UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECT OF WATER STRESS ON GROWTH AND YIELD OF RICE

(*Oryza sativa* L.)

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DECLARATION

I, Abdul Rahman Abdul Basit Iddrisu hereby declare ownership of this work in sincerity and that no previous submission has been made in this University or elsewhere in relation to this work.

This is in partial fulfillment of the requirement for the award of MPhil Crop science (Agronomy) Honours Degree. References to other peoples' work cited in my work were fairly acknowledged.

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ABSTRACT

It is generally known that drought affects rice production in Northern Ghana, which has negative impact on productivity of rice yield and food security. Over 200 million tonnes of rice is lost annually through adverse environmental conditions such as water stress. Farmers require modern cultivar such as aerobic rice to improve crop performance in areas where there is limited and irregular rainfall pattern. In an attempt to identify drought tolerant rice variety, pot experiments were conducted at the experimental site of the University for Development Studies, Nyankpala to investigate the responses of seven exotic and two local accessions of rice under different moisture conditions during the periods, starting from December 2016 to May 2017 and January 2018 to May 2018. Nine genotypes of rice DKA 23, DKA 21, DKA-M8, GBEWAA, AGRA, UPL RI 7, IR 55419-04, IR 79913-B-179-B-4 and APO were evaluated under 100% Crop Water Requirement, 100% Crop Water Requirement-Split, 80% Crop Water Requirement and 60% Crop Water Requirement. The study was laid out in a 9 x 4 factorial experiment in Randomized Complete Block Design (RCBD) with three replications. Rice plants cultivated under 100% Crop Water Requirement and 100% Crop Water Requirement-split recorded a relatively better growth parameters compared to 80% Crop Water Requirement and 60% Crop Water Requirement. Also, number of tillers, number of leaves, number of panicles, grain yield and chlorophyll content at maturity were highest with DKA 23 genotype. DKA-M8 recorded the highest Plant height, panicle length and above ground biomass. Results of the study indicated that DKA 23 was the best drought tolerant among the genotypes. Phenotypic traits such as number of tillers, number of leaves, number of panicles, total grain yield and chlorophyll content appeared to be linked with moisture stress tolerance. Also, genotype IR 55419 14 clearly showed susceptibility to soil moisture stress. DKA 23, UPL R1, APO and DKA 21 are the best genotypes for farmers to cultivate in dryland conditions under 100% crop water requirement. The study needs to be advanced under field conditions across the two agroecological zones of Northern Ghana.

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DEDICATION

This thesis is fully dedicated my parents, Mr. Abdul-Rahman Iddrisu and Mrs Fati Ali and my family members Faiza Musah, Abdul Shakur, Iddrisu and Abdul Rahman.

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GLOSSARY OF ACRONYMS

Acronym	**Meaning**
ACE	Atmosphere, Climate and Environment
APAT	Advance Portable Analysis Tool
AWD	Alternate Wetting and Drying
CEC	Cation Exchange Capacity
CF	Continuous Flooding
Cm	Centimeters
CO_2	Carbon dioxide
CRI	Crop Research Institute
CSIR	Council for Scientific and Industrial Research
CWR	Crop Water Requirement
d. f.	Degree of Freedom
DAP	Days After Planting
DAT	Days After Transplanting
ETo	Crop evapotranspiration
ETc	Crop evapotranspiration under standard conditions
FAO	Food and Agriculture Organization
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate
Statistical	
DB	Database
FC	Field Capacity
g	Gramme

GDP	Gross Domestic Product
HI	Harvest Index
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
kPa	Soil-leaf Hydraulic Conductance
***K*c**	Crop coefficient
Kg	Kilogramme
LAI	Leaf Area Index
Lp	Hydraulic Conductivity
Lp_r	Root Hydraulic Conductivity
LSD	Least Significance Difference
M	Leaf Mass
m. s.	Mean Square
NAES	Nyankpala Agricultural Experimental Station
NS	Not significant
s. s	Sum of Squares
S.E.M	Standard Error of Means
SARI	Savannah Agricultural Research Institute
SLA	Specific Leaf Area
SLW	Specific Leaf Weight
SPAD	Soil and Plant Analysis Development
SSC	Saturated Soil Culture
TDM	Total Dry Matter
UN	United Nation

USDA	United State Department of Agriculture
WAP	Weeks After Plant
WP	Water productivity
WPET	Water that can no longer be reused
WPI	Productivity of Irrigation Water.
WPIR	Water Input by Irrigation and Rainfall
WPT	Water productivity with respect to transpiration
WPT	Weight of grains over cumulative weight of water transpired

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Rice (*Oryza sativa* L.) is an essential basic cereal crop which serves as food for over seventy percent of the world's population (Dowling *et al.*, 1998). As a result, it can be considered as the most vital production that is consumed globally. It is the only grain crop that is produced solely for consumption. The world's population may increase to about 8 billion people in 30 years (UN, 2002; Rosegrant *et al.*, 2002) with rice dependent increasing to about 5 billion people (IRRI, 2002). Feeding this population will need a bigger effort in rice production across the globe. To satisfy the global consumption of rice due the ever-increasing world population, it is estimated that cultivation of rice must be increased to 760 million tonnes in 2020, compared to the total requirement of 518 million tonnes in 1990 (IRRI, 2002).

Nevertheless, it is globally projected that climate change effect could contribute to about twenty percent increase in water shortage. The Intergovernmental Panel on climate change has anticipated that severe droughts and floods could occur as a result of sharp fluctuations in precipitation patterns with regards to global warming (Davis, 2007). Generally, these phenomena will adversely affect crop production globally (especially rice, because of its high-water requirement), with the consequent effects on food and nutritional security. Moreover, there is also enough evidence that drought has already impacted several rice farms negatively where rice farmers required improved production knowledge to sustain their farming businesses. Where technologies were developed to cultivate rice with little amount of water (Tuong and Bouman, 2003). Drought tolerance is the capacity of a crop to sustain their metabolic activities even when leaf water potential is severely low (Athar and Ashraf, 2009). In rice plant, variety, degree and duration of stress have different effect and varies with different stages of growth (Kato *et al.*, 2004). For this reason, the ability to develop drought tolerant genotypes of various crops (including rice) becomes critical.

1.2 Problem Statement and Justification of the study

Drought is among the major limiting factors affecting production of crops, and increasingly affecting production of rice in several areas (Passioura, 2007). Globally, land areas affected by water shortage have increased by more than hundred percent for the past 30 years (Isendahl and Schmidt, 2006). Again, over 200 million tonnes of rice are lost annually in the world through adverse environmental conditions such as water stress (Herdt, 1991).

Drought remains the most serious natural disaster, affecting a larger proportion of the human population than any other hazard. It is the most significant climatic constraint for rice production in sub-Saharan Africa (SSA) (Reynolds et al., 2015). About three-quarters of the most severe droughts in the last ten years have been in Africa, the continent which already has the lowest level of crop production and drought adaptive capacity (Ravallion et al., 2012). According to the United Nation, drought and flood affected 70, 500 hectares of farmland in Northern Ghana which resulted in an estimated loss of 144,000 tonnes of crops such as rice (UN, 2007). Farmers require modern system of rice production from the traditional flooded method to aerobic system. That is by developing high-yielding genotypes that can be cultivated under upland conditions (Castaneda *et al*., 2002). In order to increase crop productivity, it is important to know the response of plant to water stress with the aim of improving crop performance in areas where there is limited and irregular rainfall pattern (Passioura, 2007). According to Rodrigues *et al.* (2013) water scarcity is addressed by either the development of drought tolerant rice or the practice of highly efficient water management system. The development of water stress tolerant cultivars or genotypes of rice by either selection or breeding is more economical in improving rice productivity around drought affected areas (Subbarao *et al.*, 2005). Northern Ghana is one of the areas where rice cultivation suffers from low precipitation.

In developing drought-tolerant varieties, it is necessary to design a constructive screening systems and good selection methods. Agronomic criteria employed in selecting of drought tolerant varieties include grain yield, harvest index, total dry matter and leaf water potential (Neumann, 2008). Improving rice yield in dry-land conditions calls for engineering of cultivars "aerobic rice" that has upland rice qualities with the appreciable yield potential of lowland rice (Lafitte *et al.*, 2002; Atlin *et al.*,2006).

1.3 Objectives of the study

The main objective of this study was to examine the responses of some rice varieties to drought in northern Ghana and to determine their suitability in the prevailing environmental conditions which is under high moisture stress.

Specifically, the study was conducted to

1. Study the overall response of seven exotic and two local accessions of rice to moisture stress.
2. Study the growth and yield potential of these genotypes under moisture stress conditions.
3. Identify important phenotypic traits associated with moisture stress tolerance.

CHAPTER TWO

LITERATURE REVIEW

2.1 Taxonomy and botany of rice

The genus *Oryza* L. is found in the tribe *Oryzeae*, subfamily *Oryzoideae*, of the grass family Poaceae (*Gramineae*). This genus is made up of two cultivated species (*O. sativa* L. and *O. glaberrima* Steud.) and has more than 20 wild species across the tropical belt. The Asian cultivated rice (*O. sativa*) is an important staple food crop for over fifty percent of the global population while the wild species in this genus serve as an important gene pool which are employed to expand the genetic activities in breeding programs of rice (Brar and Khush, 1997; Bellon *et al.*, 1998).

The two different kinds of cultivated rice *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) have peculiar adoption background. To determine the differences in selection and history with rice, we should examine the parents of today's varieties. The domesticated genus *Oryza* has 21 undomesticated relatives which are grouped into four classes: The *O. sativa*, *O. officialis*, O. *ridelyi* and *O. granulate* species complexes (Vaughan et *al.*, 2003) The *O. sativa* has two main species: *O. sativa* and *O. glaberrima* with five or six wild species: *O. rufipogon*, *O. nivara* (an ecotype of *O. rufipogon*), *O. barthii*, *O. longistaminata*, *O. meridionalis* and *O. glumaepatula*, all the above mentioned are diploids. *Oryza sativa* is highly concentrated around Asia and *O. glaberrima* is mostly cultivated in West Africa. However, *Oryza rufipogon* is found across Asia and Oceania. *Oryza barthii* and *O. longistaminata* are both African species but *O. barthii* is common in only West Africa while *O. longistaminata* is seen in almost all African countries. *Oryza meridionalis* can be traced to Australia while *O. glumaepatula* is traced to Central and

South America. However, African varieties were obtained from *O. barthii* (*O. breviligulata*) while the Asian cultivars were obtained from *O. rufipogon*. Even though, it is uncertain whether *O. rufipogon* (perennial species), *O. nivara* (annual species) or both were the true parents of the Asian rice (*O. sativa)* (Sweeney and McCouch, 2007).

Li (2003) defined grain of rice as rough rice or paddy, which is made up of brown rice together with the hull. Brown rice include the endosperm, embryo and the differential thin layers (the ovary wall), the seed coat together with the 5 nucellus. Li (2003) added that, the seed coat is made up of six cell layers where aleurone layer is found in the inner part.

The enclosed plumule, the unsheathed primary root and the joining part of the mesocotyl formed the embryo. Mostly, the endosperm is starch in a protein formed together with crude fibre, sugar, fats, and organic matter. About twenty percent of the total grain weight is hull and this include the palea, lemmas and rachilla. Others rice cultivars possess rudimentary glumes and little part of the pedicel. The lemma is bigger compared to palea, tough, archmenlike and sometime awny. Ripening stage of the grain is segment into stages as milky, dough, yellow-ripe and maturity stages depending on the content and color of the grains at maturity. According to Hammermeister (2008), insight of grain quality begins with understanding the anatomy of a grain and the purpose of production as well.

2.2 Origin and distribution of rice

Several evidences support *O. glaberrima*, to have come from Africa as some indigenous names such as malo, maro and mano were there before the Portuguese names came about (Blench, 2006). Archaeologists also suggested impressions about rice grains far back from 1800 BC to 800 BC in Niger town called Ganjigana (north-east). Scientist observed abundant charred grains of rice at certain areas near Kursakata around 1200 BC (Klee *et al.*, 2000). Even though, records were not accessible to prove whether those grains were cultivated. However, the first adopted *O. glaberrima* was documented between 300 BC and 200 BC in Mali around Jenne-Jeno near the Inland Niger Delta (McIntosh, 1995). Studies from isozyme, simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) seconded the genetic relationship of African rice to *O. barthii* (Semon *et al.*, 2005). Sweeney and McCouch 952 rice domestication selections were employed to cutivate upland fields under rainfed condition where *O. sativa* was brought into *O. glaberrima's* territory (West Africa) after domestication and both are now cultivated (Sweeney and McCouch, 2007).

Apparently, NERICAs (New Rice for Africa) was developed by crossing *O. sativa* and *O. glaberrima* in order to combine the drought tolerance of Africa rice to the yield potential of Asian rice (Gridley *et al.*, 2002).

Nguyen (2001) reported that 85% of total rice production is directly for human consumption. According to Li (2003), rice is grown almost everywhere apart from the Antarctic areas. A study by De Datta (1981) revealed 112 countries around the world that are involved in rice cultivation. The whole Asian continent and most parts of Africa including West, North, East, and Central Africa, Australia, South and Central America are also deep into rice cultivation.

2.3 Rice environments

Considering the hydrology of rice cultivation, rice ecologies can be grouped into irrigated lowland rice, rainfed low-land rice (paddy rice), flood-prone rice and upland rice. Lowland rice has saturated soil culture with ponded water for a minimum of 20% of total crop duration in the field. On the other hand, irrigated lowlands maintained ponded water for a minimum of 80% of the crop life cycle (Maclean *et al.*, 2013).

Under rainfed lowlands, the only source of water during cultivation is the rainfall and water availability solely depends on the rainfall pattern. However, in flood-prone environments, the fields frequently experience successive flooding as a result of uncontrollable amount of water which can stay for 10 days and above at 25 cm depth. Floating rice or deep-water culture is normally practiced in this environment. Upland condition or aerobic system consist of drained, non-saturated and non-ponding land preparation. (Maclean *et al.*, 2013). Wet season irrigated rice fields are supplemented unlike dry season where irrigation is done throughout the season (Timsina and Connor, 2001; Dawe, 2005).

2.4 Production and economic importance of rice

Rice (*Oryza sativa* L.) is a common food for over three billion people worldwide (FAO, 2011) and one of the most important crops which together with wheat serve as a large source of nutrition to majority of people in the world (Juliano, 1993).

Asia is the global hub of rice cultivation and consumption where the latter is over 90%. Rice type, individual preference and location are some of the factors influencing the consumption of rice (Juliano, 1993). According to Li (2003), a total of 596.5 million tonnes of paddy rice is produced annually from 155 million hectares of land size globally. This makes rice one of the common foods for a vast population in West Africa (Basorun, 2003). According to Basorun (2003), the demand for rice was estimated to grow over 8 million metric tonnes per annum due to the steady increase in population growth, change of lifestyle and the ease in cooking and preservation. For the past forty years, rice production has been growing at a rate of 5.1% with more than 60% of this growth resulting from increase in farm size with only small percentage due to the use of high yielding cultivars (Anonymous, 2008a). It is estimated that West Africa alone has a total rice field of 4.4 million hectares (Somado *et al*., 2008). Producing around 6.2 million tonnes (Anonymous, 2008b).

Berisavljevic *et al.* (2003) reported that agriculture contributes to about 15% of Ghana's Internal Generated Fund (IGF) apart from providing employment to a lot of people in rural areas. Rice consumption has increase over the years due to shift in diet and this has caused high importation of rice in Ghana. More than 50% of the rice consumed are imported due to the high demand (Berisavljevic *et al.*, 2003). Consumption of rice in Ghana has increased over the years by more than 20% and thereby increasing the rate of importation (Berisavljevic *et al.*, 2003). However, the perceived quality or imported rice is priced higher than the local rice. This is because, West Africa does not cultivate enough rice to satisfy the demand of the people leading to high importation to meet the high consumption level. The Food and Agriculture Organization of the United Nations (FAO) revealed that rice importation has increased in the world to over six million tonnes annually leading to a total revenue of over $1.5billion (Somado *et al*., 2008). Simply because local rice production hardly meets their annual demand (Takoradi, 2008).

2.5 Rice water use

Limited records are taken in the quantity of water involved in irrigating rice fields around the world. Despite that, it is possible to calculate the amount of withdrawal water for irrigation purposes base on the size of irrigated area (compared with other crops), and the amount of water involved in the irrigation (Falkenmark and Rockström, 2004). Approximately, about 3,600 km^3 per annum is withdrawn and 2,500 km^3 is used for irrigation of crops (Falkenmark and Rockström, 2004). Industry and domestic activities account for the rest of the water consumption. Asia possess more than 50% of the world's 271 million ha of irrigated area where rice accounts for averagely 43% of all crops under irrigation (Dawe, 2005). Moreover, rice needs about 2 or 3 times the amount of water given to other crops, but an unknown amount of the lost water may be used by downstream crops. With the assumption of a reuse water of 25%, and it can be calculated that 34–43% of the total world's irrigation water is used for irrigating rice fields or an average of 27% of freshwater is withdrawn for irrigation of rice (Dawe, 2005). Tuong and Bouman (2003) predicted that, by the next 20 years, about 17 million ha of irrigated rice fields will be affected by water shortage. Even though, no sign of reduction has occurred in some of Asia's irrigated areas. However, in Southern part of Asia, large rivers sometimes overflow to the sea which is affecting rice fields located in the down streams (Postel, 1997).

Apparently, overused of groundwater is posing a challenge in Asia (Postel, 1997; Shu *et al.*, 2001; Singh, 2000) which is affecting cultivation of rice. This led to a drop-in groundwater tables by averagely 1.5 m per year, by 0.6 m in Indian states and its environs, where majority of the people practice flood-rice system. Bangladesh also had a drop-in groundwater resulting in the collapse of shallow wells in the dry season (Ahmed *et al.*, 2004).

However, the serious demand of water by the states and other industries is contributing to the scarcity of water on large rice growing areas in southern India and in Thailand (Postel, 1997). Technically, dry season spells moisture stress all over due to high temperatures and limited precipitation making irrigation the only alternative cropping system (Bouman *et al.*, 2007).

Several studies suggest that water scarcity is the major factor for low yields both at the research level and farmers field (Papadimetriou, 2001). Irrigated agriculture is predominantly water dependent which accounts for almost 80% in the world and 86% in Africa and other developing countries (Rosegrant *et al.*, 2002). Up to 75% of the rice produced in the world is from Irrigation. However, there is also an increase in water demand for non-agricultural activities around the world. This led to the classification of 40% of the total land as arid and semi-arid land (Gamo, 1999). Rapidly increasing population growth also put heavy pressure on limited freshwater resources which makes shifting to cultivation of less water-demanding crops easy since rice cultivation needs more water (Kijne *et al.*, 2003).

The agriculture sector in Ghana provides livelihoods for 56 percent of the labor force nationwide and job opportunities for 85% of the rural communities. However, less than 50% of Ghana's agricultural land is being used and less than 1.6% of land suitable for irrigation has been cultivated due to water scarcity. Majority of the population use cassava, yam, maize, and rice as staple foods. Except for rice, these crops are generally not irrigated which makes water availability an important factor in rice production. Rice production in

Ghana is basically practicing rain-fed agricultural with traditional methods which exposes local farmers to high risk in drought conditions (FAO, 2014).

The Northern Region of Ghana possesses a great potential for rice cultivation and lowlands represent the largest area but are mostly unused. Inland valley production systems (lowlands and midlands) account for 75% of domestic rice production. They have the highest potential for rice production due to their hydrological characteristics such as high-water retention capacity. Despite this high potential, current rice yields are relatively low due to irregular rainfall pattern and the lack of modern water management systems (LRDP, 2001).

2.6 Water balance and cultural operations of rice

Irrigated lowland rice is cultivated with flooded soil condition. Generally, rice is nursed in a different nursery bed and later seedlings of 2 to 3 weeks old are transplanted to the field. On the other hand, rice is grown by direct seeding either after pre-germinating of seed form or direct planting of the dry seeds. It was revealed that 20% of Asia cultivate rice by direct seeding (Pandey and Velasco, 2002).

In irrigated field, continuous flooding is used to control weeds and preparation of field is done in wet conditions. Soaking, ploughing, and puddling is done at a shallow submerged level before transplanting. The water balance in this field is maintained at a level which is different from upland crops. The field balance includes inflows and outflows. Irrigation, rainfall, and capillary rise are regarded as inflows while transpiration, evaporation, over bund flow, seepage, and percolation are considered as out flows. In aerobic soil condition, the upwards movement of water may reach roots surface to support plant growth (Bouman *et al.*, 2007). However, percolation occurs in flooded fields conditions as a result of downward movement of water below the plough pan which limits capillary rise of water for plant use. Basically, capillary rise is not considered in rice fields water balance. Roots of rice are mostly not too deep and are available within the puddled region. Plough pan drastically minimizes the rate of percolation in rice fields (Bouman *et al.*, 2007).

Before transplanting of crops into the main field, water is needed for puddling. The field is left flooded for 7 to 30 days before transplanting. Quantity of water needed for this preparation varies when few days are given between soaking and transplanting or when using direct wet seeding. In large irrigation scheme without good water control, the turn-around can go as high as two months (Tabbal *et al.*, 2002).

Field is normally ponded with 5–10 cm layer of water from crop establishment to until 1 to 2 weeks prior to harvest. In all the turn-around time and growing period, the water outflows are through runoff, evaporation, seepage and percolation and transpiration during growth. Out of these outflows is only transpiration which falls under water productivity as it directly links total dry matter production (Bouman *et al.*, 2007).

2.7 Water availability and rice production

Rice falls second after corn among other cereal crop and serves as a food crop for a very large population around the world (Anonymous, 2008a), yet rice cultivation is facing several challenges (Ferrero, 2007) that impedes the possibility of improving productivity and economic benefits. One of the main dilemmas of rice-cultivation in the Sahara region is water scarcity. The effects of climate change (Fischer *et al.*, 2007; Giorgi and Lionello, 2008) are also strong contributing factors to water availability for agriculture (Mancosu *et* *al.*, 2015; Garrote *et al.*, 2015). The competition for this resource (water) among different sectors (Elliot *et al.*, 2014) and purposes is increasing (García de Jalón *et al.*, 2014) hence the need for considering water requirements with availability is very necessary. Again, the quantity of water supply proportionally affects agricultural output (Maeda *et al.*, 2011), revenue and economic consequence of rice-growing farms (Blanco-Gutierrez *et al.*, 2013). The use of additional water sources (Dono *et al.*, 2011; 2010) or the adoption of modern irrigation systems is needed to mitigate water scarcity (Rodrigues *et al.*, 2013).

In rice cultivation, water scarcity is basically addressed by either breeding of new rice cultivars with improved traits or employing an efficient and modern water management system. The latter case includes the amelioration of crops (Clément and Louvel, 2013) with screening of more tolerant or resistant water stress and introduction of high yielding short-cycle varieties (Tesio *et al.*, 2014).

Water remains relevant in agriculture due to the role it plays in global food security. It is projected that by 2050, Population is expected to grow up to over 10 billion, and this population will require food and fiber from agriculture for sustenance. To meet this demand, agricultural production should be increased by approximately 70%. Therefore, the need to use minimum water to improve production and productivity is the key element of sustainable agriculture. If the production must not to be increased by massive conversions of more land and the negative impact on carbon emissions, then effective water management in irrigation needs to be adopted. Since agriculture water management can double productivity per unit area compared to traditional irrigation. This will support crop production against increasing climate change as it promotes global food production and nutrition (World bank, 2017).

2.8 Rice water productivity

Water productivity (WP) is a formula used to determine the number of products especially grain yield over the quantity of water. Irregularities are usually high in reported values of WP (Tuong and Bouman, 2003). These are partly because of the large differences in rice yield potential, which ranges between 3 and 8 tonnes per hectare. Diversity in calculation of WP may also cause some of these discrepancies. To do away with any controversy, it is necessary to carefully identify the type of WP used and how it came about.

Mostly used components of WP are:

- WPT: grain weight over total weight of transpired water
- WPET: grain weight over total weight of evapotranspired water
- WPI: grain weight over total weight of irrigation water (Bouman *et al.*, 2007).

Normally, breeders' interest is the productivity of the quantity of transpired water (WPT), while farmers and other stake holders' interest is maximizing the productivity of water supplied (WPI). In national water management, the interest is in the volume of food that can be produced by a certain amount of water resources. Water productivity that has to do with total water input (WPIR) or total (irrigation and rainfall) or volume of water that are lost (WPET) will not be more necessary (Bouman *et al.*, 2007). Current cultivars, when planted in flooded conditions, have no difference in productivity with regards to transpired water (WPT) (Bouman and Tuong, 2001). Other findings revealed that water productivity regarding evapotranspiration is not different to that of C_3 (Tuong *et al.*, 2005). In C_4 crops like maize, evapotranspiration is at a higher level in relation to water productivity which ranges between 1.1 and 2.7 g grain kg^{-1} water. However, Water productivity of rice in total water input (irrigation and rainfall) is equivalent to half of that of wheat (Tuong *et al.*, 2005). More importantly, the concept of water productivity becomes very necessary in water shortage (Bouman *et al.*, 2007).

2.9 Water requirement for rice production

Water is very relevant for plant growth as well as crop production. Unfortunately, there is competition among municipal, industrial and agricultural sectors on the little available water. For this reason, accurate estimation of water requirements is needed for water planning and management of projects (Michael, 1999). Hess (2005) defined crop water requirements as the total amount of water needed for evapotranspiration throughout the crops cycle in a specific climate condition, when enough soil moisture is maintained either by rainfall or irrigation so that it does not prevent plant growth. Generally, it consists of only crop evapotranspiration for crop water requirement. But total water supply used for paddy crop: deep percolation (vertical), horizontal percolation (from field to drain) and other losses must also to be considered. Crop water requirement depends on the state of soil development, fertilizer type and amount, volume of water used and climatic factors.

Crop evapotranspiration under normal conditions is calculated as; $ET_c = K_c \times ET_o$, where ET_o is the crop evapotranspiration determined from the Penman–Monteith equation and stands for weather conditions, K_c is the crop coefficient in which crop characteristics are incorporated, and is largely independent of the weather, enabling it to move from one location to another.

Regarding two crop coefficient approach, *K*c is divided into two different coefficients: one represents crop transpiration *K*cb while the other soil evaporation *K*e. According to Allen (2000) Crop evapotranspiration under standard condition is given by:

$ET_o = (K_{cb} + K_e)$.

ET_o pot experiments and greenhouse studies have revealed that rice plants cultivated under irrigation transpired 500–1,000 litres of water to give 1 kg of unmilled rice.

About 600 million tonnes of rough rice is produced worldwide per annum from the 859 cubic kilometers. Averagely, it takes about 1,432 liters of evapotranspired water to produce 1 kg of unmilled rice but about 2,500 liters of water is required by rainfall and/or irrigation produce 1 kg of rough rice from the field. These 2,500 liters stand for all the outflows from planting to harvest. This mean value is calculated from several experimental work at different levels. There is huge variation which ranges from 800 liters to more than 5,000 liters as a result of crop management, weather condition and soil type (IRRI, 2009).

Although rice water productivity regarding evapotranspiration is comparable to cereals like wheat, but rice need two to three times more water at field level than any grain crops because of high outflows (IRRI, 2009). However, some of these outflows are often reused by downstream crops, this makes rice water-use efficiency at modern irrigation systems higher than at rainfed field. Averagely, 25 to 30% of the world’s freshwater resources developed are supplied to irrigate rice field. Therefore, for water scarcity to be permanently addressed, water saving technologies like aerobic rice must be deployed (IRRI, 2009).

2.9.1 Aquacrop model

The recent challenge of the agricultural industry today is to produce enough food from little amount of water. With rapid population increase, the limited freshwater available is under heavy pressure. This makes crop water requirement an essential component of planning, designing and monitoring irrigation activities. Suggested methods for crop water requirements are considered since it is difficult to obtain accurate measurements on the field. Food and Agriculture Organization (FAO) has provided steps in calibrating crop water requirements in different climatic conditions and agronomic characters. These steps need to be followed carefully for such climatic conditions and agronomic characters, which are not the same from those originally developed. Generally, testing for the accuracy of this method is not only laborious but also time consuming and for that reason computer software with authorized modifications to match the site conditions may be the best alternative (Pawar *et al.,* 2017). Several models with respect to crop performance, management and yield estimates may assist managers to choose which management system best suit their work by accurately estimating crop water productivity and yield. Some of the commonly used crop yield models include CropSyst, CERES, DSSAT, EPIC, CropWat, SWAP/WOFOST, and AquaCrop (Hunink and Droogers, 2011). Aqua-Crop is mostly used because it seems to balance accuracy, simplicity and robustness as it is an update form of CropWat by featuring new adjustment options in order to give more detail. AquaCrop model tends to explain the yield response to water as proven by various researchers (Abedinpour *et al.,* 2012; Andarzian *et al.*, 2011; Araya *et al.*, 2010; Heng *et al.*, 2009; Hsiao *et al.*, 2009; Stricevic *et al.*, 2011; Wellens *et al.*, 2013).

2.9.2 Saturated soil culture (SSC)

Water is supplied above field capacity, therefore minimizing ponded activities which reduced rate of water loss. Practicing system means keeping the field under shallow irrigation to attain ponded water layer of 1 cm deep for not more than three days after withdrawing the water (Bouman *et al.,* 2007). Bouman and Tuong (2001) reported that irrigation water is reduced by approximately 23% using this method. Thompson (1999) also reported that SSC in some part of the world minimize the use of water input by 10% and above.

Under alternate wetting and drying (AWD) system, the field is flooded and drained after some few days. The soil is kept dry for a minimum of one day and a maximum of ten days. Even though some findings recorded low yield in practicing AWD (Stoop *et al.*, 2002), but recent works gave an exceptional result rather than a rule of thumb (Belder *et al.*, 2004; Cabangon *et al.*, 2004; Tabbal *et al.*, 2002). According to Bouman and Tuong (2001), more than 90% of work using this system recorded low yield ranging from 0% to 70% depending on the dry period. Despite these results, AWD favoured water productivity (WPIR) regarding water used efficiency because the decreased in irrigation water was more relative to yield reduction. Variations in AWD was due to period of dryness between watering regimes. Even in the absence of ponding, roots still utilized the "hidden" moisture in the soil. Water is reserved in practicing water productivity in dry period with only minor stress which normally goes with a yield penalty (Bouman and Tuong, 2001).

AWD is a modern water management strategy which is largely embraced and practiced in China (Li and Barker, 2004), India and Philippines (Lampayan, 2005). However, there are not enough research evidence to prove the effect of AWD on outflows in rice fields. The available data predicts that AWD generally minimizes outflows (Bouman and Tuong, 2001). Belder *et al.* (2007) and Cabangon *et al.* (2004) recorded 2 to 33% reduction in outflows under AWD relatively to flooded field.

