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Physiological and Developmental Response of Selected Upland Rice Genotypes to Water and Nutrient Stress Condition

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Abstract: Drought is a major challenge for all agricultural crops, but for rice, it is even more serious, because of its semi aquatic phylogenetic origins and the diversity of rice ecosystems and growing conditions. The most important source of climate-related risks for rice production in rain-fed areas is drought.Crop physiology has made a significant contribution to understanding the mechanisms underlying crop growth and development, and bridging the "phenotype gap" generated by the recent progress in genomics. The study aimed to determine growth and physiological response of IRAT 109 and Lemont to water deficit and fertilizer application. Plants were subjected to water nutrient stress treatment in the field. Water and fertilizer treatment were initiated at 42 days after sowing (das). Fertilizer treatment was applied at 60 Kgha-^{1}N and 60 Kgha^{-1}N+45 Kgha^{-1}P. Morphological and physiological measurements were done at 21, 42, 63 and 84th das. Root sampling done during the periods, at depths of 0-10 cm, 10-20 cm, and 20-40 Cm. The soil moisture content had a significant effect and decreased with increasing water deficit. The plant height, plant biomass both shoots and root reduced with decreasing water content and nutrient load in the soil. Lemont was significantly affected and registered lower values for various growth indices compared to IRAT 109. The was significant reduction in yields between the two rice cultivars under drought stress condition, though IRAT 109 exhibited relatively higher yield index under drought stress condition, the improved performance could be attributed to its ability to escape drought stress due to its early maturing ability. Fertilizer application has a significant effect on yield and yield component in rice, thus the proper fertilizer application is a key in achieving good yield in rice production. The finding of this research will help farmers in adopting high precision fertilizer application to ensure a good yield. In addition, rice breeders can utilize IRAT109 in developing more resilient and highly adaptive rice cultivars.

Keywords: Drought; Phenotypic gap; ecosystems; Diversity; Fertilizer; Growth indices

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Introduction

Drought is the most important abiotic stress factors with immense effects not only for rice production but to other agricultural crops [1]. It is estimated that the overall effects of drought stress accounts for over 50% of losses incurred in crop production [2]. Rice is being a hydrophytic plant, it requires sufficient amount of water to sustain its production, and disruption in fresh water supply negatively impacts on its production [3]. In the recent past, several researches have been done in order to develop a more water use efficient rice cultivars, known as the upland rice cultivars or rainfed rice types [4]. The use of African rice, *Oryza glaberrina* and Asian rice, *Oryza sativa*, led to the production of a more stress tolerant rice genotype, often refers to New Rice for Africa (NERICA) [5]. Since the development, several lines of NERICA rice have been development, namely NERICA 1, NERICA2, NERICA 3, NERICA 4 among others [6].

Despite the development of a more water use efficient upland rice, such as NERICA rice, and other upland types of rice such as LEMONT, IRAT109, the optimum production in rice is still a challenge [7]. Drought stress during vegetative growth, flowering and terminal period of rice cultivation, can interrupt floret initiation resulting in to spikelet sterility and grain filling, respectively [8]. Plant growth occurs through cell division, cell enlargement and differentiation, and which do involves genetic, physiological, ecological and morphological events and their complex interactions [9]. A number of yield-determining physiological parameters in plants respond to drought stress. Yield integrates many of these physiological parameters in a complex way. Thus interpreting how plants accumulate, combine and display the ever-changing and indefinite physiological processes over the entire life cycle of crops becomes a challenge. For drought stress, severity, length of drought exposure and time of drought incidence, as well as responses of plants after stress relieve, and interaction between stress and other factors are extremely important [10].

Low water availability under drought stress conditions do affects the plants ability to nutrient uptake and their diminished tissue concentrations in crop plants [11]. An important effect of water deficit is on the acquisition of nutrients by the root and their transport to shoots [12]. However, plant species and genotypes do vary in their response to mineral uptake under drought stress. In general, moisture stress induces an increase in nitrate, a definitive decline in phosphate and no definitive effects on potassium [13].

In this research work, we explored the response of the two rainfed rice genotypes, IRAT109, and LEMONT to drought stress and varying nutrient application in different soil types and multiple locations in western of Kenya. The result showed that IRAT109 had an improved performance compared to the other two rainfed lines and can be adopted in various regions to improve rice production.

Materials and Methods

Study site

The study was done at Maseno University, within the University Botanical garden, Maseno, Kisumu County, western part of Kenya. The area receives a mean annual precipitation of 1,750 mm with a bimodal distribution. The mean temperature at Maseno is 28.7^{o}C and it is approximately 1500 m above the sea level. Maseno lies at latitude 0^{o}1'N-0'12'S and longitude 34^{o} 25'E-47'E. The soils at Maseno are acrisol being well-drained, deep reddish brown clay with pH range of 4.6-5.4 [14].

Plant materials

Two rice cultivars were used in this experiment, IRAT109 and LEMONT. IRAT 109, an upland japonica cultivar, was selected because of its deep-rooting behavior and expected tolerance to drought [15,16]. Lemont (*Oryza sativa* L.), is

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an early maturing, semi dwarf, long-grain cultivar developed in United States Of America (USA). It was developed from a 1974 cross of Lebonnet and the first filial (F1) generation of the cross of C19881 and P133158, the same cross from which Bellomont was developed [17]. The seeds were soaked a day prior to planting and the spacing was 20 cm x 20 cm. Four seeds were sown per hill with the two selected upland cultivars, IRAT 109 and Lemont. The plots were hand tilled before planting with two seeds of upland rice cultivars, a path of 0.5 m was left between the two plots with similar treatment to prevent contamination due to overflow or underground seepage. The plots were kept weed free by hand pulling the weeds, this was to maintain the soil structure for compaction was to be evaluated. Soil moisture measurements were determined by the use of soil profile probe, obtained from Delta T.

Treatment and design

The experiment was carried out during the short drought season of the months of September to the month of onset of long rainy periods January. The seeds of IRAT 109 and Lemont were planted in 2 m x 2 m plots. The experimental design was split-split plot design with four different fertilizer application and two watering regimes. The fertilizer application levels were applied as follows; nitrogen applied plot (60 Kg/ha of urea), phosphorous fertilized plots (45 kg/ha of triple super phosphate) and nitrogen-phosphate applied plots (60kg/ha of urea + 45 kg/ha triple super phosphate). And for drought stress treatment, water and no water plots were initiated.

The experiment was based on rainfall and irrigation among the irrigated plots (Wet plots), while the non-watered plots (dry plots) were completely sheltered off from rainfall. For irrigated plots, 1. 20 litres of water was used for irrigating each plot among the irrigated plots and twice the amount, 40 litres was used to irrigate the drought simulated plots when the plants leaf roll score was above three.

