Japan Journal of Research

Effect of Tillage System, Herbicide Weed Management, and N-Split Application on Yield and Milling Quality of Irrigated Rice (Oryza Sativa L.) in the Guinea Savannah Zone of Ghana

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Abstract

In the Guinea Savannah agro-ecological zone of Ghana, rice productivity is hampered by suboptimal tillage practices, ineffective weed management, and poor soil fertility. To address these constraints, a field experiment was carried out in Botanga and Golinga to evaluate the effects of tillage systems, herbicide application methods, and N-split fertilizer regimens on irrigated rice (Oryza sativa L.) yield and milling quality. The study used a 3 x 3 x 3 factorial design arranged in a split-split-plot with three replications. Results revealed that soils at both sites were clay loam, slightly acidic (pH 5.10), with low total nitrogen (0.10%), available phosphorus (2.88 mg/kg), and exchangeable cations. Amon the treatments, minimum tillage combined with pendimethalin + triclopyr significantly reduced weed density compared to other combinations. The application of pendimethalin (0.40 kg a.i. ha^{-1}) + triclopyr (0.03 kg a.i. ha^{-1}), coupled with 120 kg N ha^{-1} split into four applications, enhanced tillering (19 and 17 tillers per hill at Golinga and Botanga, respectively, at 6 weeks after planting). This treatment also produced the highest filled spikelets per panicle and maximum 1000-grain weight at both locations. The same fertilizer and herbicide combination yielded the highest grain production, 8,487 kg/ha at Golinga and 8,016 kg/ha at Botanga, and showed positive correlations with panicle weight, seeds per panicle, and straw weight. Additionally, it resulted in the highest unbroken grain recovery (7.5 mm) and benefit-to-cost ratio. The study recommends applying pendimethalin + triclopyr at 0.40 kg a.i. ha^{-1} combined with 120 kg N ha^{-1} split into four doses to maximize rice yield, quality, and income. Overall, the research underscores the significance of tailored, evidence-based agronomic practices to improve rice productivity in Ghana's Guinea savannah zone.

Introduction

Rice (*Oryza sativa*) and (*Oryza glaberrima*) are globally vital cereal crops, serving as primary sources of calories and nutrition for over half of the world's population, especially in Asia where rice is a staple diet (FAO, 2021). Rice ranks as the second most-produced cereal after maize, contributing over 20% of the total caloric intake worldwide (FAO, 2020). In sub-Saharan Africa, rice has become the most critical cereal crop in terms of production volume and consumption, with Ghana's rice sector expanding significantly over recent decades. In 2005, rice consumption in Ghana was approximately 500,000 tons, with a per capita intake of roughly 22 kg, largely produced by smallholder farmers (Ghana Statistical Service, 2006).

Between 1961 and 2013, Ghana's rice cultivation area increased from 27,518 hectares to over 215,905 hectares, accompanied by a surge in annual consumption from about 30,400 to 569,524 tons during the same period, driven by population growth and urbanization (FAO, 2023; MOFA, 2018). Despite this expansion, Ghana continues to rely heavily on rice imports—valued at approximately US$500 million annually—due to limited local productivity and resource constraints (WTO, 2020).

Rice is cultivated across diverse ecological zones in Ghana, including the savannah, rainforest, and coastal regions. The Northern, Volta, and Upper East regions are key rice-producing areas, with annual production ranging between 45,000 and 160,000 tons. Notably, the Volta region has experienced the highest growth, with production increasing from 43,944 metric tons in 2008 to approximately 125,450 metric tons in 2015 (Ghana Rice Development Strategy, 2023). However, low yields persist due to poor land management, inadequate inputs, and water constraints, emphasizing the importance of adopting sustainable agronomic practices.

Water management remains critical, as rice cultivation consumes over 85% of accessible

water resources in many agricultural systems (FAO, 2020). Given the escalating water scarcity driven by climate variability and competing demands, precise water management strategies are essential to ensure sustainable production.

Tillage practices, which modify soil structure to enhance crop growth, significantly affect soil health, crop productivity, and weed control. These include operations such as plowing, harrowing, and minimal tillage, aimed at creating optimal conditions for seed germination and crop development. Additionally, weed management—primarily through herbicide application—is vital in reducing weed competition that can substantially diminish yield. Proper herbicide timing and methods are critical to maximizing control and yield improvements (Mwangi *et al.*, 2017).

Nitrogen (N) is an essential nutrient for rice, influencing growth and yield across various ecologies. Challenges such as declining soil fertility, improper N management, and ineffective weed control hinder sustainable rice production, particularly among resource-constrained smallholders with land tenure issues (Agyare *et al.*, 2023). Optimizing nitrogen use through split applications, aligned with crop growth stages, helps improve nutrient efficiency, enhance yields, and support sustainable production systems.

Objective

The primary objective of this study was to evaluate the impact of tillage systems, herbicide application, and N-split fertilizer methods on yield components, overall yield, milling quality, soil properties of irrigated rice, and the economic benefits stemming from these practices.

Materials and methods

Location and site characteristics

The research was carried out in irrigated fields located in Golinga and Botanga, from January to May 2023. Golinga is positioned between latitude 09°15 and 10°02 N and longitudes 0°53 and 1°25" W, standing at an altitude of 183 m above sea level. On the other hand, Botanga is situated between latitude 9°30" and 9°35" N and longitude 1°20" and 1°04" W. Before the study, these sites were used for Okra cultivation. Both locations fall within the Guinea-savannah agroecological Zone of Ghana and feature sandy loam soil texture at depths of 0–15 cm and 15–30 cm. The average annual rainfall recorded at these sites is 1000 mm, with daily temperatures ranging from 19°C to 41°C.
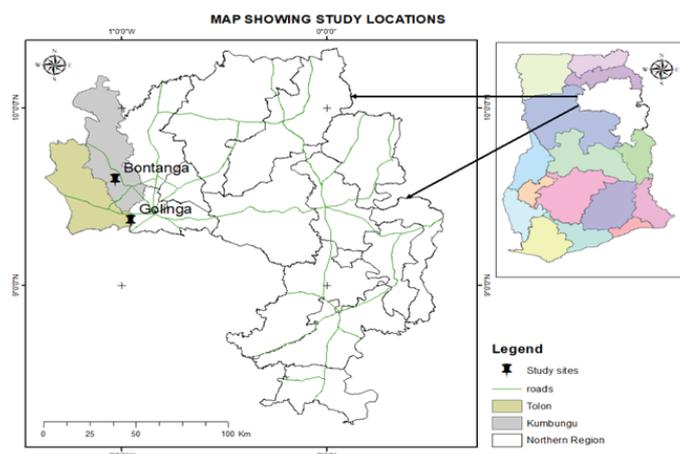
Map of Botanga and Golinga Irrigation Schemes

Basal soil sampling and analysis

Soil initial chemical properties analysis

Prior to planting, soil samples were collected along two diagonals of the experimental field to determine baseline soil physico-chemical properties. At each diagonal, five cores were extracted from a 0–20 cm depth at regular intervals, combined, and air-dried on a shallow tray in a well-ventilated area. Care was taken to crush soil lumps without damaging roots, organic residues, or gravel. The crushed soil was then sieved through a 2 mm mesh to separate debris and larger particles.

Soil analysis was performed at the Soil Chemistry Laboratory of the Savanna Agricultural Research Institute (SARI) in the Northern Region of Ghana. Soil pH was measured using a glass electrode in 0.01 M $CaCl_2$ solution (OECD, 2000). Particle-size distribution was determined via the hydrometer method as described by Ashworth et al. (2001). Organic matter content was analyzed using the Walkley-Black (1934) dichromate digestion method, and total nitrogen was determined via the micro-Kjeldahl technique (Bremner, 1992). Available phosphorus was assessed following the protocol of Murphy and Riley (1962). Exchangeable potassium, calcium, and magnesium were extracted using ammonium acetate; potassium levels were measured with a flame photometer, and calcium and magnesium were quantified via EDTA titration (Chapman, 1965).

Soil pH to determine the pH of each air-dried soil sample, the fine earth fraction was mixed with distilled water at a 1:1 ratio using a microprocessor pH meter. 10 grams of soil and 10 ml of distilled water were combined in a 50 ml polythene beaker. The mixture was vigorously stirred with a magnetic stirrer for 30 minutes and left to settle for an hour for suspended particles to sink. The pH meter was calculated with standard pH 4.0 and pH 7.0 buffer solutions. The electrode was inserted into the supernatant for pH measurement, which was repeated and averaged for each sample. Readings were captured after stabilization, indicated by a steady signal after 2 minutes, followed by rinsing of the electrode with distilled water between measurements.

Soil organic carbon Organic carbon content was determined through the wet combustion method by Walkley and Black (1934). Soil samples were mixed with potassium dichromate and sulphuric acid in a titration flask, followed by agitation and a 30-minute stand. The remaining dichromate was titrated, and the oxidizable organic carbon was calculated. The organic carbon values were converted to organic matter using the specified equation.

Total nitrogen (N). Total nitrogen content was analyzed using the Kjeldahl procedure with modifications to capture all nitrates in the soil. After digestion, the solution was distilled, and the ammonium content was titrated for nitrogen determination.

Available phosphorus (P) The Bray 1 extraction solution (Bray and Kurtz, 1945) method was employed for available phosphorus determination. Extracted phosphorus was quantified using a spectrophotometer at a specific wavelength.

Exchangeable potassium (K+) Exchangeable potassium was extracted with NH4OAc solution and measured via atomic absorption spectrophotometry.

Cation Exchange Capacity (CEC). The CEC, representing the soil's ability to retain cations, was determined using the Bacl2 Compulsive Exchange Method.

Soil physical and chemical properties after harvesting, post-harvest, soil samples were collected to assess soil properties

influenced by irrigation and mulching. Samples were analyzed for bulk density, pH, and infiltration at depths of 0-20 cm and 20-40 cm to evaluate the experimental field's soil conditions.

Field experiment

Experimental design and Treatments

The study was a 3 x 3 x 3 factorial experiment laid out in a split-split-plot design, comprising of a tillage system, herbicide and N split application method, respectively as main-plot, sub-plot and sub-sub-plot factors in three replications. The tillage system consisted of conventional tillage, minimum tillage, and no tillage, whilst herbicide application comprised of sole pre-emergence herbicide, sole post-emergence herbicide and pre-+ post-emergence herbicide and N-split application method consisted of 60 kg N ha-1, 120 kg N ha-1 applied in two splits, and 120 kg N ha-1 applied in four splits. Each measured 256 m2 as the main plots. The main plots were divided into three sub-plots (80 m^2 each), which were further divided into three sub-sub-plots (25 m^2). Spacing of 0.5 m, 1 m, and 2 m was left between sub-plots and sub-sub-plots, main plots, and replications, respectively. The rice variety used in the test was CRI-Dartey.

Land preparation and treatment structure

Conventional tillage

The land was prepared with a disc plough at a depth of 15-20 cm and harrowed once using a tandem disc harrow to break clods and eliminate weeds before lining and pegging.

Minimum tillage

Minimum tillage plots were sprayed with glyphosate at a rate of 4 liters ha-1 2 weeks before tilling the land at a depth of 5 to 7 cm. The plots were planted after lining and pegging.

No-tillage

No-till plots were sprayed with glyphosate at a rate of 4 liters ha-1 2 weeks before planting. The plots were left unploughed and planted after lining and pegging.

Pre-emergence herbicide application

Pendimethalin (0.4 kg a.i. ha-1) was applied in a 16-liter knapsack sprayer as a pre-emergence herbicide a day after planting. Pre-emergence was preceded by one-hand weeding 30 days after sowing.

Post-emergence herbicide application

Triclopyr (0.03 kg a.i. ha-1) was applied in a 16-liter knapsack sprayer as post post-emergence selective herbicide 30 days after planting. Application of post-emergence selective herbicide was, however, preceded by hand weeding at 15 days after triclopyr application.

Pre-+ post-emergence herbicide application

Pendimethalin 0.4 kg a.i. ha-1 applied PRE 1 DAS + Trichlopyr 0.03kg a.i. ha-1 applied in a 16-liter knapsack sprayer as post-emergence at 30 DAS.

N split application Method

Recommended rate of inorganic N 60 kg N ha-1 was applied at 4 WAP, 120 kg N ha-1 applied in 2 splits at 2 and 4 WAP (60 kg N ha-1 each) for both basal and top-dress for the conventional practice. In the multi-split experimental units, 120 kg N ha-1 was applied in 4 splits at 2, 4, 6, and 8 WAP (30 kg N ha-1 each) and applied at two-week intervals starting from 2 WAP. The fertilizer (Urea) application was done by side placement to a depth of approximately 5 cm.

Cultural practices

Planting

CRI Dartey rice is one of the new varieties that was released in 2023, and its pedigree is NIL2/IR841 with a yield potential of 9,000 kg ha-1. The seeds were obtained from the Savanna Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR), and four seeds per hill and later thinned to one. Plant spacing of 20 cm by 20 cm was used giving a plant population of 250,000 plants ha-1.

Irrigation

The experimental site had been part of a continuous vegetable-rice cropping system for the preceding five years. Furrow irrigation was employed to deliver water to each furrow, with concrete lining along the canals to prevent seepage and facilitate the targeted flow of water into specific basins. Following transplanting, all plots received irrigation to maintain uniform moisture levels, ensuring optimal seedling establishment. For the initial week, irrigation was maintained at 3 to 5 cm above the soil surface. Subsequently, a continuous flooding method was adopted, with water levels maintained at 5 to 7 cm above the soil surface every week until ten days before harvest.

Pests and Diseases Management

The CRI Dartey rice variety exhibits tolerance to various pests and diseases, such as rice blast, rice yellow mottle virus, as well as insects, including stem borers, leafhoppers, and rice bugs. To manage these potential threats effectively, a systemic insecticide formulation (Emamectin benzoate 12g/L + Imidacloprid 50g/L) was applied through spraying on the plants approximately four weeks after transplanting

Data Collection and Analysis

Five plants were randomly chosen and labeled per plot for the collection of agronomic data. Various growth and yield parameters, including plant height, number of leaves per plant, number of tillers, panicle length, panicle weight, number of spikelets per panicle, number of filled grains per panicle, 1000-grain weight, grain yield, rice dry matter yield, and weed dry matter yield, were assessed.

Plant Height and Number of Leaves per Plant

For each plot, five plants were tagged to measure plant height and number of leaves. Data was recorded weekly from the fourth to eighth week post-planting. Plant height was measured from the soil surface to the plant apex using a meter rule, while the number of leaves was counted per plant.

Number of Tillers

Tiller count was conducted at 4, 6, and 8 weeks after planting for each plot using the tagged rice plants.

Number of Panicles, Panicle Length, Panicle Weight, and Number of Spikelets per Panicle

The number of panicles, their lengths, weights, and spikelets were determined from the five tagged rice plants in each plot pre-harvest. Measurements were taken, and averages.

Data Analysis

Split-split-plot model in Analysis of variance (ANOVA) was used in GenStat Statistical package (12th Edition) to analyze the data. Treatments differences were compared using LSD procedure at 5% level of probability. Treatment differences were compared using the Least Significant Difference (LSD) procedure at 5% level of probability. The results were presented in Figures and Tables.

Results

Initial and Post Soil Physico-Chemical Properties

The assessment of initial and post-soil physico-chemical properties at Botanga and Golinga revealed that the experimental soil exhibited a clayey loam texture, a slightly acidic pH, and low levels of total nitrogen, available phosphorus, and exchangeable cations. Additionally, moderate values of organic matter and organic carbon were observed (Table 1 and 2).

In the soil chemical analysis detailed in Table 1, the pH ranged from a low of 5.1 in the low soil quality category to a high of 5.5 in the high soil quality category. Conductivity levels were higher in the high-quality soil category (0.047 ds/m) compared to the low-quality category (0.022 ds/m). Available phosphate content varied from 2.88 mg/kg in the medium soil quality category to 3.90 mg/kg in the high soil quality category. Total nitrogen content ranged from a minimum of 0.10% in the low soil quality category to a maximum of 0.14% in the high soil quality category.

Organic carbon (OC) levels ranged from a low of 0.41% in the low soil quality category to 0.71% in the high soil quality category, reflecting significant differences in organic matter content across soil quality classes (Lal, 2004). Similarly, calcium and potassium ion concentrations were highest in the high soil quality category, at 2.539 cmolc/kg and 0.136 cmolc/kg, respectively, and lowest in the low-quality soils, at 1.656 cmolc/kg and 0.055 cmolc/kg. These variations indicate notable differences in soil fertility and nutrient status across the different soil quality categories (Johnson & Smith, 2018).

Weed occurrences

At Botanga, the dominant weeds observed in the experimental field included broadleaves, grasses, and sedges. Cyperus rotundus (10.42%), Oryza barthii (10.42%), and Amaranthus spinosus L. (10.12%) were the most prevalent weed species. This was followed by *Euphorbia hirta L.* (9.51%), *Tridax procumbens* (9.20%), and *Cyperus eragrostis* (9.20%). The least dominant weed was Eleusine indica (L.) Scop (4.91%). Total

weed density across all categories, grasses, sedges, and broad-leaved weeds was 38.65%, 19.62%, and 41.73%, respectively, at Botanga (Table 3).

