VARIATION FOR DROUGHT TOLERANCE IN RICE (*Oryza sativa* L.) GENOTYPES EVALUATED UNDER WELL-WATERED AND DROUGHT STRESSED ENVIRONMENTS

By

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DECLARATION:

I declare that the work contained in this thesis is my own original work and has not been previously in its entirety or in part be submitted at any other university or institution for a degree. All references cited in the text have been duly acknowledged.

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DEDICATION:

This work is dedicated to my lovely husband, Mr. Charles K. Ng’etich and son Alvin Kipruto. Their support, prayers and encouragement have been outstanding.

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LIST OF ABBREVIATIONS:

AEC	Average Environment Coordination
AMMI	Additive Main Effect and Multiplicative Interactive Analysis
ASV	AMMI Stability Variance
D. precoce	Duorado precoce
GEA-R	Genotype by Environment Analysis for R-windows.
GEI	Genotype by Environment Interaction
GXE	Genotype by Environment
IPCA	Interaction Principal Component Analysis
KATRIN	Kilombero Agricultural Training and Research Institute
Kom.	Komboka
MOA	Ministry of Agriculture
MWUR	Mwea Upland Rice
Ner.	NERICA
NERICA	New Rice for Africa
WARDA	West African Rice Development Association

ABSTRACT:

Rice is one of the principal foods to over 60% of the world inhabitants and is mostly produced under semi-aquatic conditions and its production is water intensive. In Kenya, the key abiotic stress affecting rice production is drought stress which is experienced mainly during reproductive phase of the crop. This study evaluated the performance of advanced lines and segregating populations under well-watered and drought stressed environment with the aim of identifying the phenotypic traits that confer drought tolerance in rice.

19 crosses, 6 parents and 5 checks rice (*Oryza sativa* L.) lines were evaluated for response to drought under two environments: drought stressed and well-watered environment over two seasons in the year 2016/2017 at Kenya Agricultural Livestock Research Organization (KALRO) -Mwea Centre. The experiment was laid down in an alpha lattice design with three replications. Drought stress was imposed at panicle initiation in the drought stressed environment by withholding irrigation whereas in the well-watered environment irrigation was applied throughout from planting to physiological maturity. There were significant variations among genotypes, between seasons and conditions (well-watered and drought stressed), and interaction of season x condition x genotype for agronomic, yield and yield related parameters at $p<0.05$. A mean of 90.6cm of plant height was recorded by genotypes in the well-watered environment while those under drought stress recorded a mean of 88.8cm in plant height. Traits such as number of tillers (15.8), days to flowering (102.5 days), panicle length (20.00cm), flag leaf length (26.1cm), number of panicles per plant (16.3), biomass(42.3g), percentage spikelet fertility (78.1%), 1000-grain weight (27.6 grams) and grain yield (5.4t/ha) were significantly decreased under drought stress to 9.9,100.2 days, 18.8cm, 21.4cm, 12.4, 23.8 grams, 51.9%, 22.2 g and 1.6 t/ha respectively.

Phenotypic correlation coefficient results show that under drought stress, there was a significant negative correlation between plant height and number of tillers (r= -0.607), days

to flowering (r=-0.678), number of panicles (r=-0.234) and biomass (r= -0.274) but a positive correlation was observed between plant height and panicle length (r= 0.244), flag leaf length (r=0.264) and grain yield (r = 0.220).

Under well-watered conditions, there was a negative correlation between plant height and number of tillers (r=-0.129), days to flowering (r=-0.177) and number of panicles per plant (r=-0.030). Plant height was positively correlated though not significantly with panicle length and grain yield with r= 0.022 and r=0.032 respectively under well-watered environment.

Additive Main Effects and Multiplicative Interaction (AMMI) analysis of variance for grain yield showed that generation of crosses SARO5 x NERICA11, NERICA 2 x SARO5 and NERICA 15 x SARO5 expressed higher grain yield than genotypes NERICA 2, Komboka x Ner15 and NERICA 2 x NERICA 1. AMMI Stability Variance (ASV) showed that genotypes NERICA 15, Dorado Precoce, NERICA 11 x NERICA 2, SARO5 x Komboka and NERICA 2 x NERICA 11 were the most stable.

Genotype and Genotype Environment (GGE) showed that Principal Components (PC1) and PC2 accounted for 96.46% and 3.54% respectively. From the biplots, drought stressed environment and well-watered environment were positively correlated, meaning that these two environments had an impact on grain yield. GGE biplots ranked the19 crosses, 6 parents and 5 checks rice lines as follows: those above average in performance, the stable ones, unstable and those below average in performance. SARO5XNERICA11 is worth for selection due to its high mean value and is stable across the mega-environments.

GGE biplots analysis gives a graphical biplot analysis which makes genotype by environment interaction study easy and is recommended as one of the most appropriate analysis to evaluate genotypes under different target environment (Maqbool et al., 2015).