Plants were subjected to two soil moisture treatments. Well watered and drought re-watered conditions. Water treatment commenced at 42 DAS, after, the plants had been exposed to the same conditions; received equal amount of rainfall and watered in case of dry spell to ensure proper establishment of the rice plants in the plots. In the dry blocks a shelter consisting of a clear polythene sheets was constructed, as shown in appendix 15, to enclose the plants at night and any time, rain was foreseeable until the plants showed drought symptom, (leaf roll score of 3-5) and measured soil water potential of - 30 kPa at 20 cm depth, this as per the standard irrigation scheme of aerobic rice fields [18]. A leaf roll score of 3-5 was evidenced by a deep V-shaped leaves orientation. This as per the scale given by Gregorio and Cabuslay [19], whose description of the leaf roll score runs from 0-9, whereby, 0= healthy leaf, 1= mild stress, with a shallow V shape, 3=moderate stress, the leave exhibit deep V, 5=stressed plant, the leaves shows fully capped leaves, 7=heavily stressed, the leaf margin are tightly held in U shape and 9= the plant is beyond recovery point, the leaves are tightly rolled. Watering of the wet plots was done up to 84th DAS. Three fertilizer treatments were carried out, nitrate (urea), phosphate (TSP), nitrate-phosphate (Urea+TSP) and a control (no fertilizer). Fertilizer treatments were done at 42 DAS and 56 DAS.

Soil moisture determination

Rainfall, air temperature, relative humidity, and dew points were monitored daily in nearby weather station, located exactly 100 meters from the experimental plots. The soil water content was determined by the soil moisture Profile Probe, (Model-PR 2/6). The PR 2 measured at 6 depths down to 100 cm. The soil moisture, measurement, was taken, at the following soil depths 10 cm, 20 cm, 30 cm, 40 cm, 60 cm and finally at 100 cm, from the soil surface, the measurement begun 21 DAS and was done in the morning hours, 0900 -1000 hours, at an interval of 2 days.

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Soil Compaction, Moisture and Nutrient Load Determination

The soil compaction was determined by using a soil compaction meter, (Spectrum-6101-SN 627-MFG code.1002) with a measuring range of 0-6000 PSI, and accuracy of ±30 PSI. The measurements depths marked at every 3 inches up to 24 inches and designed to ASAE standards. The compaction measurements was done a long side the soil moisture content measurements.

Samples of soil from different depths were extracted by using a soil auger, from depths of 0-5 cm, (the top most soil), 10 to 15 cm, 20 to 25 cm, 35 to 40 cm and 55 to 60 cm. The soil samples collection was purely based on the homogeneity of the soil across the soil profile pit, rice rooting depths are within the sampled depths. A profile pit dug was 1 m deep, and by the use of a meter rule, demarcation was made from the top surface to the lower end of the pit. The various soil samples were then collected by the use of the soil auger. The soil samples were then analysed at the laboratory managed by the Kenya Plant Health Inspectorate Services (KEPHIS).

Physiological Measurements

Stomatal Conductance

The stomatal conductance's (Cs) were quantified by using a portable leaf porometer, (Model -SC-1, sensor serial number-LPS 0004). The measurements was done on the third fully expanded mature leaf on cloud free days between 0930-1130 hours local time at 46, 67 and 88 days after sowing (DAS) and on six randomly selected plants per plot per treatment.

Nitrogen Content Determination

The foliar chlorophyll content was measured by use of SPAD Konica Minolta SPAD-502. Chlorophyll meter, SN 79613012, using the principles of closure method, the measurement was done, on the third fully expanded and mature leaf, six leaves were randomly selected per plot, the chlorophyll measurements, was done during the day, from 1030-1230 hours, at interval of 21 days from, 46 DAS till the harvesting period.

Plant Tissue Analysis

The plants leaves were harvested at panicle initiation, dried at 40^{0}C for tissue analysis, (macronutrients analysis), young and fully developed leaves were harvested, twenty within a plot in six hills. The analysis was done at the KEPHIS laboratory, the harvested leaves were dried and then crushed, using a blender, Wonder Blender, a minimum of 200 grams of the crashed plant tissue were subjected to macronutrient analysis, by the atomic absorption spectroscopy (AAS). The result obtained was then compared to the reference sufficiency ranges at panicle initiation, the reference sufficiency as provided by agronomic division, department of Agriculture and consumer services, 2000 (http://www.ncagr.gov/agronomi/saaesd/rice.html.)

Morphological Parameters and Biomass

Plant Height

Shoot height was determined on six hills per treatment and per replication at 46, 67, 88, 109, and 130 DAS. Measurements were made using a metre rule from the shoot base to the tip of the flag leaf.

Shoot Biomass

The shoot biomass was obtained from two plants hills per plot per treatment, the two hills were obtained from the marked six hills, which were being used to obtain the plant height, tiller number, stomatal conductance and the Nitrogen status by the nitrogen meter (SPAD-values). The largest and the smallest hills were selected, then each was harvested separately, and clearly labelled, the shoot biomass was then dried in the oven at a temperature of 80^{0}C for four days until a constant mass was achieved. Each was weighed by using Analytical-weighing balance (FX 300i WP). The weights obtained were used to determine the shoot-root ratios.

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Root Biomass

Of the harvested shoots, their roots were removed at different depths, from 0-10 cm, 10-20 cm and 20-40 cm, per hill. Each extracted root was put in a well labelled polythene bag, having the plot number, plant number, and the extraction depth. Once extraction was done, each root samples were washed separately, dried and latter preserved with a 75% ethanol this was done due to huge number of samples to measure. The preserved roots were later dried at 80^0C for four days until a constant weight was achieved; their weights were determined by using Analytical-weighing balance (FX 300i WP). The dry weights obtained were used to determine root to shoot ratio and the different weights per depths gave a root density per depth and penetration behaviour of the roots of selected rice cultivars.

Yield and Yield Components

Tiller Number

Tiller number for all the varieties and the treatments was determined by observing, counting, and recording all emerging shoots in the hills from the time of planting to the flowering stage.

Panicle Lengths

This was determined using a metre rule. Measurements were done from the panicle base to the tip of six plants per treatment and per replication.

Grain Yield

The grain yield was determined at harvesting from an area of 1 m^2 in the field. The number of grains per 5g, and filled grains per panicle were determined. The yield was extrapolated in kilograms per hectare.