At Golinga, *Oryza barthii* (10.15%) was the most dominant weed species, followed by *Amaranthus spinosus L.* (8.59%) and *Solanum nigrium* (8.29%), *Cyperus eragrotis* (7.68%), *Tridax procumbens* (7.37%), *Cyperus rotundus* (7.37%), and *Cynodon dactylon (L.) Pers.* (7.06%) and *Cyperus alternifolius* (7.06%). The least dominant weeds were Digitaria sanguinalis (L.) Scop (3.68%) at Golinga. Among all weed categories, grasses, sedges, and broad-leaved weeds accounted for 30.41, 22.11, and 47.48% respectively at Golinga (Table 4).

Weed density and biomass.

At Botanga, no significant two-way interactions were observed ($P > 0.05$) between treatments across the different weeks. However, weed density showed a significant influence on the tillage system ($P < 0.05$) in 6 and 8 weeks after planting (WAP). Minimum tillage exhibited the lowest weed density of 1.56 plants/m², compared to 2.93 plants/m² in no tillage and 3.19 plants/m² in conventional tillage at 6 WAP in Botanga (refer to Figure 3). A similar trend was observed at 8 WAP.

Furthermore, herbicide application had a significant impact on weed density ($P < 0.05$) at 6 and 8 WAP in Botanga. The combination of pendimethalin + triclopyr resulted in the most substantial reduction in total weed density, recording 1.56 plants/m² at 6 WAP compared to other treatment combinations (see Figure 4). At the same time point, triclopyr alone showed a weed density of 2.48 plants/m², while pendimethalin recorded 3.63 plants/m². By 8 WAP in Botanga, the pendimethalin + triclopyr combination achieved a total reduction in weed population to 0.89 plants/m². In comparison, triclopyr alone had 1.52 plants/m², and pendimethalin alone resulted in the highest weed density of 3.22 plants/m² (refer to Figure 4).

At Golinga, herbicide application significantly affected weed density. Pendimethalin + triclopyr treatment combination resulted in a total reduction in weed density of 1.59 plants/

Table 1. Baseline physico-chemical properties of the soil at Botanga and Golinga used for the study.

Soil parameter	Botanga (Initial)	Golinga (Initial)
pH (1:2.5 H2O)	5.40	5.10
Organic Carbon (%)	0.82	0.62
EC (1:2.5 mS/cm 25oC)	21.50	40.50
Total Nitrogen (%)	0.12	0.10
Available Phosphorus (mg/kg)	2.88	3.76
Exchangeable Bases		
Potassium (mg/kg)	86.50	85.50
Na (mg/kg)	72.00	72.50
C.E.C. (cmol/kg)	15.24	10.25
ESP (%)	4.72	6.07
Particle size distribution (%)		
Sand	53.7	52.6
Clay	0.36	0.67
Silt	45.8	46.7
Texture	Clayey Loam	Clayey Loam

Table 2. Post physico-chemical properties of the soil at Botanga and Golinga used for the study.

Soil parameter	Botanga (Post)	Golinga (Post)
pH (1:2.5 H2O)	5.60	5.50
Organic Carbon (%)	0.70	0.41
EC (1:2.5 mS/cm 25oC)	19.50	38.50
Total Nitrogen (%)	0.14	0.12
Available Phosphorus (mg/kg)	3.88	3.90
Exchangeable Bases		
Potassium (mg/kg)	87.54	86.80
Na (mg/kg)	72.80	72.30
C.E.C. (cmol/kg)	16.27	13.25
ESP (%)	4.54	5.07
Particle size distribution (%)		
Sand	53.7	52.6
Clay	0.36	0.67
Silt	45.8	46.7
Texture	Clayey Loam	Clayey Loam

Table 3: Quantitative scoring of weed species frequency (F), density (D), and summed dominance ratio (SDR) at Botanga experimental rice field during irrigation season 2020.

Weed species	Number of quadrats							SDR%
	1	2	3	4	5	F	D	
	Weed density(m2) (scale 0-4)							
Grasses								
Cynodon dactylon (L.) Pers	0	3	3	2	4	4	12	7.36
Digitaria sanguinalis (L.) Scop	3	1	0	3	2	4	9	6.45
Eleusine indica (L.) Gaertn	1	0	4	2	0	3	7	4.91
Euphorbia hirta L	4	4	3	3	2	5	16	9.51
Oryza barthii	4	4	4	4	3	5	19	10.42
Sedges								
Cyperus eragrotis L.	3	3	2	4	3	5	15	9.2
Cyperus rotundus	4	4	3	4	4	5	19	10.42
Broad-leaved weeds								
Ageratum conyzoide L	3	2	4	2	1	5	12	8.29
Amaranthus spinosus L.	3	4	4	3	4	5	18	10.12
Commelina benghalensis L.	0	4	3	2	0	3	9	5.52
Solanum nigrium L.	2	4	2	2	2	5	13	8.59
Tridax procumbens L.	3	3	4	1	4	5	15	9.2
Total						54	164	100

Weed score. 0 = species not seen, 1= species is rare, 2 = occasional occurrence of species, 3 = species are common and 4= species are abundant.

Table 4: Quantitative scoring of weed species frequency (F), density (D), and summed dominance ratio (SDR) at Botanga experimental rice field during irrigation season 2020.

Weed species	Number of quadrats							SDR%
	1	2	3	4	5	F	D	
	Weed density(m2) (scale 0-4)							
Grasses								
Cynodon dactylon (L.) Pers	0	2	3	2	4	4	11	7.06
Digitaria sanguinalis (L.) Scop	1	1	1	3	0	2	6	3.68
Eleusine indica (L.) Gaertn	1	0	3	2	0	3	6	4.61
Euphorbia hirta L	0	2	3	0	2	3	7	4.91
Oryza barthii	3	4	3	4	3	5	17	10.15
Sedges								
Cyperus alternifolius L	2	0	2	3	4	4	11	7.06
Cyperus eragrotis L.	1	2	2	3	2	5	10	7.68
Cyperus rotundus	1	2	2	1	3	5	9	7.37
Broad-leaved weeds								
Ageratum conyzoide L.		2	3	0	1	4	8	6.14
Amaranthus spinosus L.		2	1	3	4	5	13	8.59
Centrosema pubescens (L.) Benth	1	0	2	1	2	4	6	5.53
Commelina benghalensis L.	0	2	1	2	1	4	6	5.53
Sida acuta L.		2	1	3		4	8	6.14
Solanum nigrium L.	2	3	2	3	2	5	12	8.29
Tridax procumbens L	1	3	2	1	2	5	9	7.37
Total						62	139	100.00

Weed score. 0 = species not seen, 1= species is rare, 2 = occasional occurrence of species, 3 = species are common and 4= species are abundant.
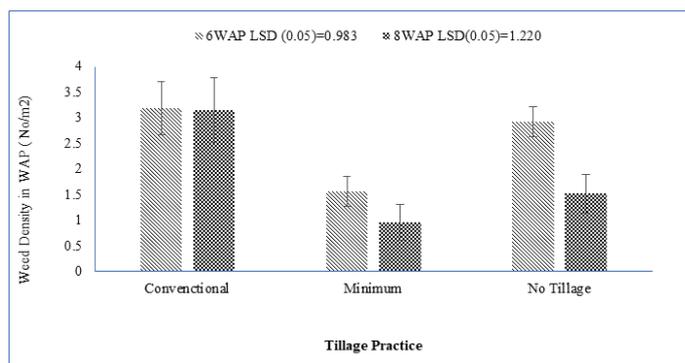
Figure 3: Effect of tillage system on weed density of irrigated rice at 6 and 8 WAP, at Botanga, 2023 cropping season. Error bars: +/- SE.
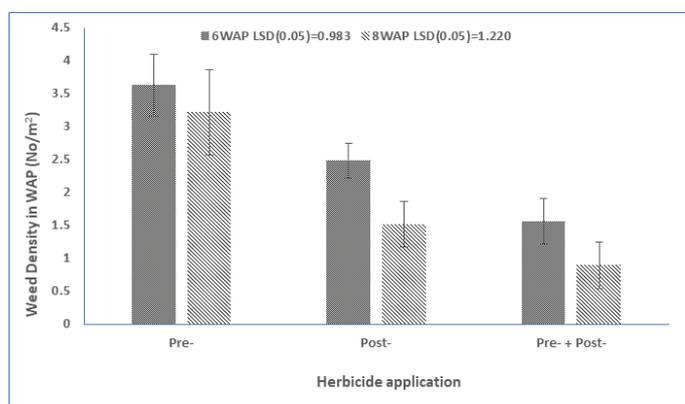

Figure 4: Effect of herbicide application on weed density of irrigated rice at 6 and 8 WAP, grown at Botanga, 2023 cropping season. Error bars: +/- SE. Pre = Pre-emergence herbicide, Post = post-emergence herbicides, pre-+ post-= pre-+ post-emergence herbicide..
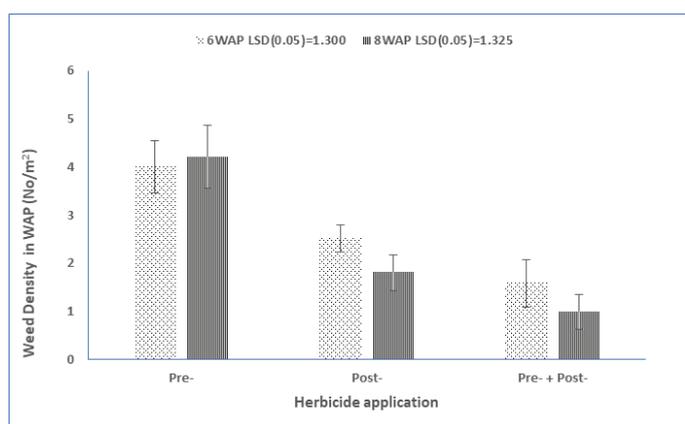

Figure 5: Effect of herbicide application on weed density of irrigated rice at 6 AND 8 WAP, grown at Golinga, 2023 cropping season. Error bars: +/- SE. Pre = Pre-emergence herbicide, Post = post-emergence herbicides, pre-+ post-= pre-+ post-emergence herbicide..

m² at 6 WAP (Figure 5). This was followed by sole triclopyr application, which obtained 2.52 plants/m², while sole pendimethalin recorded the maximum weed density of 4 plants/m² at Golinga.

Measurement of Plant Growth

Plant height

At Botanga, there was no three-way interaction $(P > 0.05)$ between the treatments at the various weeks on plant height. There was, however, a two-way interaction effect $(P < 0.05)$ between herbicide application and nitrogen application on plant height at 6 and 8 WAP. The combination of pre-emergence herbicide application with 60 kg N ha^{-1} recorded the highest plant height of 44.7 cm and 60.5 for weeks 6 and 8 respectively but recorded similar results with pre- + post-emergence plus 120 kg N ha^{-1} applied in 2 splits (Figure 6). This was followed by pre- + post-emergence selective herbicide application plus 120 kg N ha^{-1} applied in 2 splits, which recorded similar plant height of 60.4 cm at 8WAP. Sole post-emergence selective herbicide plus 120 kg N ha^{-1} applied in 2 splits, sole pre-emergence herbicide application plus 120 kg N ha^{-1} applied in 4 splits and sole post-emergence selective herbicides plus 60 kg N ha^{-1} produced similar plant height of 58.8 cm, 58.3 cm, and 58.0 cm respectively at 8WAP, and were the least entries. The lowest plant height of 52.0 cm was recorded on pre- + post-emergence herbicide application plus 60 kg N ha^{-1} at 8 WAP. The plant height of rice was also affected $(P < 0.01)$ by the tillage system. Conventional tillage recorded the highest plant height of 61.0 cm, with no tillage system recording the least plant height of 53.1 cm at 8 WAP.
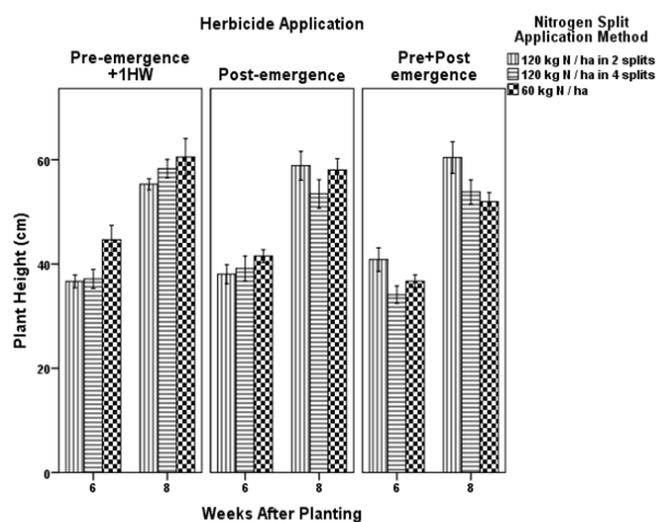

Figure 6: Effect of herbicide application and nitrogen application method on plant height of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE..

At Golinga, there was a three-way interaction effect $(P < 0.01)$ between Tillage system x herbicide application x nitrogen application on plant height at 6 WAP. Treatment combinations between pre- + post-emergence herbicide application with 120 kg N ha^{-1} applied in 4 splits under conventional tillage system recorded the highest plant height of 82.9 cm (Figure 7). This was followed by pre-emergence herbicide application plus 120 kg N ha^{-1} applied in 2 splits under conventional tillage system gave plant height of 80.9 cm at. Also, pre- + post-emergence herbicide application plus 120 kg N ha^{-1} applied in 2 splits under minimum tillage system produced similar results of plant height at 76.0 cm. The lowest plant height of 46.5 cm was recorded

between pre- + post-emergence herbicide application plus 60 kg N ha^{-1} under no-tillage system at 6 WAP.

At 4 WAP, plant height was significantly affected *(P < 0.001)* by herbicide application and nitrogen application method. Post-emergence herbicide application with 60 kg N ha^{-1} recorded the highest plant height of 49.2 cm (Figure 8). This was followed by pre-emergence herbicide application plus 120 kg N ha^{-1} that recorded 48.8 cm but was like post-emergence herbicide application with 120 kg N ha^{-1} applied in 4 splits also recorded 48.6 cm at 4 WAP.

Plant height was significantly affected *(P < 0.002)* by the tillage system at 4 WAP. Minimum tillage recorded the highest plant height of 94.00 cm at 4 WAP. The least plant height of 63.9 cm was recorded on no-tillage at 4 WAP.
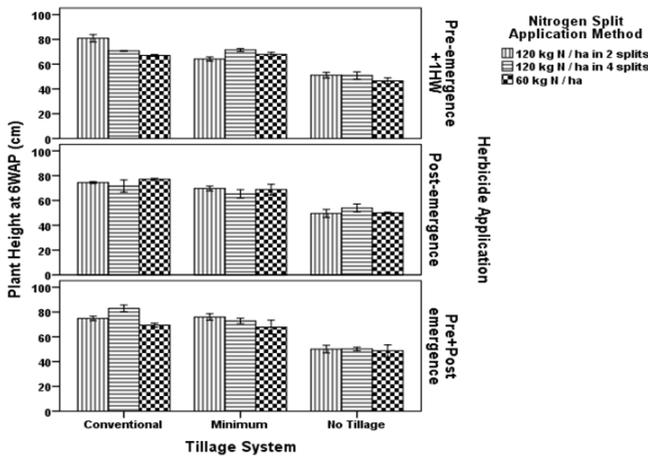
Figure 7: *Effect of tillage system, herbicide application and nitrogen application on plant height at 6 WAP of irrigated rice, at Golinga, 2023 cropping season. Error bars: +/- SE..*
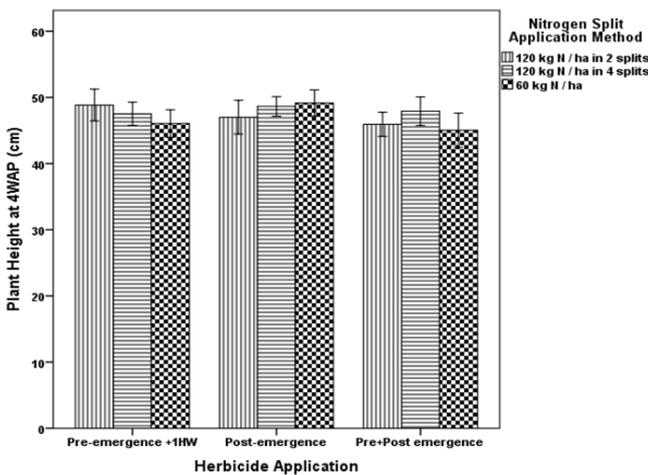

Figure 8: *Effect of herbicide application and nitrogen application on plant height at 4 WAP of irrigated rice, at Golinga, during the 2023 cropping season. Error bars: +/- SE..*