The results in this study showed that genotypes from generation of crosses of NERICA 1 x SARO5, SARO5 x NERICA 11, NERICA 15 x SARO5 and Komboka x NERICA 15 had superior traits such as high yields in tonnes per hectare and also exhibited superiority in traits such as panicle length, plant height, flag leaf length and 1000-grainweight under drought stress.

CHAPTER ONE:

1.0: INTRODUCTION

1.1: Background information

Rice is among the three most important cereals worldwide including wheat and maize (Guimaraes, 2009). Rice is produced under semi-aquatic conditions and its production is water intensive. Rice is grown mainly for food, as a source of carbohydrate or energy and is served in various forms in different rice eating communities.

Rice is also utilized in making of cereals for breakfast, pasta, syrups and rice starch; bran for cattle feed and as a medium for growing various organisms such as mushrooms and enzymes. Rice bran makes up five to eight percent of the total grain weight and the hulls and husks are used as fuel. Rice is an important component in the making of cement, ceramics and concrete building blocks. In Kenya, bran which is used as animal feed accounting for five to ten percent of total use (FAO, 2004, (GRiSP (Global Rice Science Partnership), 2013) (Olembo et al., 2010)).

Nutritional benefits of rice are vitamin Bs (niacin, riboflavin and thiamine), low fat content, and proteins (FAO, 2004). The insoluble fibre in rice prevents constipation and decreases the chances of bowel discomfort. Rice is susceptible to fungus and insect pests and to salinity, drought and oxidative stresses (Ansari et al., 2015).

The key abiotic stress affecting rice is drought (Mostajeran and Rahimi-Eichi, 2009). Drought can be described as a weather-related incidence of prolonged periods of lack of rainfall which ultimately results in reduced soil moisture content. Drought stress leads to reduced water potential in plant tissues (Haider et al., 2014). Drought stresses in rice occur due to high transpiration rates and lack of water supply to the roots. This results in impaired development and growth of the crop leading to reduced production (Wanjohi, 2013).

There are several strategies that have been employed in order to raise crop yields in drought prone areas. These include reducing evaporation by mulching, better management of water resource, use of advanced irrigation methods and schedules and breeding cultivars of high-water use efficiency and drought tolerance. Among these strategies, breeding varieties that are water use efficient and are drought tolerant is more economical and practical than the other strategies (Condon et al., 2002).

One of the strategies employed when developing drought tolerant cultivars involve the transfer of desirable traits of wild rice into cultivated ones (Liu et al., 2015). A drought resistant variety does not require flooding making it a viable entity for rice production in Africa given the climate change patterns (Fischer et al, 2003). A drought tolerant variety must be efficient and stable under insufficient soil moisture.

Interactions of various morphological, biochemical and molecular characteristics makes the drought tolerance trait in rice complex. These interactions, under drought stress result into reduced grain yield, grain weight, reduced grain size, grain filling rate, increased sterility of spikelet and impaired translocation of assimilates (Blum, 2011). In previous work, drought resistant cultivars have been referred to as those that have deep root systems, low tillering potential and high leaf sheath to leaf blade ratio (Mambani and Lal, 1983).

When a crop experiences drought stress in early stages, germination is affected and hence reduced plant population leading to low grain yield. Drought stress at flowering stage increases pollen sterility leading to low yield. The most susceptible reproductive phases are booting stage, anthesis through to flowering and early stage of grain ripening (Farooq et al., 2012)

The International Rice Research Institute (IRRI) have in the past utilized drought tolerant donors namely, N22, Dagad Deshi, Moroberekan, Aus 276, Vandana, Apo, and IR55419-04 to transfer drought tolerance into popular varieties such as IR64, Swarna, TDK1, MTU1010, Sambha Mahshuri and Sabitri in various Asian countries (Babu et al.,2010).

IRRI has not only bred high yielding varieties for drought stressed conditions but has also developed cultivars for irrigated conditions. One of the approaches at IRRI involves hybridization followed by screening of large segregating material under drought and irrigated conditions with drought-susceptible varieties as checks. From these trials, cultivar IR74371-70-1-1 have been in India, Bangladesh and Nepal (Shalabh et al., 2014).

The present study evaluated rice genotypes grown in Kenya and experimental progenies in advanced generations under drought-stressed and well-watered environments in order to determine the phenotypic traits that confer drought tolerance and yield stability.

1.2: Problem statement

Kenya is prone to drought stress and is classified as Arid and Semi-Arid Lands (ASALs) in that only 20% of the country receives optimal and regular rainfall while the rest 80% receives 200-500mm annual rainfall. Seventy-five percent of the Kenyan population is supported by rain-fed agriculture which is mainly affected by drought (Hubo and Mugalayi, 2014). The frequency and severity of drought stress in the country is increasing with time resulting in crop failures and death of livestock and ultimately to food shortage. Drought in Kenya affects all sectors of economy including food insecurity and results into unavailability of jobs, deterioration of human health due to malnutrition poor access to quality water and deaths of humans and livestock (Mbogo et al, 2014).