2.9.3 Aerobic rice

A unique strategy in minimizing irrigation water on rice fields is to cultivate rice in an aerobic condition or as an upland crop. Upland crops such as maize is cultivated with a very little water or in aerobic soil condition without any layer of water. When rainfall is irregular, water is supplemented to beef up the moisture level to field capacity after going down below root zone which is between field capacity and wilting point (Doorenbos, 1975).

The volume of applied water must match evapotranspiration including losses during irrigation. There is a wide range of water reductions in the process of cultivating rice aerobically, particularly in soil that is susceptible to seepage and percolation (Bouman, 2001). The technology of breeding aerobic rice is compared to recent times, aerobic rice can yield between the range 1.5 and 7.4 t ha^{-1} when grown in aerobic conditions with annual rainfall of 2,500 to 4,500 mm. Normally, first planting produced up to 6 t ha^{-1} than the subsequent yields which ranges between 2 and 3 t ha^{-1} George *et al.* (2002) and Atlin *et al.* (2006) recorded grain yields ranging between 3 and 4 t ha^{-1} in farmers' fields using recently developed aerobic cultivars under rainfed upland conditions. Even though no data on the amount of rainfall was available but the conditions were stated under well-watered treatment. Bouman *et al.* (2005) and Peng *et al.* (2006) reported that one of the currently developed aerobic rice "Apo" was tested under upland and flooded conditions, and the upland condition gave the highest yield of 4−5.7 t ha^{-1} while a grain yield of 4.2 - 5 t ha^{-1} was recorded in flooded conditions.

Breeders have aerobically developed new rice cultivars with high yielding potential of 6-7 t ha^{-1} (Wang *et al.*, 2002). Xiaoguang *et al.* (2005) and Bouman *et al.* (2006b) recorded grain weight ranging from 2.5-5.7 t ha^{-1} in aerobic rice from 500 - 900 mm of water including rainfall and supplementary irrigation but recorded higher yields ranging from 5.4 - 6.8t ha^{-1} from flooded conditions in lowland with water of 1,300 mm. The least yields of 3.6 - 4.5 t ha^{-1} were obtained from the total water of 688 mm. Generally, maximum yields were obtained under upland conditions due to the selection criteria involved in developing aerobic rice (Xue *et al.*, 2007). Bouman *et al.* (2007) stated that farmers recorded around 5.5 t ha^{-1} using aerobic rice under upland conditions with minimum of 566 mm of total water input. According to Piñheiro *et al.* (2006), high yielding aerobic rice of 6 t ha^{-1} surfaced in attempting to improve upland cultivars.

Upland rice is grown with little amount of water as aerobic rice but has a consequential yield penalty in most cases (Lafitte *et al.*, 2002). Most upland rice cultivars have some level of tolerance to drought but give severe lower yields. An attempt to give them more external inputs like fertilizer and supplemental watering will also cause lodging. On the other hand, lowland rice with high yielding potentials that can be grown in upland environment without irrigation seen to be the best alternative (McCauley, 1990).

2.9.4 Climate change and rice production

Rice being among the most essential cereal crops in fighting hunger and food insecurity in the world (Fageria, 2003), must be increased to about 60% to satisfy its demand by 2025 to meet the explosive population increase (Fageria, 2007). Unfortunately, the steady increase in environmental stress causes severe deterioration and shrinkage on agricultural land and water leading to devastating threat to rice cultivation (Garg *et al.*, 2002). However, food security and climate change are some of the serious battle of this century since the source of raw material for providing food and fibre for the over growing population is under heavy pressure (Lal and Uphoff, 2005).

Considering the effect of climate change to rice cultivation especially temperature (Schlenker and Roberts, 2009) and rain fall (Yoshida *et al.*, 2015), coping with rice demand in the future seems to be a challenge. Again, increase in growth duration caused rice plants to suffer from high temperatures which affects rice yield and scare farmers away from rice cultivation to other alternate crops (Korres *et al.*, 2016). Apparently, majority of the rice growing areas fall in regions where optimal temperatures for rice growth are recorded, so any increase in average temperature can cause abortion and negatively affect grain yield (Krishnan *et al.*, 2011). In recent times, the impact of climate change had already been felt by the world with regards to drought, food shortage and to a large extent human health (Magadza, 2000). Experiment on impacts of climate change and strategic remidies have become key areas of scientific issues (Howden and Leary, 1997). For this reason, water balance in relation to crop productivity have been under research with different models of crop growth using the climatic factors. As climate change is one of the key elements affecting crop production and yield. More attention has now been given to the consequence that comes with climate change especially in food security (Reddy and Pachepsky, 2000). According Fujihara *et al.* (2008), water shortage will be prevented if irrigation is done efficiently but if irrigated areas increased without efficient water management system, water shortage will probably occur.

West Africa is known to be susceptible to climate change due to rain-fed agriculture, high climate variability and struggling economy, and less technical know-how in addressing issues of climate change. This makes knowledge of climate change and how it affects crop production and productivity very critical to policies in order to counteract its effects. The widespread warming experienced in recent time is as a result of rapid climate change through monsoonal precipitation (Sultan and Gaetani, 2016). Also, the already recurrent extreme signs like droughts, excessive rains and floods which affect productivity and food security are all due to climatic variability (Dilley *et al.*, 2005; Haile, 2005). The food insecurity is very likely to increase in the near future since the demand for food is projected to increase by more than five times in Africa by 2050 (Collomb, 1999).

The observed climate variabilities are expected to move in the same trend in this twenty-first century with either moderate or high emission scenarios. Since our weather in particular is temperature-driven though there may be uncertainties in some cases (Sultan and Gaetani, 2016).

2.9.5 Water stress and yield components of rice

Water stress has negative effects on key agronomic parameters of rice especially yield components. Moisture stress occurring at vegetative stage reduced effective tiller and panicle number (Wopereis *et al.*, 1996). Bouman and Tuong (2001) stated that drought reduced the tiller and panicle number when occurred either at seedling or tillering stage. According to Zain *et al.* (2014), number of tillers decreased as water deficit is increased. Yield and plant morphological characters of rice reduced with intensity of water deficit as was reported by Wan *et al.* (2009). Also, long duration of water stress cycle significantly reduced yield, biomass production, grain filling, 1000 grain weight, panicle production, height and tillers (Zain *et al.,* 2014).

Sokoto and Muhammad (2014) also reported that water deficit at tillering significantly reduced tiller number compared to other growth stages. The reduction in tiller number observed could be due to the sensitivity of flowering to drought as photosynthetic activities were intercepted. Also, plants need water to produce leaves during tillering but growth is retarded due to insufficient water available. Initiation of leaves gets disrupted with moisture stress which affects tiller number and plant height (Ramacrisnayya and Murty, 1991). RRDI (1999) also reported that when stress occurred during vegetative stage, height and tiller are significantly affected. Yang *et al.* (1994) reported that water deficit at vegetative stage of crop decreased number of tillers produced per plant. According to Teng *et al.* (2014), water deficit limits plant water uptake thus minimizing cell division in meristematic tissues which affects plant food preparation. Tripathy *et al.* (2000) also reported that moisture stress caused stunted plant growth thereby affecting tiller production. Islam *et al*. (2005) in their experiment found that number of tillers showed similar pattern as plant height due to decreased soil moisture levels, but all the varieties had their highest number of tillers at 100% Filled Capacity (FC) and lowest at 30% FC. Islam and Grelancher (2001) conducted an experiment involving nine rice genotypes by subjecting them to water stress at booting and flowering stages to ascertain the morphological and physiological parameters. Morphological characters such as plant height, tiller number and leave number were suppressed with moisture stress and the genotypes recorded different degrees of reduction.

Rahman *et al.* (2002) observed that moisture stress significantly reduced plant height and tiller number. Yield components such as panicle number, panicle length, number of filled grains per panicle, 1000 grain weight, harvest index and grain yield were also affected negatively. They explained that, the reduction in yield was mainly as a result of the affected yield components. Fukai *et al.* (1999) also reported in their experiment that maintenance of leaf water potential before flowering was attributed to higher panicle water potential, which promotes flowering, increase grain fertility and therefore contributes to higher yields. According to Rahman *et al.* (2002), harvest index values showed an efficient movement of nutrients towards the sink. This means lower harvest index indicates the harmful effect of drought in translocation of nutrients towards the grain

Islam *et al.* (1994b). Added that yield parameters such as number of filled panicles decreased drastically with water stress at all growth stages relative to well watered plants. The percentage of unfilled grain under moisture stress at flowering was higher compared with well watered treatment. Pantuwan *et al.* (2002) also reported that moisture deficit before flowering normally prolong flowering time which affects spikelets fertility and percentages of filled grains. Castillo *et al.* (1992) stated that genotypes which takes longer time to flower use more water at early part of the stress period and suffer more at reproductive stage. According to Islam (1999) and Isam *et al.* (1994b), 1000-grain weight of plants subjected to moisture stress was 17% lower than well watered plants. Hossain (2001), Yamboo and Ingram (1988), Begum (1990) and Islam *et al.* (1994a) all reported that number of filled grains was heavily reduced with soil moisture among genotypes, but the levels of reduction were different. Bouman and Toung (2001) reported that cultivars reacted differently in responses to different drought stresses like timing and intensity.

Pirdashti *et al.* (2004) observed that number of panicles and grain yield were significantly reduced in moisture stress condition compared to well-watered situation. Water stress at flowering had the higher grain yield reduction compared to moisture stress at all other growth stages (Fukai and Cooper, 1995).

Zubaer *et al.* (2007) indicated that, soil moisture and genotypes had significant interaction for grain yield. Water stress normally influences grain yield through reduction of seed numbers, dry matter and direct disruption of pollen or ovule activities which limits seed set. Drought also affects grain filling by limiting the movement of assimilates which leads to the production of poor-quality seed size and consequently low yields (Wheeler *et al.*, 1996).

According to Mohamad *et al.* (1994), harvest index is a feature that measures the ratio of photosynthesis to the distribution of reproductive (seed) compared to the vegetative parts (stem, young leaves, and roots). Harvest index can be adopted as a standard for selecting cultivars with high yield potentials. Since plants with high harvest index have good efficiency in the distribution of photosynthesis to the plant that has economic value, such as rice grains (Khanna, 1991). Zubaer *et al.* (2007) found that soil moisture and rice genotypes had interaction on harvest index and that HI of the genotypes were negatively affected by water deficit. Harvest index indicates the smooth transfer of nutrients towards the grain. Lower HI describe why moisture stress is more harmful during grain filling (Rahman *et al.*, 2002).

Yakan and Sürek (1990) recorded no significant difference among the comparison of continuously saturated, continuous flooded and interval irrigation in rice field. Borrell (1991) found a significant difference in comparing flooding irrigation and intermittent irrigation, with flooding irrigation giving the higher grain yield. Beser (1997) also recorded a significant difference in grain yield of rice under different irrigation systems. Sokoto and Muhammad (2014) conducted an experiment to determine the effect of water stress and variety on Harvest Index (HI) of three rice varieties and observed that water stress during flowering and grain filling is more detrimental to HI than during tillering. Sharma *et al.* (2003) also obtained highest HI with well irrigated plants relative to moisture stress conditions.

2.9.6 Water stress and days to 50% flowering of rice

Flowering time is a very relevant parameter in determining grain yield with long period or in an intense drought environment (Abdul Rahim *et al.*, 2010). According to Pantuwan *et al.* (2002), genotypes that flower early escaped prolong water stress and gave the higher yield compared to long duration cultivars. Abdul Rahim *et al.* (2010) also reported from their experiment on advanced mutant that water stress conditions delayed flowering.

Grain yield is a very economical component in developing cultivars for aerobic conditions. Therefore, indepth understanding of water stress and how it affects flowering and grain formation is necessary (Valliyodan and Nguyen, 2006). According to Sikuku *et al.* (2010), rice varieties (Nerica 2, 4, and 11) showed significant difference to flowering days at different soil moisture regimes. Well-watered plant (control) took fewer days to flower compared to intermittent irrigation. Pascual and Wang (2016) also stated in their work that heading of rice was first sighted in continuous flooding, which was followed by 3-days watering and then 7-days watering regime. Number of days taken for panicle heading was also reduced by 165.64% and 195.58% for intermittent irrigation at 3-day interval and intermittent irrigation at 7-day interval respectively as compared with continuous flooding (CF).

2.9.7 Water stress and vegetative growth of rice

Water stress is considered as the most key elements of plant growth which influences plant growth and development (Anjum *et al.*, 2003a; Kusaka *et al.*, 2005; Shao *et al.*, 2008). Sokoto and Muhammad (2014) observed that moisture stress resulted in significant reduction of tiller number. Also, irrigation regimes affected average plant elongation, tiller production and leaf area. However, plant height decreased by 20% in 7-day intermittent irrigation interval and 12% in 3-days intermittent irrigation interval. Plant height reduced by 10.93% at heading in intermittent irrigation as compared with continuous flooding (Pascual and Wang, 2016). Sokoto and Muhammad (2014) observed that the effect of drought on plants may vary with type of cultivar, intensity, period and time of occurrence. According to Zubaer *et al.* (2007), soil moisture and rice genotypes interacted significantly on height in all growth stages. But the highest plant height was obtained from100% Field Capacity and the shortest at 40% among genotypes. Their results also showed that plant height decreased further when moisture stress is increased. The variability in plant height suggest that genotypes had individual difference in responding to moisture stress. (Singh *et al.*, 1995).

Singh *et al.* (1995) observed in their experiment that moisture stress had a significant effect on plant height, but Plants were tall when grown without moisture stress. The differences among cultivars were reduced with increases in water application (Budiman and Syamsuddin, 2015). Drought stress affects growth of stems and plant height (Prasad *et al.*, 2008). Plant height is reduced with intensifying soil moisture stress (Bouazzama *et al*., 2012; Hussein and Alva, 2014) and this was related with a decrease in cell enlargement (Bhatt and Srinivasa-Rao, 2005).

Leaf rolling is useful for quick screening of lines. The early sign of soil water declining is leaf rolling which is a simple expression of leaf wilting (Lafitte *et al.*, 2003). Fischer *et al.* (2003) have suggested leaf rolling as a standard for scoring tolerance to drought in rice genotypes, and reduced soil moisture produced lower leaf area. Zubaer *et al.* (2007) observed in their experiment that significant interaction effect of soil moisture and rice genotype occurred in leaf area. However, the largest leaf area was found at 100% FC at booting stage. Similar trend was observed at flowering and maturity. They observed that flowering stage was more critical than other stages. According to Hossain (2001), increase soil moisture stress leads to a production of smaller leaf, and this could be due to limitation in cell division caused by moisture stress. Cultivars that retained green leaf may possess drought tolerant gene which allows plant to continue its metabolic functions even in hash conditions (Fukai and Cooper, 1995).

Moisture stress had effects on leaf area index in rice plants with significant genotypic differences and this had effects on grain yield potential. The photosynthetic processes in rice is reduced as a result of moisture stress (Henderson *et al.*, 1995). Specific Leaf Area (SLA) was observed to be sensitive to changes in the external environment of the plant and was negatively affected by moisture stress (Gunn *et al.*, 1999; Niinemets, 2001; Poorter and Nagel, 2000).

According to Zubaer *et al.* (2007), leaf number was affected severely by varying moisture stress. In an experiment, 107 leaves were recorded at booting, 85 at flowering and 58 at maturity. The maximum leaf number was obtained in 100% field capacity and leaf number was reduced systematically as moisture stress increased. Photosynthetic activities were retarded due to less production of assimilates for manufacturing of leaves (Fukai and Cooper, 1995).

Not much is done on the specific mechanisms of rice water uptake. However, in-depth understanding of rice water uptake by root in drought conditions will assist rice breeders to determine genotype x environment interactions and select the traits of high interest in developing drought tolerant genotypes. (Serraj *et al.*, 2011). Lafitte and Bennett (2002) suggested that the growth and potential of plant root in absorbing water are expected to play a key role in ground water and plant relations. Some experiments have revealed that aerobic conditions severely limit the growth of plant root in rice relatively to flooded conditions (Kato *et al.*, 2010). Root size and architecture are the main determinant of soil-leaf hydraulic conductance (kPa) in field crops. Therefore, modification of root development by soil water management may affect the rate of transpiration in plant (Adachi *et al.*, 2010; 2011).

Variability in soil water absorption by different cultivars under aerobic conditions have been noticed (Lilley and Fukai, 1994), which are linked to the root length, size and architecture (Gowda *et al.*, 2011), and over all function of the root, amount of water uptake per root length and root hydraulic conductivity (Lp_r); (Kamoshita *et al.*, 2000; Miyamoto *et al.*, 2001). Axial hydraulic conductance of a root is bigger compared to the radial conductance (Steudle, 2000). Hydraulic conductance of any complete root system is divided into two parts, which are total root length (total root surface area) and root hydraulic conductivity (Lp) (Adachi *et al.*, 2010, 2011). In well-watered aerobic conditions hydraulic conductance (Lp) of roots are higher than under flooded conditions but in most cases decreases under soil water stress leading to further reduction in leaf hydraulic conductance (Matsuo *et al.*, 2009).

Even though root growth is triggered under aerobic conditions, but this does not completely coverup the reduction in the adventitious root emergence and lateral root branching caused. Normally, hypoxia stress which is triggered by the death of epidermal cells at the stem node regulates the adventitious root emergence in rice plants (Mergemann and Sauter, 2000). The function in root emergence regulations are augmented by ethylene and subsides by abscisic acid (Steffens and Sauter, 2005). However, root anatomy is temped as a result of soil moisture stress which consequentially impedes root growth and development (North and Nobel, 2000). This process is seen as system to promote soil dryness in order to delay root or plant growth (Enstone *et al.*, 2003). Same changes in root architecture occurs in rice plants cultivated under well-watered aerobic conditions (Mostajeran and Rahimi-Eichi, 2008), meaning that plant roots of rice are very sensitive to water management compared to dryland conditions. Rice roots tend to react to water saving technologies as they respond to water stress conditions. Since lateral roots is not the same as pericycle of adventitious roots, it must pass through all the outer cell layers, including endodermis, exodermis and sclerenchyma. In water saving culture, any changes in root architecture may limit lateral root branching (Pe´ret *et al.*, 2009).

According to Kato and Okami (2011), morphological components of rice root system such as root length, breath and lateral root proliferation significantly decreased in total root length when put under water stress conditions. Zain *et al.* (2014) reported similar findings with root length under well-watered rice plants having longest root compared to plants under soil moisture stress and suggested that this could be due to little accumulation of root biomass of plant under soil moisture stress condition. Recently, research has pointed to a rhizospheric effect of water relations and soil-root interface which includes mucilages, root exudates and accumulation of solute (Carminati and Vetterlein, 2013). In a prolong drought, root plasticity and root growth will be affected drastically with a decrease in root length and biomass (Sekhon *et al.,* 2010). In most cases, root growth is observed at the early stages of moisture stress but as it prolongs, it retards the overall growth of the root resulting in destruction of carbon production in leaves and root (Muller *et al.*, 2011). The effect of soil moisture stress on root growth and function depends mainly on the plant species and the root architecture (Vadez *et al.*, 2012).

The stunted shoot growth and the reduced dry matter observed in water stress conditions could be tied to the smaller leaf size and the limited photosynthetic activities that occur under harsh conditions (Sinaki *et al.*, 2007; Zubaer *et al.*, 2007). Suralta and Yamauchi (2008) stated that nodal root production was decreased in moisture stress conditions which affected the formation of plant biomass such as root, leaves and stalk. In water stressed soil, oxygen supply is minimal which couples with physical barrier (hardpans) making exploitation of deeper soil layers very inaccessible, hence decreasing plant biomass production like root, shoot and other propagules (Samson and Wade, 1998). According to Wang *et al.* (2002), the decreased observation in the total biomass under moisture stressed treatment can be attributed to limited nutrition and photosynthetic activities with oxidative tissue damage that is usually experienced in drought environments. However, moisture stress also suppresses leaf growth, tillering of plant and mid-day photosynthetic activities that can limit overall biomass production (Bunnag and Pongthai, 2013). Sokoto and

Muhammad (2014) observed lower biomass under water stress at tillering compared moisture stress at flowering and grain filling. Zubaer *et al.* (2007) revealed that moisture stress and rice genotypes interacted significantly in total dry matter, though well-watered regime produced higher dry matter while moisture stress treatment produced the least biomass. This trend was observed in all the rice varieties at different growing stages of the plant.

Surajit (1981) reported that water stress decreased dry weight of plant as number of tillers reduced. Yield of dry matter decreased with increasing drought stress (Budiman and Syamsuddin, 2015), but contrary to Abdul Rahim *et al.* (2010), water stress had no significant effect on plant biomass. According to Peng *et al.* (2000), grain yield will increase per plant as plant biomass increase.

Pigments play a very important role in photosynthetic activities by absorbing of light and production of powers. However, chlorophyll such as Chlorophyll “a” and “b” are highly vulnerable to water stress (Farooq *et al.*, 2009). Chlorophyll content in leaves was usually higher at panicle initiation and significantly affected by moisture stress (Farooq *et al.*, 2009). Low chlorophyll content was observed in continuous flooding (CF) regimes compared to intermittent irrigation indicating that leaf senescence easily surfaced in CF (Pascual and Wang, 2016). Mishra and Salokhe (2010) also observed high levels of leaf chlorophyll content with fluorescence efficiency and high photosynthetic rate in alternate watering and drying compared to continuous flooding under system of rice intensification. Soil moisture stress caused proportional changes between chlorophyll “a” and “b” and carotenoids (Anjum *et al.*, 2003b; Farooq *et al.*, 2009). Nurul *et al.* (2014) also reported that prolonged moisture stress can lower total chlorophyll content and cause changes in chlorophyll a/b ratio. Water stress also increased leakage in plant electrolyte with consequential reduction of total leaf chlorophyll (Petrov *et al.*, 2012). Bansal *et al*. (1999) found that total chlorophyll content ranged from 1.44 to 3.337 mg/g fresh leaf sample of aromatic rice at mid anthesis under normal condition but decreased with increased soil moisture stress.

CHAPTER THREE

MATERIALS AND METHODS

The experiment was conducted at the experimental site of the University for Development Studies, Nyankpala. Two experiments were conducted. The first experiment of the study was conducted from December 2016 to May 2017 while the second experiment was conducted from January 2018 to May 2018.

3.1 Experimental site

The study site falls within the Guinea savanna agroecological zone. Nyankpala is located at 16 km West of Tamale, the capital town of Northern Region of Ghana. The area lies on latitude 9° 25' 41” N and longitude 0° 56' 42” W with an altitude 183 m above sea level. This area experiences a monomodal rainfall pattern (April-October) with a mean annual rainfall of 1000 mm and relative humidity varying between 15 and 20% (Kasei, 1988). The mean annual temperature is about 28˚C with the daily maximum sometimes being around 42 ˚C during the hottest months of March and April, and the lowest temperature (about 20 ˚C) recorded in December and January when the area comes under the influence of cold dry North-East Trade winds (Harmattan’ winds) (Kasei, 1988).

The soil in the study is an alfisol with the USDA system of classification. The soil is brown, moderately drained sandy-loam, free from concretion, very shallow with a hardpan under the top few centimetres, developed from voltaian sandstone and classified as Nyankpala series also known as Plinthic Acrisol. The soils have pH 4.96 – 5.23; Effective CEC of 2.70 – 3.87 C mol/kg; 0.15g / kg available N; 2.94 mg / kg P; 9.0-9.2 mg / kg K; and 0.86 % organic matter (Kasei, 1988).

3.2 Planting materials

The planting materials used were nine (9) rice varieties (Table 1) which were collected from International Rice Research Institute (IRRI), Africarice in Mali and Council for Scientific and Industrial Research Institutes (station at SARI and CRI).

Table 3.1: List of planting materials and their sources

No	Variety	Source
1	DKA 23	Mali (Africarice)
2	DKA 21	Mali (Africarice)
3	DKA – M8	Mali (Africarice)
4	GBEWAA	Ghana (SARI)
5	AGRA	Ghana (SARI & CRI)
6	UPL RI 7	IRRI
7	IR 55419-04	IRRI
8	IR 79913-B-179-B-4	IRRI
9	APO	IRRI

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3.3 Experimental design

The experiment was conducted in pots. A total of one hundred and eight (108) pots were used and their individual weight recorded in grammes (g). Each pot was 26 cm deep with 30 cm diameter (volume of 18,380 cm^3). Each pot was filled with 10 kg of soil collected from the Savannah Agricultural Research Institute (SARI) rice experimental site (lowland). Soil collected from the field was air dried and pulverized; inert materials and other plant propagules were removed. Calibrated amount of water (3 liters) was added to the soil to keep it saturated a day before transplanting. Two Seedlings of three weeks old were transplanted in each pot and later thinned to one seedling per pot a week after transplanting. The experiment consisted of 36 treatment combinations (Factor 1 = 9 genotypes and Factor 2 = 4 moisture stress regimes). Levels of the factors were factorially combined in Randomized Complete Block Design (RCBD) with three replications. The four moisture stress regimes imposed two weeks after transplanting were as follows:

- 100% Crop Water Requirement (CWR): application of 1500 ml of water every two days
- 100% Crop Water Requirement-split (CWR-split): application of 750 ml of water every day
- 80% Crop Water Requirement (CWR): application of 1200 ml of water every two days
- 60% Crop Water Requirement (CWR): application of 900 ml of water every two days.

NOTE: 100% Crop Water Requirement (CWR) = application of 1500 ml of water every two days was used as check

3.4 Fertilizer application

The soil was fertilized with NPK (15: 15: 15) at the rate of 90%N: 60%P: 60%K (Kg/ha). All P and K and two third of N were applied as a basal dose. The remaining one third of the N was applied 21 days after transplanting (DAT). Both application of the fertilizers (basal and top dress) were done by dibbling.

3.5 Data collection

The following data were recorded during the various stages of the experiment

3.5.1 Number of tillers of rice

Tillers were counted of each plant of pot at maximum tiller stage (7 weeks old)

3.5.2 Days to 50% flowering of rice

The data was obtained by counting number of days of flowering of plants in each pot when half of all the plants had already flowered.

3.5.3 Plant height of rice

Plant height was taken at 10, 14 and 18 Weeks After Planting (WAP). Measurement was made from the ground level to the tip of the longest panicle.

3.5.4 Number of leave of rice

Total number of leaves of each genotype was counted at three different stages (booting, flowering and maturity).

3.5.5 Total dry matter of rice

Plants collected for this measurement were oven dried at 80^{o}C for 72 hours. Root weight, stem weight, leaf weight and panicle weight (where applicable) were obtained. The total dry matter was calculated using the formula below.

Total dry matter (TDM) = Root dry weight + stem dry weight + leaf dry weight + panicle dry weight (where applicable). Plants harvested from each pot at maturity were used for this measurement.

3.5.6 Leaf chlorophyll content of rice

A portable SPAD-502 chlorophyll meter (Spectrum Technologies, USA) was used to acquire a rapid estimation of *in situ* leaf chlorophyll content (Jahan *et al.*, 2014, 2013b).

Data on chlorophyll content were recorded six weeks after stress imposition and at two weeks intervals until maturity.

3.5.7 Number of panicles of rice

Panicle number was taken from each plant of the genotype by carefully counting the panicles on each plant at harvest.

3.5.8 Panicle length of rice

Each panicle was measured with a plastic rule from the basal node of the panicle to the apex of the last grain.

3.5.9 Total grain yield of rice

Grains were harvested from all panicles of each genotype per pot and weighed using electronic digital balance (scale)

3.5.10 Spikelet fertility of rice

All panicles were harvested separately from each entry for calculating percentage of spikelet fertility. The fertile florets were removed by pressing the spikelets with thumb. Fully filled grains and unfilled grains were separately counted and percentage of spikelet fertility was calculated by the following formula:

$$\text{Spikelet fertility (\%)} = \frac{\text{(Fully filled grains / number of spikelets)}}{\text{Number of panicles}} \times 100$$

3.5.11 Leaf area of rice

Data for leaf area were collected from 10 leaves from each plant at heading and calculated following the methods of Tadesse *et al.* (2013) and Yoshida (1981). Leaf area $cm^2 = L \times W \times K$

Where, L is leaf length; W is maximum width of the leaf and K is a correction factor of 0.75.

3.5.12 Leaf rolling and leaf drying of rice

These were done by visual observation using Standard Evaluation System for rice with an interval of 0-9 scale (IRRI, 2002) (Table 2 and 3).

Table 3.2: Leaf rolling score descriptions of rice

Scale	Leaf description
0	Healthy leaves
1	Start to fold
3	Deep V-shape folding
5	U-shape folding
7	O-shape folding
9	Tightly rolled

Source: IRRI, 2002

Table 3.3: Leave drying score descriptions of rice

Scale	Description	Rate
0	No symptoms	Highly resistance
1	Slight tip drying	Resistance
3	Tip drying extended to ¼ length in most leaves	Moderately resistance
5	¼ to ½ of the leaves fully dried	Moderately susceptible
7	More than 2/3 of all leaves fully dried	Susceptible
9	All plant apparently dead	Highly susceptible

Source: IRRI, 2002

3.5.13 STATISTICAL ANALYSIS

Data collected were analyzed statistically using GenStat computer package (12th edition). Tukey's 95% confidence interval was used to compare mean differences at 5% level of significance. Means of the data collected for the two experiments were determined prior to entering into spread sheet for statistical analysis.