Number of Tillers

At Botanga, interaction between tillage, herbicide application and nitrogen application significantly *(P < 0.05)* enhanced the number of tillers at 6 WAP. Maximum tillers of 17.00 per hill were obtained with pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits under minimum tillage system. (Figure 9). This was followed by pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits under conventional tillage system and 120 kg N ha^{-1} applied in 2 splits with pre- + post-emergence under minimum recorded similar number of tillers per hill. 60kg N ha^{-1} with pre-emergence herbicide under no tillage recorded the least number of tillers per hill.
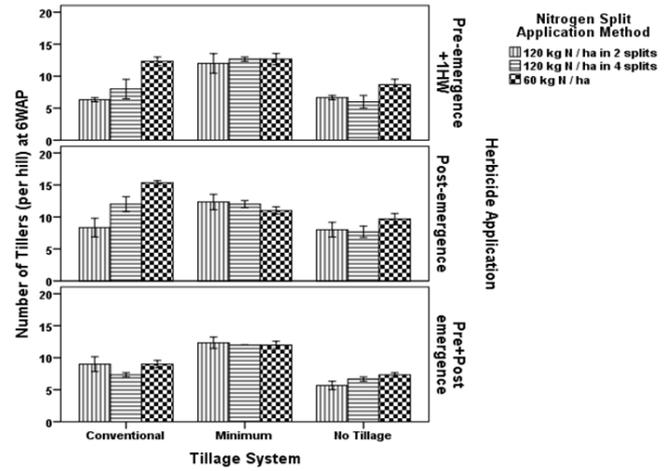

Figure 9: *Effect of the tillage system, herbicide application and nitrogen application method on tiller numbers of irrigated rice, at Botanga, during the 2023 cropping season. Error bars: +/- SE.*
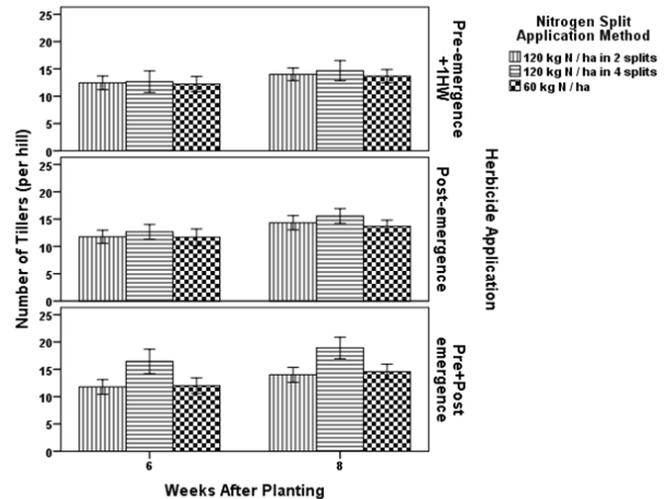

Figure 10: *Effect of herbicide application and nitrogen application method on tiller count of irrigated rice, grown at Golinga, 2023 cropping season at 6 and 8 WAP. Error bars: +/- SE.*

At Golinga, there was a two-way interaction effect between herbicide application and nitrogen application *(P < 0.001)* on tiller number of rice at 8 WAP. Maximum number of tillers 18.89 no/hill were attained with pre- + post-emergence herbicide plus 120 kg N ha^{-1} applied in 4 splits both at 6 WAP and 8 WAP (Figure 10). Pre- + post-emergence herbicide with 120 kg N

ha^{-1} applied in 4 splits produced similar tiller numbers of 16.44 no/hill at 8 WAP but was like post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits. Post-emergence herbicide with 60 kg N ha^{-1} and pre-emergence herbicide plus 60 kg N ha^{-1} produced the same tiller numbers but recorded the least tiller count per hill at 8 WAP.

Effective tiller count

At Botanga, there were no three-way nor two-way interaction effect between tillage system, herbicide application and nitrogen application method *(P > 0.05)* on effective tiller count. However, effective tiller count of rice was significantly *(P < 0.05)* affected by tillage system with the highest under conventional tillage system (8 plants per hill) and lowest for no-tillage system (6 plants per hill) (Figure 11).
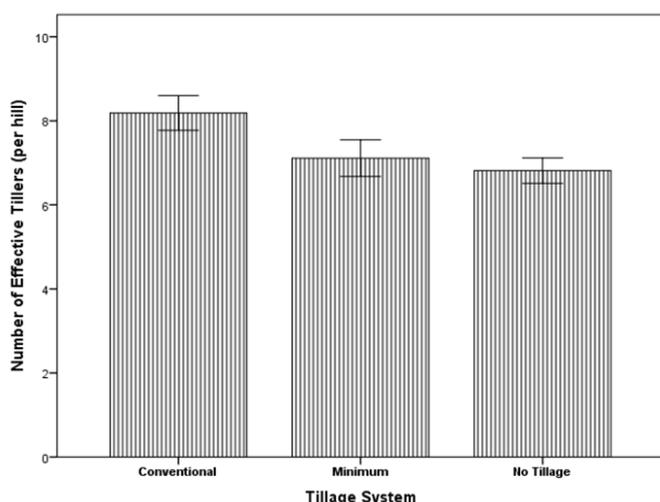

Figure 11: Effect of tillage system on effective tiller count of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.
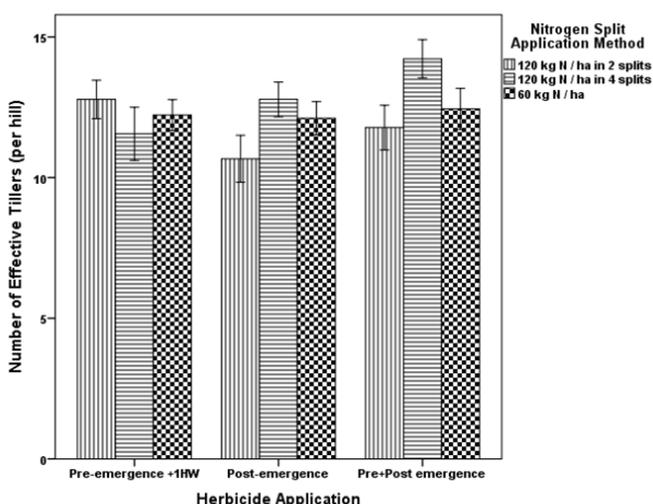

Figure 12: Effect of herbicide application and nitrogen application on effective tiller count of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.

At Golinga, a two-way interaction effect was observed between herbicide application and nitrogen application *(P < 0.05)* on effective tiller count. Among the treatments, pre- + post-emergence herbicide with 120 kg N ha^{-1} in 4 splits gave the highest effective tiller count of 13 per hill (Figure 12). This was followed by sole post-emergence with 120 kg N ha^{-1} in 4 splits but like sole pre-emergence herbicide plus 120 kg N ha^{-1} in 4 splits. The least effective tiller count was recorded with the application of post emergency herbicide plus 120 kg N ha^{-1} in 2 splits.

Chlorophyll content

At Botanga, the interaction effect was significantly *(P < 0.001)* observed between herbicide application and nitrogen application on chlorophyll content 8 WAP. Pre- + post-emergence herbicide x 120 kg N ha^{-1} applied in 4 splits gave the highest chlorophyll content of 45.2 mg m^{-2}. Pre- emergence herbicide alone plus 120 kg N ha^{-1} applied in 2 splits that gave similar results as 44.6 mg m^{-2} at 8 WAP (Figure 13). Post-emergence herbicide by 120 kg N ha^{-1} applied in 4 splits; post-emergence herbicide by 60 kg N ha^{-1} produced similar chlorophyll content. The application of pre- emergence herbicide with 60 kg N ha^{-1} recorded the lowest chlorophyll content at WAP and showed no significant differences among treatments.
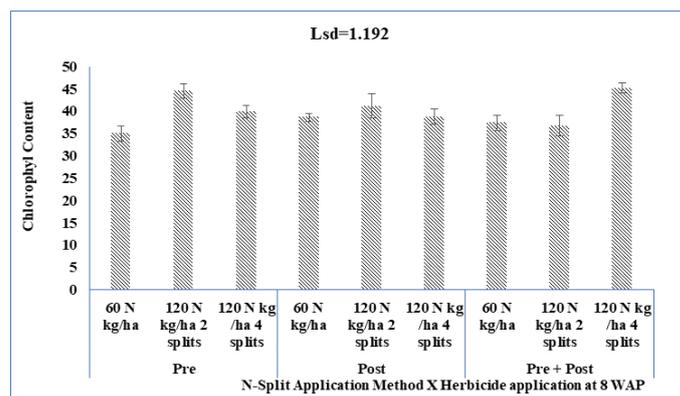

Figure 13: Effect of herbicide application and nitrogen application method on chlorophyll content of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE. Pre = Pre-emergence, Post = post-emergence, pre-+ post-= pre-+ post-emergence.

At Golinga, there was a three-way significant interaction effect *(P < 0.05)* between tillage systems, herbicide application, and nitrogen split application method on chlorophyll content at 8 WAP. Pre-emergence herbicide alone with 120 kg N ha^{-1} applied in 2 splits under no tillage; and post-emergence herbicide alone with 120 kg N ha^{-1} applied in 2 splits under minimum system, gave the highest and statistically similar results of chlorophyll content 50.6 and 50.4 mg m^{-2} at 8 WAP, respectively (Figure 14). This was followed by pre- + post-emergence herbicide plus 120 kg N ha^{-1} applied in 4 splits, minimum tillage system. Pre- + post-emergence plus 120 kg N ha^{-1} applied in 4 splits under conventional tillage; pre- + post-emergence with 120 kg N ha^{-1} applied in 4 splits under no tillage obtained similar results. The least chlorophyll content was recorded with the application of pre-emergence herbicide plus 60 kg N ha^{-1} under no tillage 8 WAP.

Days to 50% Flowering

At Botanga, there was no three-way nor two-way interaction effect *(P > 0.05)* between tillage system, herbicide application, and nitrogen application on days to 50% flowering of rice.
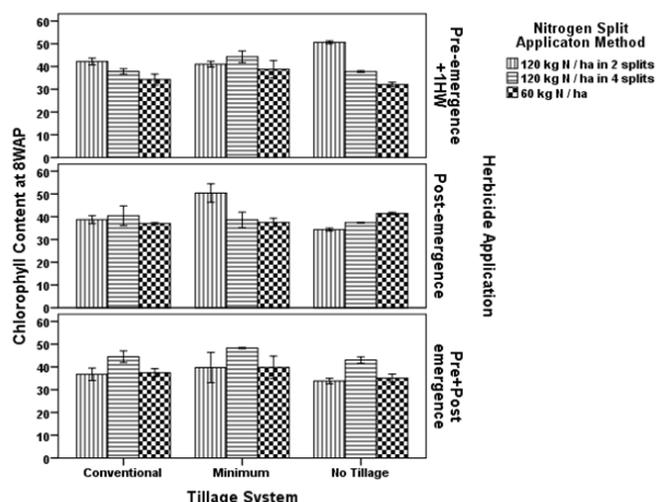
Figure 14: *Effect of tillage system, herbicide application and nitrogen application method on chlorophyll content of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE. Pre = Pre-emergence, Post = post-emergence and pre-+ post-= pre-+ post-emergence.*

However, days to 50% flowering of rice was highly significantly *(P < 0.001)* affected by tillage systems and nitrogen fertilizer. No tillage system recorded the longest days to 50% flowering. The days to 50% flowering content was at par for both conventional and minimum tillage. However, the application of nitrogen splits 120 kg N ha⁻¹ applied in 4 splits recorded the highest days to 50% flowering (Figure 15). This was followed by the application of nitrogen fertilizer with 120 kg N ha⁻¹ applied in 2 splits and 60 kg N ha⁻¹.

At Golinga, results indicated that days to 50% flowering were highly significant *(P < 0.001)* affected by tillage system, with no-tillage system giving the highest (91.74) days to 50% flowering content of rice (Figure 17). Minimum tillage and conventional tillage systems recorded similar values as 83.59 and 83.56, respectively.

Head length of rice

At Botanga, rice head length was significantly *(P < 0.05)* affected by the interaction between herbicide application and nitrogen application. The head length of rice 26.22 cm was found with the combination of pre- + post-emergence herbicide with 120 kg N ha⁻¹ applied in 4 splits gave the best head length. (Figure 18). This was followed by sole post-emergence herbicide plus 120 kg N ha⁻¹ applied in 4 splits that recorded 24.09 cm. Similar results were obtained from sole pre-emergence herbicide with 60 kg N ha⁻¹, sole post-emergence plus 60 kg N ha⁻¹, pre- + post-emergence herbicide with 60 kg N ha⁻¹, and pre- + post-emergence with 120 kg N ha⁻¹ applied in 2 splits. The least head length of 23.22 cm was recorded with the application of pre-emergence herbicide plus 120 kg N ha⁻¹ in 2 splits.

At Golinga, there was a significant interaction effect (*P < 0.001*) between herbicide application and nitrogen application on the head length of irrigated rice. Head length 27.99cm of rice was the best with a combination of pre- + post-emergence herbicide plus 120 kg N ha⁻¹ applied in 4 splits. (Figure 19). Comparable results were attained from pre-mergence herbicide with 60 kg N ha⁻¹, post-emergence plus 60 kg N ha⁻¹, pre- + post-emergence herbicide with 60 kg N ha⁻¹. The least rice head length of 24.96 cm was recorded with the combination of pre- + post-emergence selective herbicide plus 120 kg N ha⁻¹ applied in 2 splits.
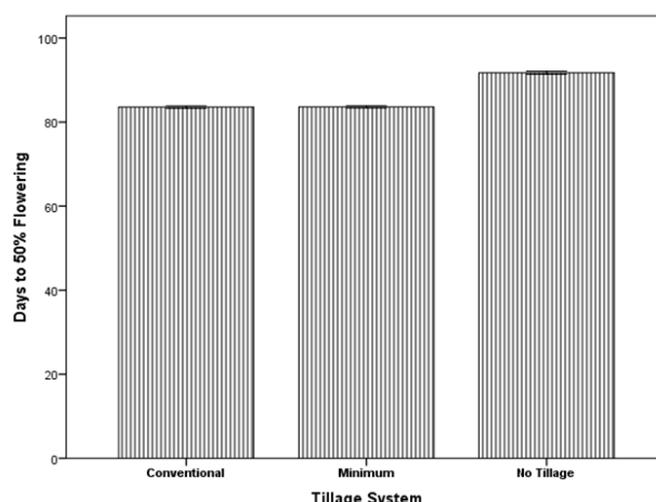

Figure 15: *Effect of tillage system on days to 50% flowering of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.*
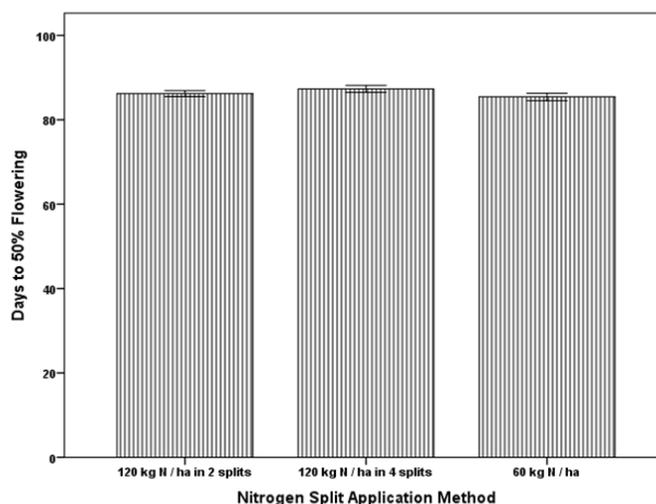

Figure 16: *Effect of nitrogen splits on days to 50% flowering of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.*
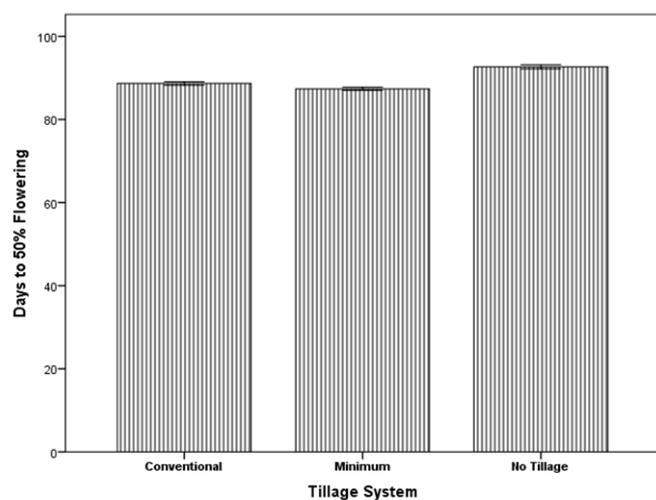