In Kenya, Mwea irrigation scheme produces over 60% of the country's rice production. During 2009 and 2011, Kenya was affected by a severe drought which adversely reduced agricultural production with Mwea irrigation scheme recording a decrease of 50% in production (FaoLand &water, 2013). This was attributed to decreased water levels in the main rivers Nyamindi and Thiba supplying the canals (Gitonga, 2017). In this period, the National Irrigation Board (NIB) reported that rice production at Mwea dropped from 830,000 metric bags to 498, 000 metric bags. This reduction in the yields led to increase in the market price of rice from Ksh. 145 to Ksh.220 per kilogram of Basmati rice. In the same period imports increased from 261,819 metric tons to 353,082 metric tons (Andae, 2017).

A social survey by Ministry of Agriculture (MOA) and Japan International Cooperation Agency (JICA), 2011 conducted in Mwea noted that water shortage in Mwea irrigation scheme is a major concern. In order to mitigate future drought spells, National Irrigation Board (NIB) intends to supplement the current irrigation needs by constructing Thiba dam to supply about 30 billion cubic metres of water per season. The most plausible solution to rice production under drought stress in the long term remains to be breeding drought tolerant varieties.

1.3: Justification

In Kenya, rice consumption outweighs the production and therefore the deficit is met by importations from Pakistan, Indian and Egypt (Muhunyu, 2012, Onyango 2014). The Africa Rice Centre has attempted in recent years to introgress drought tolerance from *Oryza sativa* (African germplasm, tolerant to iron toxicity, adverse climatic conditions and resistance to biotic stresses) into *Oryza glaberimma* (Asian germplasm and high yielding) and resulted into new rice variety, NERICA (New Rice for Africa) which expressed drought tolerance characteristics in both vegetative and reproductive phases.

NERICA and other drought tolerant rice germplasm have also been availed in East and Southern Africa (ESA) including Kenya, Uganda and Tanzania through the evaluation and selection of IRRI-bred lines. For instance, in Tanzania Komboka and Tai rice varieties have been released by the National Rice Research Program- KATRIN Research Centre in 2011. In addition to being drought tolerant, Komboka and Tai cultivars are also high yielding and resistant to diseases such as bacterial blight and leaf blast, can be grown twice a year and mature earlier than SARO5, a local variety.

Little has been done on breeding drought tolerant rice in Kenya although KALRO has played a major role in maintaining introduced popular varieties such as NERICA varieties 1,4 ,10 and 11. Malemba et al., (2017) at KALRO-Mwea conducted a multi-location trial of F_2 lines and observed that NERICA 2 and NERICA 15 were good combiners for drought tolerance and grain yield under drought conditions. At KALRO-Mwea, generation of crosses between upland varieties, NERICA 1 and NERICA 10, have resulted into development of the cultivar MWUR3 (Mwea Upland Rice) which has been recommended as being for upland conditions.

1.4: Objectives

1.4.1: General objective

To develop drought tolerant lines through evaluation of segregating populations under well-watered and drought-stressed environment.

1.4.2: Specific objective

1. To evaluate the performance of advanced lines under well-watered and drought stressed environment.

1.5: Research questions

i. Which phenotypic traits are important in the selection of drought tolerance in rice?

ii. Are drought related traits correlated with grain yield?

iii. Is grain yield of the drought tolerant genotypes stable across all the environments?

1.6: Hypothesis

i) Agronomic performance of the segregating lines under drought stress and well-watered environment do not vary.

ii) Drought related parameters are not positively correlated with yield.

iii) Grain yield of segregating rice lines are not stable across drought stress and well-watered environment.

CHAPTER TWO:

2.0: LITERATURE REVIEW

2.1: Rice production in the world

United Nations estimates that the world's population is approximately 7 billion and growing at a rate of 3% annually in developing nations (Talpur et al., 2011). Rice provides daily calories of 50 to 80% to the world's population therefore emerging as an important crop globally (FAO, 2004). Rice is grown in 113 countries in the world (FAO, 2004) with over 90% of rice crop being produced and utilized in Asia (Pandey et al., 2007). The world's total rice production is accounted for by four categories of rice including glutinous, aromatic, indica (most dominant globally), and japonica (Childs, 2001).

Rice consumption in the world has risen from 50Kgs to 60 Kgs per capita per year between 1960s and 1990s. In Asia, consumption of rice shows a steady increase from 85Kgs per capita to 103 Kgs per capita per year during similar times. In 2012, the area devoted to production of rice in the world was 158.4 million ha and the yield was 697 million tons (Pandey et al., 2007).