CHAPTER FOUR

RESULTS

4.1 Days to 50% flowering of rice

There was a significant difference in days to 50% flowering between the different soil moisture regimes ($p < 0.05$). The least number of days (99.1) was recorded by plants grown from 100% CWR which was not statistically different to values recorded by plants grown from 100% CWR-split (99.2). The highest number of days (106) was found with plants from 60% CWR (Figure 4). There was also a significant difference among the genotypes ($p < 0.05$). Genotype DKA 21 recorded the least number (77.3) of days to 50% flowering and the highest number (109.0) was observed in DKA-M8 (Figure 4.2)

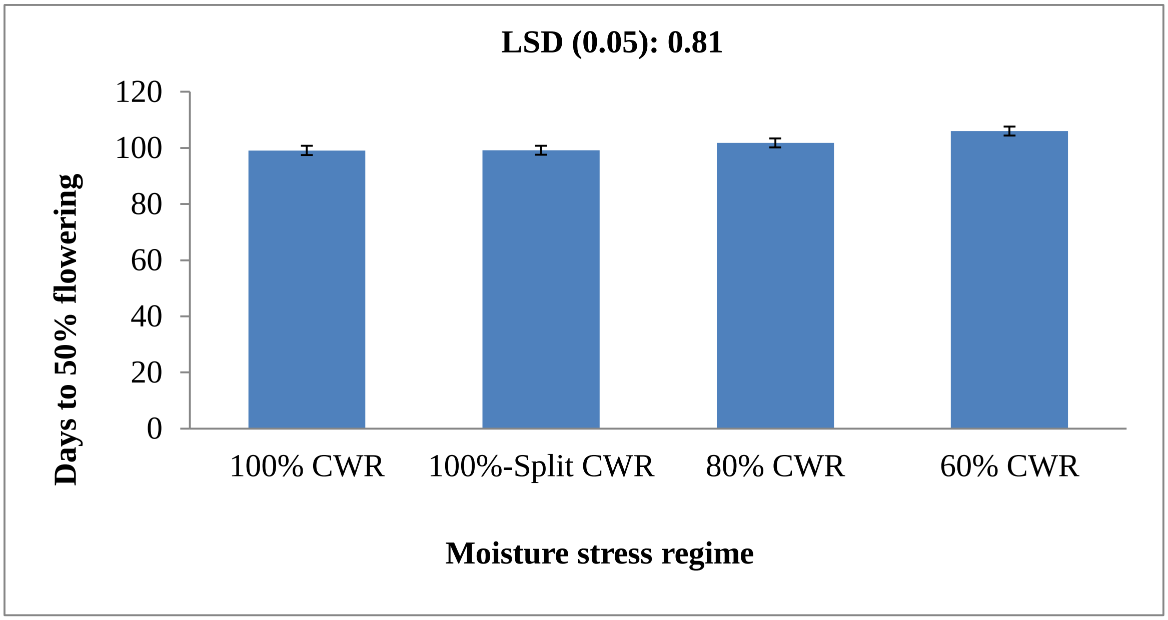

Figure 4.1: Days to 50% flowering of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

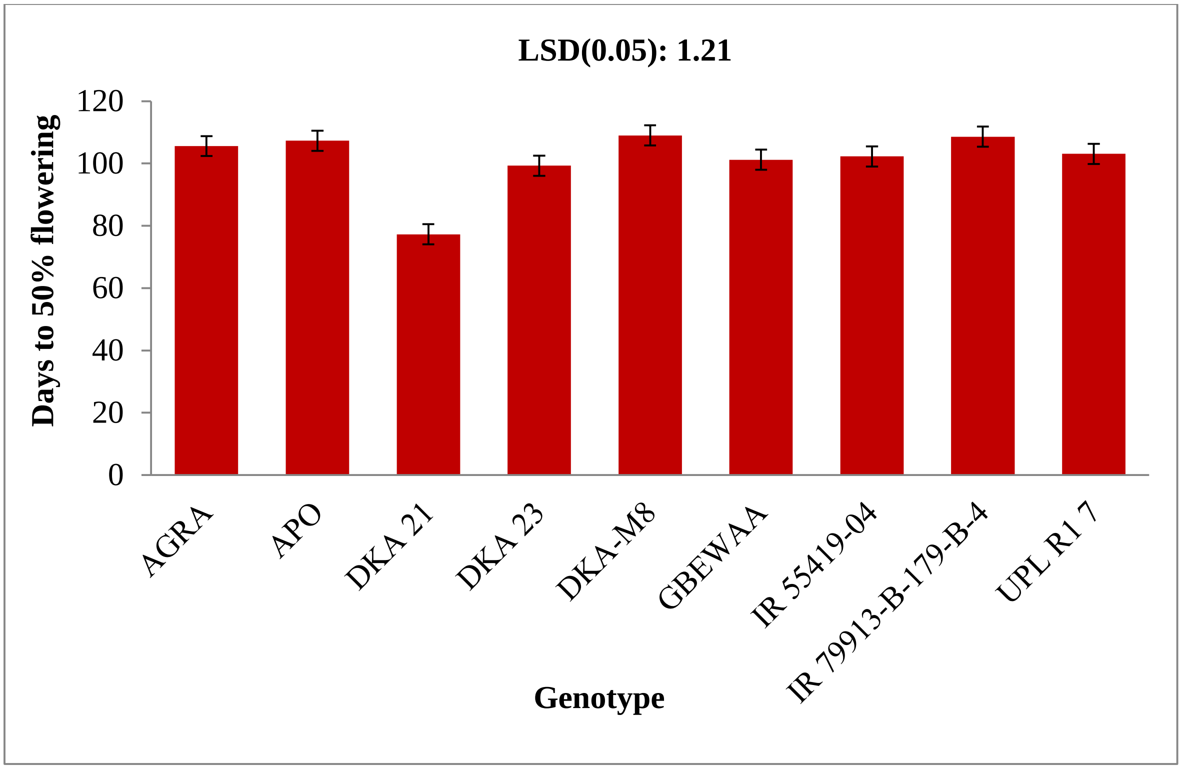

Figure 4.2: Days to 50% flowering of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

There was a significant difference in the interaction of water stress regimes and the genotypes at day to 50% flowering ($p < 0.05$). Genotype DKA 21 x 100% CWR recorded the least number (73.33) while the highest number (113.00) was recorded in DKA-M8 x 60% CWR (Table 4.1).

Table 4.1: Variation in days to 50% flowering of genotypes in response to varying moisture stress

	Moisture stress regime			
Genotype	**100% CWR**	**100% CWR-Split**	**80% CWR**	**60% CWR**
AGRA	104.00	103.33	106.00	109.00
APO	106.00	105.00	107.67	110.67
DKA 21	73.33	74.67	78.33	83.00
DKA 23	95.33	96.67	98.33	107.00
DKA-M8	107.33	106.67	109.00	113.00
GBEWAA	98.67	101.00	100.67	104.33
IR 55419-04	100.00	99.67	103.00	106.67
IR 79913-B-179-B-4	106.67	107.00	108.67	112.00
UPL R1 7	100.33	99.00	104.33	108.67
LSD (0.05): Genotype x moisture stress regimes = 2.42				

100% CWR = application of 1500 ml of water every two days; 100% CWR-split = application of 750 ml of water every day; 80% CWR = application of 1200 ml of water every two days; 60% CWR = application of 900 ml of water every two days.

4.2 Plant height measurement at 10 WAP

At 10 weeks after planting the effect of soil moisture stress on plant height was significant ($p < 0.05$) for both the stress regimes and the genotypes as well as their interactions. The highest plant height (53.58 cm) was found with plants from 100% CWR-split which was not statistically different from those in 100% CWR (52.39 cm) (Figure 4.3). The lowest plant height (45.06 cm) was recorded among plants of 60% CWR. The highest plant height (63.19 cm) was recorded among DKA 21 and the lowest (43.97 cm) recorded among DKA 23 (Figure 4.4).

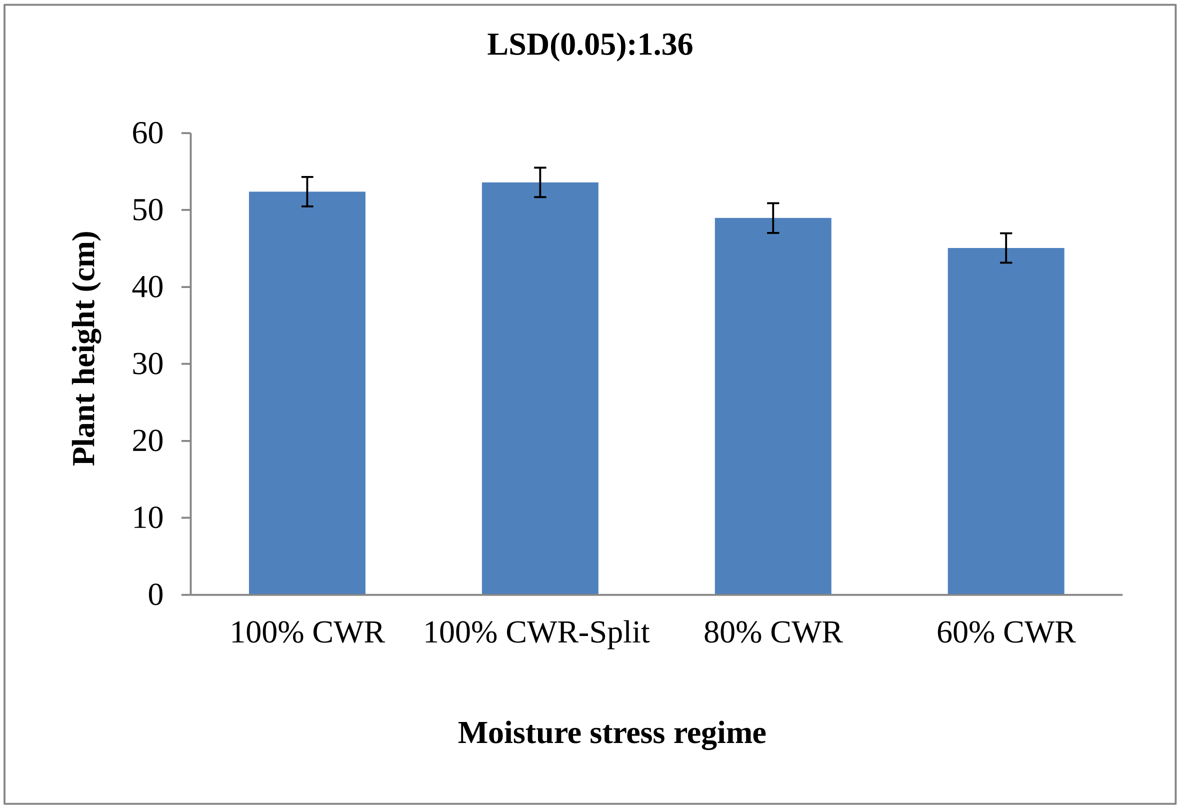

Figure 4.3: Plant height of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

LSD(0.05): 2.05

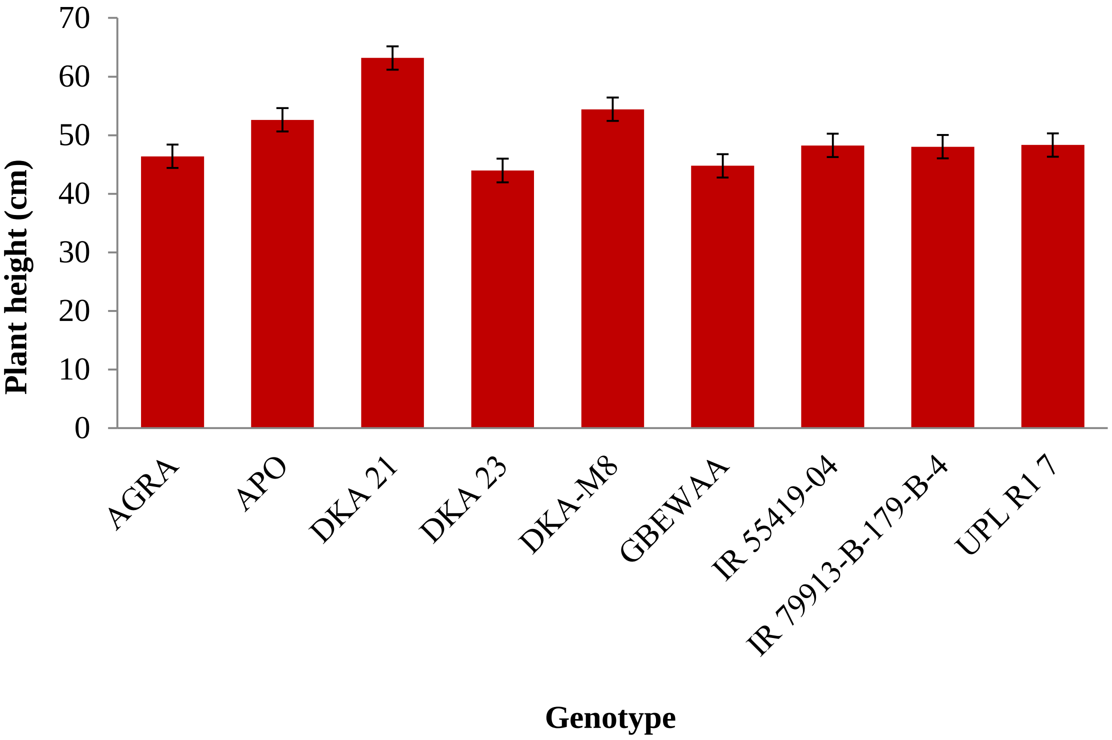

Figure 4.4: Plant height of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

At 10 WAP the interaction effects between soil moisture stress and genotypes on plant height was significantly different ($p < 0.05$). The highest plant height (69.7cm) was observed in the combination of DKA 21 x 100% CWR and the lowest (39.4 cm) in DKA 23 x 60% CWR (Table 5).

Table 4.2: Variation in plant height at 10 weeks after planting of genotypes in response to varying moisture stress

Genotype	**Moisture stress regime**			
	100% CWR	**100% CWR-Split**	**80% CWR**	**60% CWR**
AGRA	47.7	48.9	46.3	42.7
APO	57.0	57.2	50.1	46.1
DKA 21	69.7	69.1	61.9	52.1
DKA 23	45.5	47.1	43.8	39.4
DKA-M8	55.3	57.4	54.0	51.0
GBEWAA	46.3	48.4	43.0	41.5
IR 55419-04	49.9	51.0	47.6	44.5
IR 79913-B-179-B-4	50.8	51.9	46.4	43.1
UPL R1 7	49.3	51.3	47.6	45.1

LSD (0.05): Genotype x moisture stress regimes = 4.09

100% CWR = application of 1500 ml of water every two days; 100% CWR-split = application of 750 ml of water every day; 80% CWR = application of 1200 ml of water every two days; 60% CWR = application of 900 ml of water every two days.

4.3 Plant height measurement at 14 WAP

Plant height at 14 weeks after planting under moisture stress regimes was significantly different ($p < 0.05$). Plants with the highest plant height (77.9 cm) were recorded in 100% CWR-split and the lowest (61.8 cm) in 60% CWR (Figure 4.5). There was also a significant difference among Genotypes ($p < 0.05$). Genotype DKA-M8 recorded the highest plant height (86.2 cm) at 14 WAP while the least plant height (58.2 cm) was recorded in Gbewaa which was not statistically different (44.8 cm) to height recorded for AGRA (Figure 4.6)

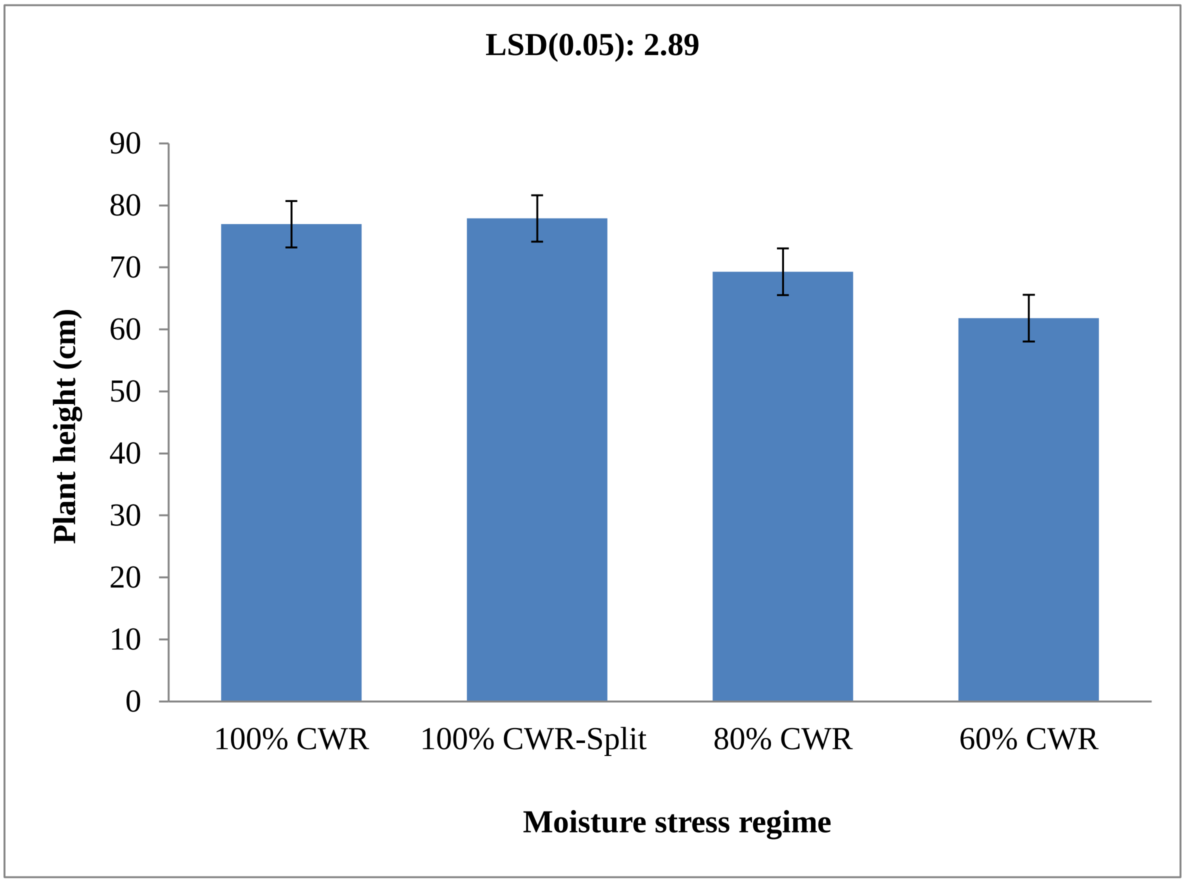

Figure 4.5: Plant height of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

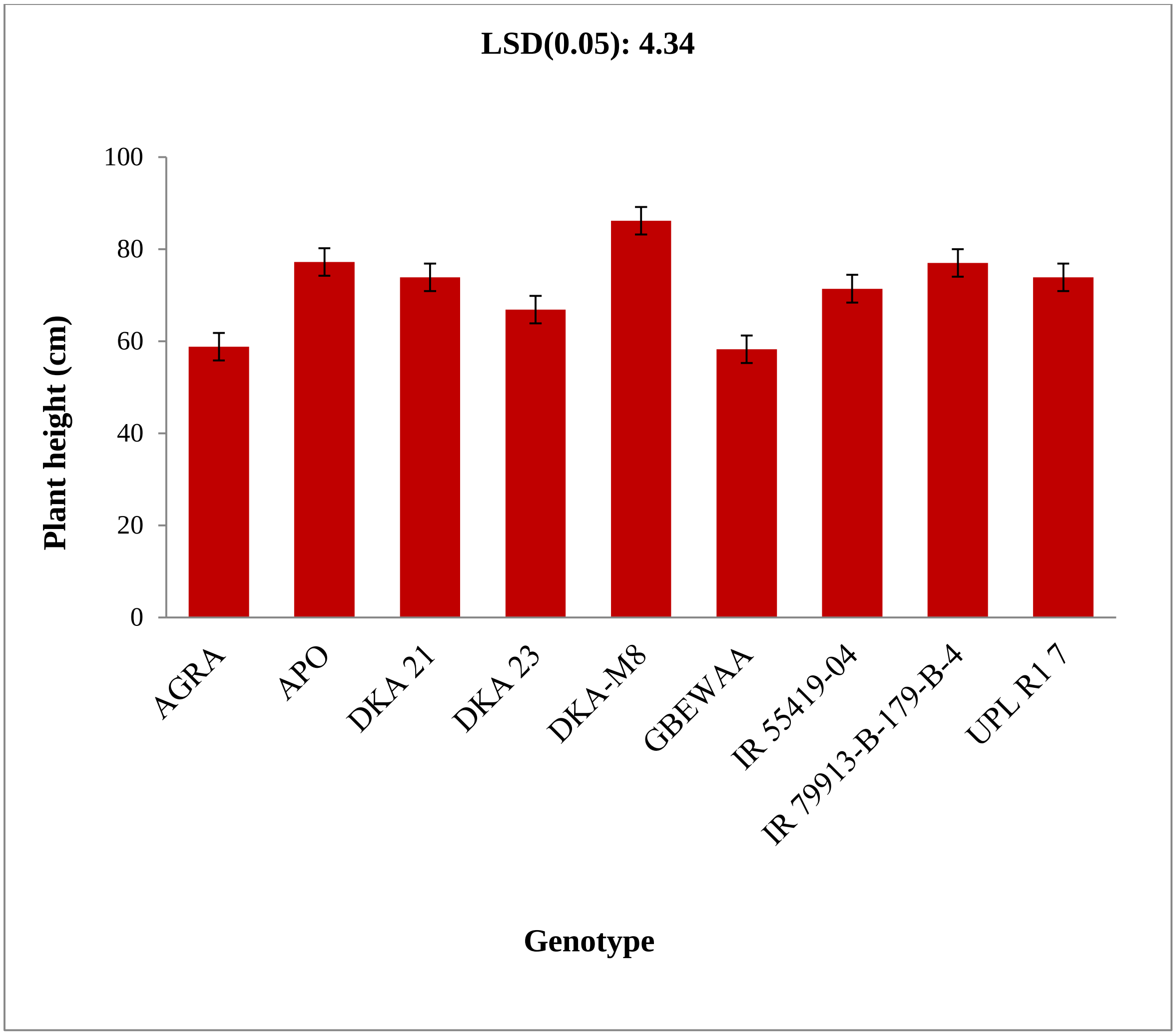

Figure 4.6: Plant height of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

There was a significant difference in the interaction of water stress regimes and the genotypes at 14 WAP ($p < 0.05$). Genotype DKA-M8 x 100% CWR-Split recorded the highest plant height (99.23 cm) while the least (53.30 cm) was recorded in AGRA x 60% CWR (Table 4.3).

Table 4.3: Variation in plant height at 14 weeks after planting of genotypes in response to varying moisture stress

Genotype	**Water Stress Regime**			
	100% CWR	**100% CWR-Split**	**80% CWR**	**60% CWR**
AGRA	63.40	62.63	55.93	53.30
APO	85.23	82.40	76.20	65.03
DKA 21	77.40	78.17	71.07	68.80
DKA 23	73.50	75.80	64.40	53.77
DKA-M8	97.90	99.23	79.53	67.93
GBEWAA	60.53	61.30	56.70	54.40
IR 55419-04	73.67	75.80	69.43	66.70
IR 79913-B-179-B-4	83.27	83.73	77.27	63.73
UPL R1 7	77.7	81.97	73.20	62.63

LSD (0.05): Genotype x moisture stress regimes = 8.68

100% CWR = application of 1500 ml of water every two days; 100% CWR-split = application of 750 ml of water every day; 80% CWR = application of 1200 ml of water every two days; 60% CWR = application of 900 ml of water every two days.

Plants height at maturity was significantly different for levels of moisture stress ($p < 0.05$) (Figure 4.7). The highest plant height (90.5 cm) was found in 100% CWR-split while the lowest (77.1 cm) was recorded in 60% CWR. Genotypes also showed a significant variation in plant height ($p < 0.05$). DKA-M8 recorded the highest (119.0 cm) plant height at maturity, while the lowest (76.0 cm) was recorded in Gbewaa (Figure 4.8).

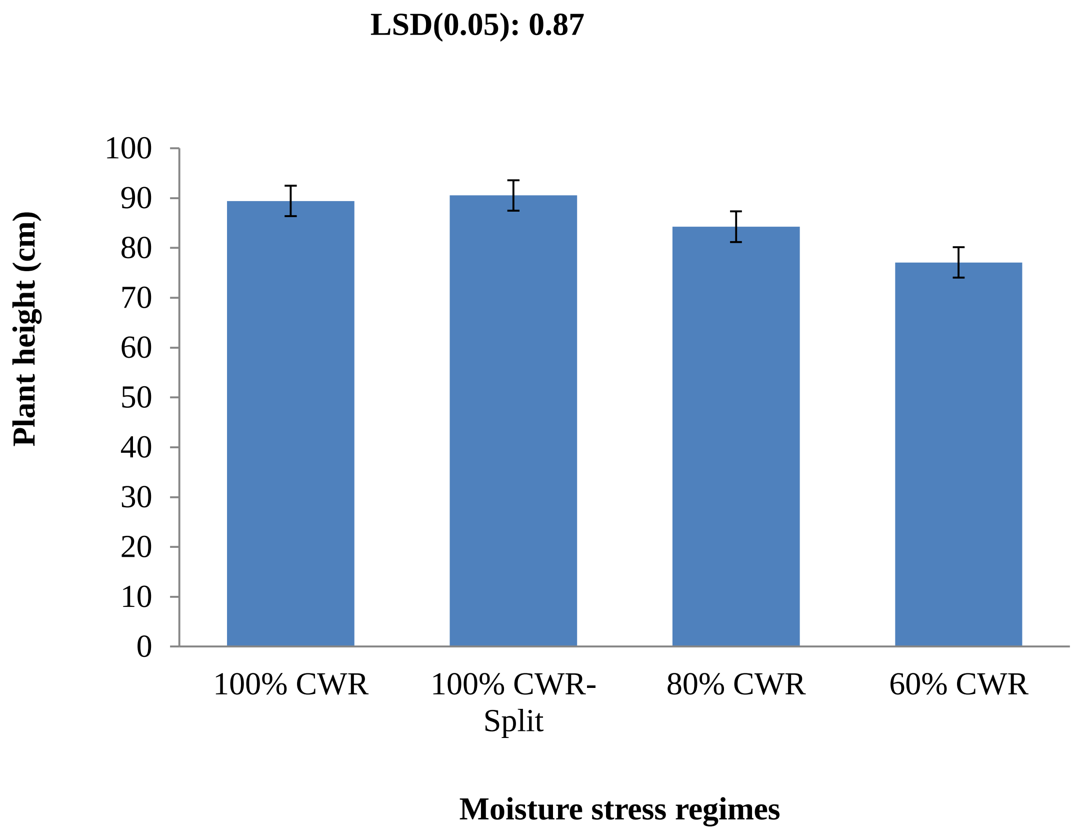

Figure 4.7: Plant height of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

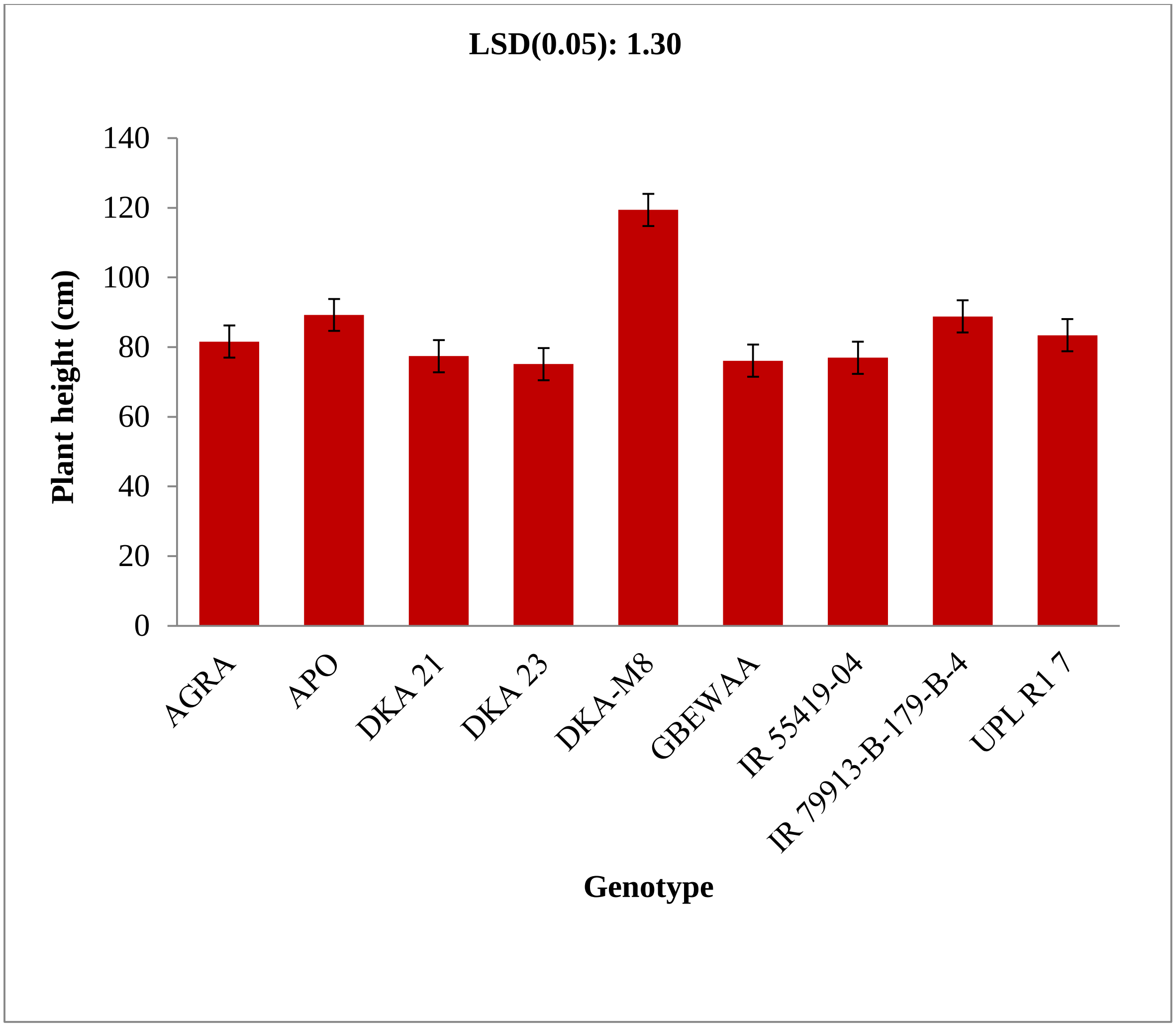

Figure 4.8: Plant height of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.5 Number of days to maturity

Moisture stress significantly affected days to maturity ($p < 0.05$). The least number of days (127) was recorded in (100% CWR) and the highest number of days (135) was recorded in 60 %CWR (Figure 4.9). There was also a significant difference among the genotypes ($p < 0.05$). DKA 21 recorded the least number of days (108) while the highest number of days (137) was recorded in DKA-M8 and IR 79913-B-179-B-4 (Figure 4.10).