Figure 17: *Effect of tillage system on days to 50% flowering on irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE..*
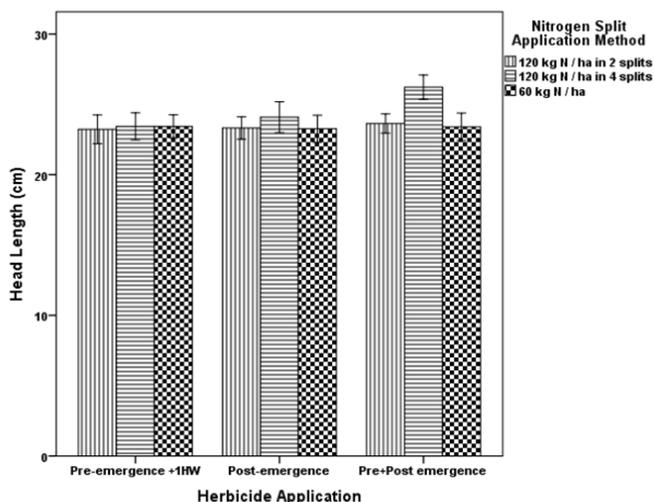
Figure 18: Effect of herbicide application and nitrogen application on head length of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.
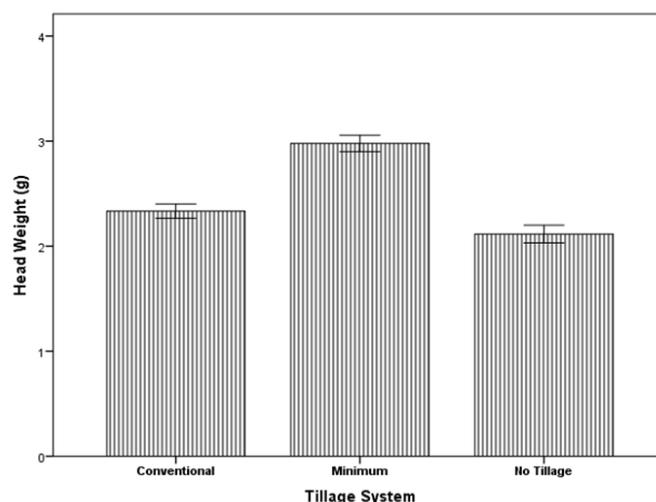

Figure 20: Effect of tillage system on head weight of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE
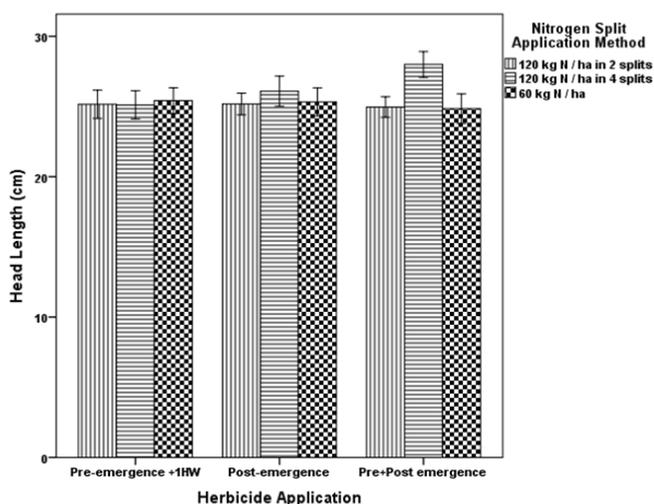

Figure 19: Effect of herbicide application and nitrogen f splits application on head length of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.
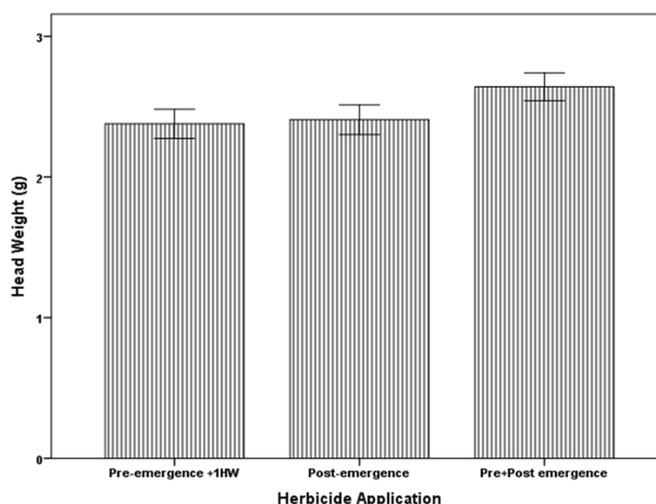

Figure 21: Effect of herbicide application on head weight of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.

Head weight of rice

At Botanga, there was no three-way or two-way interaction effect *(P > 0.05)* between treatment combinations on head weight of rice. However, the head weight of rice was significantly *(P < 0.001)* affected by tillage system, herbicide, and nitrogen application. Among the tillage systems, minimum tillage recorded the greatest head weight (2.97 g) of rice, while the least head weight (2.11 g) of rice was observed under the no-tillage system.

Among the herbicide applications, pre- + post-emergence herbicide recorded the greatest head weight (2.64 g) of rice (Figure 20). Pre-emergence herbicide and post-emergence herbicide recorded lower but statistically similar results. Among the N treatments, 120 kg N ha^{-1} applied in 4 splits recorded the greatest head weight (2.69 g) of rice. This was followed by nitrogen splits of 120 kg N ha^{-1} in 2 splits (2.41 g) and 60 kg N ha^{-1} (2.31 g), respectively.

At Golinga, the results indicated that the interaction between herbicide application and nitrogen application significantly *(P < 0.05)* affected rice head weight. The application of pre- +
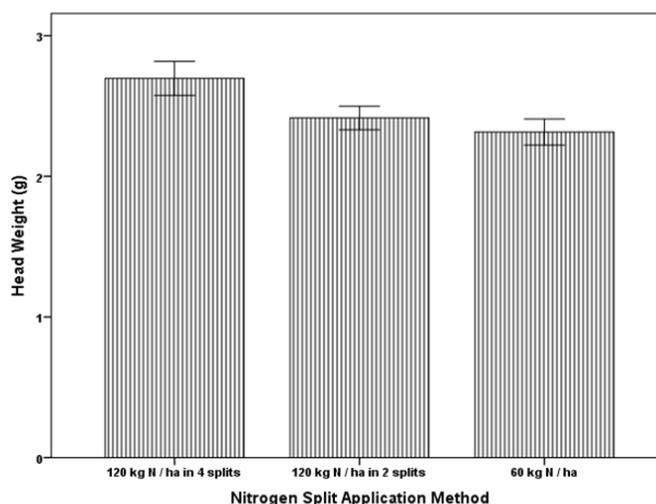

Figure 22: Effect of nitrogen splits on head weight of irrigated rice, grown at Botanga, the 2023 cropping season. Error bars: +/- SE.
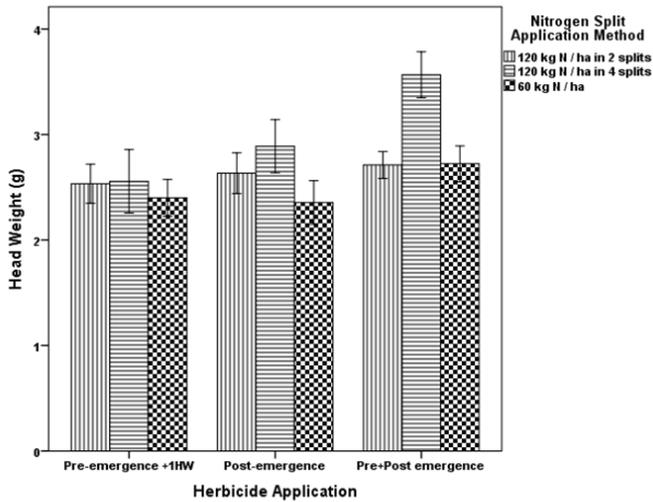
Figure 23: *Effect of herbicide application and nitrogen application on head weight of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.*

Figure 24: *Effect of tillage system and nitrogen application on number of primary branches/panicles of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.*

post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the highest head weight (3.56 g) of rice (Figure 23). Pre- + post-emergence herbicide with 60 kg N ha^{-1}; pre- + post-emergence herbicide plus 120 kg N ha^{-1} applied in 2 splits and pre-emergence herbicide plus 120 kg N ha^{-1} applied in 2 splits recorded similar results. The least head weight (2.35 g) of rice was observed under the application of sole post-emergence herbicide with 60 kg N ha^{-1}.

Number of primary branches/ panicles

At Botanga, the results showed that the number of panicles per hill was significantly ($P < 0.001$) affected by the interaction between tillage system and nitrogen fertilizer. The number of panicles per hill was highest with 120 kg N ha^{-1} applied in 4 splits under the minimum tillage system (Figure 24). 120 kg N ha^{-1} applied in 4 splits under no tillage; 120 kg N ha^{-1} applied in 4 splits under conventional tillage, and 120 kg N ha^{-1} applied in 2 splits under minimum tillage system recorded a similar number of panicles per hill. The least number of panicles of rice was recorded with 60 kg N ha^{-1} under the minimum tillage system.

At Golinga, the interaction between herbicide application and nitrogen application significantly *($P < 0.001$)* affected the number of primary branches/ panicles of rice. The application of pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the highest number of primary panicles of rice (Figure 25). Pre-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits; post-emergence herbicide plus 120 kg N ha^{-1} applied in 2 splits; pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 2 splits, and pre-emergence herbicide 60 kg N ha^{-1} obtained a similar number of panicles per hill. The least number of primary panicles of rice was recorded with pre- + post-emergence herbicide plus application of 60 kg N ha^{-1}

At Golinga, the results also showed a two-way interaction *($P < 0.05$)* between tillage system x nitrogen fertilizer and herbicide application and nitrogen splits on the number of primary panicles of rice. Among the treatments, 120 kg N ha^{-1} applied in 4 splits under minimum tillage applied recorded the highest number of primary branches/panicles of rice (Figure 26). This was followed by 120 kg N ha^{-1} applied in 4 splits under a conventional tillage system. The least number of primary branches/panicles of rice was recorded with 60 kg N ha^{-1} under the no tillage system.

Figure 25: *Effect of herbicide application and nitrogen application on number of primary branches/panicles of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.*
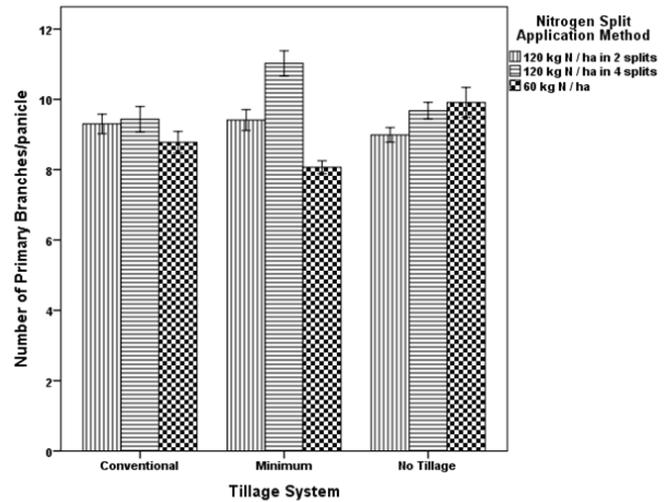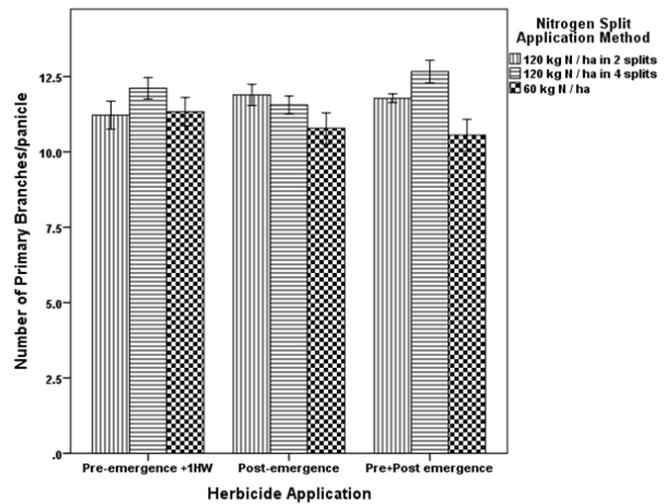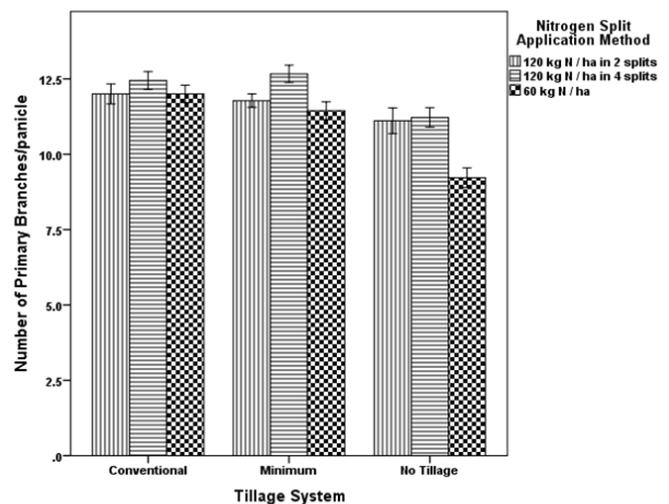

Figure 26: *Effect of tillage system and nitrogen application method on number of primary branches/panicles of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.*
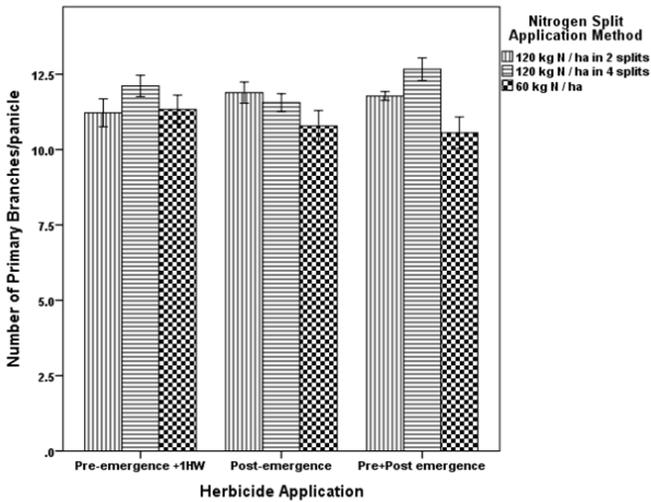
Figure 27: Effect of herbicide application and nitrogen application method on number of primary panicles of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.

Interaction between herbicide application and nitrogen application was significantly *(P < 0.001)* affected by the number of primary branches/panicles of rice at Golinga. The application of pre- + post-emergence herbicide with 120 kg N ha⁻¹ applied in 4 splits recorded the highest number of primary branches/panicles of rice (Figure 27). The least number of primary branches/panicles of rice was recorded with pre- + post-emergence herbicide plus application of 60 kg N ha⁻¹

Total spikelets/panicle

At Botanga, total spikelets/panicles were significantly *(P < 0.001)* affected by tillage system as a sole factor. Minimum tillage recorded the highest total spikelets/panicle, followed by conventional and no tillage, respectively (Figure 28).

Total spikelets/panicle were significantly *(P < 0.001)* affected by herbicide application as the sole factor. The application of pre- + post-emergence herbicide recorded the highest total spikelets/panicle of rice followed by the application of post and pre-emergence herbicide respectively (Figure 29).
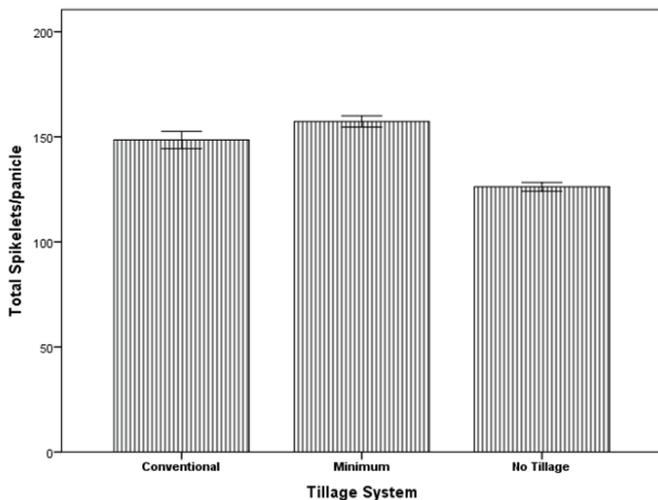

Figure 28: Effect of tillage system on total spikelets/panicle of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.
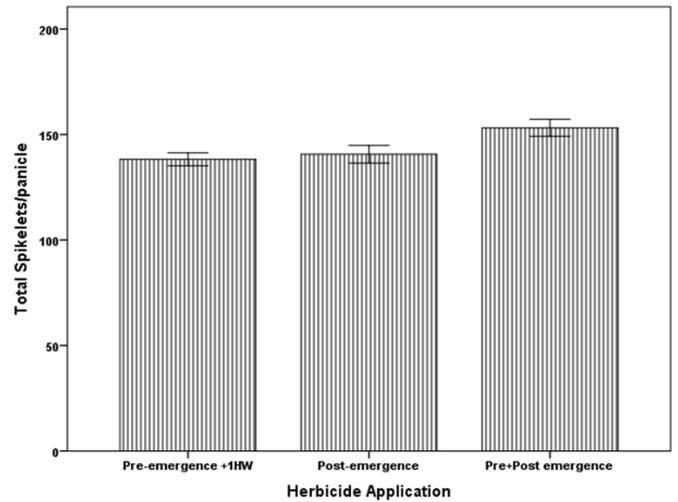
Figure 29: Effect of herbicide application on total spikelets/panicle of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE..