Statistical Analysis 0f Data

Analysis of variance (ANOVA) was carried out on the various data for the variables measured during the study period to test for differences between the treatments and the varieties and their level of interaction by using a statistical computer package (Costat). The initial analysis, to test for the interaction of all the three factors under investigation, fertilizer, water and the variety interaction, the various data both for morphological and physiological was analysed as a split-split plot design analysis, replicates were the block, water was the main plot factor, fertilizer was the sub plot factor and variety was the sub subplot factor. The means were separated by LSD at 5% level of significance. In isolation on the two cultivars response to either water and or fertilizer, the various data involved was analysed as a split plot design, and not as split-split plot design as for the three factors interaction, separation of means was also through LSD, at 5% level of significance. Correlation analysis was done, to synchronize the association of the various factors, as either contributors or non-significance in the performance of the various rice cultivars within the study, yield, and biomass accumulation, among other factors.

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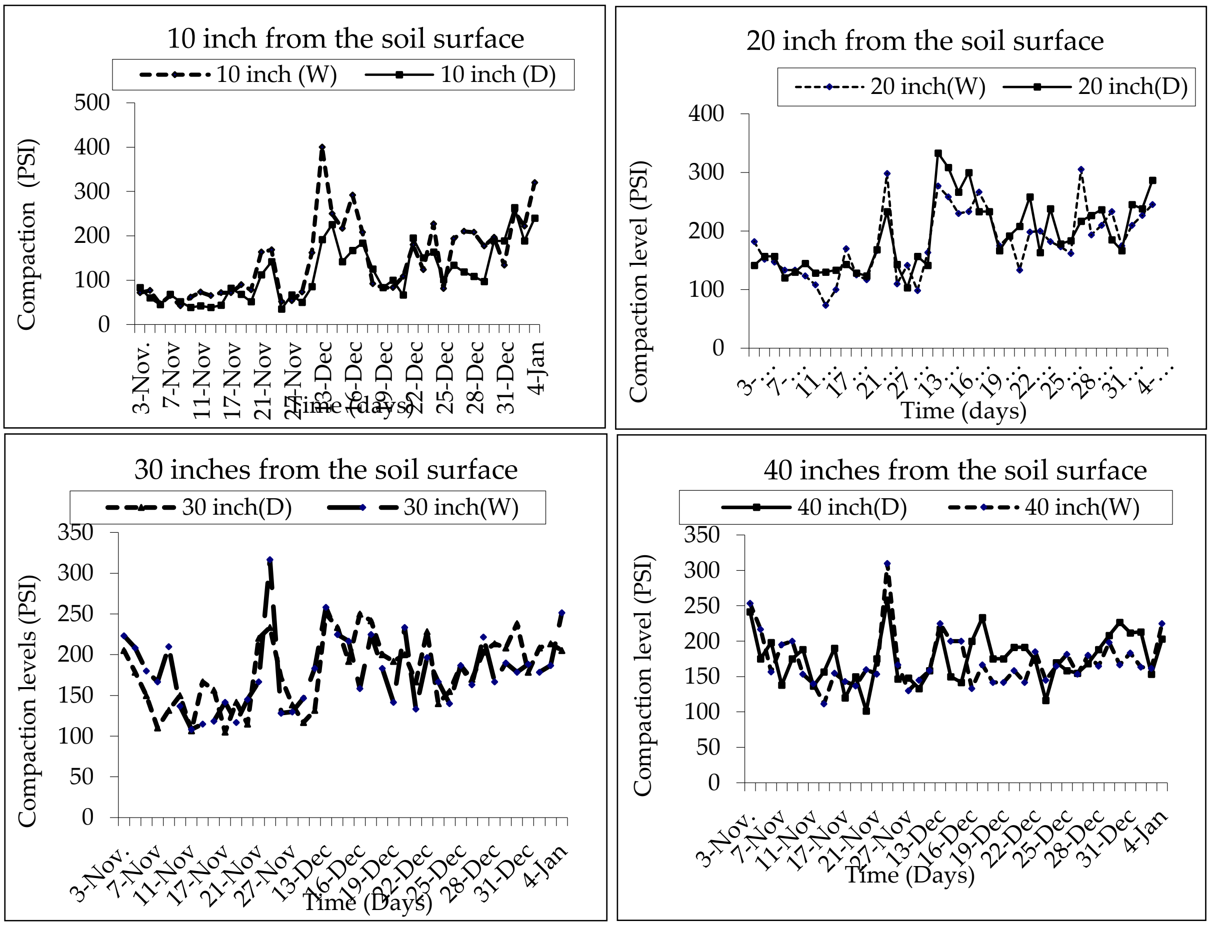
Results

Soil compaction

Plant root growth is greatly affected by soil moisture and level of soil compactions [20]. Soil moisture content (SMC), affects plants , when the soil water content is in excess, it results into a form of drought stress known as physiological drought caused by hypoxia, and when the soil moisture is below the demands by plants, then it results into a soil drought [21]. So, drought is the main environment factors responsible for the occurrence of water deficit in plant tissues and, as a consequence, for the reduction of the crop yield. The soil particle aggregation, may hinder the flow of water, thus leading to excessive run offs of water from the fields [22]. We sought to investigate the level of compactions on both irrigated and non-irrigated plots; the soil compaction in wet plots was significantly low as compared to dry plots. In the depth of 10 Inches, significantly higher compaction was recorded towards the end of the month of November and early December. Compaction increased with depth in all the plots among the treatments (Figure 1). The results obtained for varying levels of soil compaction are in agreement to previous publication, in which the level of soil compaction has been found to increase with decrease in soil moisture content [23]. Soil compaction do not only affects the root penetration but also has an effect on nutrient uptake by plants, Soil compaction and water availability have been shown to affect the uptake of various macro-nutrients such as nitrogen (N), Phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg) and sulphur (S), and some other micronutrients [24].

Figure 1: Soil compaction levels in both wet (W) and dry (D) plots from depths of 10 inch to 40inch.



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Soil nutrient load

Nutrient load in the field plots varied among the nutrient elements tested. Soil pH was relatively stable in all depths showing minimal differences, though the highest pH was noticed at the depth of 10 to 15 Cm. Sodium levels decreased with increase in soil depth. Potassium, calcium, magnesium, phosphorus and nitrogen, showed fluctuating levels, highest in concentration at depths of 0 to 25 Cm, then reduced with increase in depth as summarised in (Table 1).

Table 1: Soil fertility test for the field plots.