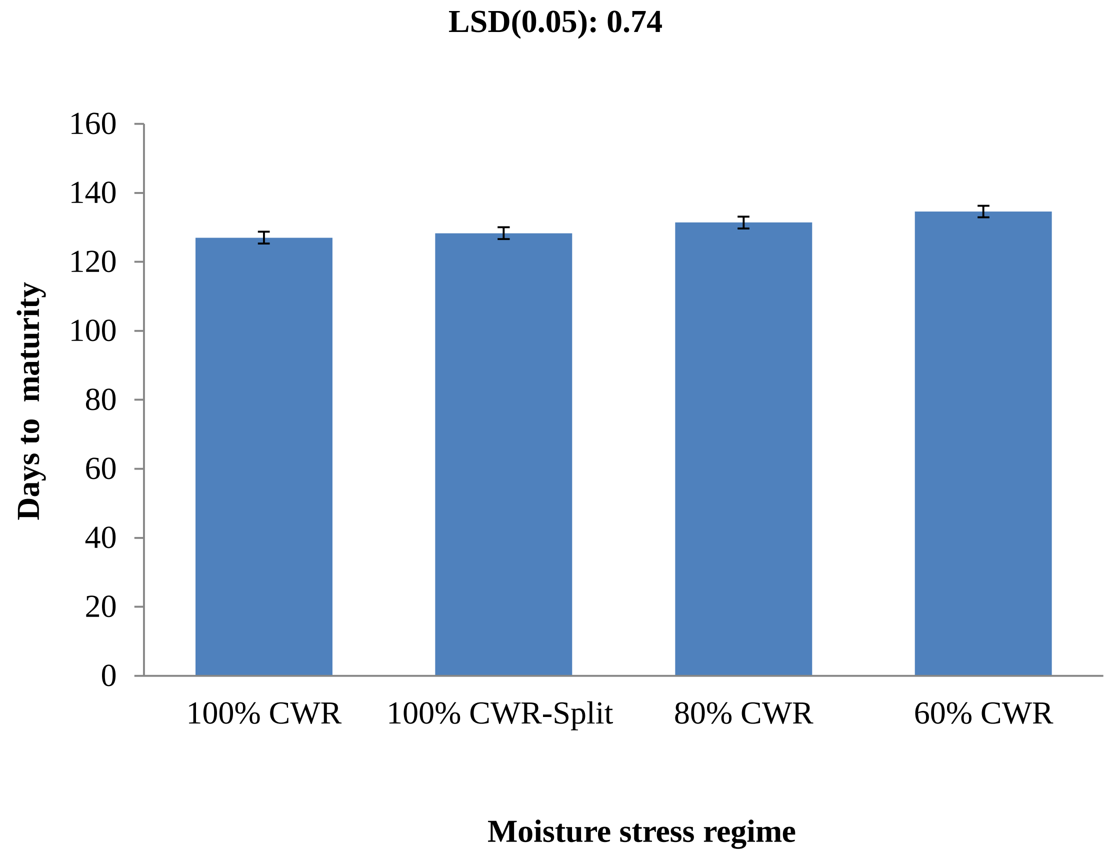

Figure 4.9: Days to maturity of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

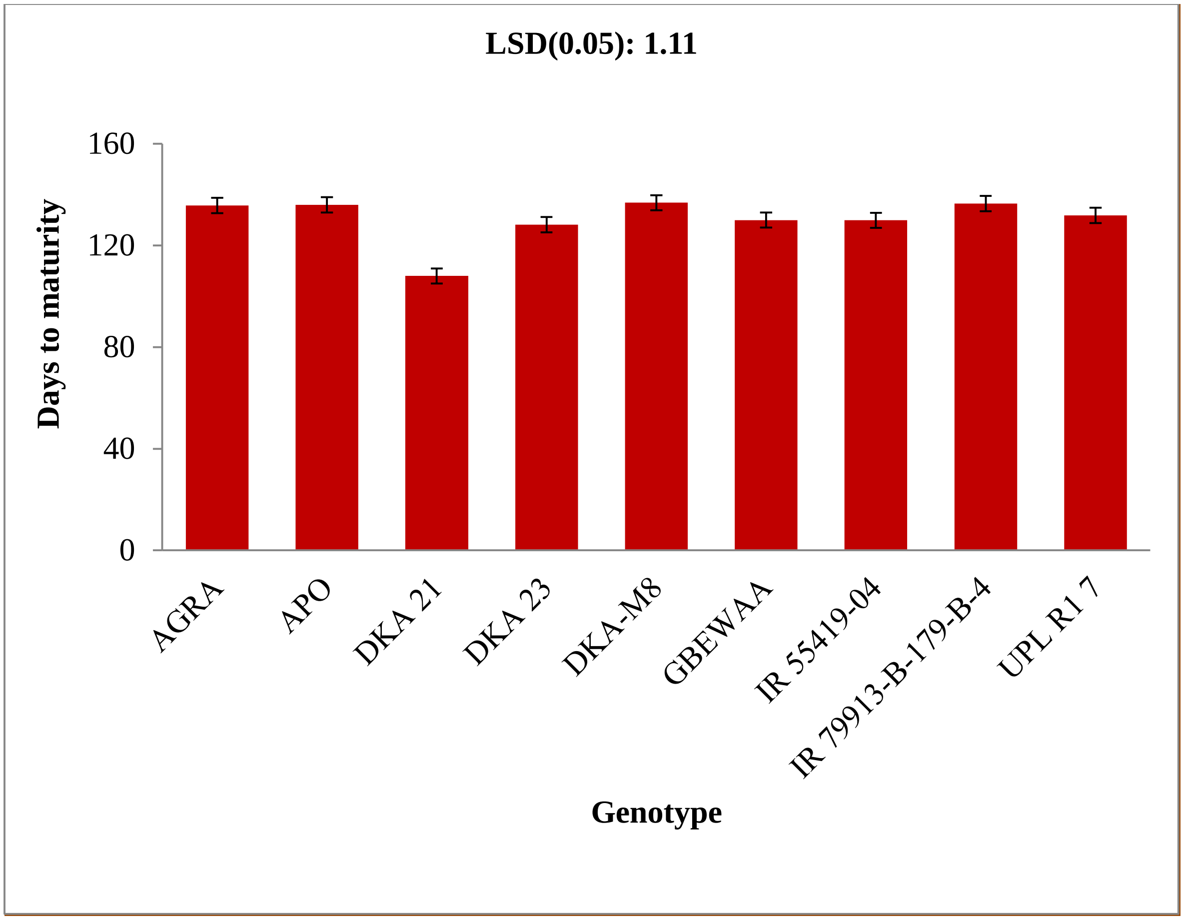

Figure 4.10: Days to maturity of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.6 Number of tillers

There was a significant difference between the number of tillers ($p < 0.05$). Number of tillers was heighest (27) in 100% CWR and lowest (17) at 60% CWR (Figure 4.11). Genotypes were also significantly different in tiller number ($p < 0.05$). The highest average number (30) of tillers was recorded in DKA 23 while the lowest number (19) was recorded in IR 55419-14 (Figure 4.12).

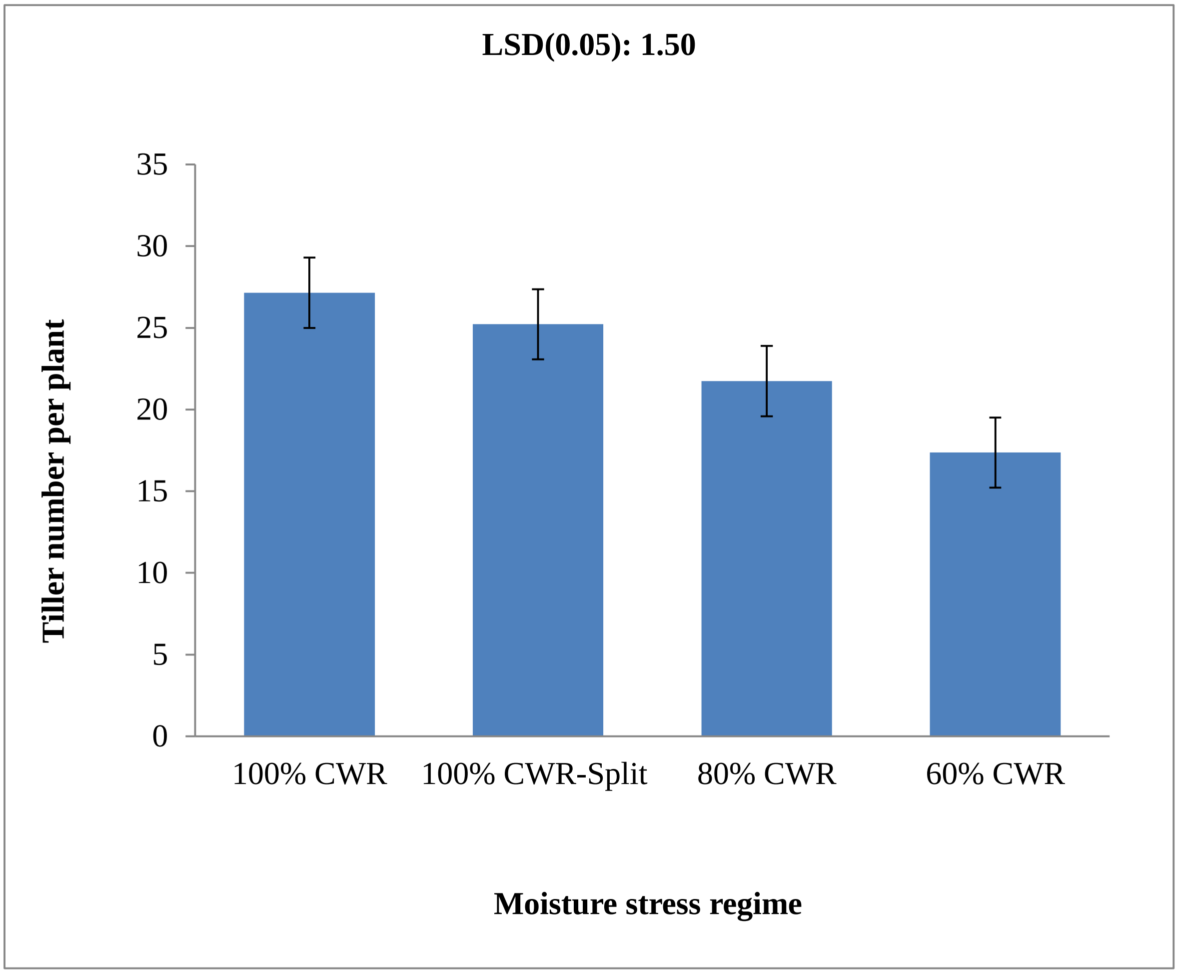

Figure 4.11: Tiller number of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

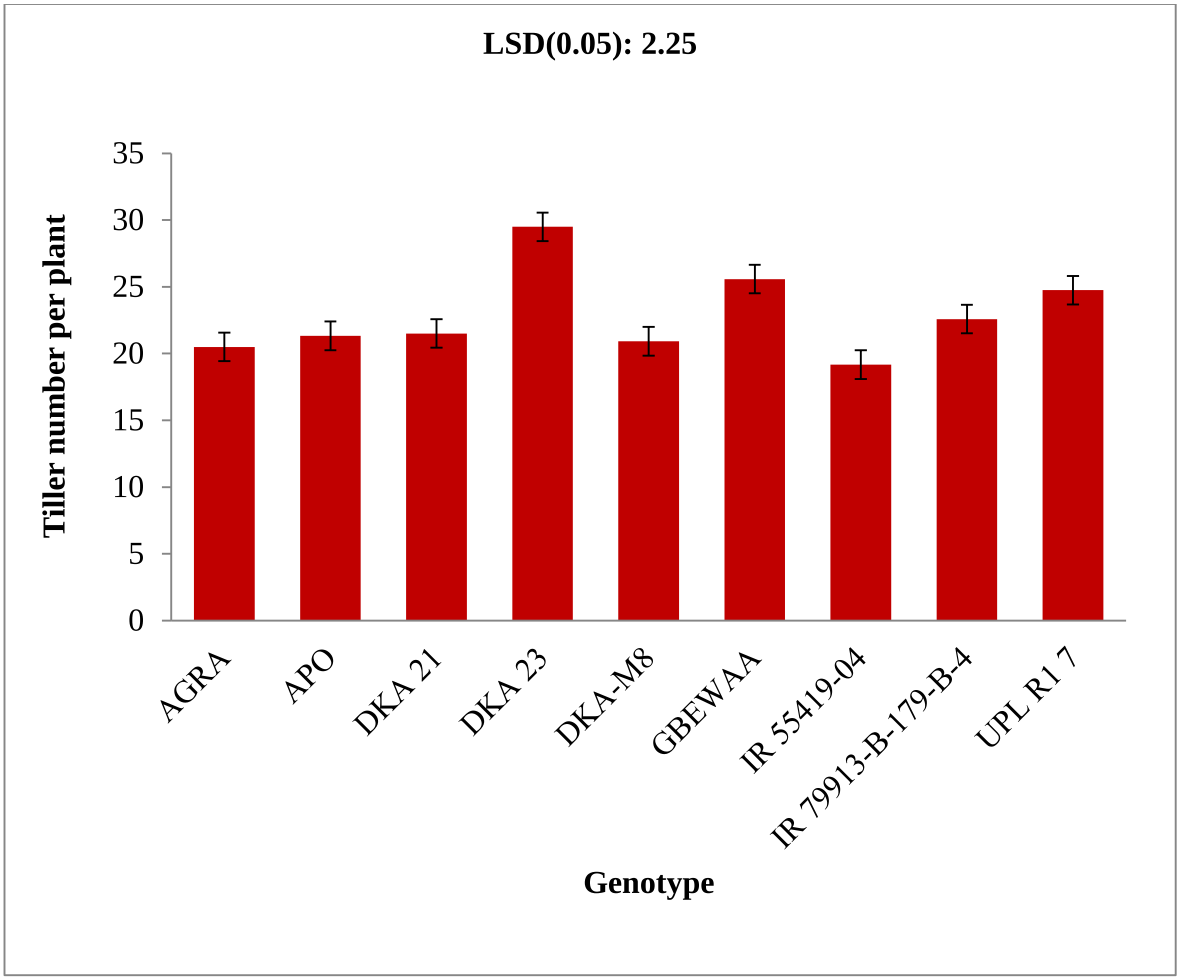

Figure 4.12: Tiller number of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.7 Number of leaves

There was a significant different in leaves at booting under the different moisture regimes ($p < 0.05$). The highest number (110.29) was recorded in 100% CWR while the lowest (82) was recorded in 60% CWR (Figure 4.13). There was also a significant genotypic difference in leaf number ($p < 0.05$). Genotype DKA 23 showed the highest (118.22) number of leaves per plant at booting while DKA 21 recorded the lowest number (70.68) per plant (Figure 4.14).

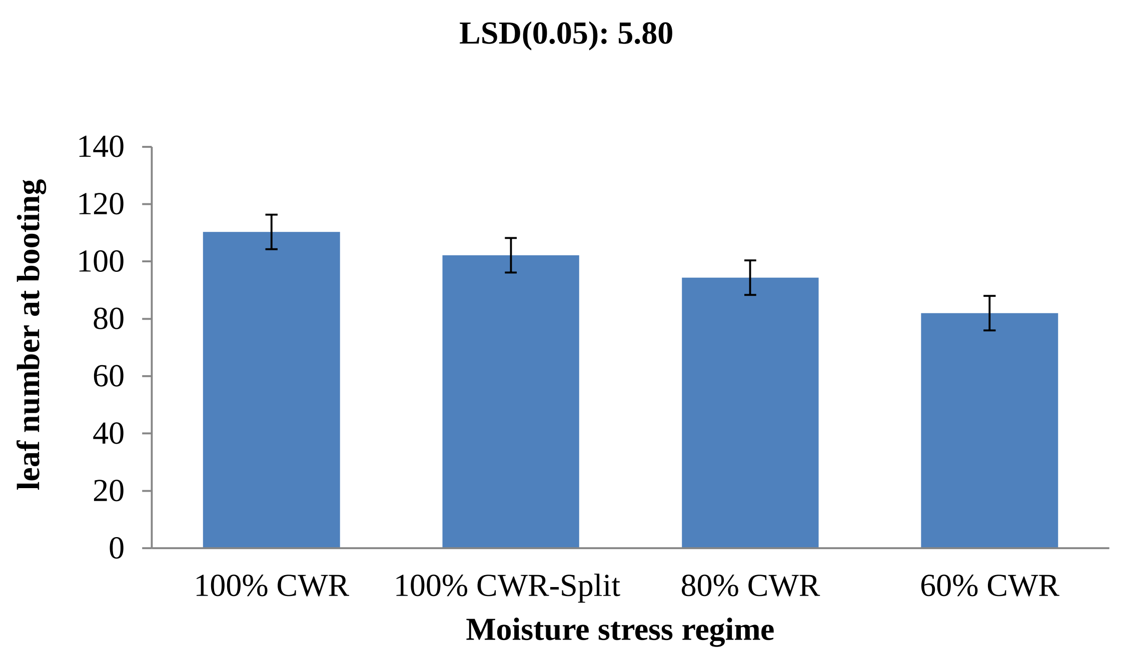

Figure 4.13: Leaf number of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

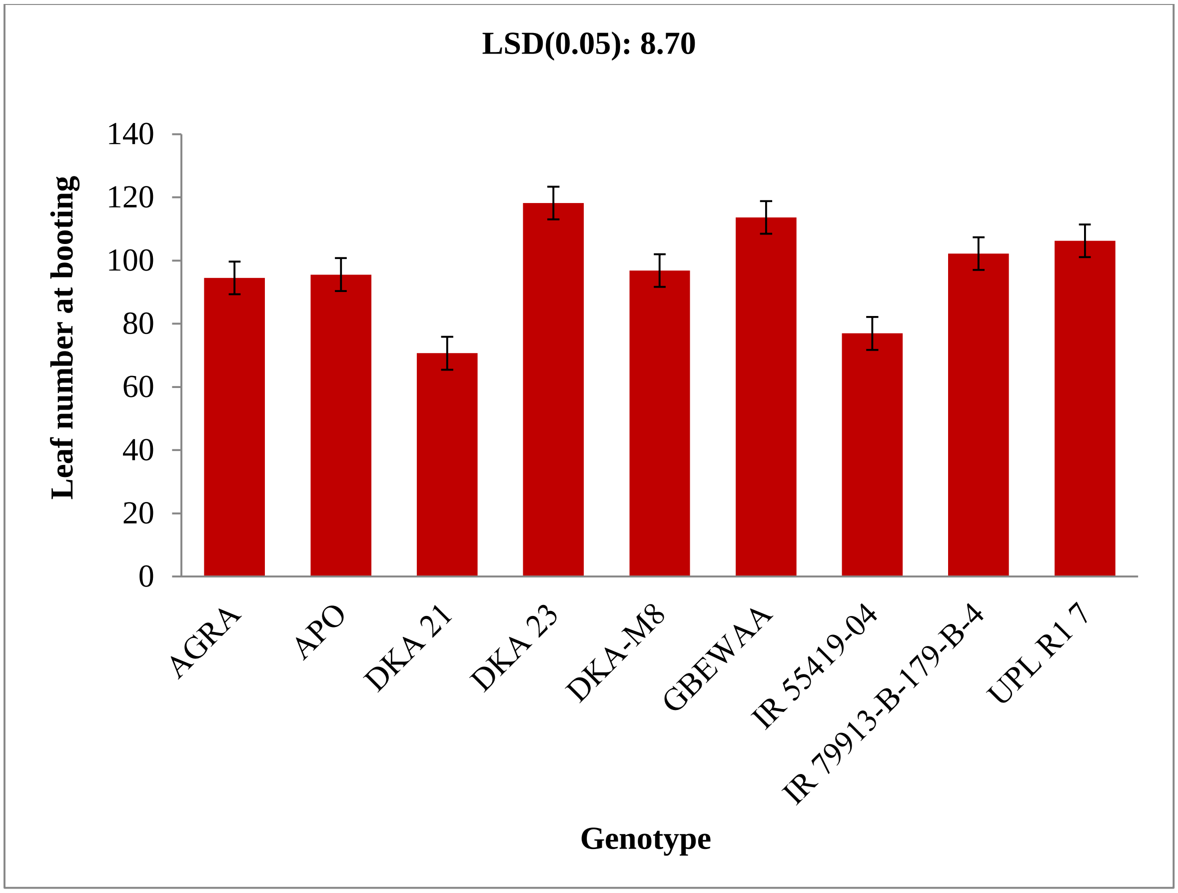

Figure 4.14: Leaf number of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

Number of leaves at flowering also showed a significant difference under different soil moisture stress ($p < 0.05$) (Figure 4.15). The highest number (99) was recorded under 100% CWR while the lowest (66) was recorded in 60% CWR. There was also a significant difference among the genotype ($p < 0.05$). DKA 23 showed the highest (118) number of leaves per plant while DKA 21 recorded the lowest number (71) per plant (Figure 4.16).

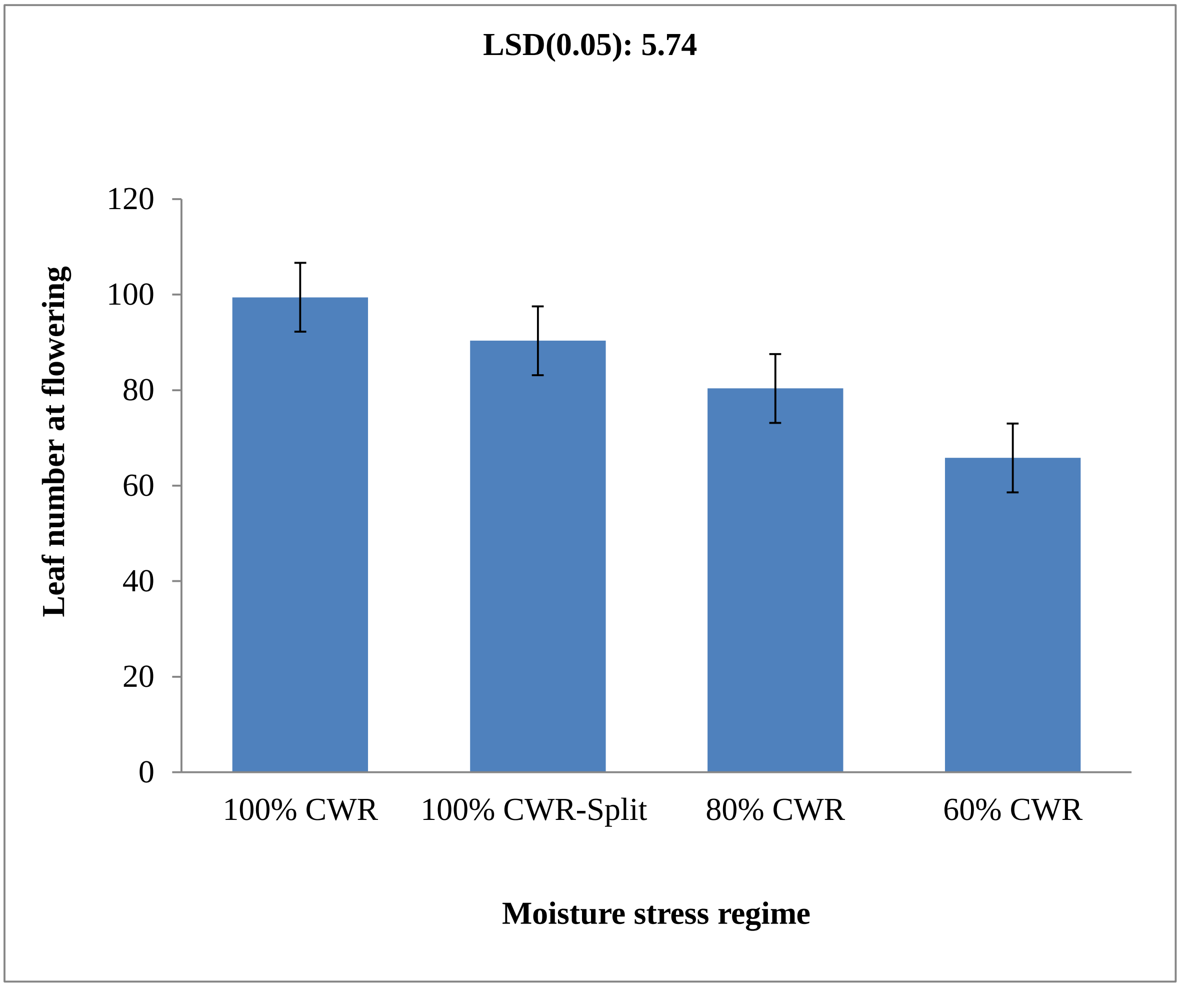

Figure 4.15: Leaf number of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

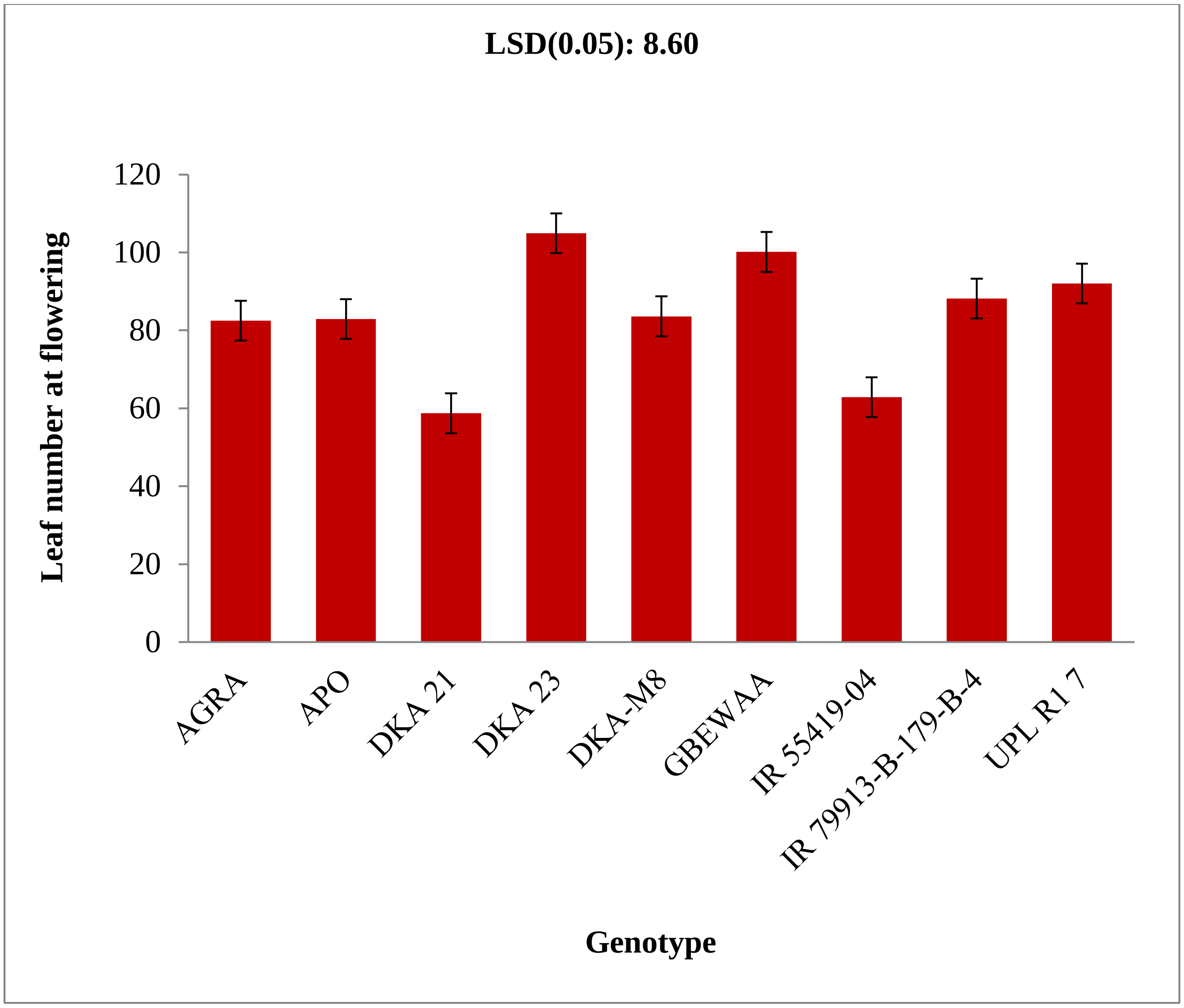

Figure 4.16: Leaf number of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

Number of leaves at maturity also showed a significant difference for different soil moisture stress ($p < 0.05$) (Figure 4.17). The highest number (85) was recorded from 100% CWR plants while the lowest (45) was recorded from 60% CWR. Number of leaves among genotypes was also significant ($p < 0.05$). DKA 23 recorded the highest (86) number of leaves per plant while IR55419-04 recorded the lowest number (47) per plant (Figure 4.18).