Figure 30: Effect of tillage system, herbicide application and nitrogen application method on total spikelets/panicle of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.

At Golinga, there was a three-way interaction effect between tillage system, herbicide application, and nitrogen application on rice total spikelets/panicle. Among the treatments, pre- + post-emergence selective herbicide with 120 kg N ha-1 applied in 4 splits under minimum tillage recorded the highest total spikelets/panicle of rice (Figure 30). The least was, however, recorded with sole pre-emergence herbicide plus 120 kg N ha⁻¹, 4 splits under a no tillage system.

3.4.10 Number of filled spikelets/panicle

At Botanga, the two-way interaction effect between tillage system and nitrogen application had a significant *(P < 0.05)* influence on the number of filled spikelets/panicle of rice. 120 kg N ha⁻¹ applied in 4 splits with minimum tillage recorded the highest number of filled spikelets/panicle of rice (Figure 31). This was followed by 120 kg N ha⁻¹ applied in 4 splits under conventional tillage, but was like 120 kg N ha⁻¹ applied in 2 splits under minimum tillage. The least number of filled spikelets/panicle of rice was observed with 120 kg N ha⁻¹ applied in 2 splits under a tillage system.

The interaction between herbicide application and nitrogen application also had a significant *(P < 0.05)* influence on the number of filled spikelets/panicle of rice. Among the treatments, pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the highest number of filled spikelets/panicle of rice (Figure 32), while the least number of filled spikelets/panicle of rice was observed with sole pre-emergence herbicide plus 60 kg N ha^{-1}.

At Golinga, the results showed the interaction between tillage system x nitrogen splits significantly *(P < 0.05)* influenced number of filled spikelets/panicle of rice. Among the treatments, 120 kg N ha^{-1} applied in 4 splits under minimum tillage system recorded the highest number of filled spikelets/panicle of rice (Figure 33). This was followed by 120 kg N ha^{-1} applied in 4 splits under conventional tillage system. However, 120 kg N ha^{-1} applied in 2 splits under minimum and 120 kg N ha^{-1} applied in 2 splits under conventional systems recorded similar results. The least number of filled spikelets/panicle of rice was recorded with 60 kg N ha^{-1} under minimum tillage system but was like 120 kg N ha^{-1} applied in 2 splits under no tillage system.
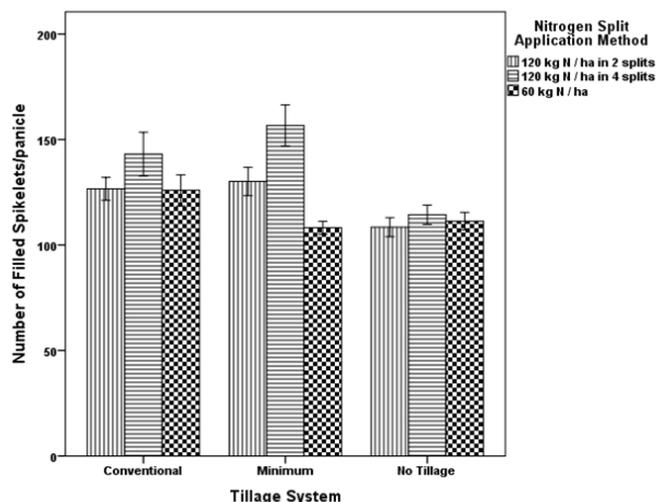
Figure 33: Effect of tillage system and nitrogen application method on number of filled spikelets/panicle of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.
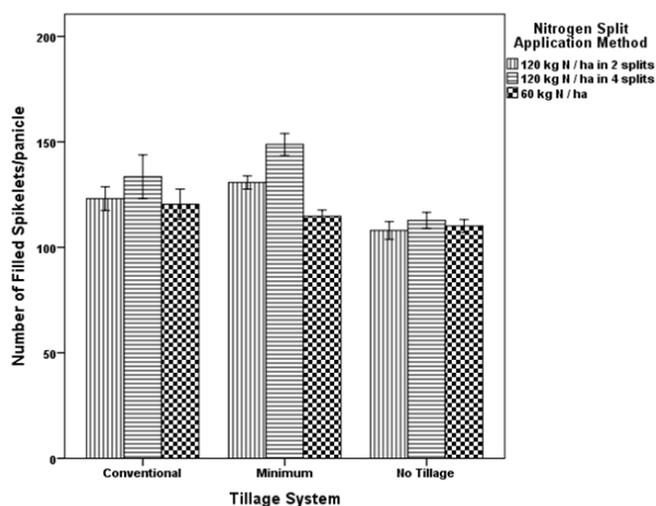
Figure 31: Effect of tillage system and nitrogen application method on number of filled spikelets/panicle of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE..
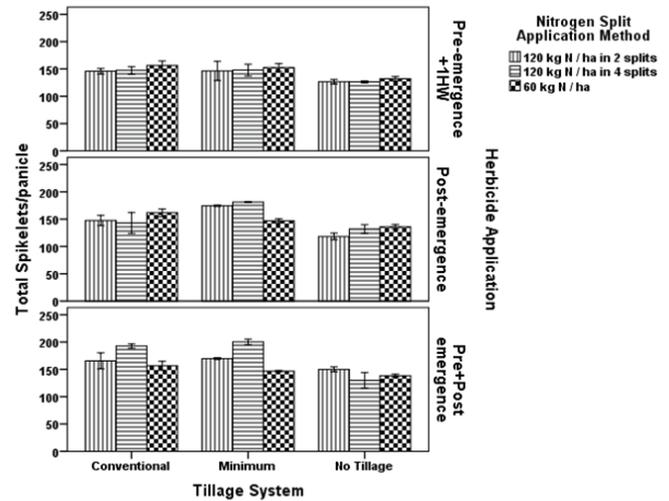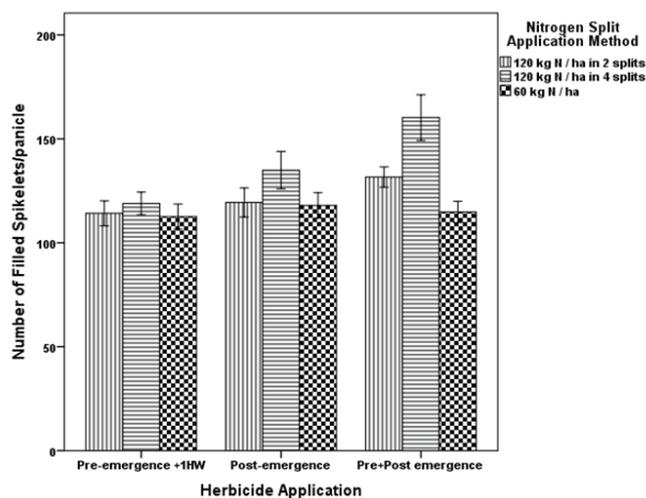

Figure 34: Effect of herbicide application and nitrogen application method on number of filled spikelets/panicle of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE..

Interaction between herbicide application and nitrogen application also had a significant *(P < 0.05)* effect on number of filled spikelets/panicle of rice. Among the treatments, the application of pre- + post-emergence selective herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the highest number of filled spikelets/panicle of rice (Figure 34). This was followed by sole post mergence herbicide plus 120 kg N ha^{-1} applied in 4 splits. The least number of filled spikelets/panicle of rice was however obtained from the application of pre-emergence herbicide with 60 kg N ha^{-1}.

Number of Un-filled spikelets/panicle

At Botanga, tillage system and nitrogen application as sole factors significantly *(P < 0.05)* affected number of un-filled spikelets/panicle of rice. The number of un-filled spikelets/panicle of rice was highest for minimum tillage and least for no tillage system (Figure 35).

The number of un-filled spikelets/panicle of rice was highest for the application of 60 kg N ha^{-1} and least for 120 kg N ha^{-1} applied in 4 splits (Figure 36).

Figure 32: Effect of herbicide application and nitrogen application method on number of filled spikelets/panicles of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE..
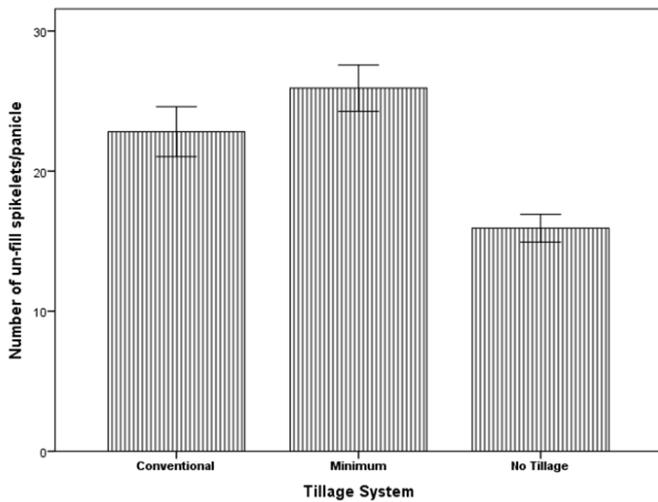
Figure 35: *Effect of tillage system on number of un-filled spikelets/ panicle of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.*
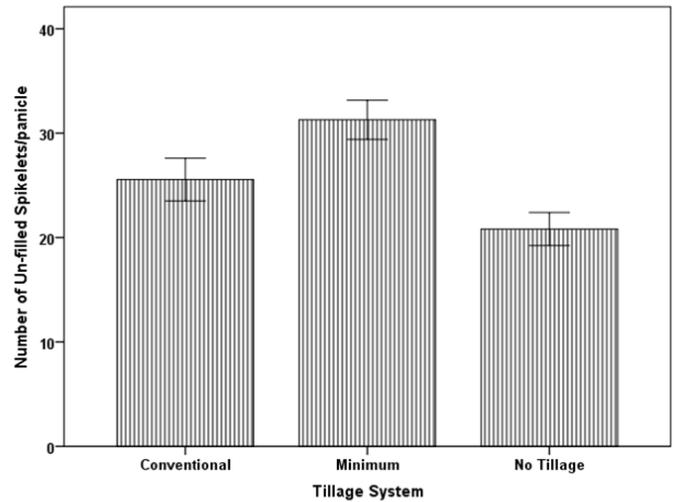
Figure 37: *Effect of tillage system on number of un-filled spikelets/ panicle of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.*
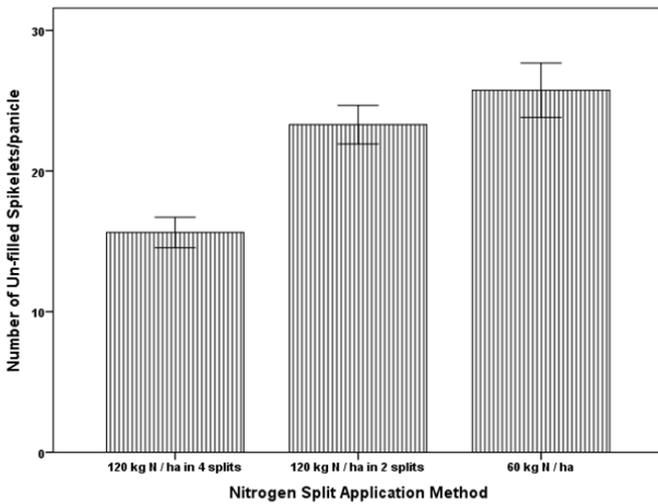
Figure 36: *Effect of nitrogen splits on number of un-filled spikelets/ panicle of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.*
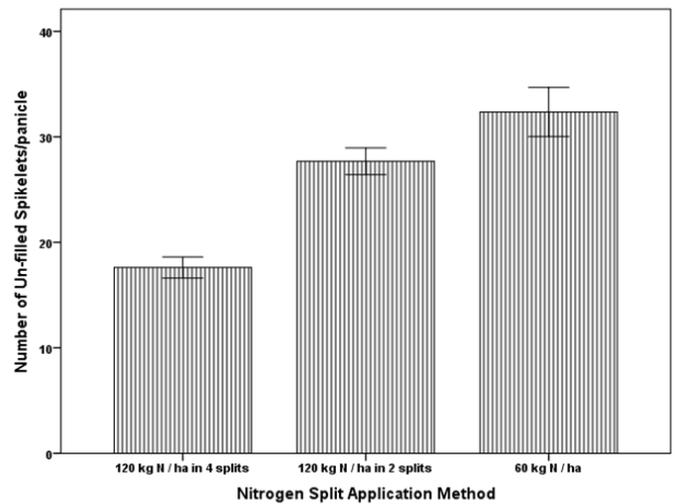
Figure 38: *Effect of nitrogen application on number of un-filled spikelets/panicle of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.*

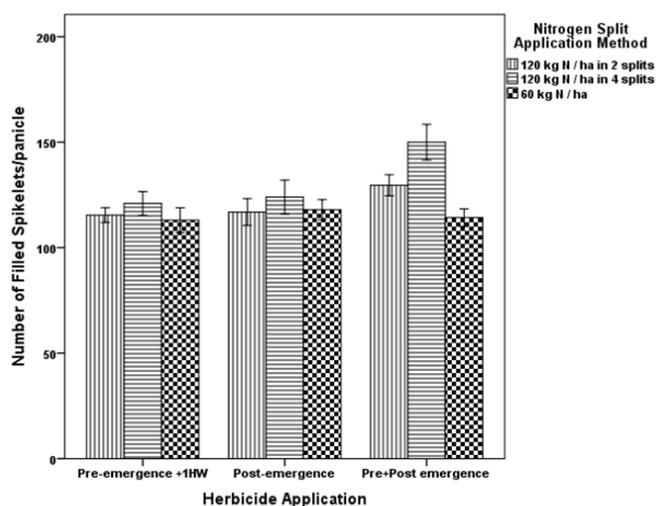At Golinga, the results showed significant *(P < 0.05)* effects among tillage system and nitrogen fertilizer as sole factors on un-filled spikelets/panicle of rice. Minimum tillage recorded the highest number of un-filled spikelets/panicle of rice (Figure 37). The least number of un-filled spikelets/panicle of rice was observed under the no tillage conditions.

The application of nitrogen fertilizer significantly *(P < 0.001)* affected by number of un-filled spikelets/panicle of rice. The number of un-filled spikelets/panicles was highest for 60 kg N ha^{-1} and least for 120 kg N ha^{-1} in 4 splits (Figure 38).

Total dry weight

At Botanga, there was a two-way interaction effect (*P < 0.05*) between tillage system and nitrogen application on fresh biomass weight of rice. The interaction effect between 120 kg N ha^{-1} applied in 4 splits under conventional tillage recorded the highest fresh biomass weight of rice (Figure 39). Statistically similar results were obtained at 120 kg N ha^{-1} applied in 2 splits under no tillage and 120 kg N ha^{-1} applied in 4 splits under no tillage system. The least fresh biomass weight of rice was observed with 60 kg N ha^{-1} under minimum tillage system.

Figure 39: *Effect of tillage system and nitrogen application on fresh biomass weight of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.*

Figure 40: Effect of herbicide application and nitrogen splits on fresh biomass weight of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.

Fresh biomass weight of rice was also significantly *(P < 0.05)* affected by the interaction effect between herbicide application and nitrogen application method. Pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the highest fresh biomass weight of rice (Figure 40). This was followed by sole post-emergence plus 120 kg N ha^{-1} applied in 4 splits while the least fresh biomass weight of rice was observed under sole post-emergence selective herbicide with 60 kg N ha^{-1}.

At Golinga, there was no three-way or two-way interaction effect *(P > 0.05)* between tillage system, herbicide application and nitrogen application were noted on fresh biomass weight of rice. Fresh biomass weight of rice was however highly significant *(P < 0.001)* for tillage system, herbicide application and nitrogen application as sole factors. Among the tillage system, minimum tillage recorded the highest fresh biomass weight of rice (Figure 41). No tillage system recorded the least fresh biomass weight of rice.

Fresh biomass weight of rice was, however, highly significant *(P < 0.001)* for herbicide application. Application of pre- + post-emergence herbicide recorded the highest fresh biomass weight of rice (Figure 42), and least fresh biomass weight of rice was observed under the application of pre-emergence herbicide of fertilizer.

 Fresh biomass weight of rice was however highly significant *(P < 0.001)* for nitrogen fertilizer. 120 kg N ha^{-1} applied in 4 splits recorded the highest fresh biomass weight of rice (Figure 43) while least fresh biomass weight of rice was observed under the application of 60 kg N ha^{-1}.

Straw biomass

At Botanga, there was a two-way interaction effect *(P < 0.05)* of tillage systems x nitrogen application, as it significantly affected straw biomass of rice. 120 kg N ha^{-1} applied in 4 splits under conventional tillage and 120 kg N ha^{-1} applied in 4 splits under no tillage recorded similar straw biomass of rice (Figure 44). The least dry straw biomass weight of rice was with 60 kg N ha^{-1} under minimum tillage system.