Soil nutrients	Soil depths				
	0-10 cm	10-15 cm	20-25 cm	35-40 cm	55-60 cm
pH (H2O) 1:2.5	4.49	4.81	4.36	4.4	4.5
Sodium (Na)	33.91	20.91	25.91	25.91	26.91
Potassium (K)	0.15	0.21	0.23	0.19	0.39
Calcium (Ca)	126.68	83.42	108.93	6.53	7.14
Magnesium (Mg)	126.68	83.42	108.93	107.54	105.66
Available Phosphorus (P)	37.33	25.56	27.78	40.33	29.44
Total Nitrogen	0.22	0.16	0.12	0.09	0.12
Carbon (C)	1.28	1.15	0.91	0.7	0.67
Copper (Cu	5.61	5.16	4.66	4.4	4.13
Iron (Fe)	89	58.15	54.21	57.52	56.35
Manganese (Mn)	7.43	3.78	4.86	4.5	4.2
Zinc (Zn)	8.64	9.12	7.59	9.46	7.72

Soil moisture content

Soil moisture is important to plant growth and development, any change in soil moisture availability, results in to drought stress [25]. We evaluated the SMC in both irrigated and non-irrigated plots. The was significant variation in the levels of SMC within the depths of 10 cm to 30 cm between the irrigated and non-irrigated plots, there was high SMC within the irrigated plots than the non-irrigated plots. For effective root establishment, sufficient SMC content is need by plants at germination and early stages of growth [26]. In all depths levels, the SMC within the irrigated plots showed the highest percentages of SMC compared to the drought simulated plots (Figure 2). The results obtained are in agreement with the previous results, in which when water is withdrawn, results into massive reduction in SMC, thus resulting in to drought [27]. Similar results were also obtained by Siddique *et al.*, [28] on wheat plant. Loss of soil moisture from the soil can be associated to either transpiration by the leaves, water uptake by plants and drainage more so in field conditions [29]. Low soil moisture content in the dry plots, at depths of 10 and 20 cm, could be attributed to drainage or absorption by the plants.

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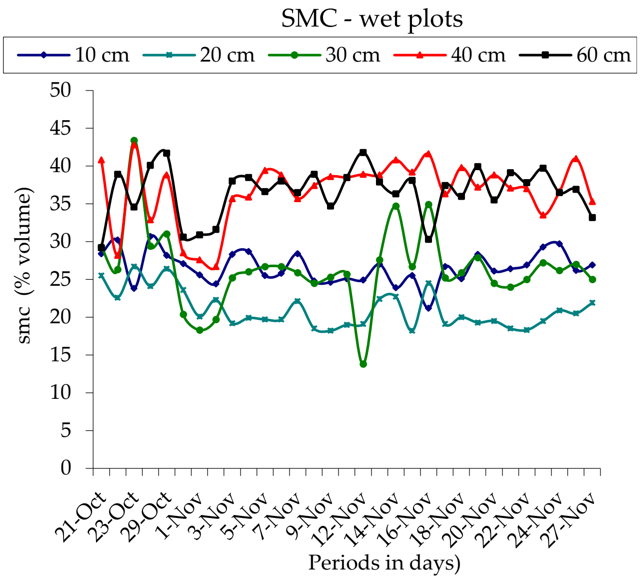
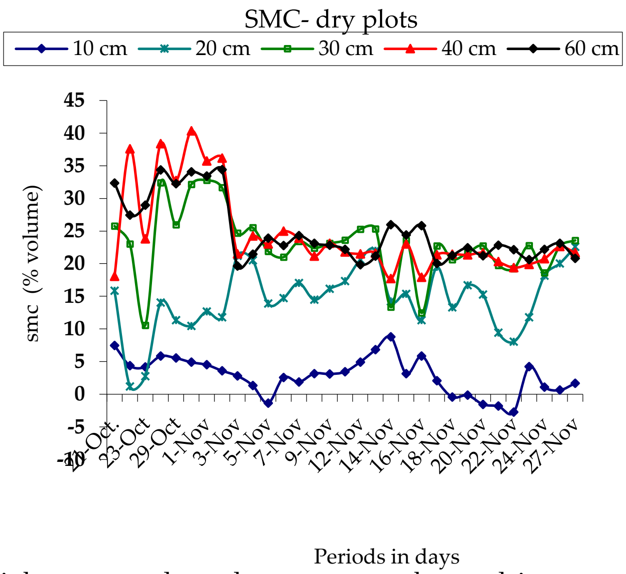
Figure 2: Soil moisture content (SMC) determination in both irrigated and non-irrigated plots. The moisture content was determined by soil moisture probe and values obtained as % volume.





Stomatal conductance

Plants grown under water deficit condition have a reduced stomatal conductance in order to conserve water. As a result of reduced stomatal conductance, carbon (IV) oxide fixation is reduced and photosynthetic rate decreases, resulting in less assimilate production for growth and yield of plants [30]. Stomatal conductance in the four levels of fertilizer application was significantly different among all the three rice cultivars. In IRAT 109, phosphorus applied plots showed the lowest stomatal conductance at 61 DAS. Higher conductance was at 77 DAS while the lowest stomatal conductance was recorded at 93 DAS. The highest stomatal conductance was achieved in nitrogen-fertilized plot while the lowest level was recorded in non-fertilized plots (controlled). In Lemont, a similar trend as in IRAT 109 was observed, except that, the controlled plots showed relatively lower levels of stomatal conductance compared to those of IRAT 109 under similar environment. Water application regime showed a significance difference, in either of the two cultivars, a higher stomatal conductance was observed in well-watered plots, denoted as the (W). Lemont showed a significance higher stomatal conductance in both conditions as compared to IRAT 109, as shown in (Figure 3).

There was a general decline in stomatal conductance between the two cultivars; the reduction in stomatal conductance could be attributed to scarcity of water in the soil, which affects the equilibrium between water uptake and transpiration, thus triggered stress in the plant. IRAT 109 recorded slightly higher stomatal conductance at higher soil moisture deficit. This result implies that IRAT 109 is more tolerant to water deficit and has ability to maintain leaf turgor at low leaf water potential [31], and thus able to exhibit higher stomatal conductance and higher transpiration rates at low soil water potentials. The results obtained were in agreement to those obtained for analysis of the stomatal conductance of ash and oak trees under drought condition [32]. Similar results have also been observed by Ackerson [33,34], who observed that in cotton, the stomata of adapted plants become less sensitive to low water potentials thereby giving higher stomatal conductance at low water potentials. The higher the stomatal conductance, the higher