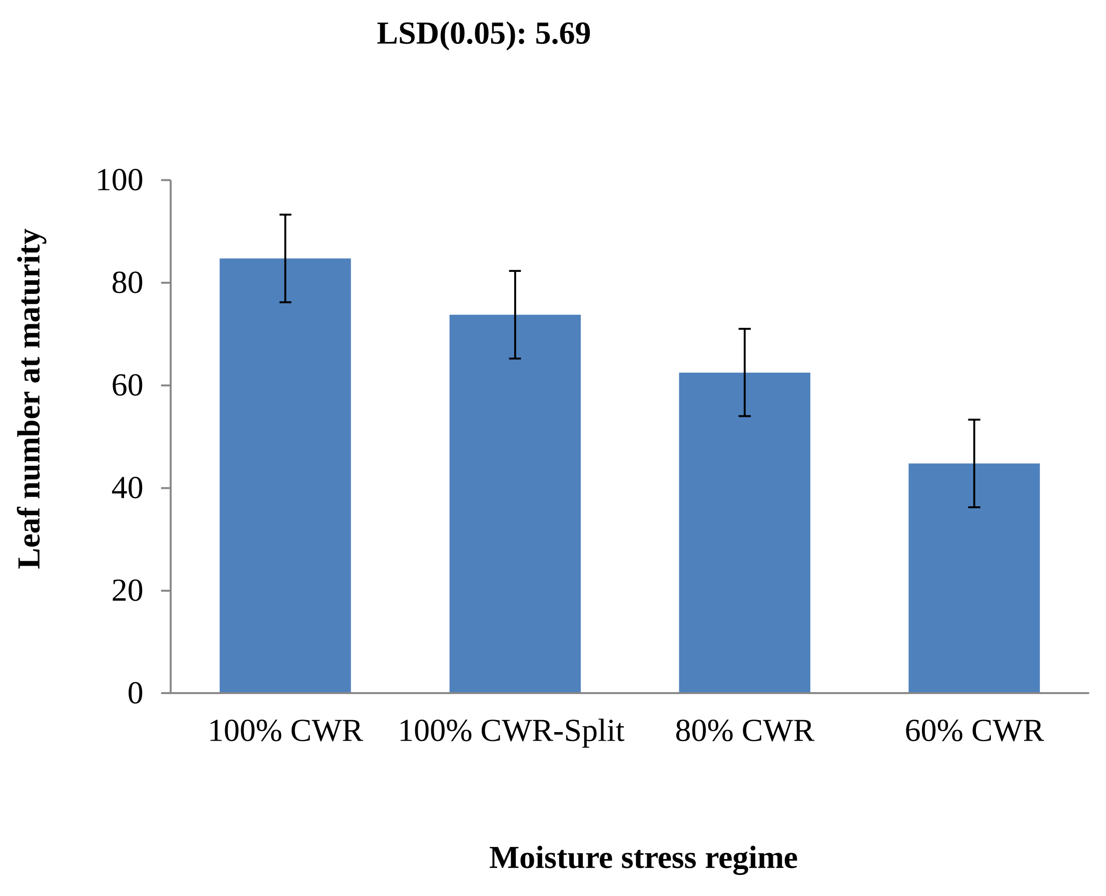

Figure 4.17: Leaf number of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

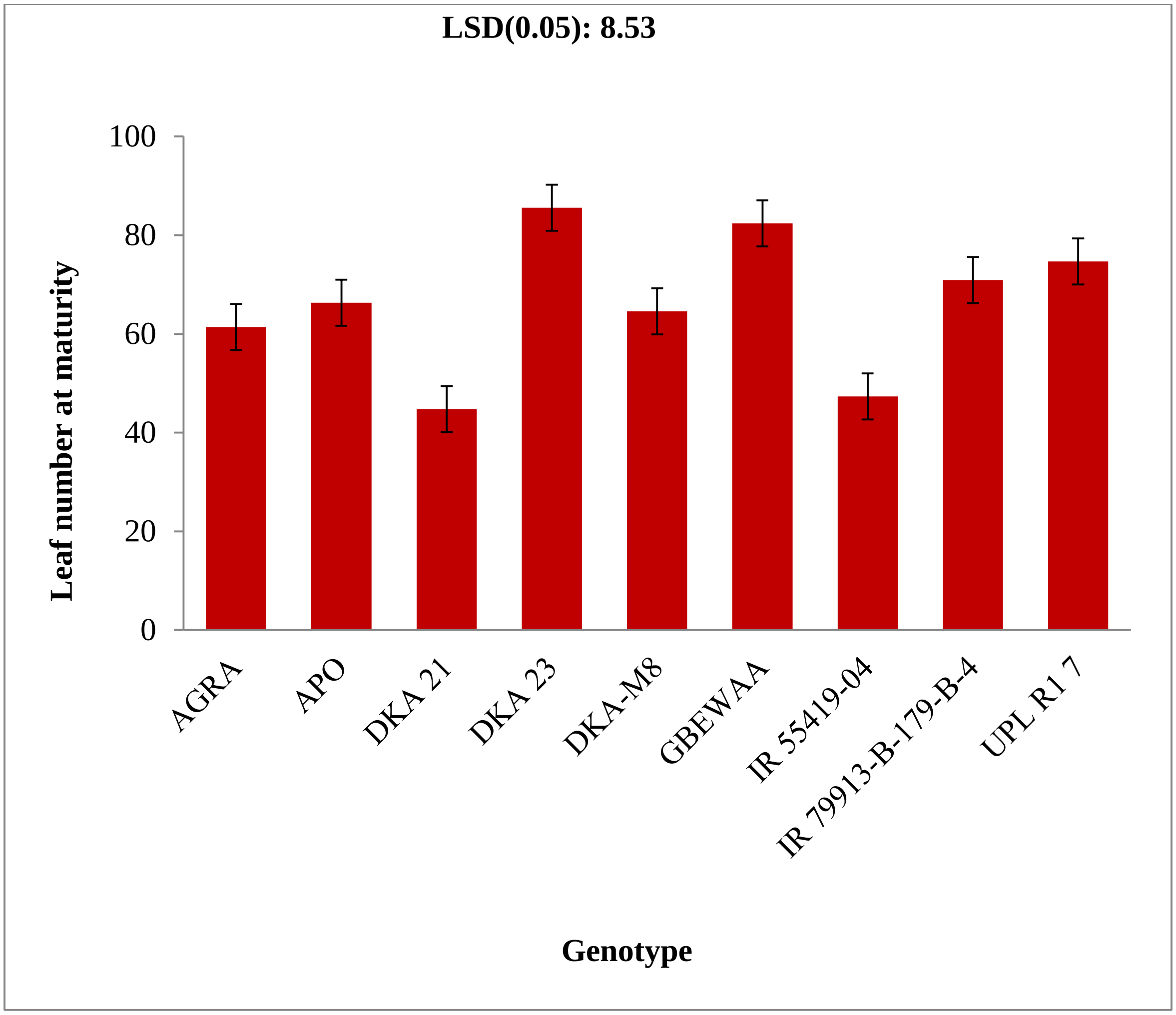

Figure 4.18: Leaf number of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.8 Leaf rolling

Leaf rolling rating was significantly different for the various moisture stress regimes ($p < 0.05$) (Figure 4.19). The highest mean rating (5.2) was recorded in 60% CWR while the lowest (0.3) was recorded in 100% CWR. There was also a significant genotypic difference in leaf rolling rating. Genotype AGRA recorded the highest (3.4) mean value for leaf rolling rating while UPL R1 7 recorded the lowest (2.1) score (Figure 4.20).

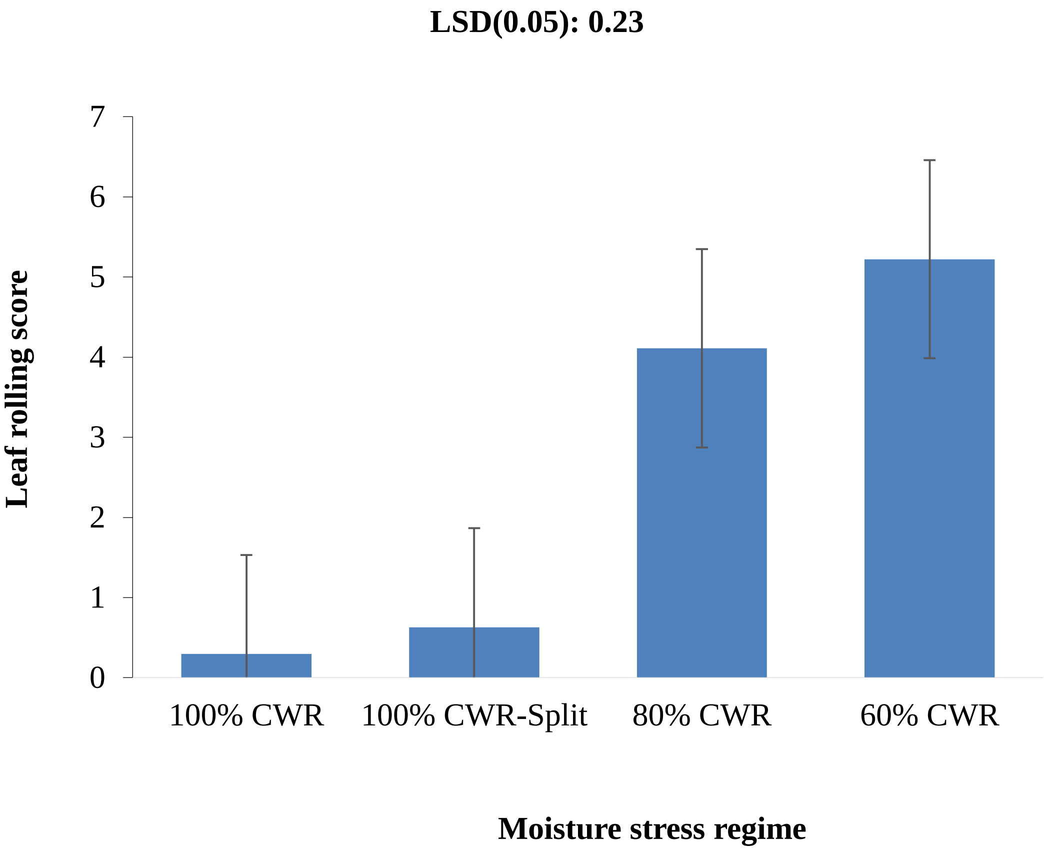

Figure 4.19: Leaf rolling of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

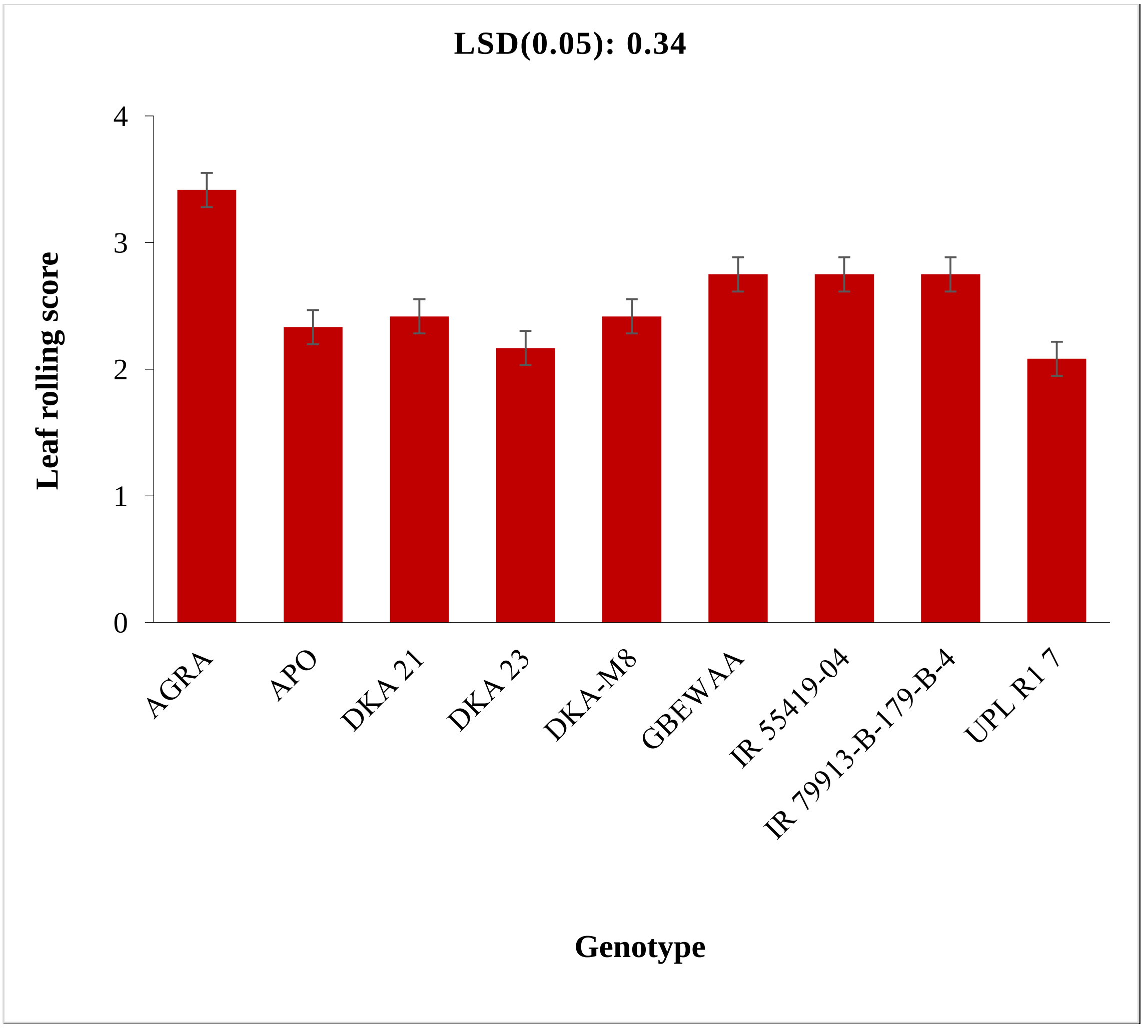

Figure 4.20: Leaf rolling of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

NOTE BOARD: Prior to analysis of leaf rolling data, the data was transformed using $\log_{10}(x + 1)$ method. Data was backed transformed for easy comparison as shown in the above graphs.

The interaction between moisture stress and the genotypes for leaf rolling was significant ($p < 0.05$). The least number (0) of leaf rolling score was recorded from 100% CWR and 100% CWR-Split in genotype UPL R1 7 and the highest number (7) was recorded from 60% CWR in genotype AGRA (Table 4.4).

Table 4.4: Variation in leaf rolling rating of genotypes in response to varying moisture stress

Genotypes	**Moisture stress regimes**			
	100% CWR	**100% CWR-Split**	**80% CWR**	**60% CWR**
AGRA	1	0	6	7
APO	1	1	2	5
DKA 21	0	1	3	6
DKA 23	1	0	3	5
DKA-M8	0	0	5	4
GBEWAA	0	1	5	5
IR 55419-04	0	1	5	5
IR 79913-B-179-B-4	0	1	5	5
UPL R1 7	0	0	3	5

LSD (0.05): Genotype x moisture stress regimes = 0.69

100% CWR = application of 1500 ml of water every two days; 100% CWR-split = application of 750 ml of water every day; 80% CWR = application of 1200 ml of water every two days; 60% CWR = application of 900 ml of water every two days.

4.9 Leaf area index

Leaf area index showed significant difference for the various moisture stress regimes ($p < 0.05$). 100% CWR recorded the highest leaf area index (24.5 cm^2) while 60% CWR recorded the lowest (17.6 cm^2) (Figure 4.21). Genotypes were also significantly different in leaf area ($p < 0.05$). The highest (26.4 cm^2) leaf area was recorded in UPL R1 7 while the lowest leaf area (15.1 cm^2) was recorded in DKA 21 (Figure 4.22).

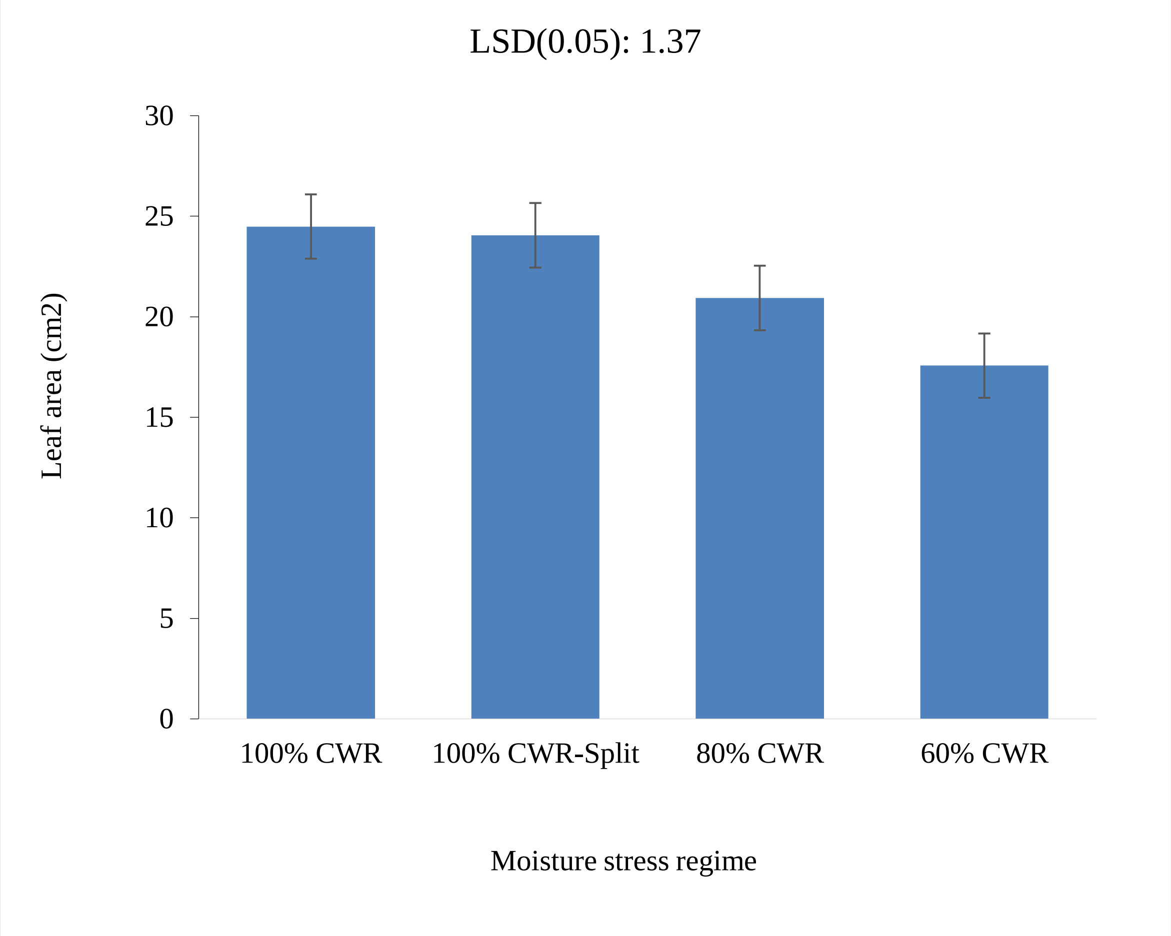

Figure 4.21: Leaf area of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

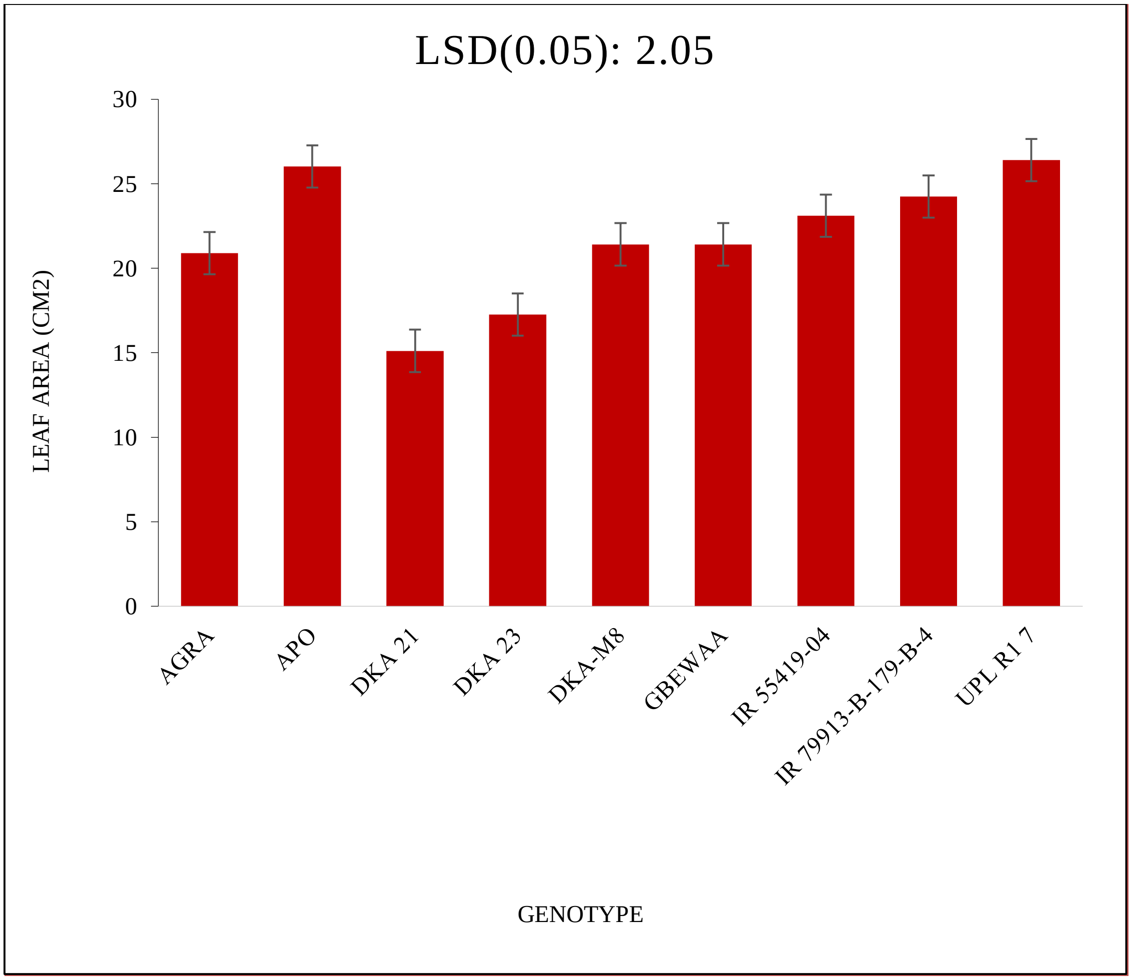

Figure 4.22: Leaf area of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.10 Number of panicles

Panicle numbers per plant were significantly different for the various moisture stress regimes ($p < 0.05$) (Figure 4.23). The control treatment (100% CWR) recorded the highest number (21) of panicles per plant while the lowest number (12) was recorded in 60% CWR. There was also a significant difference among the genotypes per number of panicles ($p < 0.05$). The highest mean panicle number (22) was recorded in DKA 23 while the lowest number (14.58) was recorded in APO (Figure 4.24).

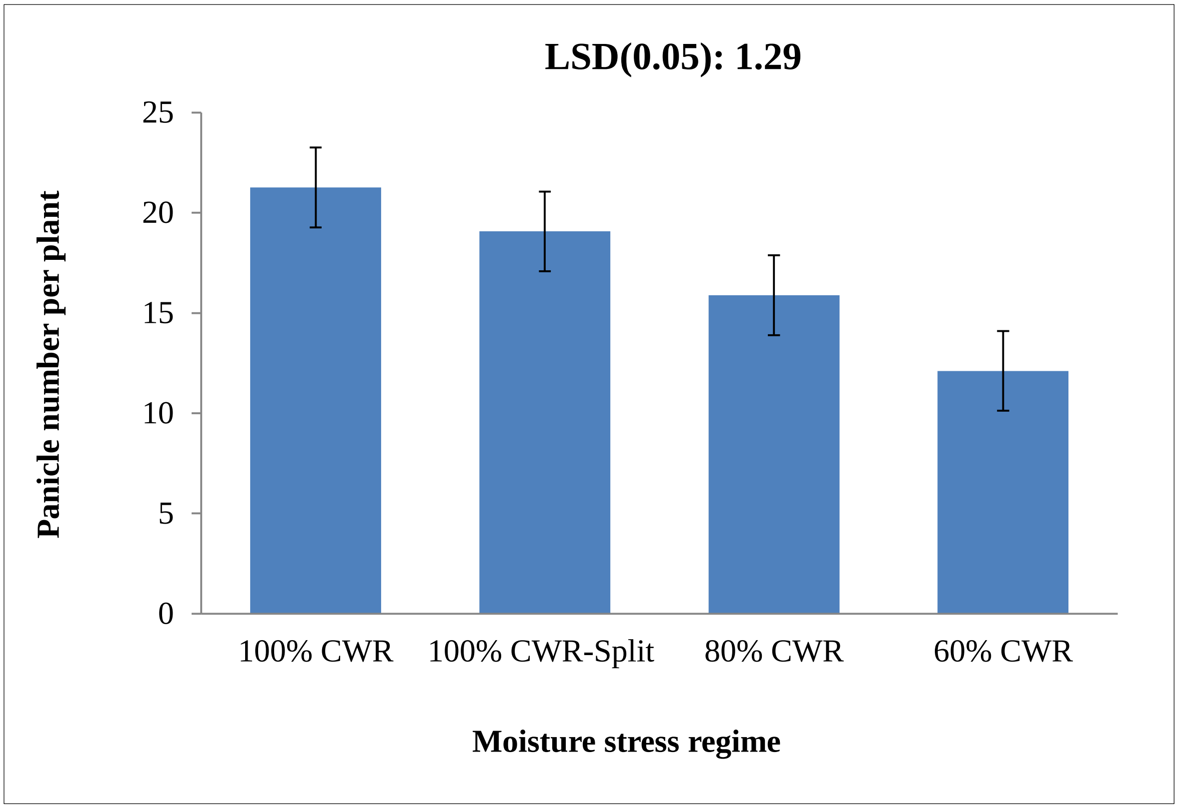

Figure 4.23: Panicle number of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

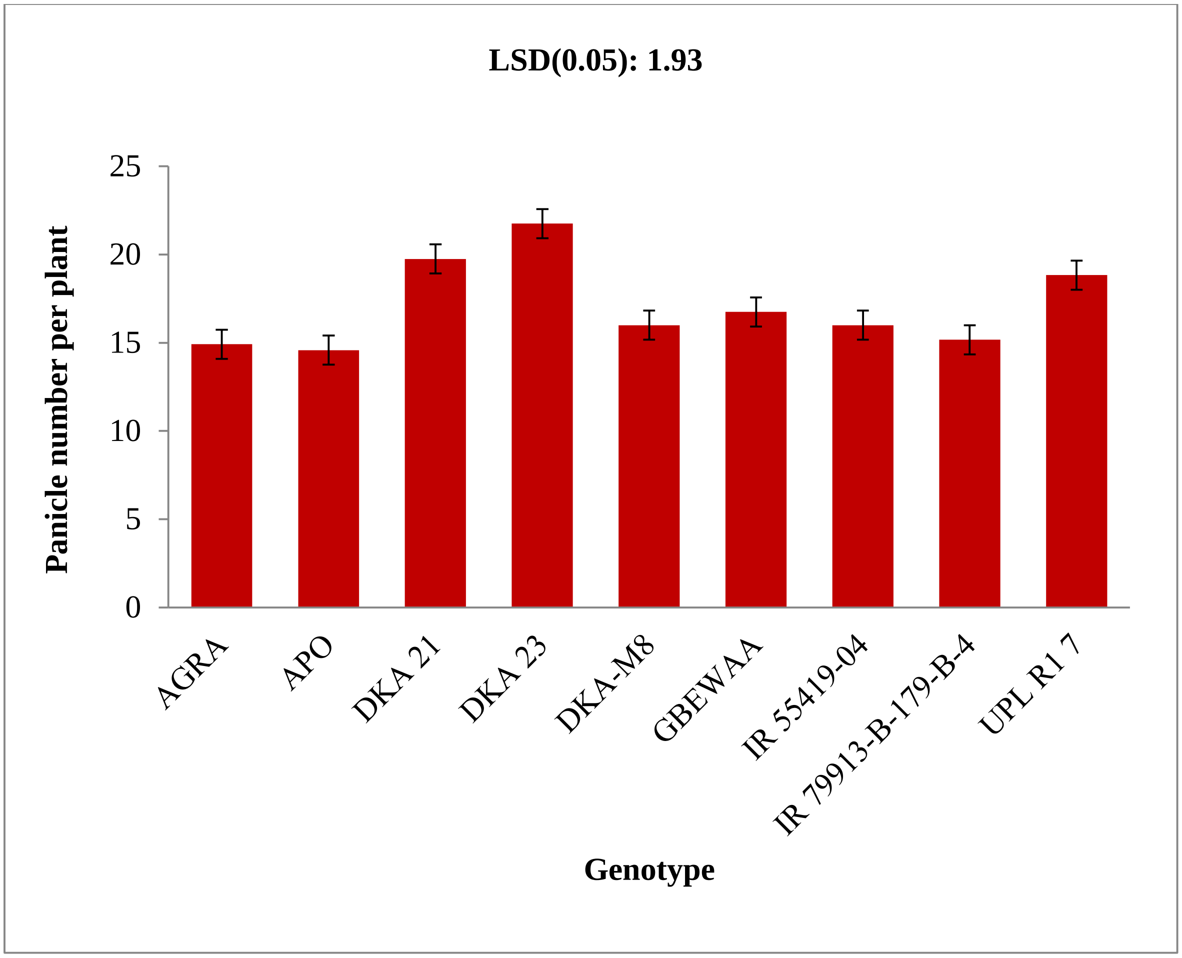

Figure 4.24: Panicle number of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.11 Panicle length

Panicle length was also significantly influenced by water stress ($p < 0.05$). The highest panicle length (24.21 cm) was recorded by plants from 100% CWR and this was not statistically different from values in 100% CWR-split (23.64 cm) while the lowest (19.33 cm) was recorded in 60% CWR (Figure 4.25). There was a significant difference in panicle length among the genotypes at different level of moisture stress ($p < 0.05$). DKA-M8 recorded the longest panicle (24.54 cm) while the shortest panicle (20.29 cm) was recorded in DKA 21 (Figure 4.26).