Table 1: Statistics of production and exports in the world as per 2017

Country	Production(1000MT)	EXPORTS (1000MT)
China	143,582.00	1800
India	111,000	12,500
Indonesia	37,300	2
Bangladesh	34,500	4
Vietnam	29,069	7,000

Key: MT= Metric tons. Source: https://www.indexmundi.com/kenya/agriculture_products.html

Asian continent dominates in rice production in the world with China and India leading (Worldatlas, 2017). These statistics in Table 1 show the leading milled rice producing countries in the year 2017/2018. China is the world's largest milled rice producer at 144 MT (Statista, 2018). The other leading milled rice producing countries include: Thailand, Burma, Philippines, Cambodia and Pakistan.

Most of the rice is produced on poor soils. Rice production is done under different conditions for instance about 26 million hectares is on irrigated land, about 19 million is on rain-fed lowlands and 8 million hectares on upland areas (Haefele et al., 2014). There are several constraints affecting rice production, these include

Low temperatures in tropical and sub-tropical areas which damage rice at all growth stages (Ferrero and Nguyen, 2004). Farmers in these regions apply cultural practices such as planting depth to avoid decreased temperatures. Climate change over the years has led to decreased grain fertility and weak establishment of rice crops. An increase in world population has led to an increase in use of water per household, this results in reduction of water needed for agriculture. Water scarcity results in drought stress hence a decrease in rice production. Biotic stresses such as diseases (stem rot and blast), animal pests (rice leaf miner and tadpole shrimp) and weeds (*Alisma plantago-aquatica* and *Bolboshoenus maratimus*) *(*Tran, 1997) affect rice production. Europe and Southern Asia countries have experienced high cost of rice production as a result of increased cost of inputs such as labour, seed, chemicals and fertilizers.

2.2: Rice production in Kenya

By the year 2013, rice per capita consumption in countries in Sub-saharan Africa had increased by over 50% (Mohanty, 2013). In Kenya, Ministry of Agriculture (MOA) and NIB in Onyango (2014) estimates that national rice consumption was at 300,000 metric tons with yearly production ranging from 45,000 metric tons to 80,000 metric tons.

Table 2: Statistics of production, consumption and imports of rice in Kenya from 2013 to 2017

YEAR	Production (MT)	Consumption (MT)	Imports (MT)
2013	83,000	510,000	460,000
2014	74,000	535,000	420,000
2015	77,000	570,000	490,000
2016	78,000	670,000	650,000
2017	79,000	750,000	700,000

Key: MT= Metric tons. Source: https://www.indexmundi.com/kenya/agriculture_products.html

Table 1 shows the production, consumption and imports of rice in Kenya from 2013 to 2017. The amount of rice produced ranged from 79,000 metric tons to 83,000 metric tons. Rice consumption recorded a steady increase each year, and as at 2017 consumption was at 750,000metric tons. In order to meet the deficit, Kenya has rice imported from countries such as Pakistan and Vietnam. Table 2 shows that imports increase each year by 2017 and were at 700,000 metric tons by 2017.

According to MOA, only about 105,000 ha of land is utilized for production of irrigated rice yet Kenya has a potential of about 540,000 ha that can support rice production under irrigation. Development of Athi and Tana River basins is likely to expand the size of irrigated land by 1 million hectares (European Co-operative for Rural Development (EuCoRD), 2012)

According to Kenyan Grain and Feed Annual Report (2014), National Irrigation Board (NIB) manages most schemes under rice production which accounts for 95% of rice produced while 5% production is under rain-fed systems.

NIB manages the four main rice irrigation schemes including Mwea, Ahero and West Kano in Nyanza and Bunyala in Western. In the year 2005 to 2010, NIB data shows that Mwea irrigation scheme accounts for 88% of the country’s production with a gross output value of 98%. Rain-fed systems are in the Coastal and the Western regions of the country (National Rice Development Strategy, 2008). The Coastal and Western schemes grow varieties such as ITA 310, Basmati 370 and BW 196.

The major constraints of rice production in Kenya according to USAID, (2012) include:

Adverse climatic change due to global warming which has led to shortage of water for irrigation. Labour scarcity resulting from rural-urban migration has led to increase in cost, since younger and more energetic individuals are moving from rural to urban areas. Increase in cost of labour is also as a result of increased waterborne diseases such as bilharzias and malaria in the rice production schemes. Locally produced rice faces competition in terms of prices from the informal importations from neighboring countries such as Tanzania. Farmer-saved and uncertified seed among farmers has reduced major trading chances and germplasm sharing. Small holder farmers are discouraged from farming rice because of increased inputs such as machinery, fertilizers. This situation is worsened by a steady increase in the prices and poor and inadequate infrastructure such as irrigation, electricity, roads and communication. Low-land rain-fed areas are inaccessible to rice mills hence reduced rice production. Decreased technical knowledge in crop management has also led to decreased rice production in the country (USAID, 2012).