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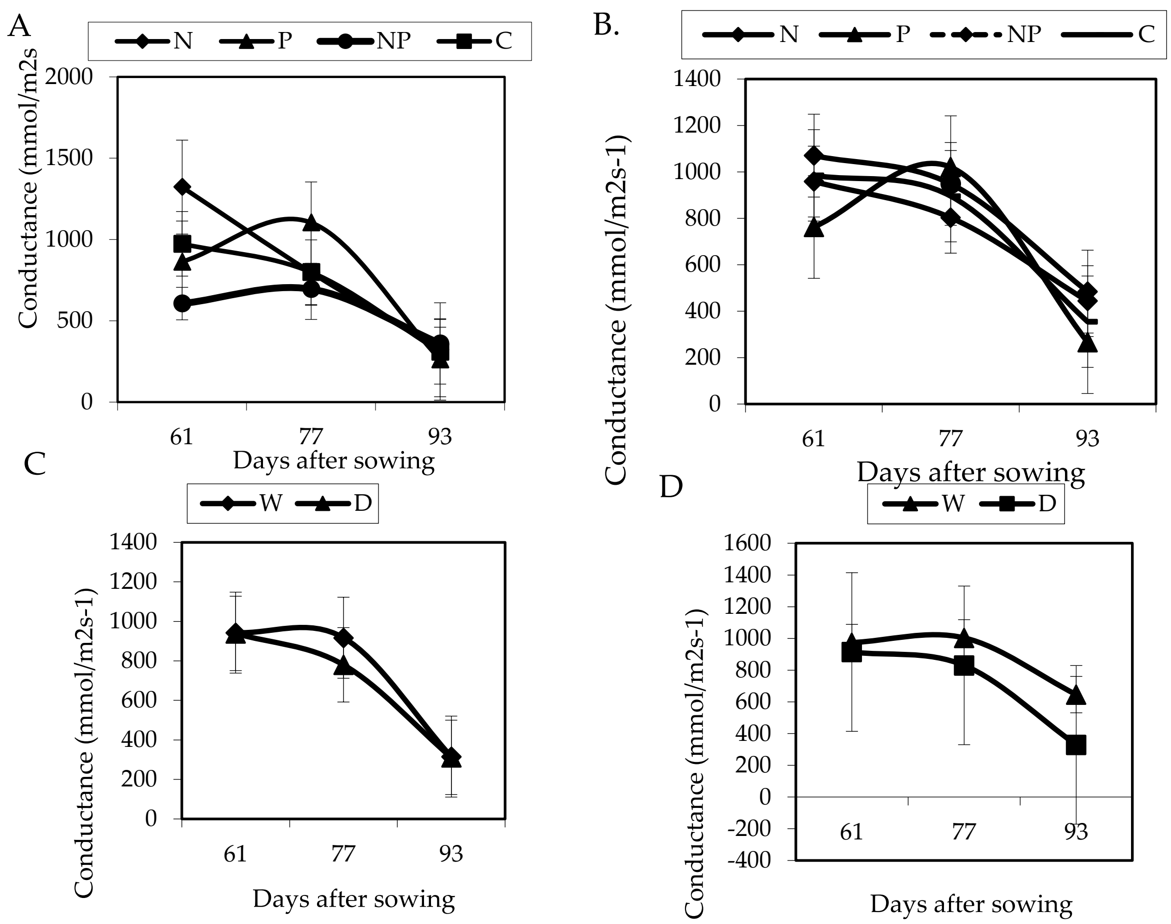
the rate of CO_2 diffusion into the leaf, which in turn leads to, increased rate of photosynthesis [35].

Figure 3: Stomatal conductance (mmol/m^2s^{-1}) the two rice genotypes under drought and varying fertilizer application condition. A: stomatal conductance in IRAT109 under fertilizer treatment; B: stomatal conductance of LEMONT under fertilizer treatment, C: stomatal conductance of IRAT 109 under drought stress and D: stomatal conductance of Lemont rice cultivar under drought stress. Each point represents the means of three replications ±STD DEV.



N content determination

Water deficit affects the nitrogen metabolism in plants and it has been found that, plants under drought stress initiates the process of hydrolysis of the proteins, which leads to an increase in amino acids in the plants tissues [36]. The level of leaf nitrogen content in the two rice cultivars were determined, in which the two showed significant different at $p \leq 0.05$. In IRAT 109, had the highest foliar nitrogen content in Nitrogen and Nitrogen-Phosphorus applied plots, an indication that the plants with no form of nitrogen application exhibited significantly lower levels of leaf nitrogen content. The lowest nitrogen content levels were recorded in non-fertilized plots (controlled experiment). In Lemont, the nitrogen content levels were similar to those of IRAT 109 (Figure 4).

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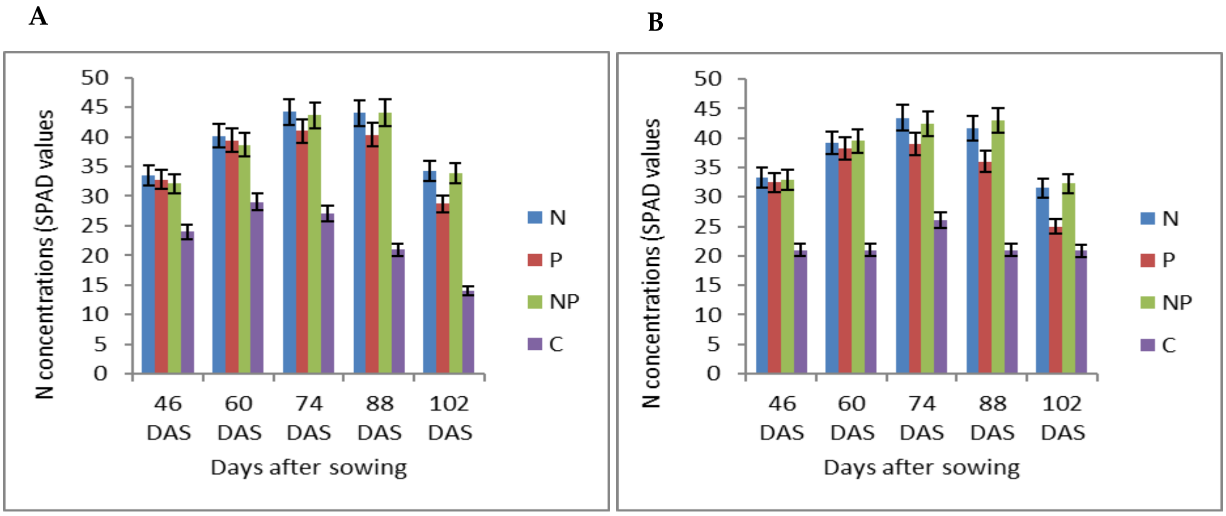
Figure 4: Nitrogen level quantification between the two rice cultivars under different fertilizer application. A. Nitrogen quantification on the leaves of IRAT 109 and B: Nitrogen quantification on the leaves of LEMONT rice cultivars. Each point represents the means of three replications ±STD DEV



Plant height

Most crop plants grow in environments that are suboptimal, which prevents the plants from attaining their full genetic potential for growth and reproduction [37]. Plants must efficiently balance resource allocation between growth and defense against stress, as responding to stress can be costly and reduce fitness in terms of growth and yield [38]. The agronomic features in relation to plant height is diverse between the two cultivars, IRAT 109 is relatively taller compared to LEMONT. Though, by evaluating their growth under different fertilizer application and with varying soil moisture load, the two rice cultivars exhibited significant differences, IRAT 109 showed superior performance compared to LEMONT rice cultivar (Figure 5 and Table 2). Maximum plant growth was achieved in Nitrogen-phosphorus applied plots. Nutrient limitation has drastic effects on plant growth and development. Under mild nutrient deprivation plant architecture may be modified to increase nutrient uptake, while severe nutrient limitation may lead to complete growth arrest. Potassium (K+) has substantial effect on enzyme activation, protein synthesis, photosynthesis, stomatal movement and water-relation in plants [39]. Increased application of K+ has been shown to enhance photosynthetic rate, plant growth, yield and drought resistance in different crops under water stress conditions.

