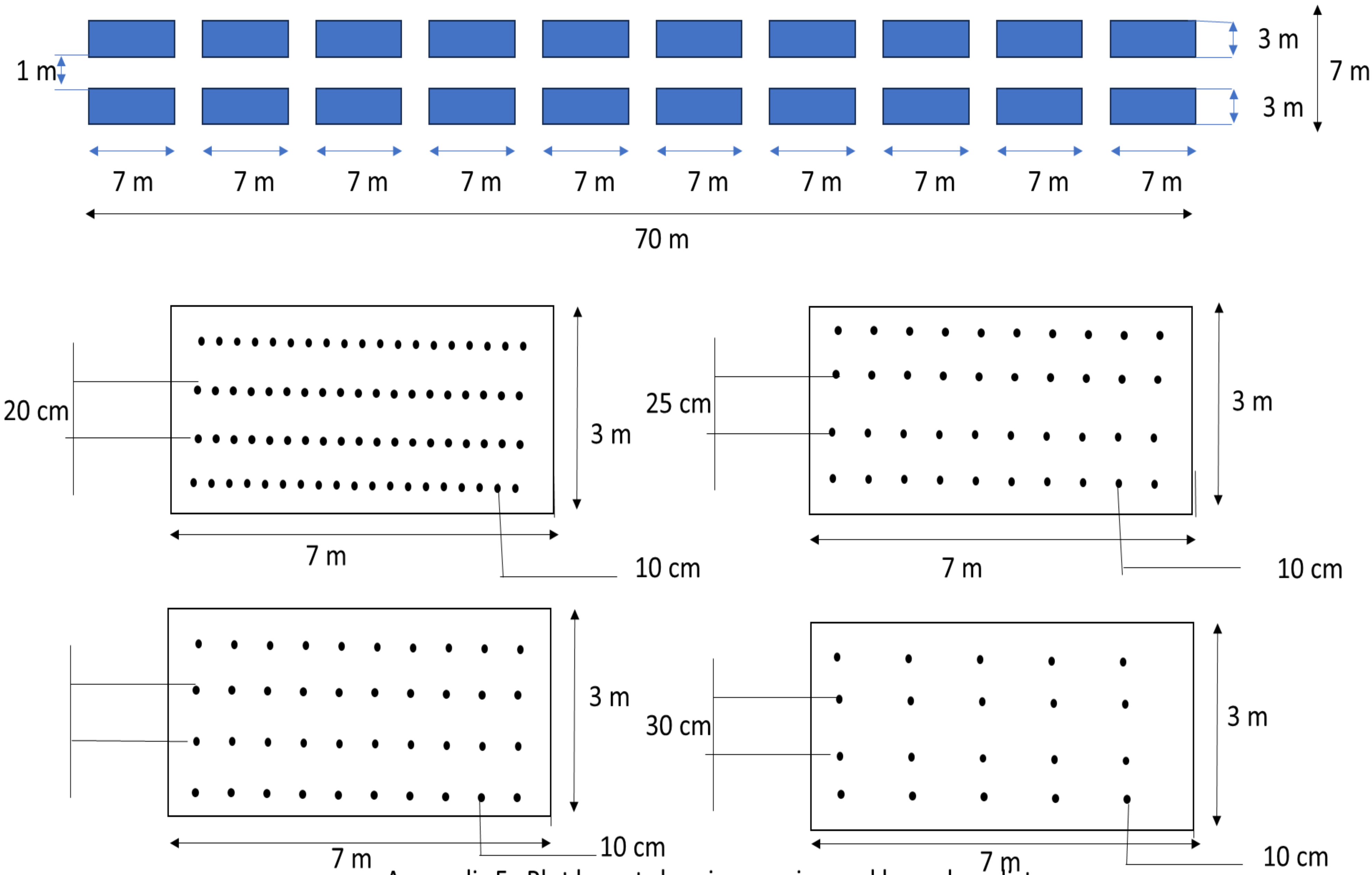
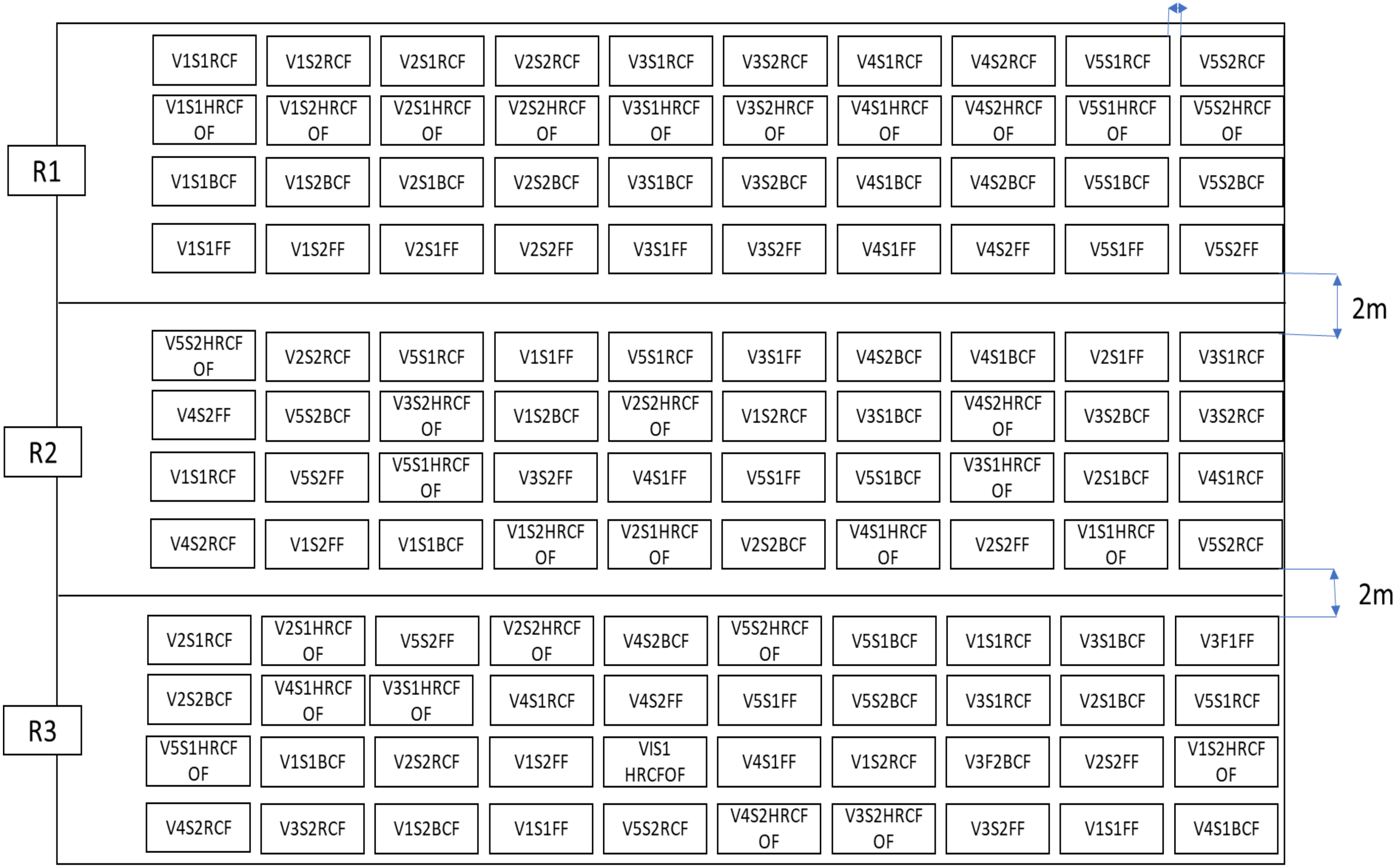
Appendix F1.2: Field layout of replication and showing spacing and boundary distance



Appendix F : Plot layout showing spacing and boundary distance

Appendix F2.1: Field layout of experimental plots – Effects of variety, spacing and amendment on growth, yield and milling characteristics of rice in the Guinea Savannah zone of Ghana



Appendix F2.2: Field layout of replication and showing spacing and boundary distance