The application of pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the highest dry straw biomass weight of rice (Figure 45). This was followed by sole post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits.

Figure 41: Effect of tillage system on fresh biomass weight of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.

Figure 42: Effect of herbicide application on fresh biomass weight of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.
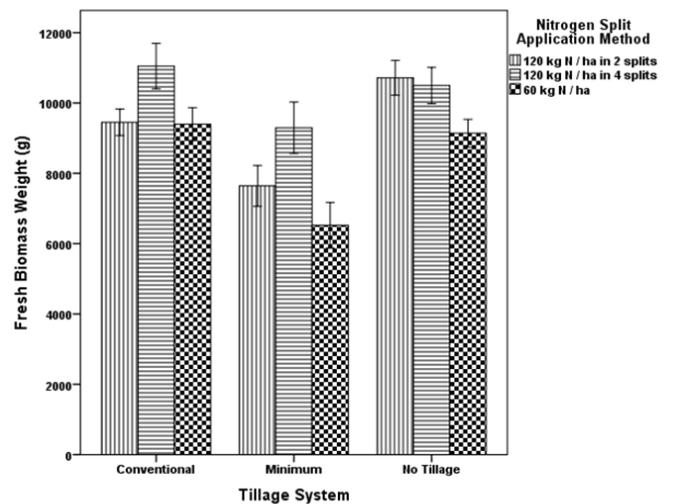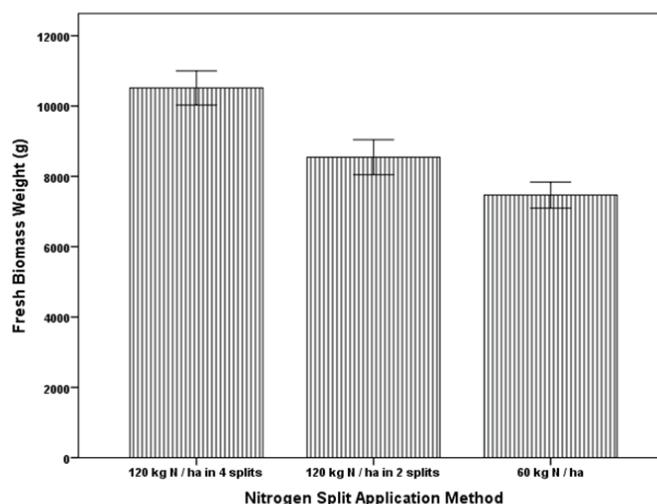

Figure 43: Effect of nitrogen application on fresh biomass weight of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.

Figure 44: Effect of tillage system and nitrogen application on dry straw biomass weight of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.
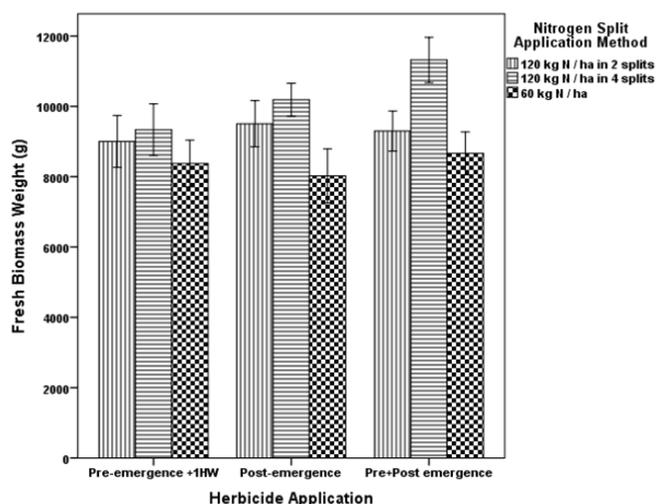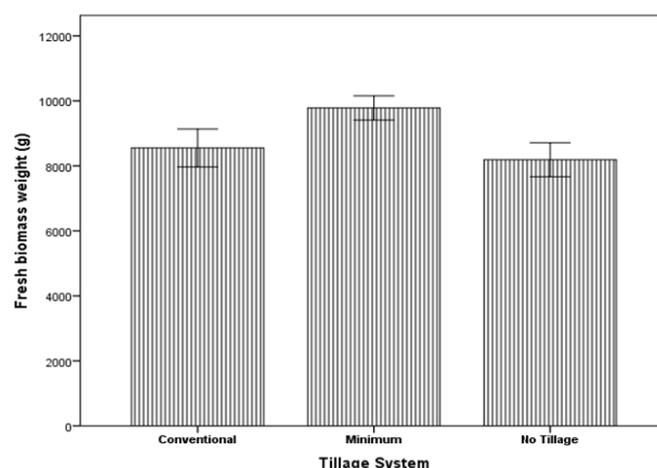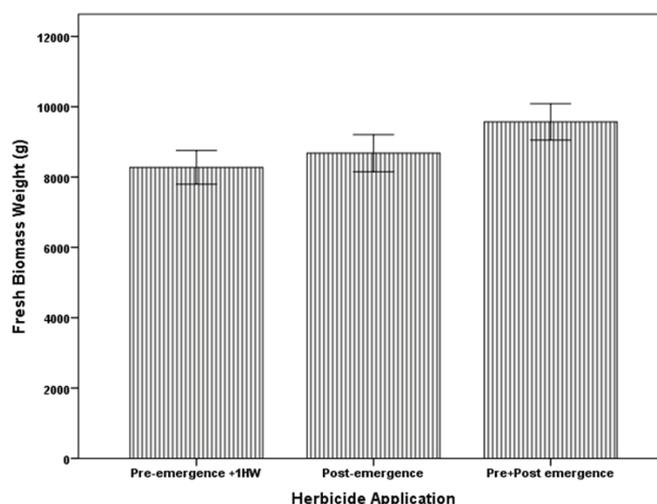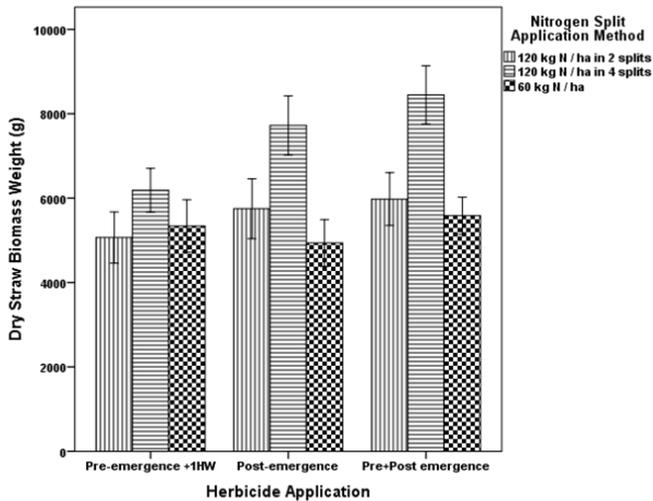

Figure 45: Effect of herbicide application x nitrogen application on dry straw biomass weight of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.
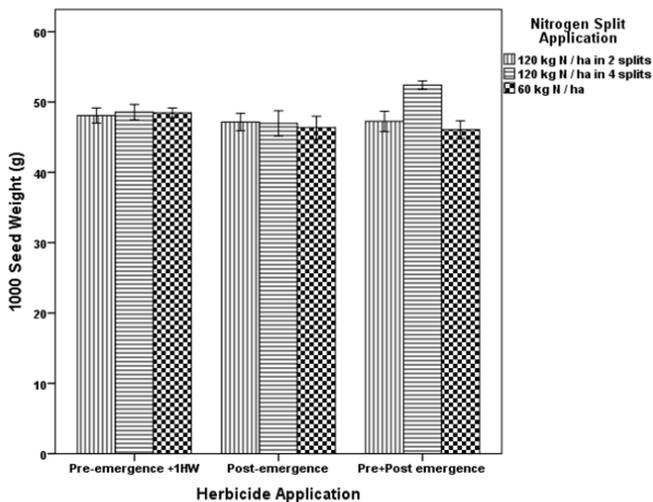
Figure 46: Effect of herbicide application and nitrogen application on 1000 grain weight of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.

The least dry straw biomass weight of rice was recorded by sole post-emergence herbicide with 60 kg N ha^{-1} and showed no significant difference among treatments.

1000 Seed weight

At Botanga, there was a two-way interaction effect *(P < 0.011)* of herbicide application and nitrogen splits fertilizer on 1000 grain weight of rice. The highest 1000 seed weight was recorded using pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits of rice. (Figure 46). This was followed by the sole pre-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits but produced similar results with sole pre-emergence herbicide plus 60 kg N ha^{-1} and post-emergence herbicide plus 120 kg N ha^{-1} applied in 2 splits. The least 1000 seed weight of rice was observed under pre- + post-emergence herbicide under with 60 kg N ha^{-1}.

At Golinga, interaction between herbicide application and nitrogen splits significantly *(P < 0.032)* affected 1000 grain weight of rice. Among the treatments, pre- + post- emergence herbicide with 120 kg N ha^{-1} in 4 splits recorded the highest 1000 seed weight of rice (Figure 47). Generally, the application of pre- + post-emergence herbicide and 60 kg N ha^{-1} under respective treatment combinations recorded the least 1000 seed weight of rice.

Grain yield

At Botanga, there was a two-way interaction effect *(P < 0.01)* between tillage system x nitrogen split application which significantly affected grain yield of rice. Treatments of 120 kg N ha^{-1} applied in 4 splits under minimum tillage recorded the highest grain yield of 8,016 kg ha^{-1} (Figure 48). This was followed by 120 kg N ha^{-1} applied in 4 splits under conventional tillage that recorded grain yield of 6,821 kg ha^{-1} but was like 120 kg N ha^{-1} applied in 2 splits under minimum tillage system that recorded 6,567 kg ha^{-1}. The least grain yield of 3,347 kg ha^{-1} was recorded by 60 kg N ha^{-1} under no tillage system.

Interaction effect *(P< 0.002)* between herbicide application x nitrogen application significantly affected grain yield of rice. Treatment combinations of pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the highest rice grain yield of 8,084 kg ha^{-1} (Figure 49). This was followed by post-emergence herbicide application with 120 kg N ha^{-1} applied
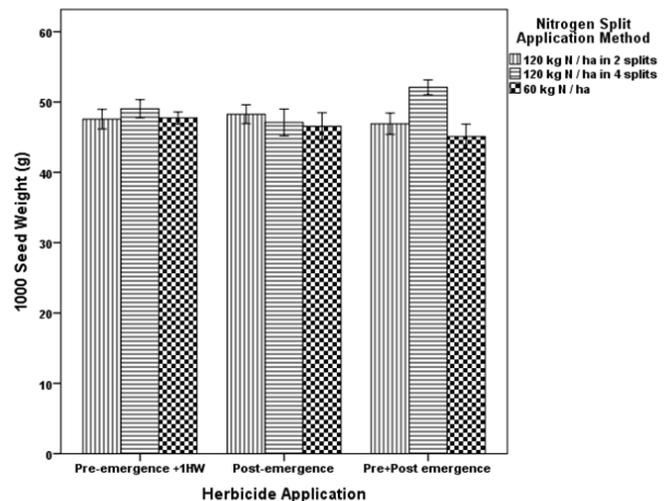
Figure 47: Effect of herbicide application and nitrogen splits on 1000 grain weight of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.
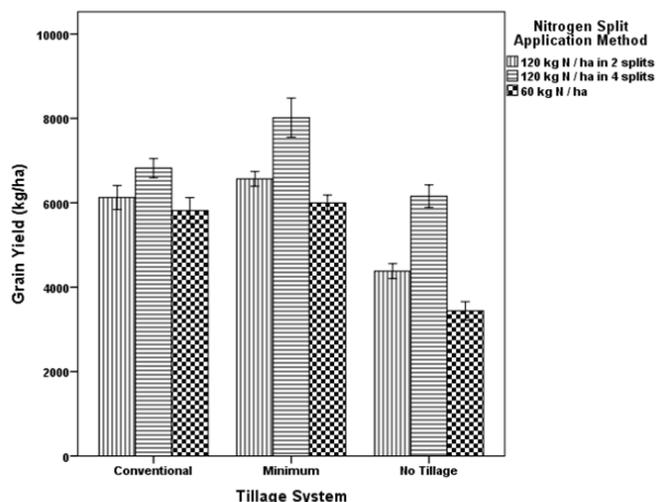
Figure 48: Effect of tillage system by nitrogen application on grain yield of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE..
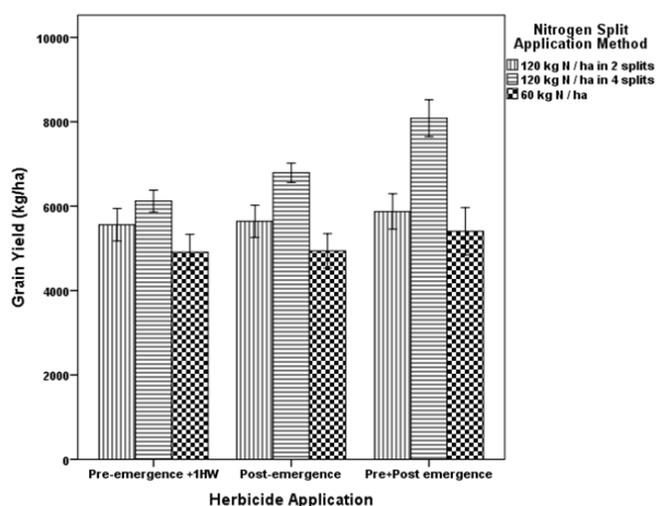
Figure 49: Effect of herbicide application and nitrogen application on grain yield of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.
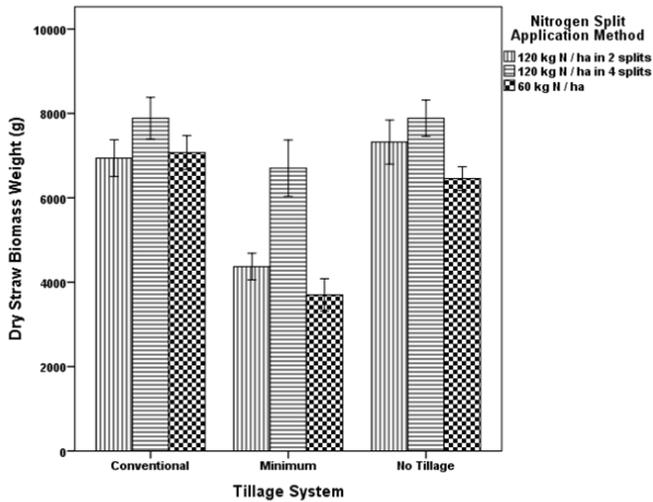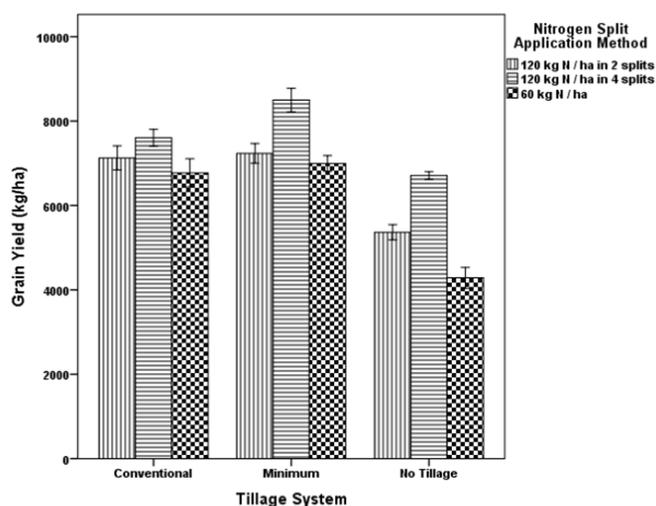

Figure 50: Effect of tillage system and nitrogen application on grain yield of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE.

in 4 splits recorded a grain yield of 6,790 kg ha^{-1}. The least grain yield of 4,907 kg ha^{-1} was recorded by pre-emergence herbicide with 60 kg N ha^{-1}.

At Golinga, there was a two-way interaction effect *(P < 0.004)* between tillage systems x nitrogen application significantly affected grain yield of rice. The application of 120 kg N ha^{-1} in 4 splits under minimum tillage recorded the highest grain yield of 8,497 kg ha^{-1} (Figure 50). This was followed by 120 kg N ha^{-1} applied in 4 splits under conventional tillage recorded a grain yield of 7,604 kg ha^{-1}. 120 kg N ha^{-1} applied in 2 splits under conventional tillage and 120 kg N ha^{-1} applied in 2 splits under minimum tillage produced similar results. The least grain yield of 4,285 kg ha^{-1} was recorded by 60 kg   N ha^{-1} under tillage system.