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Figure 5: plant height under varying fertilizer application. A. plant height measurements of IRAT 109 and B: Plant height for LEMONT. Each point represents the means of three replications±STD DEV

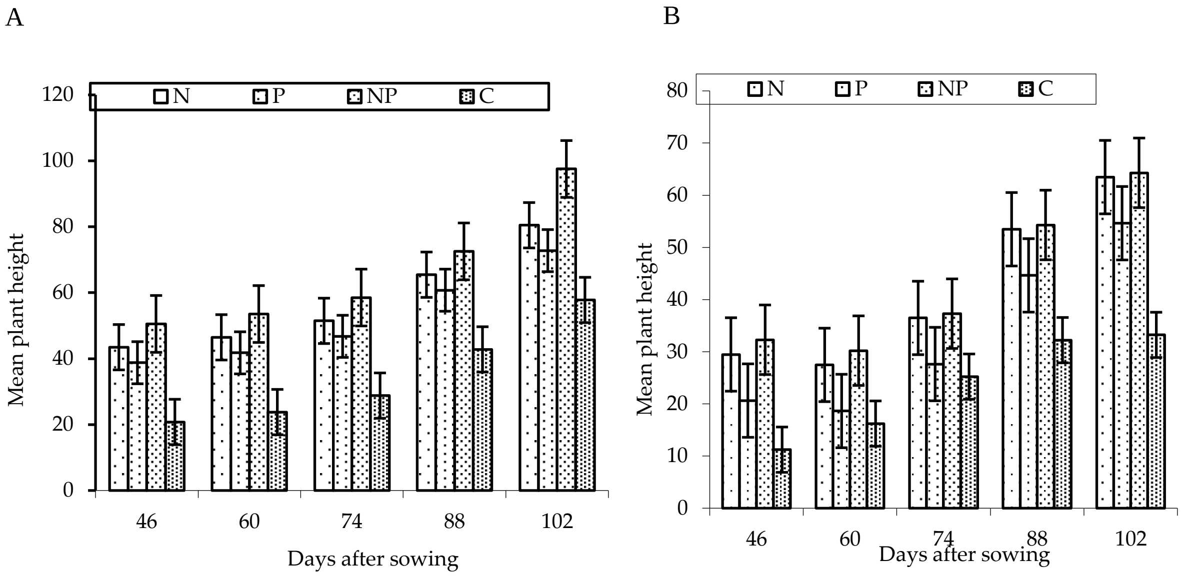

Table 2: Effects of fertilizer application on plant height (Cm) of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications±STD DEV.

Cultivars	IRAT 109						Lemont						
	Fertilizer levels				Mean	CV (%)	Fertilizer levels				Mean	CV (%)	V*F
Das	C	N	P	NP			C	N	P	NP			
46	40.8c	43.5b	38.8c	50.5a	43.4a	4.0	31.2b	39.5a	30.6b	40.3a	35.4b	2.6	0.0007***
53	43.7c	46.4b	41.8c	53.5a	46.4a	3.7	34.2b	42.5a	33.6b	43.3a	38.4b	2.4	0.0007***
60	45.8c	48.5b	43.8c	55.3a	48.4a	3.6	36.2b	44.5a	35.6b	45.3a	40.4b	2.3	0.0007***
67	48.7c	51.4b	46.8c	58.5a	51.4a	3.4	39.2b	47.5a	38.6b	48.3a	43.4b	2.1	0.0007***
74	54.8c	57.5b	52.8c	64.5a	57.4a	3.0	45.2b	53.5a	44.6b	54.3a	49.4b	1.9	0.0007***
81	62.8c	65.5b	60.8c	72.5a	65.4a	2.7	53.2b	61.5a	52.6b	62.3a	57.4b	1.6	0.0007***
88	71.8c	74.5b	69.8c	81.5a	74.4a	2.3	62.2a	70.5a	61.6b	71.3a	66.4b	1.4	0.0007***
95	77.8c	80.5b	75.8c	87.5a	80.4a	2.2	68.2b	76.5a	67.6b	77.3a	72.4b	1.3	0.0007***
102	79.8c	84.5b	79.8c	91.5a	84.4a	2.1	72.6b	80.5a	71.6b	81.3a	76.4b	1.2	0.0007***
109	85.8c	88.5b	83.8c	95.5a	88.4a	2.0	76.6b	84.5a	75.6b	85.3a	80.4	1.1	0.0007***

Das: days after sowing; C, non-fertilized plot; N urea fertilized plot; P, TSP fertilized plot and NP, combination of urea and TSP. Alphabetical letters which are not the same within the rows are significantly different. *** Significant at the P≤0.05 level of probability.