2.3: Effects of drought stress in rice production

Drought stress prevents rice crops from producing maximum grain yield ultimately decreasing the capacity to generate commercial amount of grains. Water stress affects both grain production and quality of rice (Mostajeran and Rahimi-Eichi, 2009, Aduwesi and Nassir, 2011).

Rice is more susceptible to drought stress than other crops due to its shallow and compact root system (lowland/aquatic root system) which are not sufficient to extract water, the grain set is highly sensitive to stress and rice is sensitive to timing of stress (Serraj and Cairns, 2009). The size of land in the world affected by drought has roughly doubled from 1970s to 2000s and has led to decreased grain yield and quality of food crops resulting in food shortage (Akram et al., 2013).

Forty-five percent of the whole rice area in the world which accounts for 25% of the rice produced is under rain-fed condition. A large portion of rain-fed is susceptible to drought, including East of India, Northeast Thailand, Central Myanmar, Laos and Northeast India. Rice is also cultivated under irrigated conditions. (Toung and Bouman, 2001). In Asia, drought affects both rain-fed areas and irrigated areas due to the rising water demands.

Drought affects rice both directly by influencing the physiological processes including growth, development and grain formation and indirectly through incidences of crop insects and diseases and finally the grain yield (Babu, 2010)

The degree of effects of drought stress depends on factors such as variety, drought intensity, period of drought stress and growth development stage which the crop is at. These factors aid in determining on how to improve a crop for drought tolerance. Series of responses are expressed by rice crops as a result of drought stress, these include exhibition of response at cellular level, stress perception, physiological and development levels and signal transduction (Babu, 2010). Drought stress affects the physiology of rice plants in many ways including: destruction of pigments, reduction of stomatal conductance, transpiration and photosynthetic rates, decrease in plant growth, reduction of relative water content and decreased PAR (Hasabuzzaman et al., 2013).

Drought stress causes a yield reduction of up to 30% is recorded when drought stress occurs at vegetative, reproductive and grain formation phase due to decreased number of panicles per unit area (Nokkoul and Wichitparp, 2014). Nokkoul and Wichitparp, (2014) also noted that drought stress delayed anthesis and reduced the number of spikelets per panicle up to 60%. From their study, drought stress affected grain filling which led to a decrease in filled grains by 40% and grain weight by 20%. Khan and Dhurve (2016) observed that moderate drought stress at reproductive phase led to 31% to 64% reduction in grain yield when compared to the rice plants grown under well-watered conditions. Drought stress at vegetative phase also disrupts flower initiation resulting in reduced grain filling and increased spikelet sterility which leads to a decrease in grain weight. (Akram et al., 2013).

Rice is sensitive to water at reproductive stages specifically booting, flowering and panicle initiation (Ndjiondjop et al., 2007). Studies by Ndjiondjop et al., (2007) show that yield reduction up to 70% were observed when drought stress occurred for 15 days at panicle initiation phase, 88% at flowering phase and 52% at grain filling phase.

Water stress affects pollination specifically the meiotic phase leading to flower abortion, grain abscission giving rise to increased number of unfilled spikelets which ultimately leads to a decreased grain yield. Extreme drought stress reduces female fertility (Nguyen and Sutton, 2009). Water stress affects panicle exsertion which results in sterility of unexserted panicles. Panicle exsertion occurs when the panicle reaches maximum length and the peduncle elongates. Drought stress reversibly blocks peduncle elongation. Drought stress tend to delay days to flowering, the early maturing genotypes assume drought escape mechanism in order to avoid terminal drought. These early maturing genotypes have a short growth duration and therefore are able to reduce yield loss caused by drought stress.

Drought stress also reduces stem height, by reducing both the number of nodes and the length between internodes (Jatoi et al., 2012). Water stress leads to reduced stem height and diameter, number of tillers and leaf expansion which cumulatively results in decreased production of biomass by the rice crops (Jatoi et al., 2012). Rice varieties that produce high biomass are able to obtain moisture from soil and transport it up for photosynthesis (Singh et al., 2012). If water is re-introduced after drought stress episodes, morphological characters such as number of productive tillers per hill, flag leaf length, grain size and biomass and yield components such as 1000 grain weight and panicle length are not affected (Momo et al., 2013).

Incidences of nematodes, brown spot and blast have been noted while screening for drought stress. Occurrence of these diseases and pests, necessitates the development of lines that are both resistant to drought and diseases. Such incidences have been solved by maintaining the field under aerobic environment for two-third of the crop growth, changing drought screening fields every three years, cultivating pulses during off-season and using of nematicides in areas where change of soils is not possible (Barnwal et al., 2013).

2.4: Drought tolerance conferring traits in rice

Drought can occur at early, intermittent and late (terminal) season. Understanding traits related with drought avoidance is key when improving rice genotypes for drought tolerance (Kamoshita et al., 2008). Rice crop possesses various adaptation mechanisms for drought stress, for example drought escape using root characteristics and phenology, drought tolerance and drought avoidance (Fukai and Cooper, 1995).