Rice grain quality and milling recovery of irrigated rice

Milling recovery of unbroken irrigated rice grain (g)

At Botanga, a significant two-way interaction (P < 0.05) was observed between herbicide application and nitrogen levels on the quality of unbroken irrigated rice grains. The treatment with both pre- + post-emergence herbicide and 120 kg N ha^{-1}, applied in four splits, produced the highest milling recovery of unbroken rice. The next highest was achieved with sole post-emergence selective herbicide combined with 120 kg N ha^{-1} in four splits (Figure 51). The lowest grain quality was recorded with the application of sole pre-emergence herbicide plus 60 kg N ha^{-1}, which showed no significant difference from treatments with sole emergence herbicide plus 60 kg N ha^{-1} and pre- + post-emergence herbicide with 60 kg N ha^{-1}.

Similarly, at Golinga, a significant two-way interaction (P < 0.05) was found between herbicide application and nitrogen levels. The combination of pre- + post-emergence herbicide with 120 kg N ha^{-1}, applied in four splits, again yielded the highest unbroken grain quality. This was followed by sole post-emergence selective herbicide with 120 kg N ha^{-1} in four splits (Figure 52). The lowest grain quality was observed with sole pre-emergence herbicide plus 60 kg N ha^{-1}, which was statistically like treatments with sole emergence herbicide plus 60 kg N ha^{-1} and pre- + post-emergence herbicide with 60 kg N ha^{-1}.
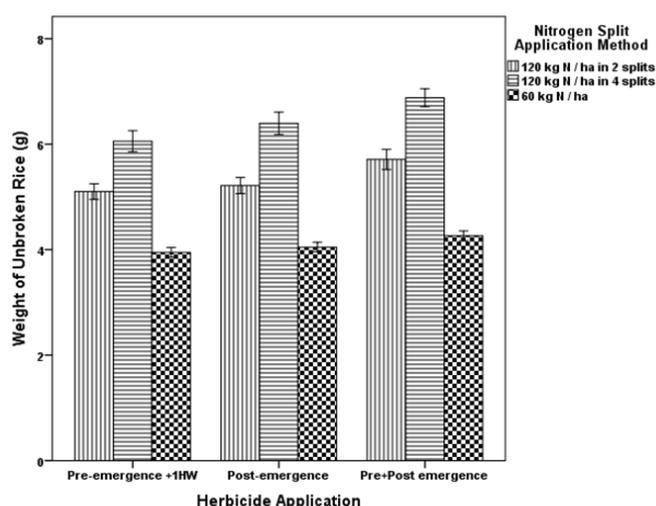
Figure 51: Effect of herbicide application and nitrogen application and on weight of unbroken grains of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE..
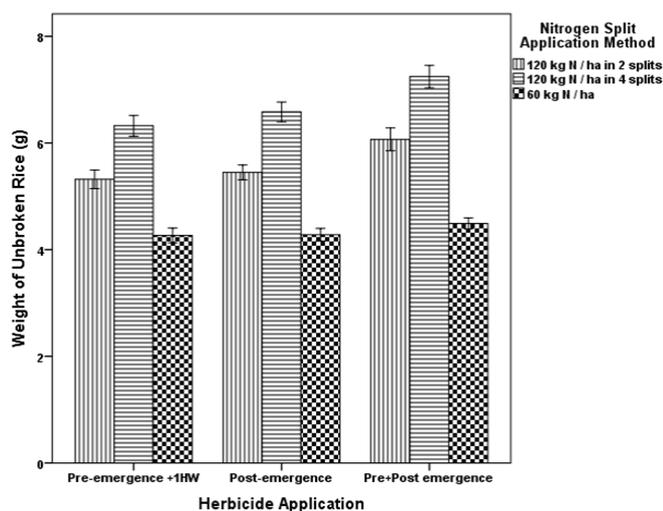
Figure 52: Effect of herbicide application and nitrogen application and on weight of unbroken grains of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE..

Figure 53: Effect of herbicide application and nitrogen application on weight of broken grains of irrigated rice, grown at Botanga, 2023 cropping season. Error bars: +/- SE.

Effect of treatments on percentage broken irrigated rice

At Botanga, there was a two-way interaction effect ($P < 0.05$) between herbicide application and nitrogen application on quality of broken rice grain. Among the treatments, the application of pre-+ post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the least grain broken rice (Figure 53). The maximum weight of broken rice grain was recorded with 60 kg N ha^{-1} plus pre-emergency herbicide and showed no significant differences among sole post-emergence herbicide plus 60 kg N ha^{-1} and pre- + post-emergence selective herbicide with 60 kg N ha^{-1}.

At Golinga, there was a two-way interaction effect ($P < 0.05$) between herbicide application and nitrogen application on quality of broken rice grain. Among the treatments, the application of pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits recorded the least grain broken rice (Figure 54). The highest weight of broken rice grain was recorded on the application of 60 kg N ha^{-1} with a pre-emergency herbicide and showed no significant differences among sole post-emergence herbicide plus 60 kg N ha^{-1} and pre- + post-emergence selective herbicide with 60 kg N ha^{-1}.

Figure 54: Effect of herbicide application and nitrogen application on weight of broken grains of irrigated rice, grown at Golinga, 2023 cropping season. Error bars: +/- SE..

Correlation Analysis

The correlation analysis between grain yield and panicle weight, seeds per panicle, 1000 grain weight and straw weight were positive with the following correlation coefficients (r=0.88**, 0.93**, 0.94**, 0.88**) (Table 5).

Benefit/cost analysis for rice using different technologies

Comparative analysis of the economic productivity of rice production techniques showed that rice production under minimum tillage applied with 120 kg N ha^{-1} in 4 splits and pre- + post-emergence herbicide gave the highest benefit/cost ratio of 4.80 (Table 6). This was followed by rice production under minimum tillage applied with 120 kg N ha^{-1} in 4 splits and post-emergence herbicide with a benefit/cost ratio of 3.70. Pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits under a no tillage system also recorded a benefit/cost ratio of 2.90. However, the application of pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits under no tillage system and pre-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits under minimum tillage system gave the same benefit/cost ratio of 2.70. The application of pre-emergence herbicide with 60 kg N ha^{-1} under a conventional tillage system gave the least benefit/cost ratio of 1.00.

Discussion

Initial and post soil physico-chemical properties

The low fertility status observed in the baseline soil analyses can be attributed to nutrient depletion caused by continuous cropping, erosion, leaching, and bush burning of the experimental field (Amarowicz *et al.*, 2023; Owusu & Asiedu, 2023). This nutrient deficiency likely contributed to the rapid response of rice to applied fertilizers, particularly NPK (Meena *et al.*, 2006). The response of rice to nutrient supplementation is well documented; for instance, Meena *et al.* (2006) reported significant yield increases with NPK application, emphasizing the importance of proper fertility management in degraded soils.

Results further showed that soil bulk density increased with depth from 1.69 to 1.27 g/cm³, being lower at 20–40 cm, which could be due to higher organic matter content in the lower soil layers resulting from long fallow periods and prior land replenishment (Bhardwaj, 2013). The bulk density within the

Table 5: *Spearman's correlation coefficients ® for parameters measured for rice in 2023.*

	PH	TL	PL	PW	NSPP	TSW	SW	GY
PH	-							
TL	0.73	-						
PL	0.80**	0.85**	-					
PW	0.78	0.82**	0.89**	-				
NSPP	0.85**	0.68**	0.92	0.77	-			
TSW	0.42	0.45	0.50	0.49	0.87**	-		
SW	0.92**	0.88**	0.73	0.81**	0.71	0.62	-	
GY	0.69	0.81**	0.86**	0.88**	0.93**	0.94**	0.88**	-

*PH= Plant height, PL=Panicle length, PW= Panicle weight, NSPP= Number of seeds per panicle, TL = Tiller, TSW= Thousand seed weight, SW= Straw weight, GY=Grain yield. **=significant at P <0.01.

Table 6: *Benefit/cost ratio analysis of rice production based on tillage, herbicide application and N splits fertilizer application at Botanga and Golinga in the Guinea savanna zone of Ghana*

Treatment Combination	Total Revenue (Ghc ha-1)	Total Cost (Ghc ha-1)	Profit (Ghc) per ha	Benefit/cost ratio
Pr60pre-E+1HW	975.00	951.50	23.50	1.00
Pr120(2sp) pre-E+1HW	1,125.00	1,061.50	63.50	1.10
Pr120(4sp) pre-E+1HW	1,200.00	1,091.50	108.50	1.10
Pr60postE	1,425.00	851.00	574.00	1.70
Pr120(2sp) post-E	1,650.00	941.50	708.50	1.80
Pr120(4sp) post-E	2,025.00	971.50	1,053.50	2.10
Pr60pre+postE	2,025.00	851.50	1,173.50	2.40
Pr120(2sp) pre-+post-E	1,875.00	851.50	1,023.50	2.20
Pr120(4sp) pre-+post-E	2,025.00	851.50	1,173.50	2.40
Rmt60pre-E+1HW	1,275.00	886.50	388.50	1.40
Rmt120(2sp) preE+1HW	2,025.00	886.50	1,138.50	2.30
Rmt120(4sp) pre-E+1HW	2,400.00	886.50	1,513.50	2.70
Rmt60post-E	1,275.00	851.50	423.50	1.50
Rmt120(2sp)post-E	2,025.00	851.50	1,173.50	2.40
Rmt120(4sp)post-E	3,150.00	851.50	2,298.50	3.70
Rmt60pre-+post-E	1,575.00	851.50	723.50	1.80
Rmt120(2sp)pre-+post-E	2,250.00	851.50	1,398.50	2.60
Rmt120(4sp)pre-+post-E	4,050.00	851.50	3,198.50	4.80
Rnt60pre-E+1HW	1,050.00	886.50	163.50	1.20
Rnt120(2sp) pre-E+1HW	1,425.00	886.50	538.50	1.60
Rnt120(4sp) pre-E+1HW	2,025.00	886.50	1,138.50	2.30
Rnt60postE	1,050.00	766.50	283.50	1.40
Rnt120(2sp) post-E	1,500.00	766.50	733.50	2.00
Rnt120(4sp) post-E	2,100.00	766.50	1,333.50	2.70
Rnt60pre-+post-E	1,725.00	851.50	873.50	2.00
Rnt120(2sp) pre-+post-E	2,025.00	851.50	1,173.50	2.40
Rnt120(4sp) pre-+post-E	2,475.00	851.50	1,623.50	2.90

Pr60preE+1hoe weeding= Ploughed rice applied with 60 kg N ha-1 and Pre-emergence herbicide + 1 hoe weeding, Pr120(2sp)pre-E+1 hoe weeding=Ploughed rice applied with 120 kg N ha-1 in 2 splits and Pre-emergence herbicide + 1 hoe weeding, Pr120(4sp)pre-E+1 hoe weeding=Ploughed rice applied with 120 kg N ha-1 in 4 splits and Pre-emergence herbicide + 1 hoe weeding, Pr60postE=Ploughed rice applied with 60 kg N ha-1 and Post-emergence herbicide, Pr120(2sp)postE=Ploughed rice applied with 120 kg N ha-1 in 2 splits and Post-emergence herbicide, Pr120(4sp)postE=Ploughed rice applied with 120 kg N ha-1 in 4 splits and Post-emergence herbicide, Pr60pre-+post-E=Ploughed rice applied with 60 kg N ha-1 and Pre- + Post-emergence herbicide, Pr120(2sp)pre+postE=Ploughed rice applied with 120 kg N ha-1 in 2 splits and Pre- + Post-emergence herbicide, Pr120(4sp)pre+postE=Ploughed rice applied with 120 kg N ha-1 in 4 splits and Pre- + Post-emergence herbicide, Rmt60preE+1 hoe weeding=Rice under minimum tillage applied with 60 kg N ha-1 and Pre- emergence herbicide +1 hoe weeding, Rmt120(2sp)pre-E+1 hoe weeding=Rice under minimum tillage applied with 120 kg N ha-1 in 2 splits and Pre- emergence herbicide +1 hoe weeding, Rmt120(4sp)preE+1 hoe weeding=Rice under minimum tillage applied with 120 kg N ha-1 in 4 splits and Pre- emergence herbicide +1 hoe weeding, Rmt60postE=Rice under minimum tillage applied with 60 kg N ha-1 and Post-emergence herbicide, Rmt120(2sp) postE=Rice under minimum tillage applied with 120 kg N ha-1 in 2 splits and Post-emergence herbicide, Rmt120(4sp)postE=Rice under minimum tillage applied with 120 kg N ha-1 in 4 splits and Post-emergence herbicide, Rmt60pre-+post-E=Rice under minimum tillage applied with 60 kg N ha-1 and Pre- + Post-emergence herbicide, Rmt120(2sp)pre-+post-E=Rice under minimum tillage applied with 120 kg N ha-1 in 2 splits and Pre- + Post-emergence herbicide, Rmt120(4sp)pre-+post-E=Rice under minimum tillage applied with 120 kg N ha-1 in 4 splits and Pre- + Post-emergence herbicide, Rnt60preE+1 hoe weeding=Rice under no tillage applied with 60 kg N ha-1 and Pre- emergence herbicide +1 hoe weeding, Rnt120(2sp)pre-E+1 hoe weeding=Rice under no tillage applied with 120 kg N ha-1 in 2 splits and Pre- emergence herbicide +1 hoe weeding, Rnt120(4sp)pre-E+1 hoe weeding=Rice under no tillage applied with 120 kg N ha-1 in 4 splits and Pre- emergence herbicide +1 hoe weeding, Rnt60postE=Rice under no tillage applied with 60 kg N ha-1 and Post-emergence herbicide, Rnt120(2sp)postE=Rice under no tillage applied with 120 kg N ha-1 in 2 splits and Post-emergence herbicide, Rnt120(4sp)postE=Rice under no tillage applied with 120 kg N ha-1 in 4 splits and Post-emergence herbicide, Rnt60pre-+pos-tE=Rice under no tillage applied with 60 kg N ha-1 and Pre- + Post-emergence herbicide, Rnt120(2sp)pre-+post-E=Rice under no tillage applied with 120 kg N ha-1 in 2 splits and Pre- + Post- emergence herbicide, Rnt120(4sp)pre-+post-E=Rice under no tillage applied with 120 kg N ha-1 in 4 splits and Pre- + Post- emergence herbicide.

0–20 cm layer (approximately 1.69 g/cm³) falls within the acceptable range for sandy loam soils, as reported by Hunt and Gilkes (1992). These findings align with Bhardwaj (2013), who observed that straw mulching reduces bulk density (1.42 g/cm³) compared to bare soils (1.50 g/cm³), indicating improved soil structure under mulch conditions. The soil was slightly acidic, with a mean pH of 5.35, consistent with earlier reports by Inusah *et al.* (2013), who observed similar pH levels in the region.

Electrical conductivity (ECe) values classified the soil as non-saline, with measurements falling within the 0–2 dS/m range as defined by the FAO (1999), indicating low salinity levels suitable for rice cultivation. The soil organic carbon (OC) ranged from 0.41% to 0.70%, which is considered low by Tadese (1991), who classified OC below 0.5% as low. Such low organic carbon levels suggest a need to enhance soil organic matter to improve fertility. Total soil nitrogen (TN) ranged from 0.041% to 0.14%, falling between moderate and low categories, with Tadese (1991) classifying TN below 0.05% as very low, 0.05–0.12% as low, and 0.12–0.25% as moderate. Nitrogen is often the most limiting nutrient in the zone, mainly due to its easy leaching (Agyare *et al.*, 2023).

Analysis of the irrigation water indicated that pH values were within the optimal range for rice cultivation (5.6–5.8; FAO, 1985), thus supporting healthy crop growth.

Weed occurrences, density, and biomass

Weeds are critical biotic constraints that can severely threaten crop productivity and sustainability if not managed promptly through effective herbicide practices within tillage systems (Dzomeku *et al.*, 2007). Particularly problematic in rice cultivation are weeds such as *Cyperus rotundus*, *Oryza barthii*, and *Cyperus eragrostis*, which are known for their resilience and difficulty to control (Smith, 1981; Abass *et al.*, 2018).

The observed variation in weed density and biomass among different herbicide application methods is mainly attributed to differences in control efficacy. Results indicated that combined use of pendimethalin + triclopyr was more effective, resulting in greater suppression of weed density and biomass over an extended period compared to the application of either herbicide alone (Figure 4). This is consistent with findings by Ofori *et al.* (2023), who reported that herbicide combinations provide prolonged control and better suppression of weed species.

In the pre-emergence herbicide treatment combined with one hand weeding at 5 weeks after planting (WAP), weed resurgence was notable at 8 WAP, particularly at Golinga. These weeds thrived despite herbicide application, and the supplementary hand weeding was insufficient to control weed growth beyond the critical stage of rice growth (Kuznetcova *et al.*, 2020). Excessive labor involvement also makes such manual practices economically unfeasible, as highlighted by Dzomeku *et al.* (2007).

Similarly, sole post-emergence herbicide application preceded by one hand weeding failed to sustain weed suppression beyond the critical growth stages. This disparity between pre- and post-emergence treatments underscores the importance of appropriate timing and combination strategies (Ahmed *et al.*, 2014). The results align with prior research indicating that combined applications of pre- and post-emergence herbicides are more effective at reducing weed interference throughout critical crop growth periods (Yadav *et al.*, 2018).