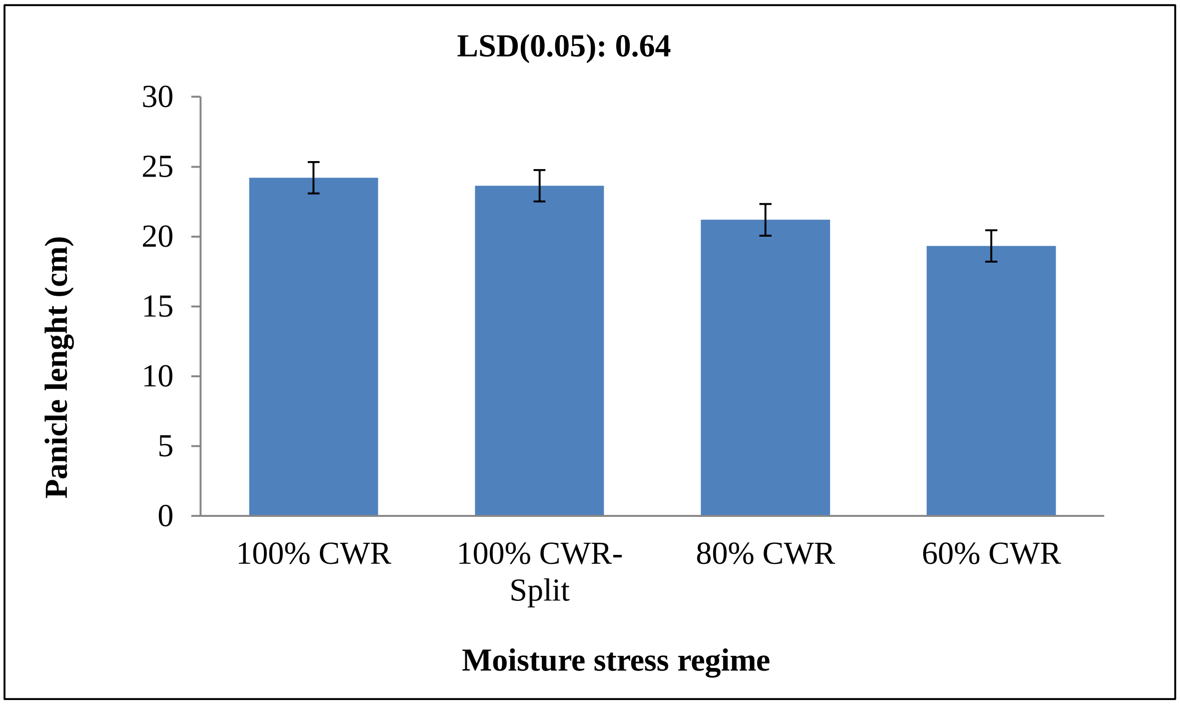

Figure 4.25: Panicle length of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

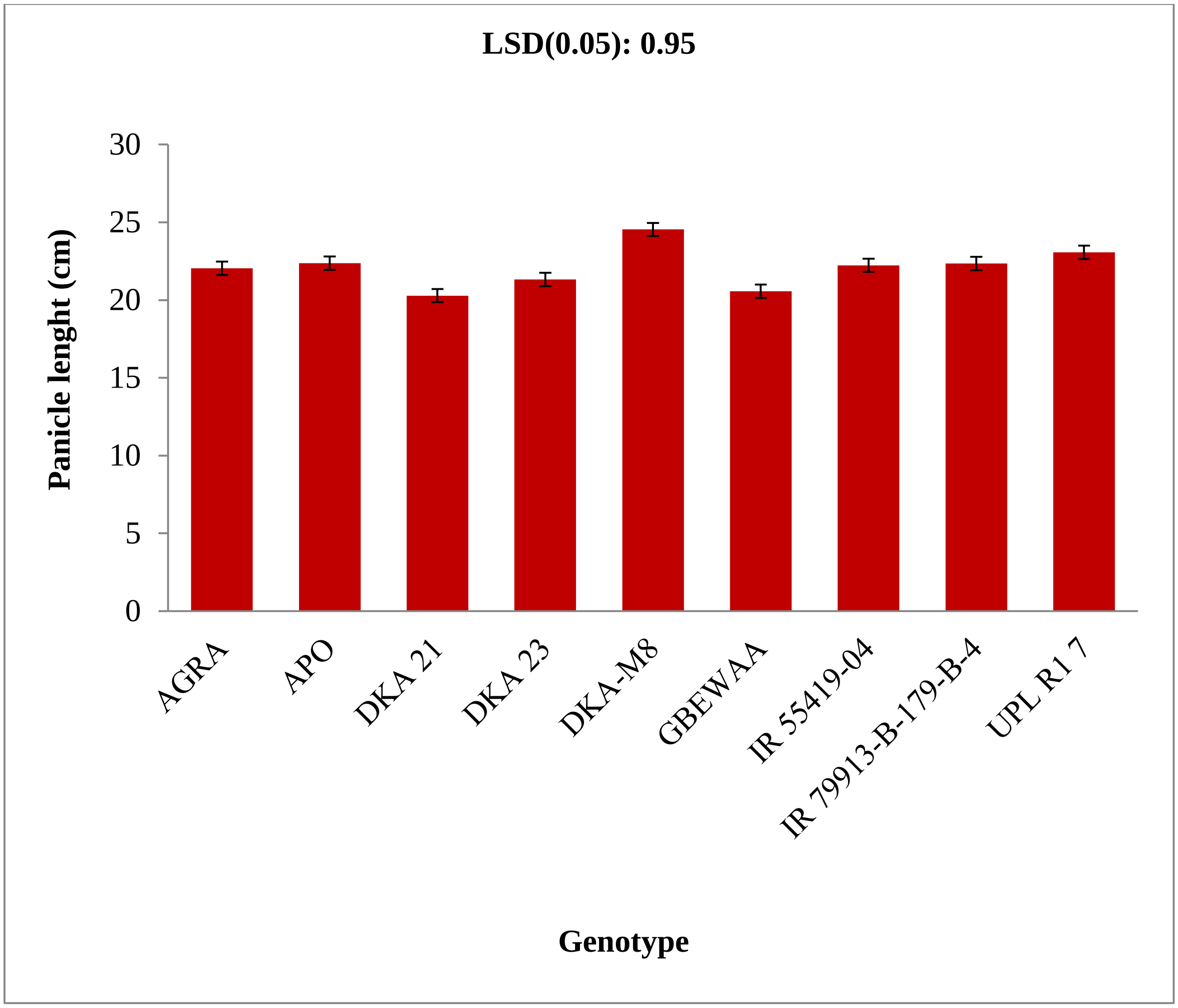

Figure 4.26: Panicle length of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.12 Number of grains

Number of grains per panicle showed a significant difference for the various moisture stress regimes ($p < 0.05$) (Figure 4.27). The highest grain number (135) per panicle was recorded in control (100% CWR) while the least grain number (73) per panicle was recorded in 60% CWR. There was a significant difference in the genotypes on number of grains per panicle ($p < 0.05$). The highest grain number (135) was recorded in APO and the lowest grain number (90) was recorded in IR 55419-04 (Figure 4.28).

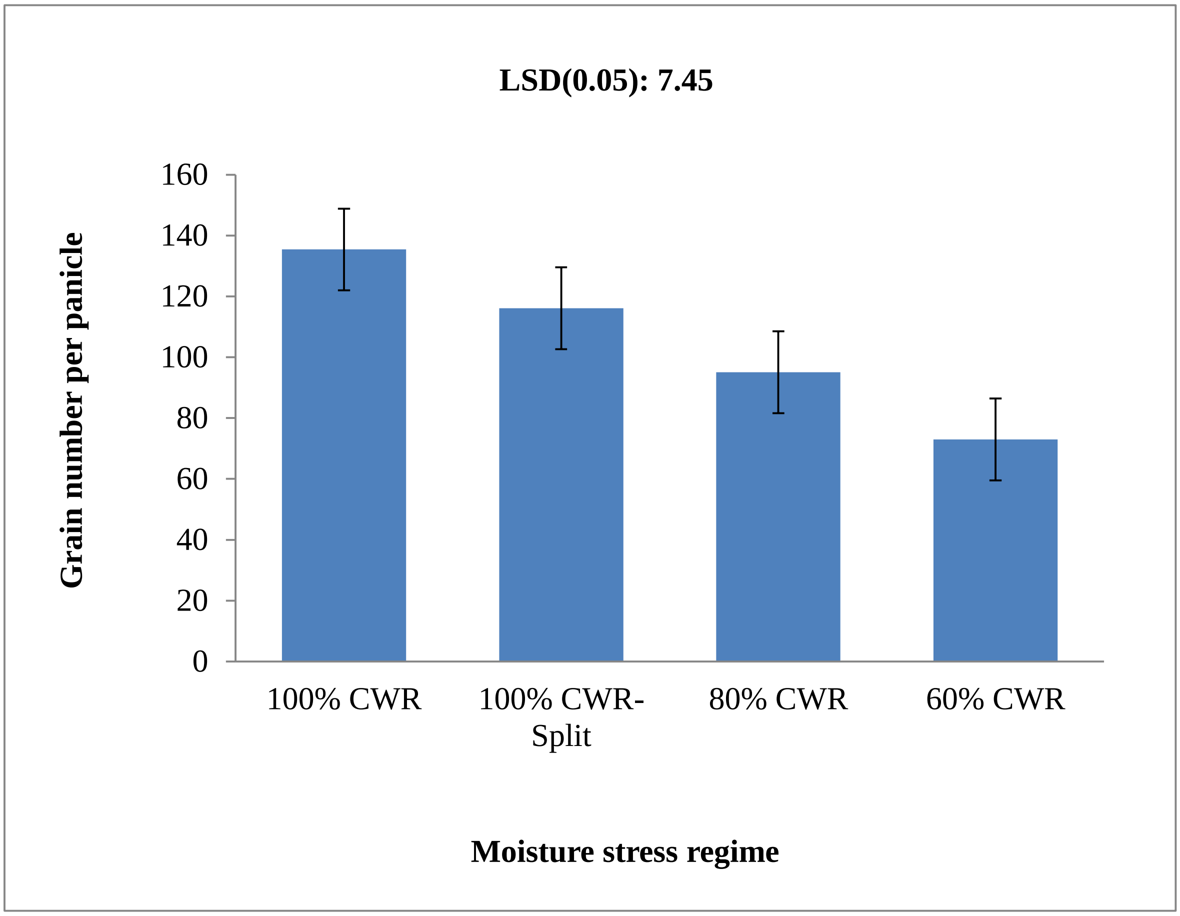

Figure 4.27: Number of grains of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

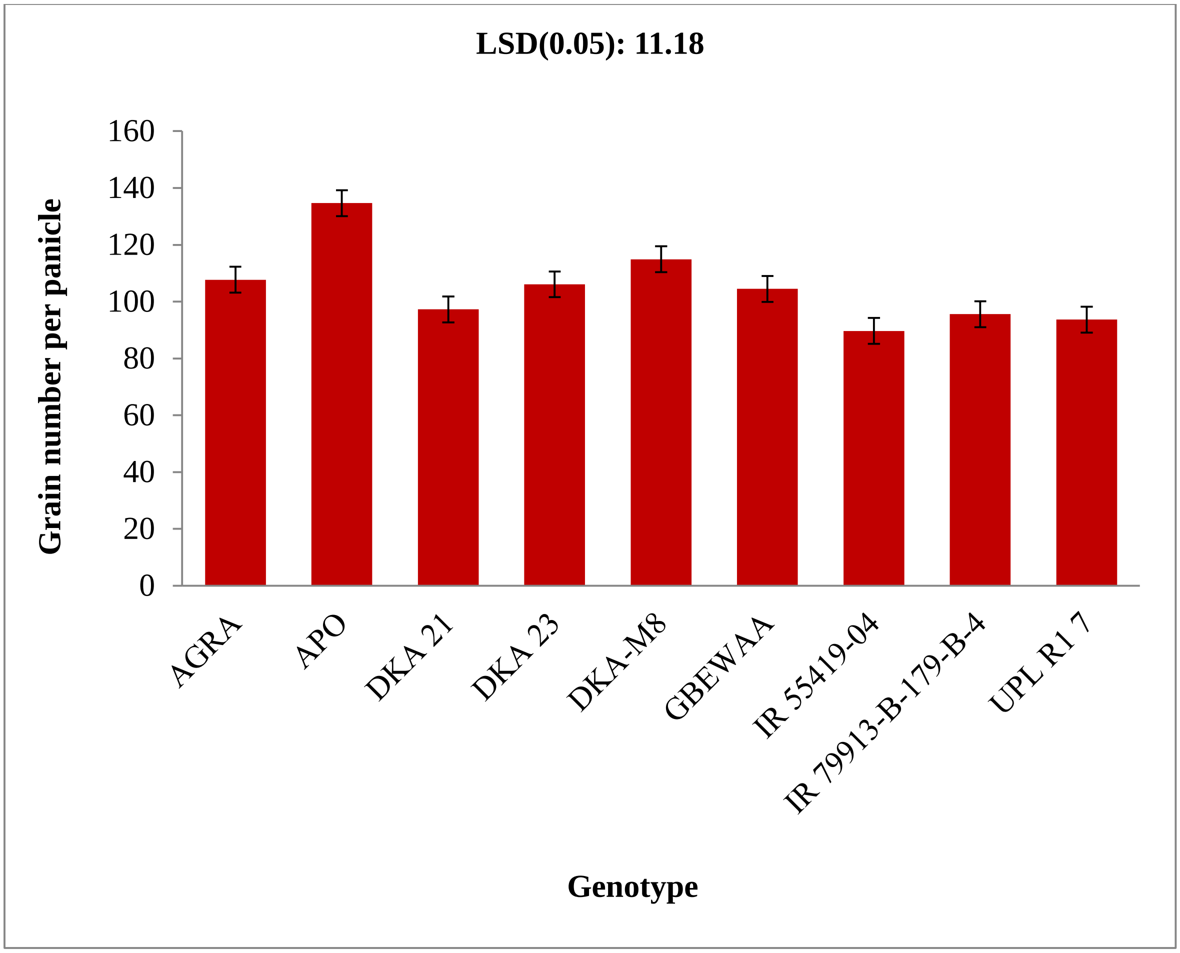

Figure 4.28: Grain number of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.13 Number of filled grains

Number of filled grains per panicle varied significantly among different moisture stress regimes ($p < 0.05$) (Figure 4.29). The control treatment (100% CWR) recorded the highest number (18) of filled grain per panicle while the lowest (1) was recorded in 60% CWR. The genotype APO produced the highest number (21) of filled grain per panicle and the genotype IR 55419-04 produced the least number (0) of filled grain (Figure 4.30).

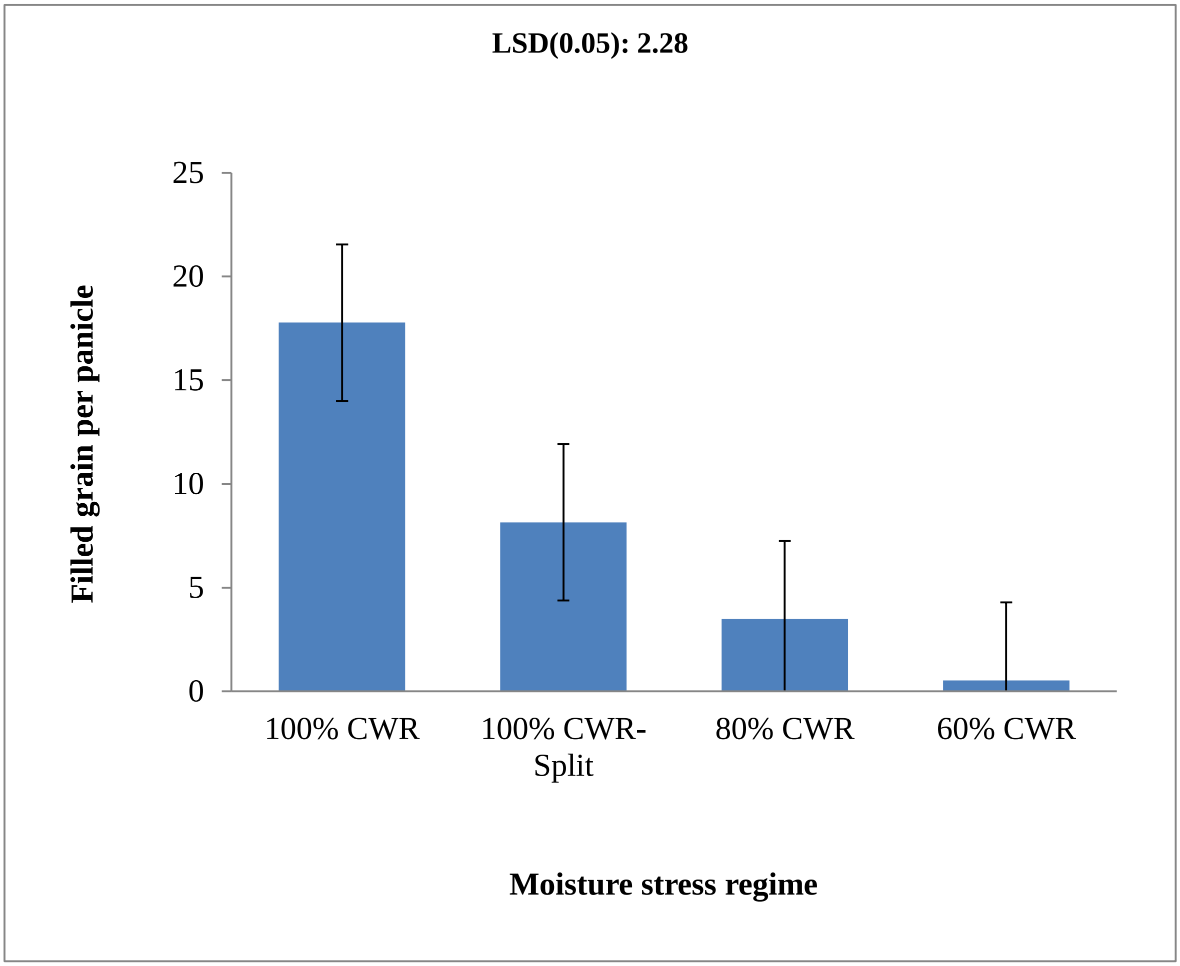

Figure 4.29: Filled grain of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

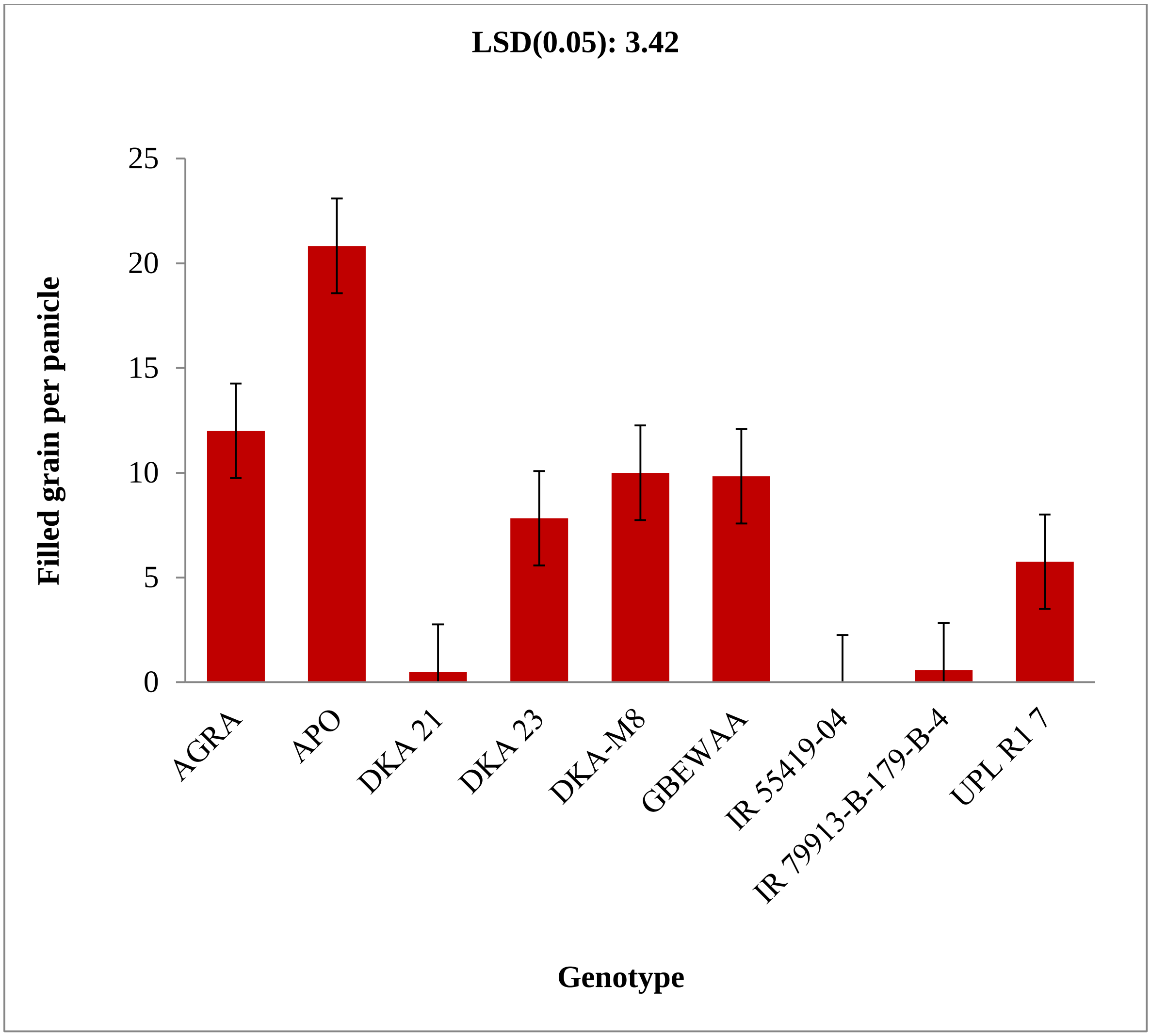

Figure 4.30: Filled grain of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

There was a significant interaction between soil moisture levels and rice genotypes on the number of filled grains per panicle ($p < 0.05$). The highest number (52) of filled grain was recorded in APO x 100% CWR while the lowest numbers (0) of filled grain was recorded in (APO, DKA 21, DKA-M8, IR 554, IR 799 and UP R17) x 60% CWR (Table 4.5).

Table 4.5: Variation in number of filled grains per panicle of genotypes in response to varying moisture stress

Genotype	**Water Stress Regime**			
	100% CWR	**100% CWR-Split**	**80% CWR**	**60% CWR**
AGRA	34	9	4	1
APO	52	21	10	0
DKA 21	1	1	0	0
DKA 23	17	9	4	2
DKA-M8	18	15	7	0
GBEWAA	21	13	4	2
IR 55419-04	0	0	0	0
IR 79913-B-179-B-4	2	0	0	0
UPL R1 7	16	6	2	0

LSD (0.05): Genotype x moisture stress regimes = 6.829

100% CWR = application of 1500 ml of water every two days; 100% CWR-split = application of 750 ml of water every day; 80% CWR = application of 1200 ml of water every two days; 60% CWR = application of 900 ml of water every two days.

4.14 Straw weight of rice

Soil moisture level affected biomass production significantly ($p < 0.05$) (Figure 4.31). The highest biomass (45.18 g) was recorded from plants in control (100% CWR) and was not statistically different from (43.54 g) plants from 100% CWR-split whereas the lowest biomass (33.22 g) was recorded in 60% CWR. The biomass accumulation of the genotypes also varied significantly ($p < 0.05$). DKA-M8 recorded the highest biomass (46.27 g) while the lowest (34.42g) was recorded in DKA 21 (Figure 4.32).

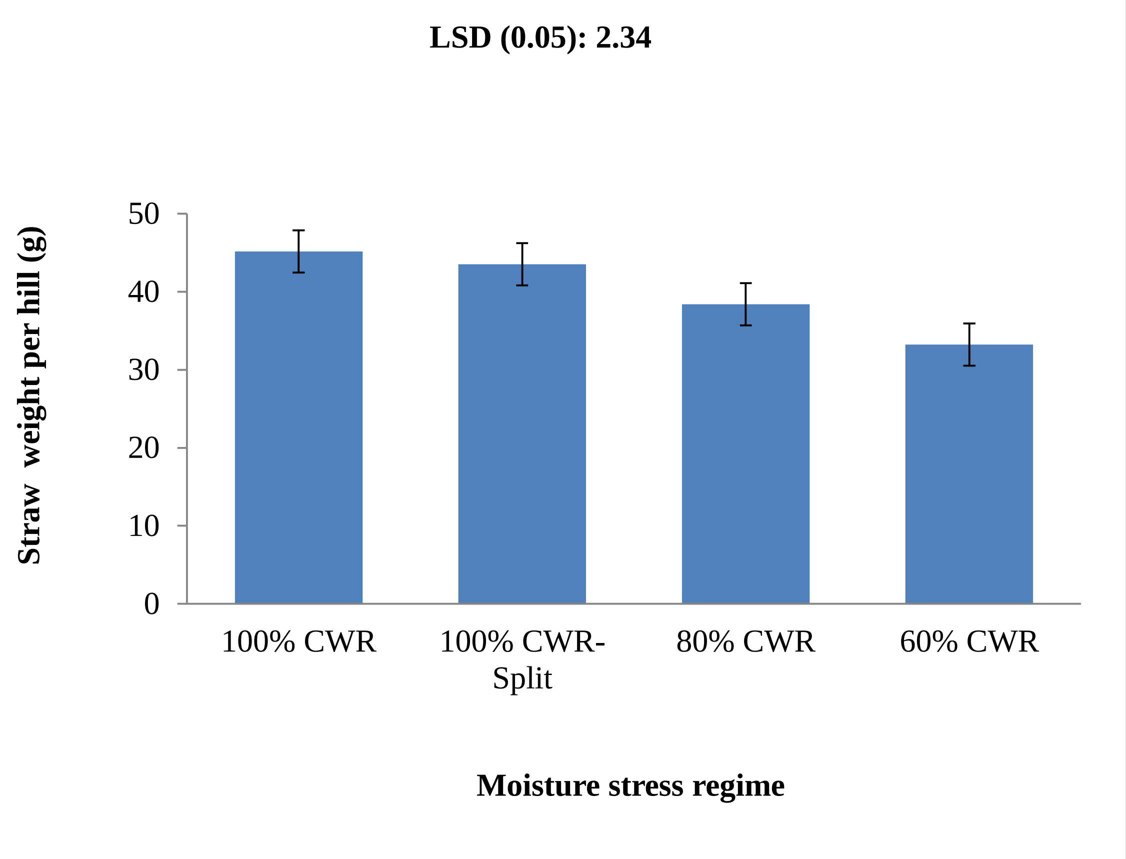

Figure 4.31: Straw weight of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

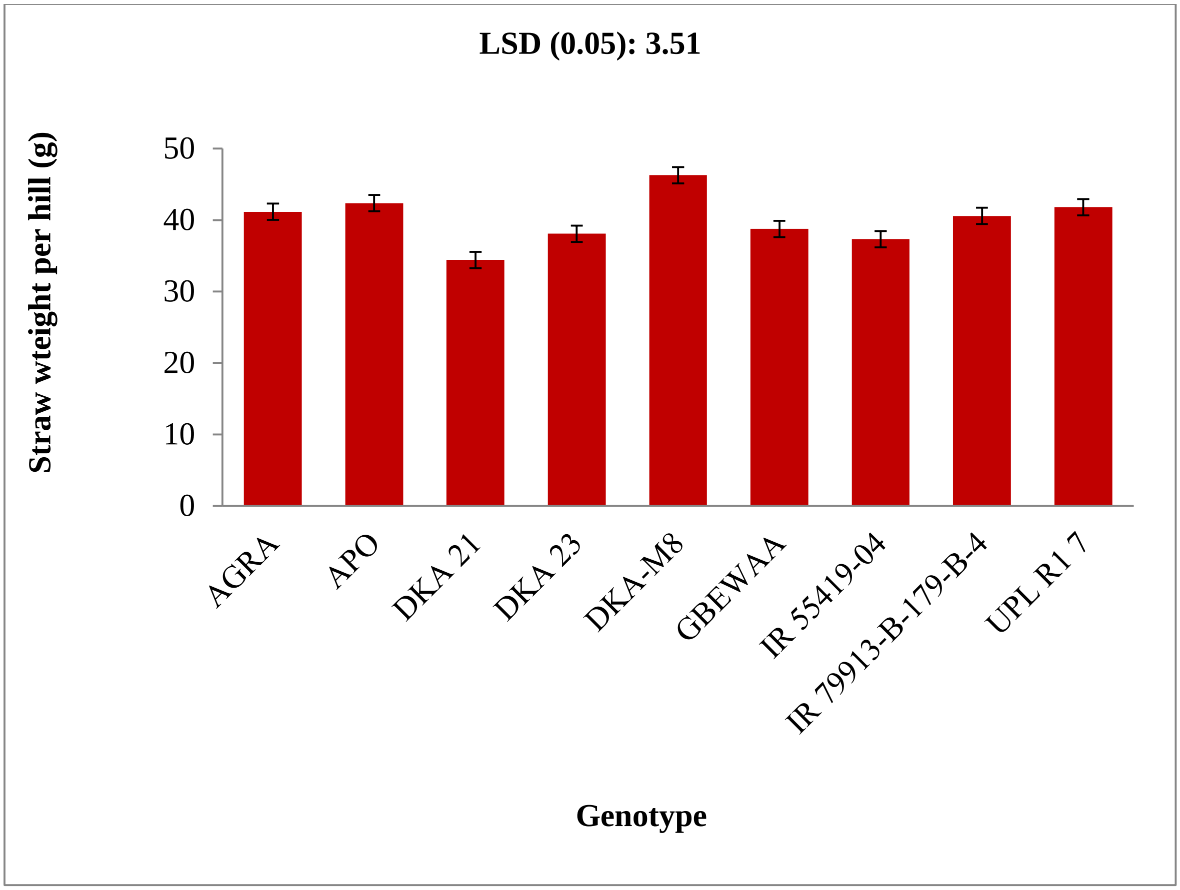

Figure 4.32: Straw weight of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.15 Root length of rice

The effect of soil moisture stress on root length was significant ($p < 0.05$) (Figure 4.33). The longest root (44.7 cm) was recorded from plant in 100% CWR while the shortest (24.1 cm) was recorded in 60% CWR. Root length showed significant difference among the genotypes ($p < 0.05$). The longest root (42.2 cm) was recorded in UPL R17 while the shortest root length (33.0 cm) was recorded in DKA 23 (Figure 4.34).