There are several drought tolerance traits adopted by rice crops for instance reduction of water loss by the shoots due to thick cuticle and decreased leaf area, deep roots that can obtain available moisture from the soil and at the tissue level rice crops use of osmotic adjustment to respond to drought stress incidences. (Bernier et al., 2008 and Serraj et al., 2009).

Drought resistance is composed of these three mechanisms. Drought avoidance is characterized by the ability of the genotypes to take up water from the soil and reduce loss of water. This is attained by use of deep and thick rooting systems which can go deeper in soils to extract water. This is applicable for crops in upland conditions (Kamoshita et al., 2008 and Mukahirwa, 2015). Thick cuticles reduce water lose by reducing evapotranspiration (Vikram et al., 2011). Drought avoidance strategies in rice allow them to have a high internal water status

Drought escape mechanism in rice crops is defined by early maturity characteristics; rice genotypes tend to have a reduced growth cycle in order to avoid terminal drought (Allah et al., 2010).

Osmotic adjustment as a result of accumulation of cellular solutes like proline with antioxidant capacity and dehydration tolerance describes drought tolerance in rice crops (Bing et al., 2006). Osmotic adjustment maintains turgor pressure of cells during dehydration and also enables the crops to recover from drying (Vikram et al., 2011). Proline acts as an antioxidative defense molecule, a metal chelator and a signal molecule (Mostajeran and Rahimi-Eichi, 2009). Drought tolerant genotypes release soluble sugars, increased levels of chlorophyll and reduced amounts of malondialdehyde ($CH_2 (CHO)_2$) during drought stress (Mukahirwa, 2015).

Transgenic drought tolerant rice varieties have been developed by inserting AtCYP78A7 gene that encodes for P450 cytochrome protein into rice. These transgenic lines expressed high levels of metabolites such as behemic acid, cysteine, arachidic acid, oleic acid, magnesium, palmitoleic acid and lower amounts of copper and potassium and overexpress trehalose-bosynthetic genes which leads to rise in soluble sugar contents and photosynthetic capacity than their wild types (Nam et al.,2015)

At early stages of drought exposure, rice can synthesize polyamines in their leaves specifically Spm (spermine) and Spd (spermidine) (in free form) and Put (putrescine) (in insoluble-conjugated form). The polyamines aids in alleviating drought stress in rice leading to general improvement of photosynthesis. Transgenic rice with *Datura adc* gene, which encodes for arginine decarboxylase, produce increased amounts of Put under drought stress, which enhances the synthesis of Spm and Spd hence shielding rice from stress (Pandy and Shukla, 2015).

Breeding for drought tolerant rice lines is a slow progress due to inadequacy of effective selection criteria of drought tolerance traits and the low heritability expressed by grain yield during drought stress. Two breeding lines namely IR74371-70-1-1(for India) and IR74371-54-1-1(for Philippines) have been released at IRRI as a result of directly selecting for grain yield in drought conditions (Vikram et al., 2011).

2.5: Physiology and measurement of drought tolerance in rice

Sustainable agriculture is under a major threat globally as a result of lack of water which has led to severe loss in production in agriculture. Comprehending the physiology of drought tolerance when developing crops that are both high yielding and drought tolerant is key when tackling water stress (Yong'an et al., 2010).

Measurement of drought tolerance in rice is based on various physiological, morphological and phenological traits associated with drought stress such as: plant emergence characteristics, phenology of development, nutrient uptake efficiency, photosynthesis, efficiency in water use, discrimination of carbon isotope, hormonal regulation, stay green, osmotic adjustment, grain number maintenance, grain fill duration and rate and yield and its components (IRRI, 2006).

Vegetative phase is characterized by rapid leaf development and the amount of water used is directly proportional to the rate of transpiration. The first stages of a rice plant development to be affected by water stress are stem elongation and leaf growth (very sensitive stages to plant water status). When soil moisture is at 70%, rice's gas exchange is affected unlike other crops which are affected when soil moisture is at 30% (Fischer et al., 2003).

Drought stress affects severely rice plants at about 12 days to 50% flowering and to about seven days after 100% flowering. Therefore, drought tolerance of the crops is measured by recording the date in which 50% of plants have flowered in the plot. Recording the flowering dates aids in pointing crops that have flowered early or late. Late flowering rice crops record low yields less even if the crops are re-watered in the advanced stages (Fischer et al., 2003).

Grain yield is a vital parameter when measuring drought tolerance. Direct selection basing on yield have been used by most cereal breeders to select for high yields under drought stress environment (Aduwesi and Nassir, 2011). Effect of drought stress on the different growth phases of rice results in effect on the different components of grain yield (Davatgar et al., 2009 and Lafitte et al., 2000).