Plant height

At both locations, the observed increase in plant height under minimum tillage combined with pre- and post-emergence herbicide application may be attributed to the weed-free environment created by herbicide use, coupled with enhanced phosphorus availability resulting from the tillage system (Roa *et al.*, 2017). Good tillage practices and efficient herbicide application are widely recognized as major determinants of optimal rice growth and sustainability (Guan *et al.*, 2014). Specifically, Guan *et al.* (2014) reported that shoot development in rice is closely linked to root growth, and that increasing tillage depth improves vegetative growth by promoting better root proliferation.

Furthermore, higher plant height associated with increased nitrogen (N) application—particularly 120 kg N ha⁻¹ split into four applications, can be explained by the enhanced availability of nitrogen, which supports vigorous vegetative growth (Zhen

et al., 2023). This aligns with previous studies demonstrating that split N application improves uptake efficiency and crop growth (Zhen *et al.*, 2023). Additionally, increased phosphorus availability from higher soil amendments can stimulate root development, facilitate nutrient absorption and promote overall plant growth (Roa *et al.*, 2017). The superior performance of combined pre- + post-emergence herbicide applications over sole pre- or post-emergence treatments may be due to their prolonged smothering effects on weeds, especially during the most critical stages of rice growth, under effective tillage or good fertility regimes (Giller *et al.*, 2009).

Tillering

At both locations, increased tillering observed with higher nitrogen split applications combined with pre- and post-emergence herbicides can be attributed to the enhanced availability of nitrogen at higher application rates and optimal timing. Nitrogen is critical for cell division and shoot development, as it directly influences tiller formation (Pramanik *et al.*, 2013). Adequate nitrogen supply during crucial growth stages promotes vigorous vegetative growth and increased tillering.

Furthermore, sufficient phosphorus nutrition, evidenced by the soil conditions in the study sites, plays a vital role in plant physiology, including photosynthesis and nitrogen fixation (Mmbaga *et al.*, 2014). Higher rates of nitrogen fertilization likely supplied adequate nitrogen, resulting in a higher number of tillers per plant, which is essential for optimizing grain yield potential.

Regarding weed management, the efficacy of combined pre- + post-emergence herbicide application was higher than sole pre- or post-emergence applications. Effective weed suppression reduced competition, allowing rice plants to allocate more resources towards growth, thus increasing tiller numbers (Swanton *et al.*, 2015). The combination of 120 kg N ha^{-1} applied in four splits alongside herbicide use demonstrated that an integrated approach combining good soil fertility and robust weed control is crucial for achieving maximum tillering and overall plant development (Figure 55).

Yield components

At both locations, the interaction between minimum tillage, combined pre- + post-emergence herbicide applications, and the application of 120 kg N ha^{-1} in four splits resulted in optimal rice yield parameters. This improvement is likely due to increased soil nutrient availability, particularly nitrogen, phosphorus, and potassium, facilitated by optimized tillage practices and effective herbicide timings that created favorable growth conditions (Riaz *et al.*, 2020). Good tillage and efficient weed control are recognized as major factors influencing rice growth and sustainability, as noted by Riaz *et al*. (2020). Moreover, Guan *et al*. (2014) observed that shoot development depends on robust root growth, which can be promoted by increasing tillage depth to improve vegetative growth.

In the case of Botanga, tillage practices significantly impacted the number of effective tillers per plant at 8 weeks after planting (WAP), with conventional tillage producing the highest tiller counts, while no-tillage resulted in the lowest, aligning with findings by Ujoh and Ujoh (2014), who documented similar trends in Nigeria.

At Golinga, an application of 120 kg N ha^{-1} in four splits combined with pre- + post-emergence herbicides recorded the highest effective tiller count and chlorophyll content, likely due to improved nitrogen accessibility resulting from split application. This approach aligns with Yutiao *et al*. (2015), who found that split manure applications promote quicker and more efficient crop development compared to uniform N applications, owing to better synchronization of nutrient supply with crop demand.

Furthermore, at Golinga, minimum tillage recorded the highest number of spikelets per panicle, followed by conventional and no-tillage practices, consistent with Zein EL-Din *et al*. (2008), who reported greater panicle weight and higher spikelet counts under conventional tillage in sandy clay soils in Egypt.

Regarding grain weight, the application of 120 kg N ha^{-1} in four splits coupled with pre- + post-emergence herbicides yielded the highest 1000-grain weight. This suggests that wider nitrogen distribution enhances its availability over time, supporting greater grain filling, as also demonstrated by Chaturvedi (2005). Additionally, effective weed suppression through pre- + post-emergence herbicides minimized competition and ensured full nutrient availability, resulting in more than a thousand seeds compared to sole herbicide applications (Giller *et al.*, 2009). The improved nutrient utilization and weed control collectively contributed to better grain quality and yield.

Grain yield

At Botanga, the interaction between tillage system, nitrogen fertilizer rate, and herbicide application significantly influenced rice grain yield. The highest grain yield of 8,016 kg ha^{-1} was achieved under minimum tillage with 120 kg N ha^{-1} applied in four splits (Table 12). This aligns with findings by Liu *et al*. (2015), who reported that increasing nitrogen rates enhance rice yield primarily through greater canopy development, improved photosynthesis, and increased leaf area index, all of which contribute to higher biomass and grain production. To maximize panicle formation, especially during early and mid-tillering stages, rice plants require adequate nitrogen, which also supports grain filling during reproductive stages (Datta, 1986). This is supported by Sun *et al*. (2021), who identified nitrogen as a critical element in chlorophyll synthesis and enzyme functions essential for crop growth. Furthermore, split application of nitrogen has been proven effective in maintaining consistent availability, enhancing crop growth and yield (Islam *et al.*, 2009), while optimal timing and rates of nitrogen are critical for maximizing rice grain yield (Doberman & Fairhurst, 2000).

In this study, applying 120 kg N ha^{-1} in four splits along with pre- and post-emergence herbicide resulted in improved growth parameters, yield components, and grain yield. Similar results were observed with 120 kg N ha^{-1} applied in two splits combined with sole post-emergence herbicide, emphasizing the importance of appropriate nitrogen management. Decreased yields with 60 kg N ha^{-1} in pre-emergence herbicide treatments reflected nitrogen deficiency, which was consistent with initial soil analysis showing low fertility levels, a common limiting factor in the region (Giller *et al.,* 2009).

At Golinga, the interaction between tillage system and nitrogen split application significantly influenced yield components. The highest grain yield of 8,497 kg ha^{-1} was recorded with 120 kg N ha^{-1} in four splits under minimum tillage (Figure 43), followed by 7,604 kg ha^{-1} under conventional tillage with the same N regime. Similar trends have been reported by Chauhan *et al*. (2012), who emphasized that split N application optimizes nutrient availability, improves plant growth, and enhances yield.

The lowest yield (4,285 kg ha^{-1}) was observed with 60 kg N ha^{-1} under no-tillage, highlighting the importance of adequate fertilization and tillage practices in achieving high productivity.

Grain quality and milling recovery of irrigated rice ecology.

The physical dimensions of rice grains size, length, and shape are critical quality parameters, as they influence market acceptance and price (Khush *et al.*, 1997). In this study, rice grains were classified into three categories extra-long, long, and medium based on the milled grain length, following the classification scale by Belnio (1980), and subsequently adopted in subsequent studies (Richman *et al.*, 2006). According to Pandey *et al.* (2021), long grains, as categorized using such scales, are preferred in international markets and are considered superior in milling quality.

Milling yield, expressed as the percentage of total milled rice from rough rice, is an important indicator of rice quality and processing efficiency (Khush *et al.*, 1997). The milling recovery rates were categorized into four grades: *Grade 1* (>70.0%), *Grade 2* (65.1–70.0%), *Grade 3* (60.1–65.0%), and *Grade 4* (<60%) (RTWG, 1979). The percentage of broken grains is heavily influenced by environmental factors such as nitrogen application, herbicide use, and tillage practices (Mutters, 1985).

Results indicated that pre- and post-emergence herbicide applications combined with 120 kg N ha^{-1} applied in four splits produced higher milling recovery rates with fewer broken grains, especially when longer grains were favored (IRRI, 2009). Interestingly, the study found that longer grains with 60 kg N ha^{-1} in pre- + post-emergence treatments achieved higher milling recovery and lower breakage, contrary to earlier reports by RTWG (1979), which suggested that long grains tend to break more easily than shorter grains. This indicates that proper nutrient management and milling practices can influence grain integrity regardless of inherent grain length characteristics.

According to Mutters (1985), broken grains typically have lower market value (30–50%) relative to whole grains. The combination of pre- + post-emergence herbicide application with 120 kg N ha^{-1} in four splits resulted in less than 30% broken grains, corresponding to *Grade* 1, resulting in higher profitability due to better milling quality and market value.

Correlation

Grain yield confirmed positive correlation with panicle weight, seeds per panicle, 1000 grain weight, and straw weight (r=0.88**, 0.93**, 0.94**, 0.88**) respectively.

Benefit-cost analysis

The minimum tillage system involves practices that minimize soil disturbance and organic matter loss, thereby reducing soil erosion and water runoff (West *et al.*, 2005). This system has been demonstrated to be the most economical among tillage methods, delivering significant economic and societal benefits. These benefits include reduced labor requirements and greater flexibility in planting schedules, leading to improved farm management and productivity (West *et al.*, 2005). Additionally, minimized tillage reduces wear and tear on machinery, saves fuel and fertilizer costs, and enhances greenhouse gas mitigation by sequestering carbon in the soil, contributing to carbon credit schemes (West *et al*., 2005). The conservation of soil and water resources through minimum tillage also supports biodiversity and habitat quality, contributing to ecological sustainability (West *et al.*, 2005). The critical role of fungi, bacteria, and other microorganisms in maintaining soil structure, processing crop residues, and cycling nutrients and carbon further underscores the environmental benefits of conservation tillage systems (West *et al.*, 2005).

Effective weed control remains a vital component of rice production, especially during critical growth periods, to ensure optimum yields (Dzomeku *et al.*, 2007). The combined use of pre- and post-emergence herbicides has been proven to be the most effective and economical weed management strategy, reducing weed interference significantly while minimizing costs (Table 9). This aligns with findings from Dzomeku *et al.* (2007), who emphasized that controlling weeds at key growth stages is essential for maximizing productivity and increasing farmers' income.

The benefit-cost analysis indicates that nitrogen split fertilizer applications—particularly at 120 kg N ha^{-1} result in higher rice yields coupled with improved grain quality. Proper nitrogen management during critical growth stages supports vigorous tillering, panicle development, and grain filling, directly impacting productivity (Yatimu *et al.*, 2015). However, fertilizer costs, especially among resource-poor farmers, remain a major limiting factor for adoption in developing countries, including Ghana (West *et al.*, 2005). Therefore, optimizing fertilizer use in combination with effective weed control strategies can enhance both economic returns and food security.

Conclusion and recommendation
Conclusion

The experiment was conducted to determine the effect of tillage system, herbicide application, and N-split fertilizer application on yield components, yield, milling quality, soil properties of irrigated rice, its economic benefits in the Guinea savannah agro-ecological zone of Ghana. At Botanga, the minimum density of 1.56 weed species/m^2 was attained with pre- + post-emergence herbicides and sole minimum tillage. The least weed biomass was achieved with pre- + post-emergence herbicides with minimum tillage, but increased with post-emergence herbicide, and further with pre-emergence herbicide to 4 kg/m^2. Maximum tillers of 17.00 per hill were obtained with pre- + post-emergence herbicide x 120 kg N ha^{-1} applied in 4 splits x minimum tillage system. Pre- + post-emergence herbicide x 120 kg N ha^{-1} applied in 4 splits gave the highest chlorophyll content of 45.2 mg m^2. The best head length of rice, 26.22 cm was obtained with pre- + post-emergence herbicide x 120 kg N ha^{-1} applied in 4 splits. Maximum panicles per hill were achieved with 120 kg N ha^{-1} applied in 4 splits x minimum tillage system. 120 kg N ha^{-1} applied in 4 splits with minimum tillage gave highest number of filled spikelets/panicle of rice. The highest 1000 grain weight was attained with application of pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits of rice. 120 kg N ha^{-1} applied in 4 splits with minimum tillage gave grain yield of 8,016 kg ha^{-1}, whilst pre- + post-emergence herbicide with 120 kg N ha^{-1} applied in 4 splits obtained a maximum grain yield of 8,084 kg ha^{-1}.

At Golinga, the minimum density of 1.59 weed species/m^2 was attained under sole conventional tillage and sole pre-emergence herbicide application + one hand weeding, but increased under post-emergence herbicide and further with pre- + post-emergence herbicides and sole minimum tillage to 4.4 weed species/m^2. Lowest weed biomass was achieved with pre- + post-emergence herbicides and, also minimum tillage but increased high biomass with post-emergence herbicide and further with pre-emergence herbicide to 4.3 kg/m^2. Maximum

panicle length of 24.11cm was attained with pre- + post-emergence herbicides application x 120 kg N ha^{-1} in 4 splits but, 120 kg N ha^{-1} in 2 splits gave similar length under the same herbicide application. The highest panicle weight was achieved with pre- + post-emergence herbicide x 120 kg N ha^{-1} in 4 split applications. The highest number of seeds per panicle was recorded with pre- + post-emergence herbicide application x 120 kg N ha^{-1} in 4 splits. maximum seed weight was attained with pre- + post-emergence herbicide application under minimum tillage system. Minimum tillage x pre-+ post-emergence herbicide application gave outstanding straw weight (7,561 kg ha^{-1}). 120 kg N ha^{-1} in 4 splits with pre- + post-emergence herbicide application supported the highest straw weight. At Botanga, pre- + post-emergence herbicides application x 120 kg N ha^{-1} in 4 splits and 120 kg N ha^{-1} in 4 splits with minimum tillage gave grain yield of 8,084 kg ha^{-1} and 8,016 kg ha^{-1} respectively. At Golinga, minimum tillage system with 120 kg N ha^{-1} in 4 splits and conventional tillage with 120 kg N ha^{-1} in 4 splits gave grain yield of 8,497 and 7,604 kg ha^{-1} respectively and have good potentials in irrigated rice production in northern Ghana. This implies exceeding 120 kg N ha^{-1} in 4 splits could be economically and environmentally useful in irrigated rice production in the Guinea savannah agroecology of Ghana.

At both locations, post-harvest soil analysis indicated increased soil fertility over baseline soil chemical properties, exhibited by a change in percent nitrogen from 0.09% to a range of 0.11-0.019% topsoil and with subsoil from 0.13% to 0.11-0.16%. Economic analysis however, revealed that pre- + post-emergence herbicides with 120 kg N ha^{-1} in 4 splits gave highest grain yield, which was accompanied with highest quality grain with less cost and made it less economical. Minimum tillage system with pre- emergence + post-emergence herbicides and 120 kg N ha^{-1} in 4 splits was the most economical treatment combination and could improve the quality of rice irrigated rice in the Guinea savannah zone of Ghana. Economic analysis further revealed that tillage system, herbicide application and N fertilizers are major contributors to production cost in irrigated rice.

Recommendation

At the end of the experiment, the following recommendations have been made:

1. At both locations, minimum tillage in combination with 120 kg N ha^{-1} in 4 splits and Pendimethalin (0.40 kg a.i. ha^{-1}) as pre-emergence herbicides + triclopyr (0.03kg a.i. ha^{-1}) applied as post-emergence herbicide gave the highest benefit/cost ratio of 4.8 across the two locations and therefore, is recommended for resource poor farmer in the Guinea savannah agro-ecological zone of Ghana.
2. At Botanga, the combination of Pendimethalin (0.40 kg a.i. ha^{-1}) as pre-emergence herbicides + triclopyr (0.03kg a.i. ha^{-1}) applied as post-emergence herbicide with 120 kg N ha^{-1} in 4 splits obtained grain yield of 8,084 kg ha^{-1} and is recommended for resource poor farmer in the Guinea savannah agro-ecological zone of Ghana.
3. At Golinga, the combination of minimum tillage with 120 kg N ha^{-1} in 4 splits obtained grain yield of 7,604 kg ha^{-1} and is recommended for resource poor farmer in the Guinea savannah agro-ecological zone of Ghana.
4. Integration of Pendimethalin (0.40 kg a.i. ha^{-1}) as pre-emergence herbicides + triclopyr (0.03kg a.i. ha^{-1}) applied as post-emergence herbicide with 120 kg N ha^{-1} in 4 splits recorder the highest rice grain quality (unbroken rice grain) at both locations and therefore, is recommended for small scale farmers in the Guinea savannah agro-ecological zone of Ghana.
5. There is the need to determine long-term effect of tillage, herbicide application and N-split fertilizer application method on rice growth, yield, and soil properties in the Guinea savannah agro-ecological zone of Ghana.
6. Future work be carried out on cooking and eating properties to determine the effect of the three factors (tillage system, herbicide and N split application) on starch properties.
7. On-farm adoptive trials are required to validate these findings to arrive at conclusive recommendations for rice production within the Guinea savannah agro-ecological zone of Ghana.

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