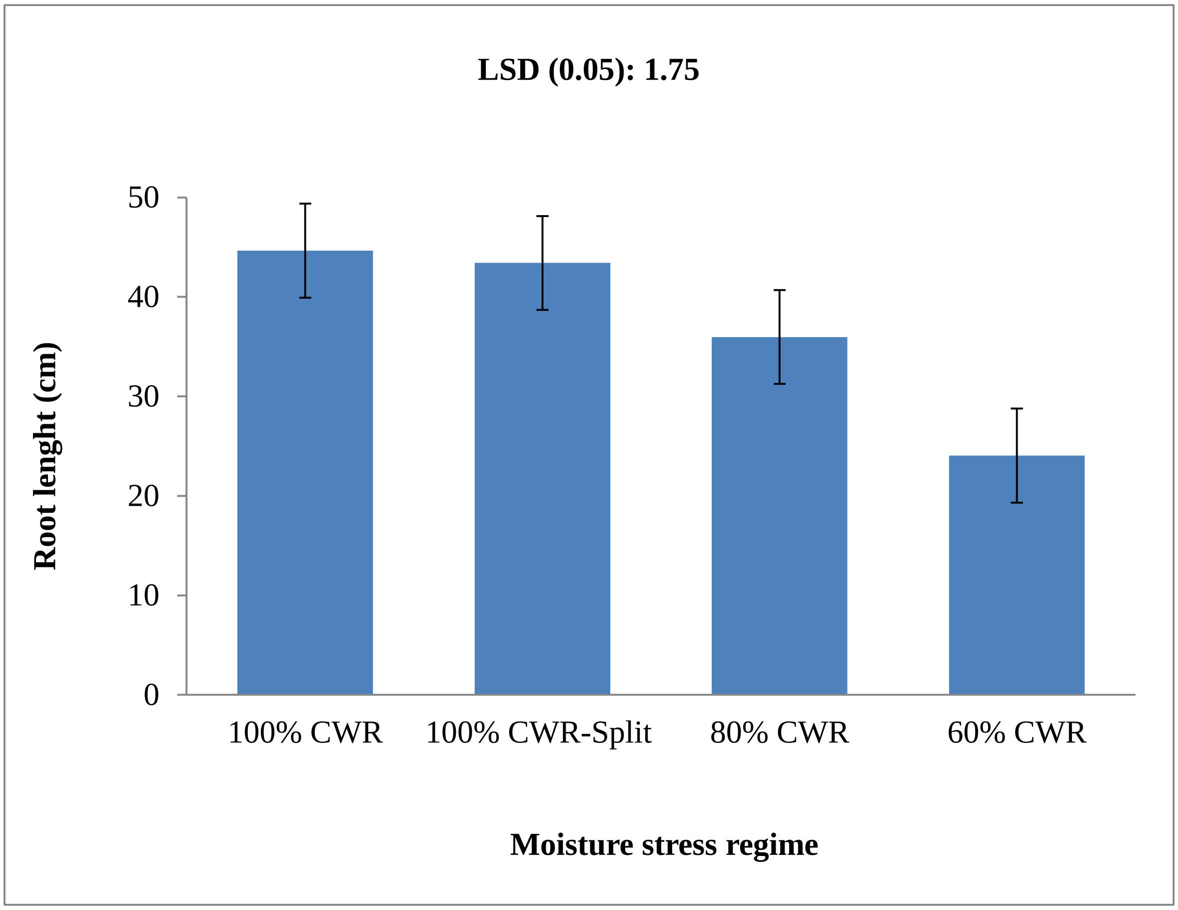

Figure 4.33: Root length of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

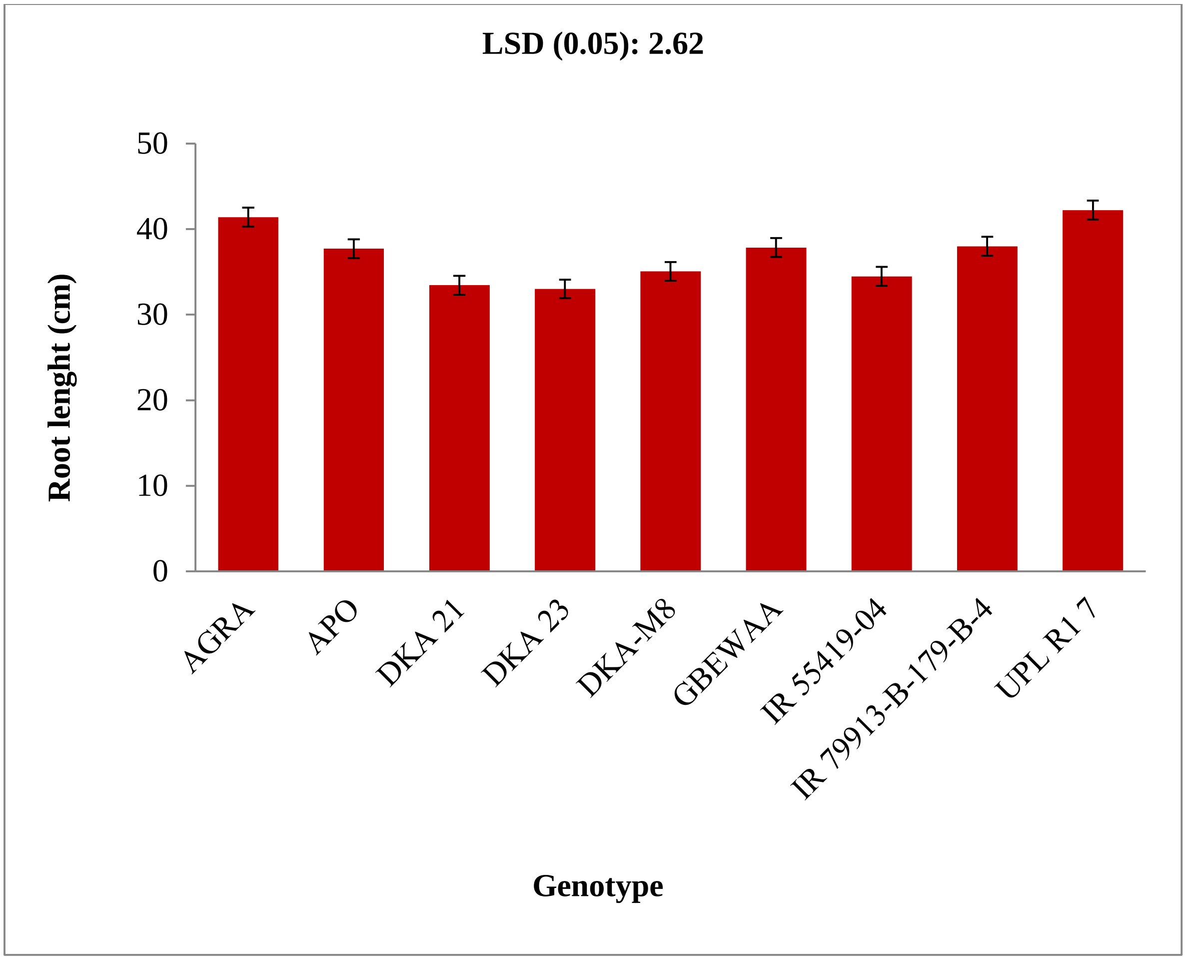

Figure 4.34: Root length of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.16 Root weight of rice

Root dry weight was significantly affected by moisture stress ($p < 0.05$). The control Plants from 100% CWR recorded the highest root weight (26.4 g) and the lowest was recorded in 60% CWR (16.3 g) (Figure 4.35). Similarly, root dry weight per plant significantly varied among the genotypes ($p < 0.05$). The highest root dry weight per plant (26.8 g) at maturity was recorded in GBEWAA while the lowest (15.1 g) was recorded in DKA 23 (Figure 4.36).

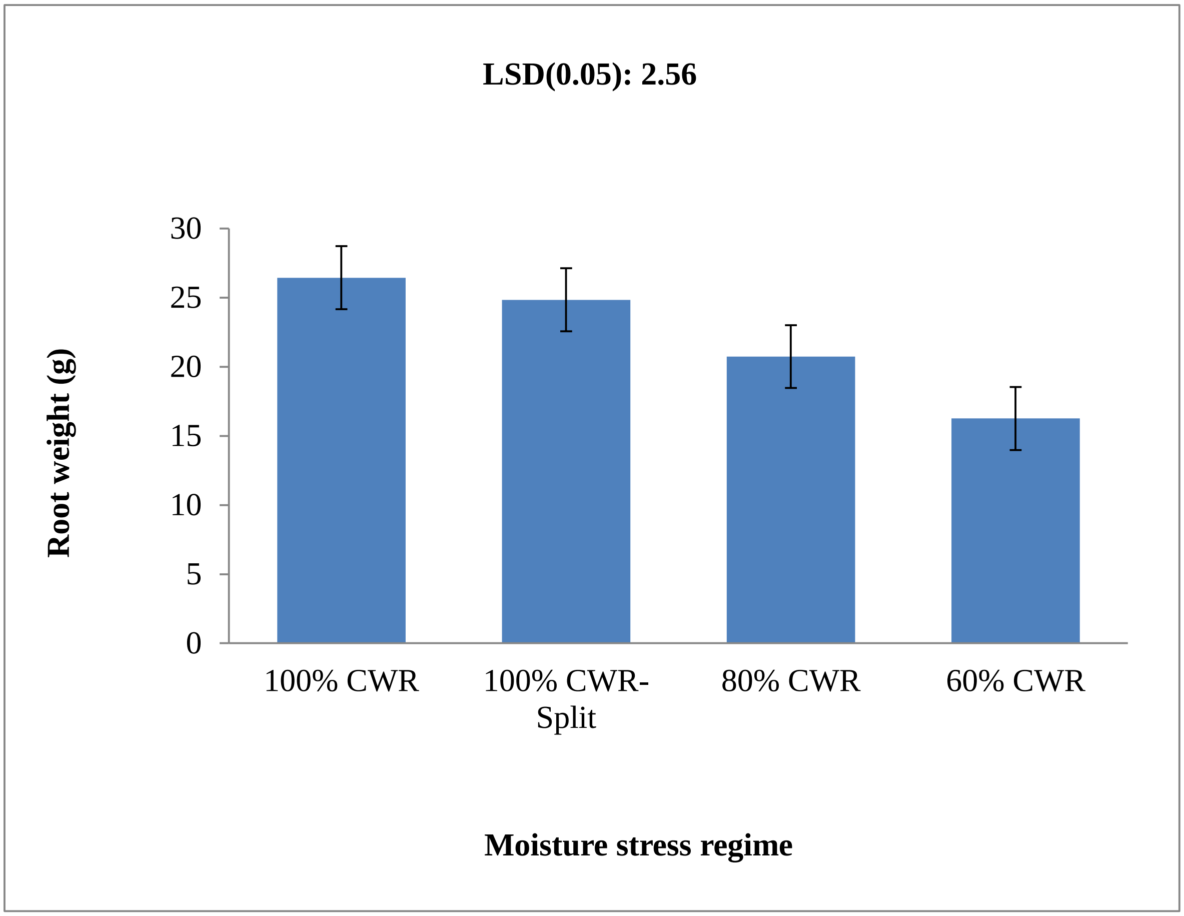

Figure 4.35: Root weight of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

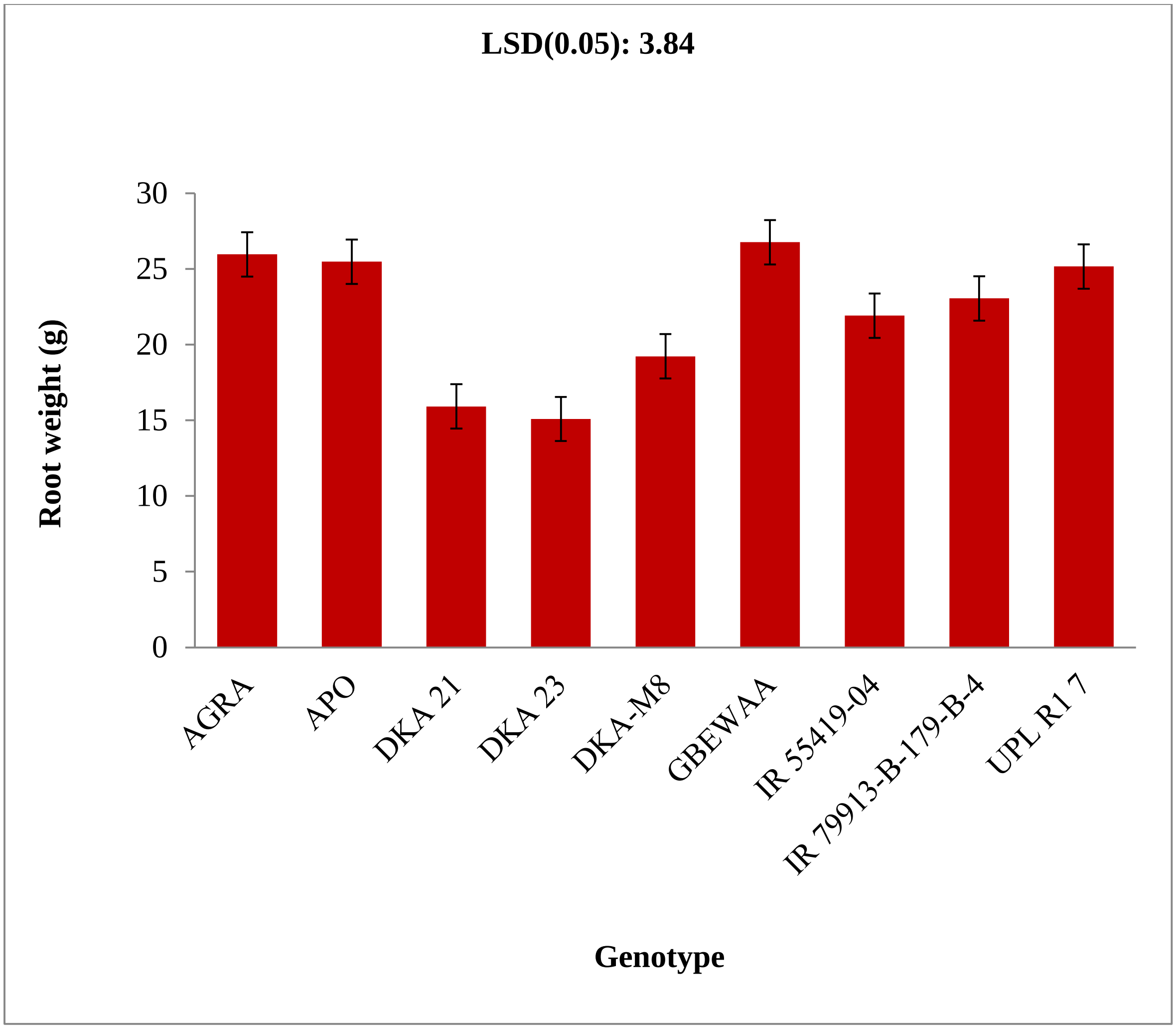

Figure 4.36: Root weight of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

4.17 Grain weight of rice

Grain weight per plant was significantly different for the various moisture stress regimes ($p < 0.05$) (Figure 4.37). The highest grain yield (14.01 g) per plant was recorded in 100% CWR while lowest (6.17 g) was recorded in 60% CWR. Genotypes were also significantly different in grain weight ($p < 0.05$). The highest grain yield (14.51 g) per plant was recorded in DKA 23 while the lowest grain yield (5.01 g) was recorded in DKA-M8 (Figure 4.38).

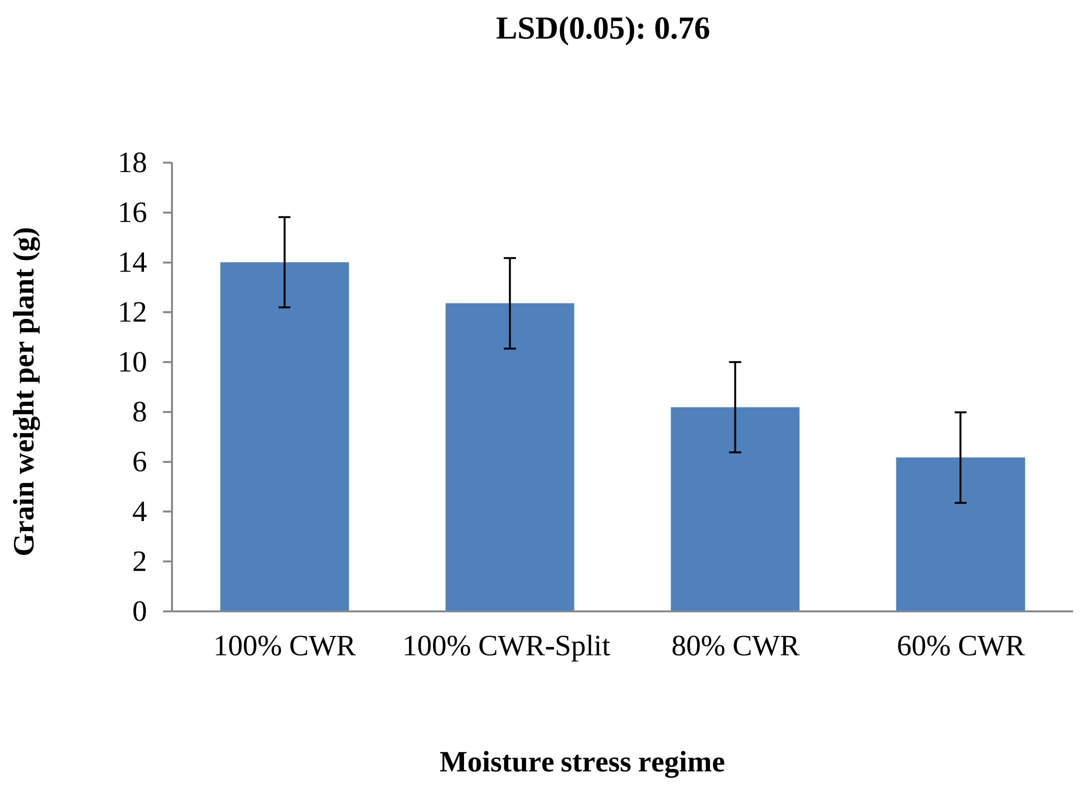

Figure 4.37: Grain weight of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

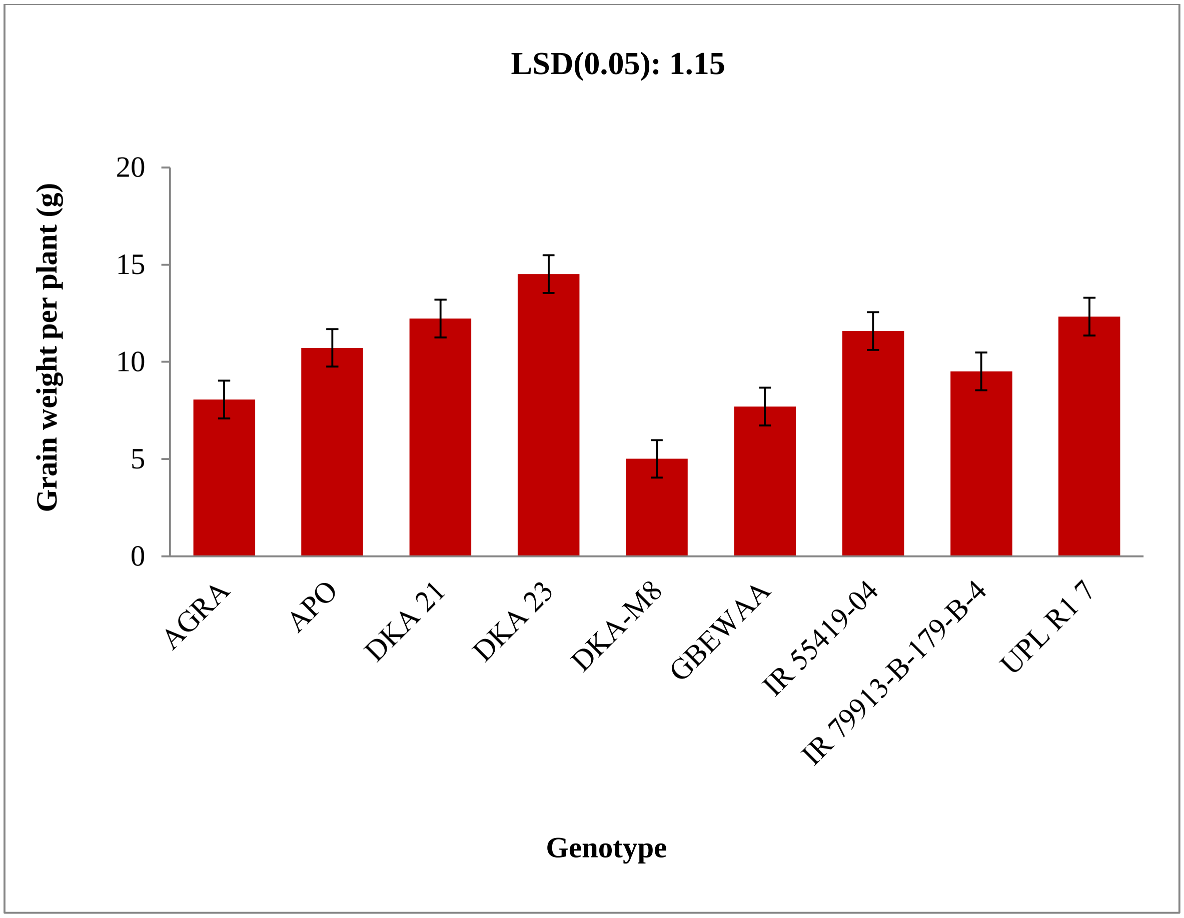

Figure 4.38: Grain weight of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

The interaction between moisture stress regimes and genotypes on grain yield per plant was also significantly different ($p < 0.05$). The combination DKA 23 x 100% CWR recorded the highest grain weight (19.27 g) per plant while DKA-M8 x 60% CWR recorded the lowest grain weight (3.07 g) (Table 4.6).

Table 4.6: Variation in grain yield per plant of genotypes in response to varying moisture stress

	Water Stress Regime			
Genotype	**100% CWR**	**100% CWR-Split**	**80% CWR**	**60% CWR**
AGRA	10.27	9.23	7.27	5.47
APO	14.80	13.47	8.87	5.73
DKA 21	16.87	15.17	9.80	7.10
DKA 23	19.27	17.53	11.40	9.83
DKA-M8	7.40	6.13	3.43	3.07
GBEWAA	10.90	9.17	5.90	4.83
IR 55419-04	16.67	14.2	9.13	6.37
IR 79913-B-179-B-4	13.73	11.87	7.57	4.87
UPL R1 7	16.23	14.43	10.37	8.30

LSD (0.05): Genotype x moisture stress regimes = 2.29

100% CWR = application of 1500 ml of water every two days; 100% CWR-split = application of 750 ml of water every day; 80% CWR = application of 1200 ml of water every two days; 60% CWR = application of 900 ml of water every two days.

4.18 Leaf chlorophyll content

Leaf chlorophyll content at 10 weeks after planting showed a significant difference for soil moisture stress ($p < 0.05$) (Figure 4.39). The highest chlorophyll content (45.1) was recorded in plants from 100% CWR while the lowest (40.0) was recorded in 60% CWR. Leaf chlorophyll content at 10 WAP also varied significantly for the genotypes ($p < 0.05$). The highest chlorophyll content (47.0) was recorded in APO while the least (40.2) was recorded in UPL R17 (Figure 4.40).

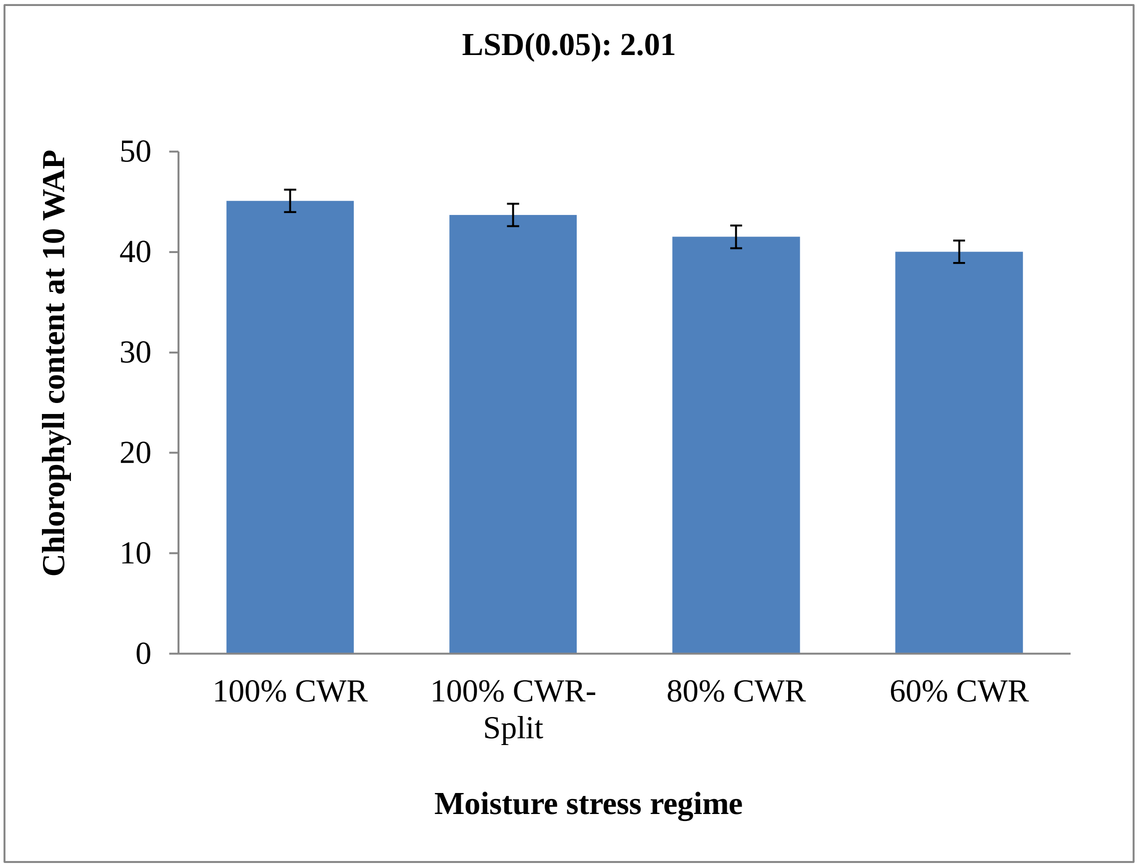

Figure 4.39: Chlorophyll content of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

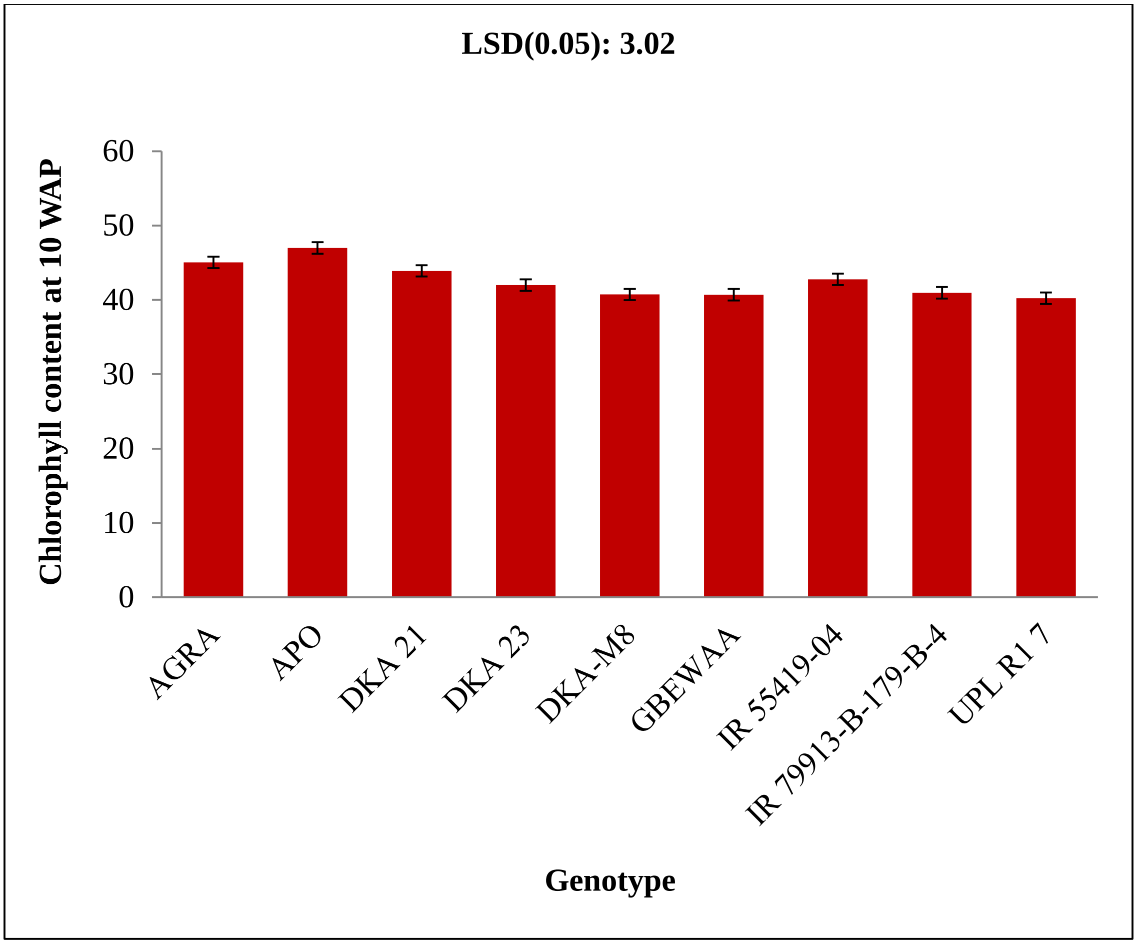

Figure 4.40: Chlorophyll content of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

Leaf chlorophyll content at 14 weeks after planting showed significant difference under different soil moisture stress ($p < 0.05$) (Figure 4.41). Plants from 100% CWR recorded the highest chlorophyll content (37.5) while the least (32.3) was recorded in 60% CWR. There was also a significant difference among the genotypes in chlorophyll content ($p < 0.05$). Genotype AGRA recorded the highest chlorophyll content of (37.6) at 14 WAP while UPL R17 recorded the least chlorophyll content (33.34) (Figure 4.42).

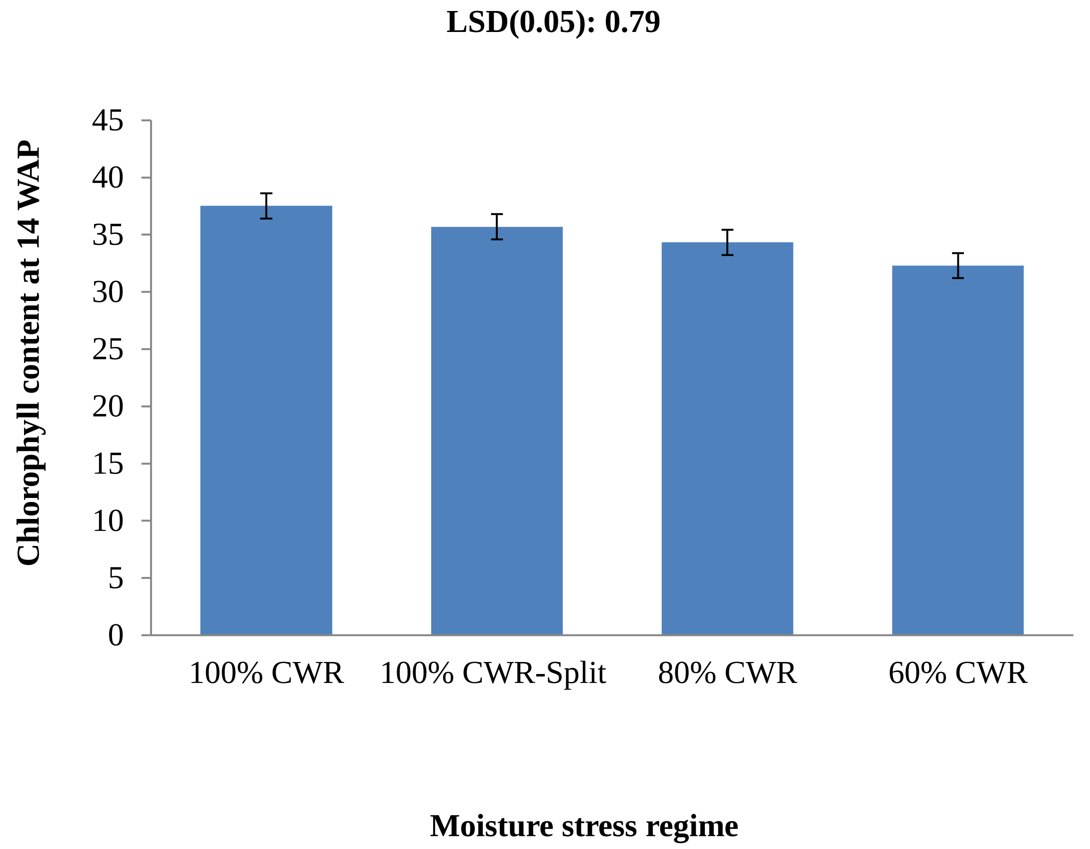

Figure 4.41: Chlorophyll content of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

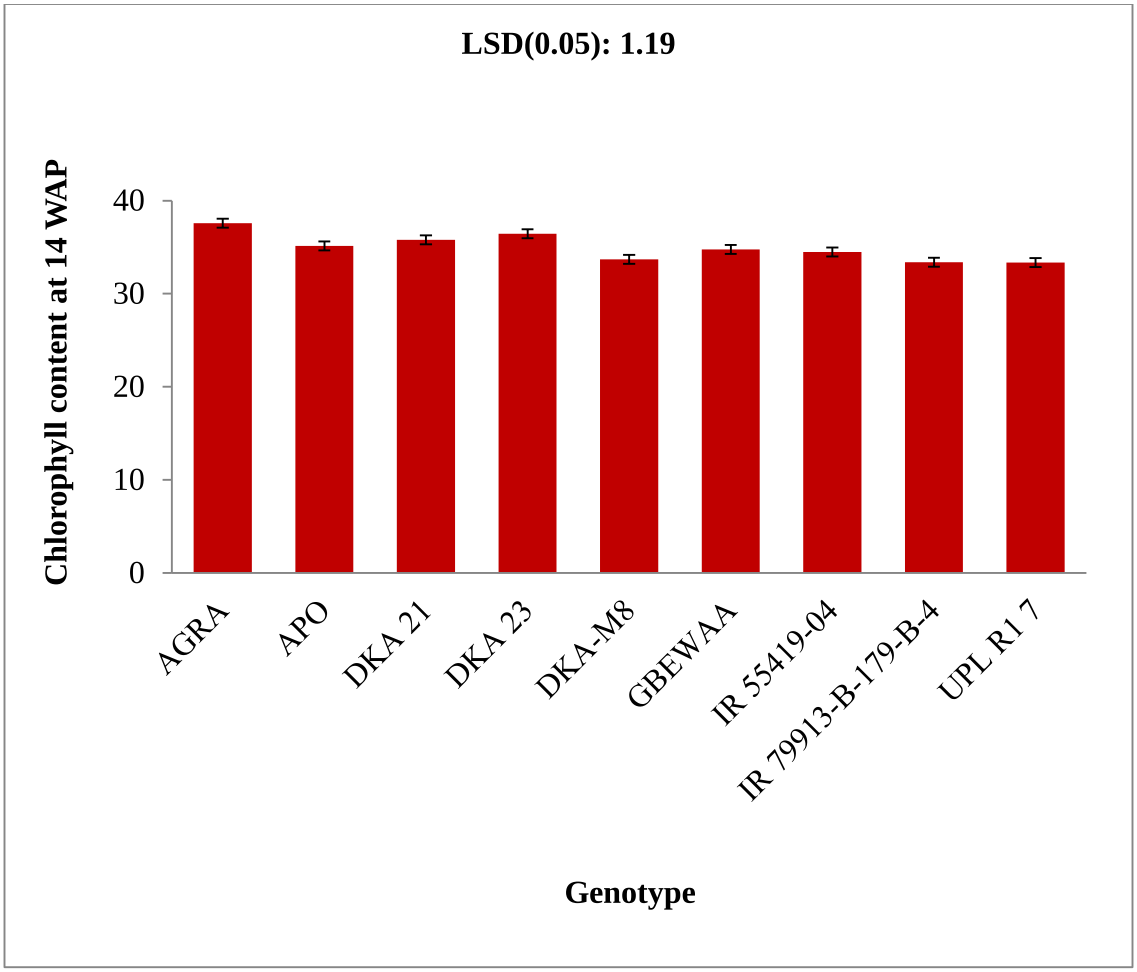

Figure 4.42: Chlorophyll content of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

Leaf chlorophyll content at 18 weeks after planting (maturity) was significant for moisture stress ($p < 0.05$) (Figure 4.43). Plant from 100% CWR recorded the highest chlorophyll content (21.6) while the least (14.4) was recorded in 60% CWR. Leaf chlorophyll content varied significantly among the genotypes ($p < 0.05$). Genotype DKA 23 recorded the highest chlorophyll content (20.0) while the least (16.32) was recorded from UPL R17 (Figure 4.44).