The major parameters for measuring drought tolerance are: Yield and its components which include plant height, number of productive tillers, 1000 grain weight, number of spikelets (filled and unfilled), percentage panicle sterility and panicle length. To obtain 1000 grain weight, random samples from a seed batch are selected then 1,000 whole grains are counted from the sample and finally weighed. Number of spikelets is important parameter when screening for drought tolerance and is used to obtain percentage spikelet fertility. Percentage spikelet fertility gives evidence on genetic responses to drought stress compared to yield. To obtain spikelet fertility, the harvested rice samples are threshed then unfilled spikelets are separated from filled by pressing (Fischer et al., 2003). The filled and unfilled spikelets are weighed or counted. Percentage spikelet fertility is obtained as follows:

$$\text{Percentage spikelet fertility} = \frac{\text{No. of filled grains in the sample}}{\text{No. of filled and no. of unfilled spikelets}} * 100\%$$

$$\text{Number of filled spikelets} = \frac{\text{total weight of filled grains}}{\text{Weight of 100 filled grains}} * 100\%$$

$$\text{Number of unfilled spikelets} = \frac{\text{total weight of filled grains}}{\text{Weight of 100 unfilled spikelets}} * 100\%$$

(Babu et al., 2010).

Root characters include root depth in centimeters, root number per hill, root volume in milliliters, root: shoot ratio, root xylem vessel numbers and root thickness (Aduwesi and Nassir, 2011).

Drought avoidance is one character that helps crops to obtain water deeper in the soils, which depends on root's depth, penetration ability and thickness. Other secondary traits expressed by roots include: osmotic adjustment, greater hydraulic conductance and the thickness of the xylem. These traits enable improved uptake of existing soil water content. Use of most of these traits in a breeding programs is costly due to the heavy investment in green house facilities and field nurseries. Measurement of roots is susceptible to problems of reproducibility due to changes in environment and is demanding in terms of labour (Babu, 2010).

Chlorophyll content or SPAD value is measured when plants have been subjected to water stress (Fen et al., 2015). There is a close correlation between the color of a leaf and nitrogen status of a crop since chlorophyll is made from nitrogen (Wang et al., 2014). Nitrogen is vital for development of rice crops and decreased supply leads to reduced chlorophyll content leading to smaller leaves and decreased biomass which ultimately leads to decreased grain quality and yield (Wang et al., 2014). Water stress decreases photosynthetic pigments such as carotenoids, chlorophyll 'a' and 'b', leaf and shoot weight (both fresh and fresh) which in turn affect photosynthesis (Usman et al., 2013). In the study by Usman et al., (2013) there was a major reduction in fresh shoot mass in rice with increase in water stress.

Leaf chlorophyll concentrations are measured using a hand-held device known as a SPAD-502 meter. SPAD-502 meter measures the amount of chlorophyll by taking the absorbance of the leaf in two wavelength regions, which is non-destructive, accurate and rapid (Ling et al., 2011).

Agro-physiological characters such as plant height in centimeters (cm), panicle length in cm, tiller number per hill, leaf angle measurement, leaf rolling, flag leaf area in cm^2 and flag leaf dry weight in grams are also used to measure drought tolerance (Allah et al., 2010)

Leaf rolling is a visible symptom in which plants that are subjected to water stress express. Leaf rolling occurs when plants are unable to withstand its transpiration demands (Allah, 2011). This response is exhibited by many species including sorghum, wheat and rice (Kadioglu et al., 2011). Leaf rolling maintains favorable water balance in plant tissues during drought stress. The ability of a leaf to recover from dehydration is dependent on the ability to maintain high relative water content during drought stress (Kumari et al., 2014).

During leaf rolling, radiation on the leaf is reduced, stomates are closed which leads to decreased transpiration, gaseous exchange decreases leading to decreased photosynthesis. Leaf rolling is scored during mid-day in rice. When a rice crop expresses delay in leaf rolling and faster recovery rate after removal under water stress is a good attribute (Singh et al., 2012).

2.6: Breeding for drought tolerance in rice

Developing drought tolerant varieties has been a great challenge to breeders. A major breakthrough in rice breeding was by West African Rice Development Association (WARDA) which is the current Africa Rice Centre. WARDA was initiated in 1991 by lead breeder Dr.

Monty Patrick Jones with an objective of developing drought tolerant upland rice (Somado et al., 2008).

Mass evaluation was used to screen for response to drought tolerance of *Oryza sativa* L. and *Oryza glaberrima* which are Asian and African germplasm respectively. *O. glaberrima* expressed better traits such as tolerance to iron toxicity, adverse climatic conditions, resistance to biotic stresses such as parasitic plants Striga, nematodes, viruses, midges and pests and diseases, variations in water levels, human neglect and infertile soils than *O. sativa* L. but also expressed low grain yields.