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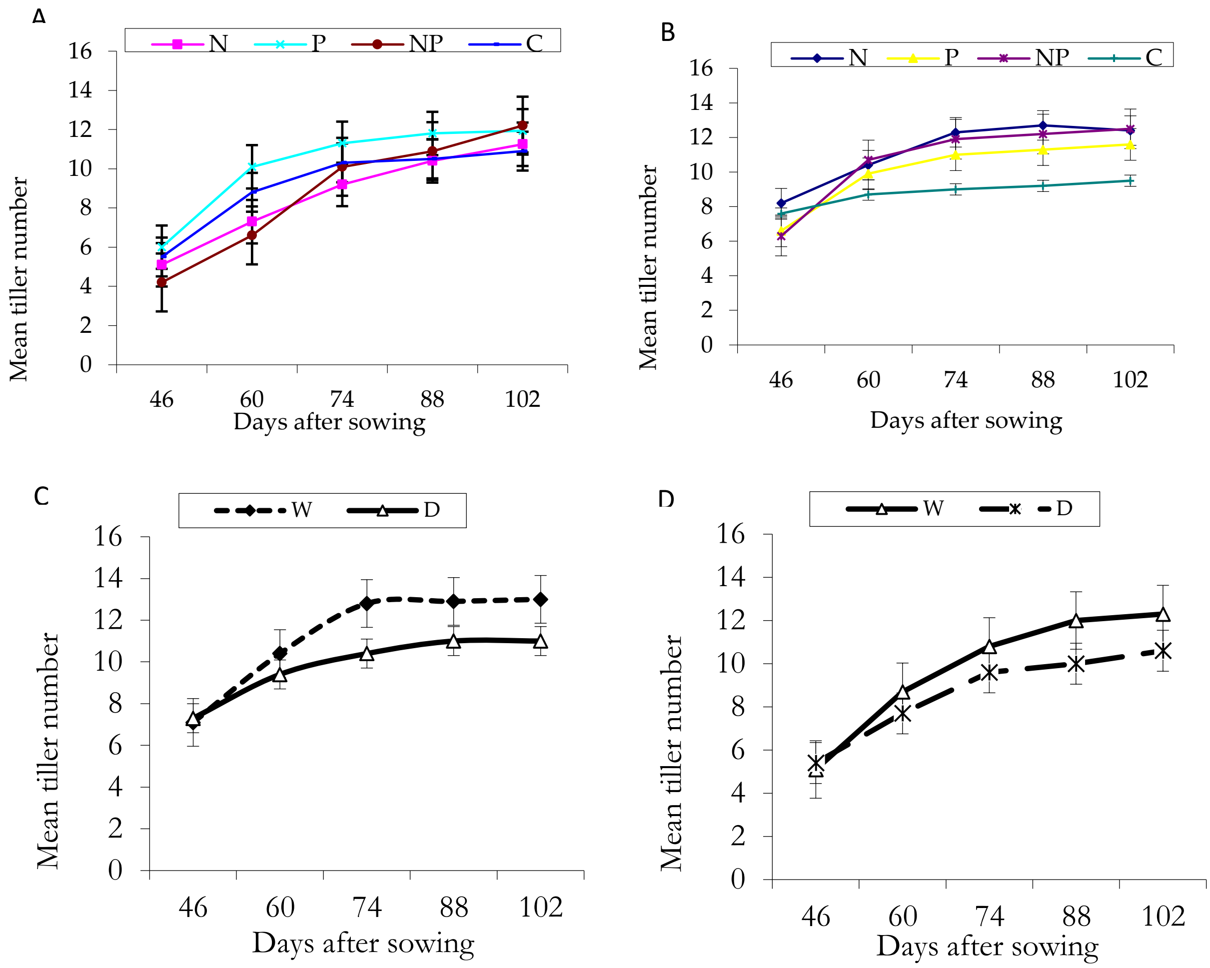
Yield and yield components

Tiller number

Plant architecture is important for rice plant, as it directly correlate to yield potential. Plants with a desirable structural form have the capacity for increased grain production in resource-limited fields compared with plants with less desirable architecture. The three main determinants of rice architecture are the tiller number, leaf angle and plant height [40]. There was significant effect (P≤0.05) in plant tiller number among the watering regime and the cultivars. Plants in well-irrigated plot registered the highest tillering ability in terms of the number per hill as compared to the same cultivars grown in dry plots, plots under water deficit conditions. IRAT 109, showed the highest tiller number in both wet and dry plots and across the four fertilizer levels. Plots fertilized with phosphorus showed the highest tiller number both in IRAT 109 and in Lemont. The lowest tiller number was registered in nitrogen and non-fertilized plots (Figure 6).

Figure 6: Tiller number quantification under drought and varying fertilizer applications. A. tiller quantification in IRAT109 under different fertilizer applications, B: tiller quantification in LEMONT under varying fertilizer applications, C: tiller number in IRAT 109 under water treatment and D: tiller number in LEMONT under water treatment. Each point represents the means of three replications ±STD DEV



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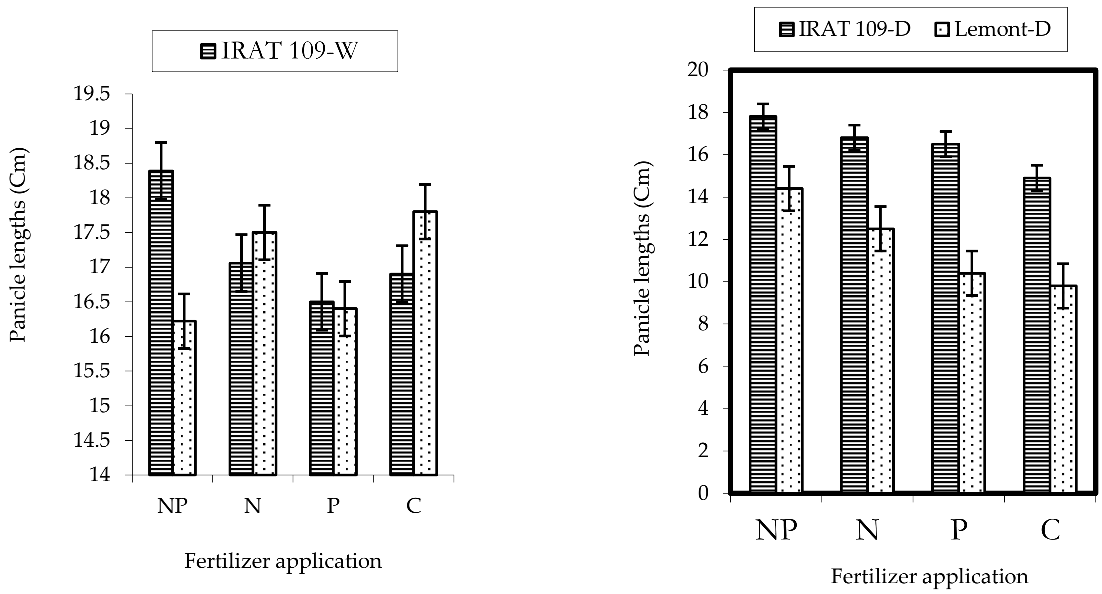
Panicle lengths

Panicle lengths were significantly affected by the water deficit conditions in the dry plots. The well-watered plants had longer panicles than the stressed plants (Figure 7). Similar results have also been obtained by Yeo *et al.*, [41], he observed that drought affects the panicle lengths and in turn reduces the grain setting which significantly contributes to low yields in rice. IRAT 109 registered the highest panicle lengths in dry plots among all the fertilizer levels. This implied that IRAT 109 is a more tolerant cultivar compared to LEMONT under water deficit condition.

Figure 7: Effects of fertilizer and water interaction application on panicle lengths (Cm) of IRAT 109 and Lemont rice cultivar. Each point represents the means of three replications±STD DEV.