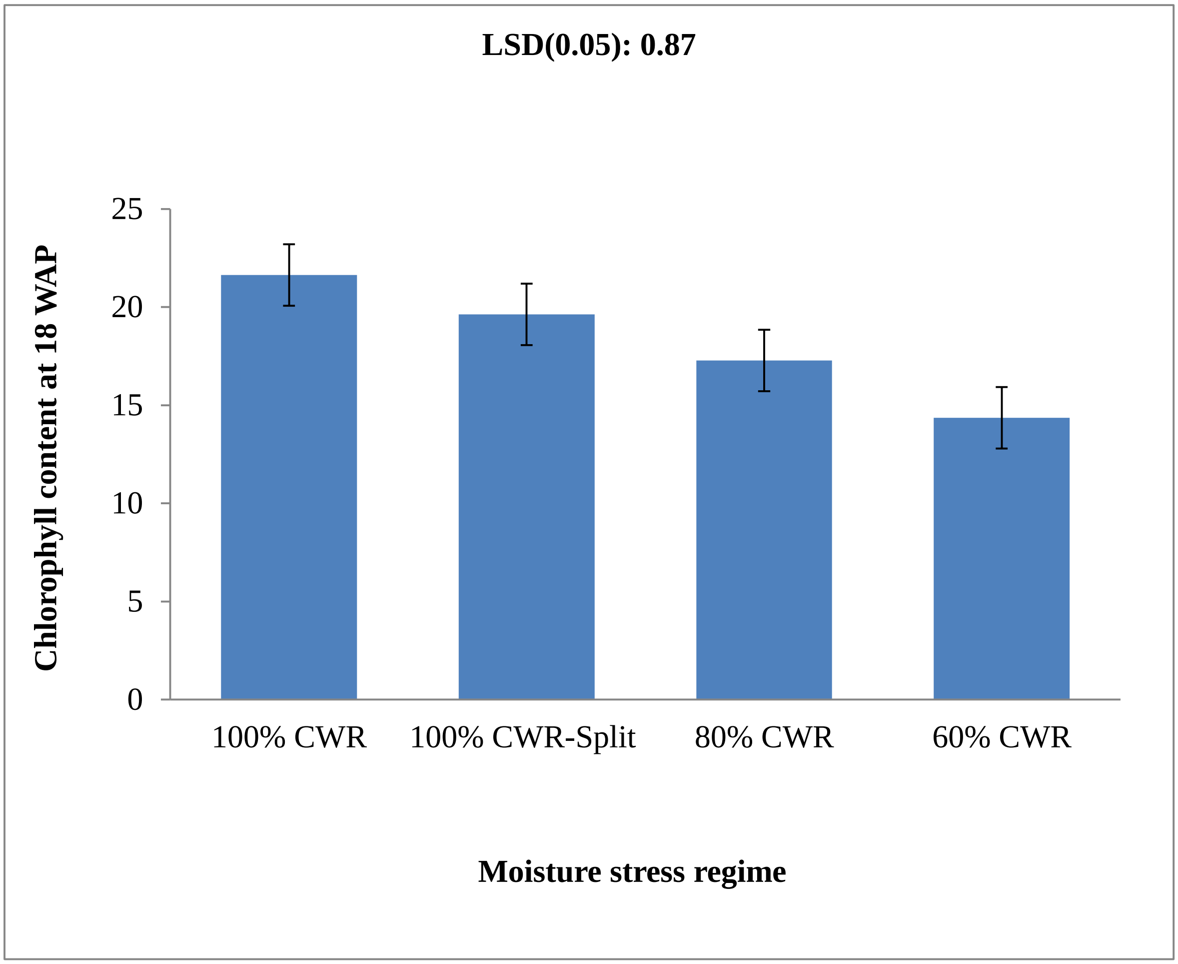

Figure 4.43: Chlorophyll content of plants subjected to various moisture stress regimes. Error bars represent means ± standard error of means (S.E.M). For 100% CWR = an application of 1500 ml of water every two days, 100% CWR-split = an application of 750 ml of water every day, 80% CWR = an application of 1200 ml of water every two days and 60% CWR = an application of 900 ml of water every two days.

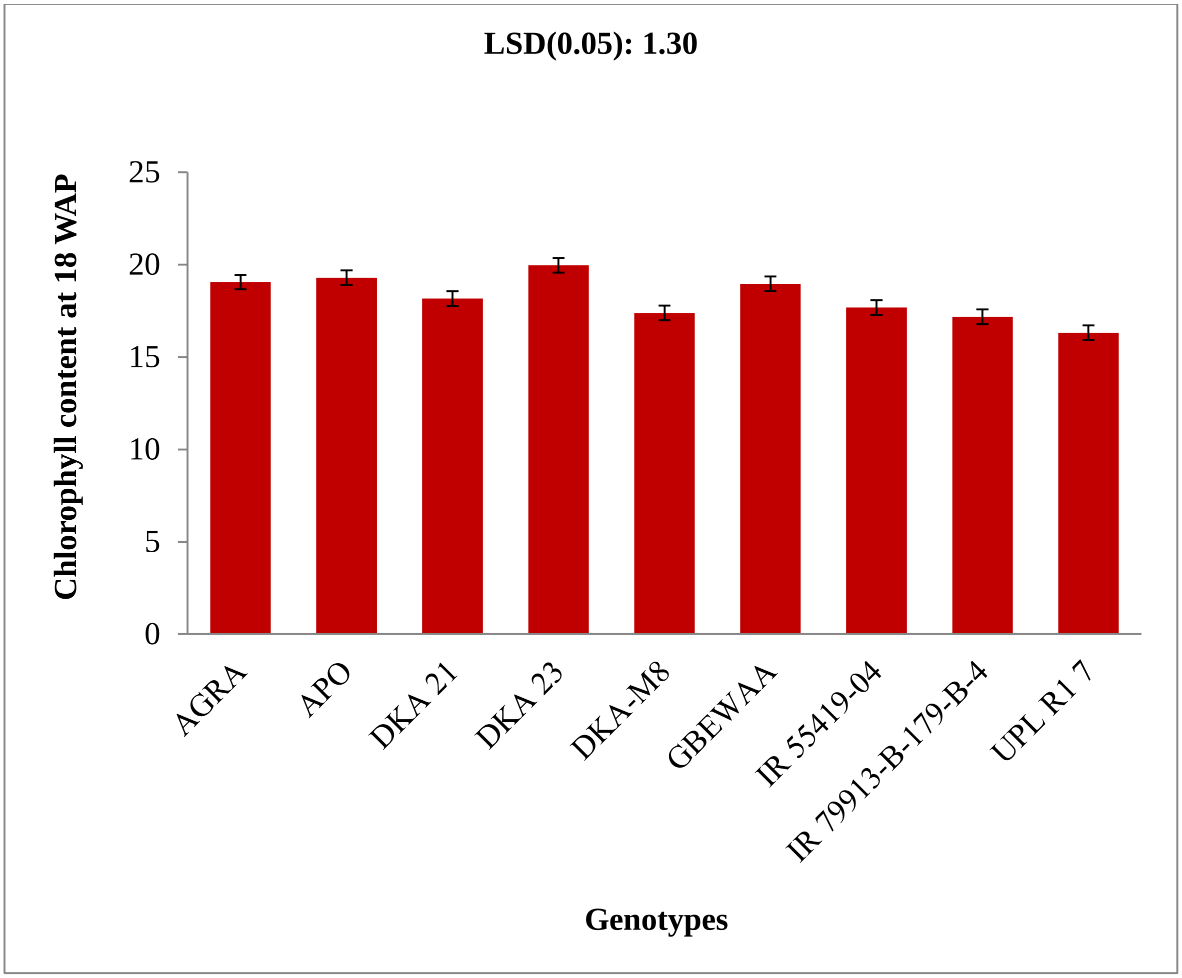

Figure 4.44: Chlorophyll content of rice genotypes evaluated in Nyankpala. Error bars represent means ± standard error of means (S.E.M).

CHAPTER FIVE

DISCUSSION

5.1 Vegetative growth of rice

Results clearly showed that moisture stress affected plant height. Plant height reduced by up to 12% due to moisture stress at 14 weeks after planting. This work supports the findings of Sokoto and Muhammad (2014) who reported in their study that water stress resulted in significant reduction in plant height. Singh *et al.* (1995) also observed that moisture stress significantly reduced plant height by about 19% in relation to well-watered treatment. Prasad and Staggenborg (2008) also concluded that drought stress can reduce the growth of stems and height. According to Bhatt and Srinivasa-Rao (2005), Bouazzama *et al.* (2012) and Hussein and Alva (2014), the decrease in height might have resulted from the decrease in cell enlargement as a result of insufficient water and nutrients.

The genotypic difference recorded in plant height for this study is in line with the study of Sokoto and Muhammad (2014) who reported that moisture stress varies with respect to variety type, intensity, stress period and growth stage of the rice plant. Variation recorded in plant height of genotypes indicates that different varieties responded differently to the different soil moisture stress levels (Singh *et al.*, 1995). Prasad and Staggenborg (2008) also stated that differences in plant height recorded among different species could be due to the effects of water stress at vegetative growth.

The result of the interaction of soil moisture stress and genotypes agrees with the findings of Zubaer *et al.* (2007) who reported interaction effect on soil moisture and genotypes in their study. Moisture stress affected the height of rice with significant differences across genotypes and treatment effects. This is also in agreement with the findings of Bhatt and Srinivasa-Rao (2005).

The results of this study showed that number of tillers decreased with decreasing soil moisture. Reduction in soil moisture could have negatively affected assimilate production because of the eventual lowering of photosynthetic rate Wang *et al.* (2002). Insufficient water uptake by plants in moisture stress conditions might have also negatively affected cell division of meristematic tissues as was reported by Hossain (2001) that tiller reduction was associated with moisture stress.

The study showed that moisture stress affected leaf number of rice. The result agrees with Zubaer *et al.* (2007) who reported that leaf number varied significantly with soil moisture stress. The reduction in leaf number could be due to impedance in photosynthetic activities and assimilates production which normally occurs in drought conditions (Hossain, 2001). The results also indicated that genotypes have different ability to produce leaves under different moisture stress levels (Hossain, 2001; Zain *et al.*, 2014).

The study further revealed that root length decreased as water deficit increased. This result agrees with findings of Kato and Okami (2011) who reported that the two main morphological components of rice root system such as adventitious root and lateral root were negatively affected by moisture stress with a resultant effect of a significant reduction of total root length. Gu *et al.* (2017) also observed a similar trend where well-watered rice fields produced the longest root compared to the root produced in dry condition. This could be due to the uncoupling effect of leaf carbon production and its use in root during continuous stress (Muller *et al.*, 2011).

There was a genotypic variation to water stress in terms of tolerance among the varieties. The variation could be due to the structure of the roots. This finding is supported by reports of studies by Gowda *et al.* (2011) and Lilley and Fukai (1994) who reported that variations in genotypic water uptake in moisture stress culture could be due to root architecture.

The study also showed that well-watered plants had higher root weight per stand compared to moisture stressed plants. Root weight per stand decreased with increasing soil water deficit. Similar trend was reported by Gu *et al.* (2017) as they reported that root length of moisture stressed plants produced fewer root biomass. The result also conforms with the findings of Suralta and Yamauchi (2008) that nodal root formation was impeded in drought conditions which influenced the production of total root biomass. These differences in root length of genotypes following water stress might be due to minimal oxygen supply coupled with physical barrier (hardpans) that makes exploitation of deeper soil layers inaccessible, hence decreasing plant biomass production (Samson and Wade, 1998).

Leaf area decreased with increasing soil moisture deficit. These results agreed with the findings of Bunnag and Pongthai (2013). They reported that drought stress suppresses leaf expansion which negatively affected total biomass production, and this can be attributed to the low rate of photosynthetic activities in drought conditions. Sinaki *et al.* (2007) also reported that drought conditions caused reduction in fresh shoot and leaf area of plants due to low photosynthetic rate.

Leaf rolling was also high in drought conditions compared to well-watered conditions. This agrees with the findings of Lafitte *et al.* (2003) who observed that soil moisture stress led to leaf rolling which is a simple expression of leaf wilting.

The fewer biomass produced under moisture stressed conditions could be linked to low nutrition and photosynthetic activities coupled with oxidative tissue damage in drought environment leading to dead of leaves, tillers and stunted growth (Surajit, 1981). Sinaki *et al.* (2007) stated that drought stress reduced rice growth and severely affected traits such as biomass production, stomatal opening, metabolic activities and plant water relations. This agrees with Zubaer *et al.* (2007). They reported that there is decrease in fresh shoot and dry matter production under water deficit conditions.

In this study the results show that, well-watered plants recorded higher chlorophyll content compared to those under water stress. This is in agreement with the findings of Nurul *et al.* (2014), who reported that prolonged drought period lowered total chlorophyll content and also affected chlorophyll a/b ratio (Chlorophyll “a” is primary photosynthetic pigment while chlorophyll “b” is the accessory pigment that collect energy and passes it to chlorophyll a). The reduction of chlorophyll content recorded for the study under moisture stress condition could be due to the leakage of plant electrolyte under (Petrov *et al.*, 2012).

5.2 Earliness of rice growth

The genotypes that received necessary water requirement happened to flower earlier than those under moisture stress. Days to 50% flowering increased with increasing soil moisture stress. This result supports the work of Pascual and Wang (2016) who reported that heading was first observed in continuous watering relatively to water stress treatment regimes. The delay observed in flowering under moisture stress could be due to the limited movement of assimilates for effective reproductive functions (Rahman *et al.*, 2002).

Flowering time is one of the key components to consider when selecting for resistant cultivars in rainfed lowland rice (Fukai *et al.*, 1999). The result of this study indicated that different varieties reacted differently to moisture stress and days to 50% flowering varies from 77 to 109 days among the genotypes. This result is in conformity with the findings of Sikuku *et al.* (2010) who reported that genotypes showed differences in days to flowering at different moisture levels and therefore water deficit affected the number of days to 50% flowering. The present results also agree with the findings of Abdul Rahim *et al*. (2010) who stated from their experiment on evaluation and characterization of advanced mutant line of rice under drought condition that, days to flowering were delayed by water deficit. The study also revealed that, there were variations in days to maturity among rice genotypes and moisture levels. Water stressed plants took a relatively longer days to mature compared to well-watered plants. As was recorded for this study water deficit has been linked with the late heading, flowering and maturity of plants (Fukai *et al.*, 1999).

5.3 Components of rice yield

The result further indicated that soil moisture stress affects the number of panicles produced by rice plant. Well-watered plants had more panicles relative to those subjected to moisture stress. Varieties also responded differently to moisture stress. These results support the of Rahman *et al.* (2002) and Islam *et al.* (1994) who reported that number of filled grains reduced significantly under water deficit situation. The result is also in line with RRDI (1999) who reported that moisture stress prior to panicle initiation or after panicle intiation affected number of panicle produced.

Soil moisture deficit affected panicle length of rice at maturity. Well-watered plants produced longer panicles than moisture stressed plants with panicle length decreasing with increasing moisture stress. The result is in conformity to that of Islam *et al.* (1994) who reported that moisture stress led to decreased panicle length. Genotypes reacted differently to soil moisture stress. The variation in panicle length under soil moisture stress agrees with the findings of Rahman *et al.* (2002) who reported that varietal differences existed in panicle length under different moisture stress regimes. Sikuku *et al.* (2010) also observed that water moisture stress affected panicles and lowered their yields.

Panicle grains were also influenced by soil water deficit. The result indicated that well-watered plants produced more grains per panicle compared to moisture stressed plants. Rahman *et al.* (2002) also stated that panicle number, panicle length, filled grains per panicle, 1000 grain weight, and yield were significantly reduced under water deficit. Well-watered plants had more filled grain ratio percentage compared to those subjected to water deficit. Grain filling showed a total reduction with increasing moisture stress. The study supports the findings of other studies such as Rahman *et al.* (2002) and Islam *et al.* (1994) who reported that grain filling per plant was significantly affected by moisture stress at all stages especially post flowering. The reduction in this trait is due to the disruption in translocation of nutrients to the sink which increased the emptiness of the grains (Fukai *et al.*, 1999).

Genotypic differences in terms of grain filling showed different genetic potential associated with different genotypes in their grain filling. This present result agrees with Hossain (2001), Yamboo and Ingram (1988), Begum (1990) and Islam *et al.* (1994) who all reported that moisture stress regimes affected grain filling of plants, but the degree of impact differed between genotypes. The result also agrees with Fukai *et al.* (1999) who reported that water deficit at any stage of plant growth affected water and nutrients translocation which tends to increase empty grains. Hossain (2001) explained that this is due to inactive pollen grain from incomplete development of pollen tube as a result of insufficient nutrients supply.

5.4 Grain yield of rice

Well-watered plants had more grain yield compared to those grown under moisture stress. Grain yield decreased with increasing water deficit. Boonjung and Fukai (1996) also reported that moisture stress reduced mean grain weight by 21% at vegetative stage and grain filling stage but moisture stress at flowering reduced grain weight further to 50%. Bouman and Toung (2001) also reported that rice crops are very sensitive to water stress and therefore caused huge grain losses. Yeo *et al.* (1996) observed that water deficit reduced yield in *Oryza sativa*. The low grain yield under water deficit treatments in the present study could be due to the fewer ears bearing tillers, grain number and high empty grains recorded (Sikuku *et al.*,2010). It might also be due to limited photosynthetic activities and less assimilates translocation towards grain as a result of moisture stress (Zubaer *et al.*, 2007).

There were variations in genotypes for grain yield production, which shows that different genotypes have different level of tolerance to soil moisture stress. Some genotypes exhibited more superiority in their capacity for sink formation such as panicle length, grain weight, grain number and filled grain than other genotypes despite being under moisture stress conditions (Sikuku *et al.*, 2010). Pirdashti *et al.* (2004) also reported that cultivars differed significantly in their inherited yield potentials and these are very important in assessing genotypes for their tolerance to moisture stress.

CHAPTER SIX

6.1. CONCLUSION

Moisture stress negatively affected growth, grain yield and yield components of rice genotypes. Well-watered plants performed better as compared to moisture stressed plants. 100% CWR gave the highest records for most of the parameters studied, followed by 100% CWR-split, 80%CWR and then 60%CWR in that order. Yield components such as number of panicles, panicle length, number of grain/panicles, number of filled grain and grain yield reduced with increasing soil moisture stress. Other parameters such as plant height, number of tillers, number of leaves, leaf area, root length, root dry weight, upper biomass dry weight and chlorophyll content also reduced with intensifying soil moisture stress. Days to 50% flowering and maturity also increased with increasing soil moisture stress. The present work revealed that DKA 23, UPL R1 7, DKA 21, IR 55419-04 and APO were the most tolerant genotypes to moisture stress in terms of grain yield. Likewise, DKA 23, DKA 21, UPL R1 7, Gbewaa and DKA-M8 recorded the highest number of panicles per hill among the genotypes. APO, AGRA, DKA-M8, Gbewaa and DKA 23 also proved to be more tolerant in grain filling. The result also revealed that DKA 23, Gbewaa, UPL R1 7, IR 79913-B-179-04 and APO maintained the highest number of leaves at maturity. DKA 23, UPL R1 7 and APO displayed high resistance to leaf rolling while UPL R1 7 and APO had the largest leaf area. Again, DKA 23, Gbewaa, UPL R1 7, IR 79913-B-179-B-4 and DKA 21 produced the highest tiller number of all the genotypes. Chlorophyll content at maturity were seen to be high in DKA 23, APO, AGRA, Gbewaa and DKA 21 despites being subjected to soil moisture stress.

In conclusion, it can be said that DKA 23, UPL R1 7, APO and DKA 21 are drought tolerant genotypes but DKA 23 has proven to be the most tolerant genotype to soil moisture stress since it recorded the highest performance in several parameters such as number of tillers, number of leaves, number of panicles, grain yield and chlorophyll content at maturity. Therefore, these varieties can be cultivated in drought prone areas of Northern Ghana.

6.2 RECOMMENDATION

The study should be extended to the field to determine tolerant genotypes under field conditions. Multi-locational trial should also be conducted to determine their tolerance to drought across the two agroecological zones in Northern Ghana.

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APPENDICES

Appendix 1: Analysis of variance for days to 50% flowering of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.556	1.778	0.81	
Rep.*Units* stratum					
Genotypes	8	8989.833	1123.729	509.32	<.001
CWR_%	3	856.769	285.590	129.44	<.001
Genotypes∗CWR_%	24	116.315	4.846	2.20	0.006
Residual	70	154.444	2.206		

Appendix 2: Analysis of variance for Plant height at 10 WAP of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	58.239	29.120	4.62	
Rep.*Units* stratum					
Genotypes	8	3442.609	430.326	68.20	<.001
CWR_%	3	1188.816	396.272	62.80	<.001
Genotypes∗CWR_%	24	286.074	11.920	1.89	0.021
Residual	70	441.681	6.310		

Appendix 3: Analysis of variance for Plant height at 14 WAP of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	149.61	74.80	2.64	
Rep.*Units* stratum					
Genotypes	8	7765.24	970.66	34.21	<.001
CWR_%	3	4571.81	1523.94	53.70	<.001
Genotypes∗CWR_%	24	1174.95	48.96	1.73	0.041
Residual	70	1986.38	28.38		

Appendix 4: Analysis of variance for Plant height at 18 WAP of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	3.11	1.56	0.09	
Rep.*Units* stratum					
Genotypes	8	18324.99	2290.62	135.82	<.001
CWR_%	3	3046.77	1015.59	60.22	<.001
Genotypes∗CWR_%	24	194.44	8.10	0.48	0.977
Residual	70	1180.59	16.87		

Appendix 5: Analysis of variance for tiller count per hill of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	69.796	34.898	4.58	
Rep.*Units* stratum					
Genotypes	8	987.852	123.481	16.20	<.001
CWR_%	3	1494.630	498.210	65.37	<.001
Genotypes∗CWR_%	24	64.370	2.682	0.35	0.997
Residual	70	533.537	7.622		

Appendix 6: Analysis of variance for number of leaves per hill at booting of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1668.8	834.4	7.30	
Rep.*Units* stratum					
Genotypes	8	23314.0	2914.3	25.50	<.001
CWR_%	3	11759.7	3919.9	34.30	<.001
Genotypes∗CWR_%	24	797.2	33.2	0.29	0.999
Residual	70	8000.4	114.3		

Appendix 7: Analysis of variance for number of leaves per hill at flowering of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1363.2	681.6	6.10	
Rep.*Units* stratum					
Genotypes	8	22470.9	2808.9	25.15	<.001
CWR_%	3	16820.5	5606.8	50.21	<.001
Genotypes∗CWR_%	24	888.8	37.0	0.33	0.998
Residual	70	7816.7	111.7		

Appendix 8: Analysis of variance for number of leaves per hill at maturity of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1416.7	708.3	6.46	
Rep.*Units* stratum					
Genotypes	8	18851.5	2356.4	21.48	<.001
CWR_%	3	23569.1	7856.4	71.60	<.001
Genotypes∗CWR_%	24	1068.0	44.5	0.41	0.992
Residual	70	7680.3	109.7		

Appendix 9: Analysis of variance for panicle count per hill of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	7.056	3.528	0.63	
Rep.*Units* stratum					
Genotypes	8	588.333	73.542	13.08	<.001
CWR_%	3	1283.880	427.960	76.11	<.001
Genotypes ∗CWR_%	24	121.370	5.057	0.90	0.602
Residual	70	393.611	5.623		

Appendix 10: Analysis of variance for panicle lenght of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	49.087	24.543	17.94	
Rep.*Units* stratum					
Genotypes	8	159.577	19.947	14.58	<.001
CWR_%	3	413.520	137.840	100.75	<.001
Genotypes∗CWR_%	24	26.546	1.106	0.81	0.714
Residual	70	95.773	1.368		

Appendix 11: Analysis of variance for number of grains per panicle of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2984.0	1492.0	7.91	
Rep.*Units* stratum					
Genotypes	8	17974.8	2246.8	11.92	<.001
CWR_%	3	58518.7	19506.2	103.45	<.001
Genotypes∗CWR_%	24	6381.1	265.9	1.41	0.135
Residual	70	13199.3	188.6		

Appendix 12: Analysis of variance for number of filled grains per panicle of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	21.63	10.81	0.61	
Rep.*Units* stratum					
Genotypes	8	4391.80	548.97	31.22	<.001
CWR_%	3	4615.41	1538.47	87.48	<.001
Genotypes∗CWR_%	24	4009.09	167.05	9.50	<.001
Residual	70	1231.04	17.59		

Appendix 13: Analysis of variance for root length of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	913.12	456.56	44.12	
Rep.*Units* stratum					
Genotypes	8	1048.32	131.04	12.66	<.001
CWR_%	3	7242.08	2414.03	233.29	<.001
Genotypes∗CWR_%	24	129.85	5.41	0.52	0.961
Residual	70	724.35	10.35		

Appendix 14: Analysis of variance for root weight (dry) of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4495.35	2247.68	100.98	
Rep.*Units* stratum					
Genotypes	8	1850.57	231.32	10.39	<.001
CWR_%	3	1682.42	560.81	25.19	<.001
Genotypes∗CWR_%	24	74.04	3.08	0.14	1.000
Residual	70	1558.13	22.26		

Appendix 15: Analysis of variance upper biomass weight (dry) of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	137.24	68.62	3.69	
Rep.*Units* stratum					
Genotypes	8	1118.80	139.85	7.52	<.001
CWR_%	3	2374.76	791.59	42.57	<.001
Genotypes∗CWR_%	24	139.44	5.81	0.31	0.999
Residual	70	1301.54	18.59		

Appendix 16: Analysis of variance for grain weightper hill of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	277.567	138.783	70.23	
Rep.*Units* stratum					
Genotypes	8	812.607	101.576	51.40	<.001
CWR_%	3	1064.772	354.924	179.60	<.001
Genotypes∗CWR_%	24	84.884	3.537	1.79	0.031
Residual	70	138.333	1.976		

Appendix 17: Analysis of variance for spad value at 10 WAP of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	82.78	41.39	3.01	
Rep.*Units* stratum					
Genotypes	8	513.38	64.17	4.67	<.001
CWR_%	3	407.45	135.82	9.88	<.001
Genotypes∗CWR_%	24	29.10	1.21	0.09	1.000
Residual	70	962.66	13.75		

Appendix 18: Analysis of variance for spad value at 14 WAP of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	30.542	15.271	7.21	
Rep.*Units* stratum					
Genotypes	8	200.897	25.112	11.85	<.001
CWR_%	3	393.662	131.221	61.92	<.001
Genotypes∗CWR_%	24	11.257	0.469	0.22	1.000
Residual	70	148.345	2.119		

Appendix 19: Analysis of variance for spad value at 18 WAP of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	113.290	56.645	22.08	
Rep.*Units* stratum					
Genotypes	8	133.819	16.727	6.52	<.001
CWR_%	3	793.461	264.487	103.08	<.001
Genotypes∗CWR_%	24	18.567	0.774	0.30	0.999
Residual	70	179.610	2.566		

Appendix 20: Analysis of variance for leaf rolling of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.1296	0.0648	0.36	
Rep.*Units* stratum					
CWR_%	3	495.2870	165.0957	921.80	<.001
Genotypes	8	15.7963	1.9745	11.02	<.001
Genotypes∗CWR_%	24	44.7963	1.8665	10.42	<.001
Residual	70	12.5370	0.1791		

Appendix 21: Analysis of variance for leaf area of rice genotypes planted in Nyankpala for screening of drought tolerant varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.577	2.789	0.44	
Rep.*Units* stratum					
CWR_%	3	836.365	278.788	43.90	<.001
Genotypes	8	1356.356	169.544	26.70	<.001
Genotypes∗CWR_%.	24	90.169	3.757	0.59	0.924
Residual	70	444.498	6.350		