Yield at 14% moisture content

The two rice cultivars were significantly different at P≤0.05. IRAT 109 registered the highest yield at 14% in all fertilizer levels. The highest yield was obtained from Nitrogen-phosphorus fertilized plots and the least yield was in the non-fertilized plots, designated as C (Figure 8). Grain yield of rice may be limited by the supply of assimilates to the developing grain or by the capacity of the reproductive organ to accept assimilates (sink capacity) [42]. Significant variation in yield and yield attributing characters were recorded between the cultivars, IRAT 109 had higher yield levels under stress and non-stressed conditions. In as much as the cultivars greatly vary or differ in inherent yielding ability, yield losses from the normal levels as a result of water deficit are useful in assessing drought tolerance [43]. Low yield of IRAT 109 under water deficit treatment may be attributed to less number of ear bearing tillers per hill, reduction in total grain number per panicle. IRAT 109, showed superior sink capacity under low soil moisture content in terms of relatively longer panicle length as compared to Lemont.

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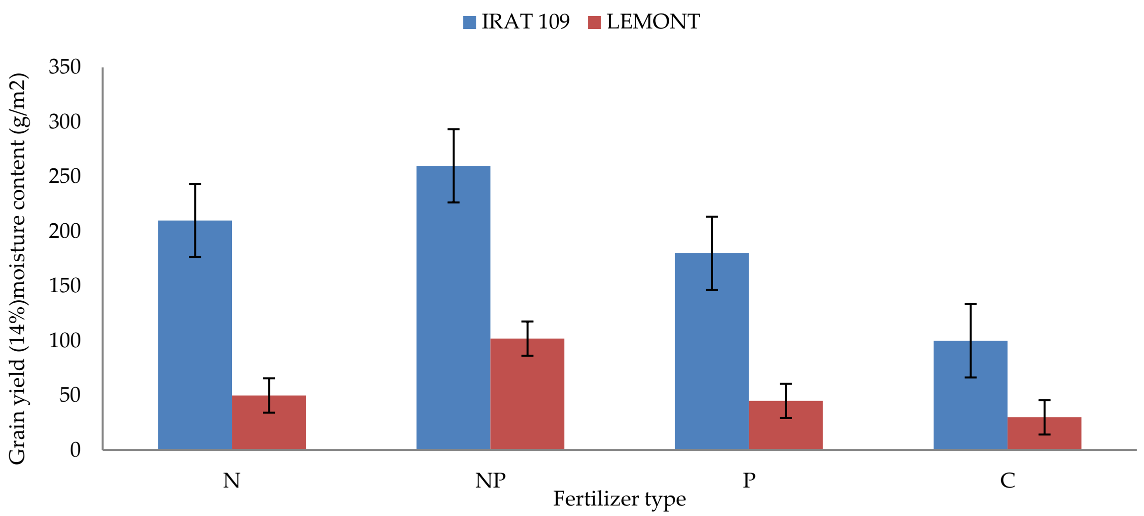
Figure 8: Effects of fertilizer and water application on grain yield at 14% moisture content of IRAT 109 and Lemont rice cultivar in experiment 1. Each point represents the means of three replications±STD DEV.



Discussion

Environmental degradation has radicalized the weather pattern, in which precipitation is erratic and the amounts are not sufficient for food production [44]. With the ever increasing human population, and decline in arable land due to human settlement, breeders have to develop more environmental resilient and highly adaptive plants, in order to meet the food demand. Rice being hydrophytic plants, tremendous efforts has been done to produce non-paddy rice to cope with the little available fresh water. The main form of abiotic stress with negative impact in agricultural crops production is drought stress [45]. Evolutionary success in annual plants is largely dependent on their efficient adaptation to environmental stresses. Previous studies have shown that plants respond to drought stress using different strategies, including drought escape [46]. In the analysis of the performance of the two upland rice cultivars, IRAT 109 was relatively more adaptive to drought-nutrient stress compared to LEMONT rice cultivar.

The ability of the plant to grow under stressful condition indicates that the plant has the ability to reduce the injury effects caused by the abiotic stress. IRAT 109 had exhibited increase in plant height, increased shoot biomass and higher yield index. Plant height and grain yield were reduced under drought compared to LEMONT. Reduction in plant growth under drought stress condition is due to various factors such as poor root development; reduced leaf-surface traits caused by reduction in size, shape, composition of cuticular and epicuticular wax and or leaf color, which affect the light interception of the leaf. Other causes of reduced plant growth are; delay in or reduced rate of normal plant senescence as it approaches maturity and inhibition of stem reserves [47]. The negative effect of water deficit on morphological, physiological and yield components concurred with the results of previous findings [48]. In this study, the observation was consistent across experiments, indicating that the traits are good indicators that could be used in drought screening tests. However, the intensity of drought effect on the traits varied with the genetic materials.

Rice being a major source of dietary protein for most people globally [49]. Fertilizer application is integral in achieving not only high yield but

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improved quality too. The performance of the two rice cultivars were significantly higher compared to those grown under controlled conditions. Several studies have shown that application of nitrogen up to panicle stage, do increase protein content and eventually high grain yield in rice [50]. In addition, foliar application of urea or triazines at the heading stage has appositive effect on grain protein content in rice [51]. High protein content improves the whole-grain or head rice content. The increased performance of the two upland rice cultivars under nitrogen-phosphorus fertilizer showed that, fertilizer application improves plants tolerance to drought stress. The results obtained was in agreement to previous findings in which exogenous application of urea improved maize performance under drought stress condition [52].

Conclusions

The results in this study indicates that water-nutrient stress affects plant growth, development and ultimately the yield of the selected rice genotypes, IRAT 109 and Lemont. Water-nutrient stress leads to a decrease in plant height, plant biomass and greatly affects the grain yield by decreasing tiller number, panicle length and filled grain percentage. The water-nutrient stress affects the physiological aspects of the plant, reduces the stomatal conductance and N foliar content levels. IRAT 109 can tolerate moisture deficit. There was a variation in the performance of the selected rice genotypes; IRAT 109 exhibited the highest tolerance to water-nutrient deficit. IRAT 109 being early maturing cultivar, it has coherent physiological traits to escape late drought and the ability to maintain growth during period of drought that may occur late in the season. The findings in this study will help rice breeders to utilize the inherent agronomic traits in IRAT 109, to aid in the development of a more resilient and high yielding rainfed types of rice cultivars with improved water use efficiency.

Author Contributions

ROM and JC designed the experiment, ROM and JNK implemented and collected the data. ROM analyzed the results and prepared the manuscript. ROM, JNK and JC revised the manuscript. All authors reviewed and approved the final manuscript.

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