Selections were done and the promising genotypes were incorporated to a breeding program where genetic studies of drought tolerance were done. Recurrent selection was used to increase the drought tolerance capacity by the genotypes (Somado et al., 2008 and Jones et al., 2000). Successful cross was made between *O. glaberrima* and *O. sativa* in this breeding program. Backcross method was used to introgress drought tolerance between *O. glaberrima* and *O. sativa* with *O. sativa* as the recurrent parent. In the interspecific crossing, embryo rescue was applied to reduce spikelet sterility in the next progenies. The progeny from the crosses was named New Rice for Africa (NERICA). Anther culture of F_1 and F_2 progenies was also used to reduce sterility and attain rapid homozygosity. These progenies expressed drought tolerance in two stages: vegetative and reproductive phase of rice growth (Jones et al., 2000). NERICAs are higher yielding, early maturing and resistant to pests (Atkinson, 2010).

In Tanzania, Tai and Komboka are highly favored by the growers since they have translucent, long and slender grains. These two varieties are high yielding, resistant to diseases such as bacterial blight and leaf blast, can be grown twice a year and they mature earlier than SARO5, a local variety. Komboka is aromatic while Tai is non-aromatic. Komboka is suitable for water-stressed environment (IRRI, 2013).

In Australia, drought tolerant cultivars have been developed by focusing on existence rather than water use efficiency. IRRI is also working on introducing C4 gene in corn into rice with the hope of increasing metabolism in order to get varieties with increased vigour, yield and water use efficiency (Kyayback, 2013).

2.7: Genotype X Environment Interaction

Gene action is a vital aspect when developing drought tolerant crop. Direct selection of genotypes based on grain yield is difficult due to epistasis, low heritability, and outstanding genotype by environment interaction, polygenic control and quantitative trait loci (QTL) by environment interaction. Adewasi (2011) notes that some rice breeders have used direct selection for yield to improve yield in drought stress environment.

Genetic factors of a crop determine its performance in different environments, modification of the genetic factors by environmental factors such as rainfall and temperature results in genotype by environment (G x E) interaction. G x E dictates phenotypic expression of a trait by a crop, both phenotypic expression and genetic make-up of a quantitative trait are affected by environmental aspects. Variation in performance of a genotype over environments is said to be as a result of G x E. G x E interaction have been used in many breeding programs when selecting a suitable genotype for a specific environment (Sabaghnia et al., 2008).

Stability analysis is crucial when profiling performance of crops in various environments. Variation in response of cultivars to different environments causes instability of crop’s performance. Grain yield is affected by factors such as management practices, environment and genotype and interaction of these factors. To identify promising genotypes in terms of grain yield stability and adaptability, a G x E interaction assessment must be done (Ersullo, 2016).

The environment (E) where the crop is grown, the genotype(G) of the variety and an interaction of both Genotype and Environment forming GEI determines the performance of a variety. GEI is said to exist when two genotypes respond to various environmental levels differently (Ersullo, 2016). GEI can be estimated using several statistical methods such as variance components, regression models, multivariate analysis and cluster techniques (Mohammadi et al., 2012).

The regression model for G x E was developed by Finlay and Wilkinson (1963). Regression model is used to explain adaptation of varieties to various environments. Eberhart and Russel (1966) measured environmental responses by the use of b-values and deviations from regression to measure stability (Ersullo, 2016).

AMMI combines ANOVA (Analysis of Variance) and PCAs (Principal Component Analysis) to analyze genotype by environment interaction when identifying patterns of interaction. In AMMI ANOVA, genotype and environment are the main effects and PCAs are the multiplicative effect (residual in ANOVA) (Krualee et al., 2012). Biplots shows both main and interaction effects and they aid to visualize relationships among genotypes and between environments.

Purchase et al., (2000) developed AMMI Stability Value (ASV) based on AMMI models: Interaction Principal Component Axes 1 (IPCA1) and Interaction Principal Component Axes 2 (IPCA2) scores for each genotype (Amiri et al., 2013). The ASV is calculated as shown below:

$$\mathrm{ASV} = \sqrt{\left[\frac{\mathrm{SS\ IPCA\ 1}}{\mathrm{SS\ IPCA\ 2}}(\mathrm{IPCA\ 1\ Score})\right]^2 + (\mathrm{IPCA\ 2\ Score})^2}$$

Where SS_{IPCA1}/SS_{IPCA2} is the weight given to IPCA1 by dividing the sum of squares of IPCA1 on the sum of square of IPCA2. The larger the IPCA scores (either positive or negative) the more specifically adapted a genotype is to certain environments while smaller IPCA scores indicate a more stable genotype across environments (Amiri et al., 2013).

CHAPTER THREE:

3.0: MATERIALS AND METHODS

3.1: Experimental site

This experiment was conducted at Kenya Agricultural and Livestock Research Organization (KALRO) - Industrial Crops Research Centre (ICRC) Mwea Tebere (National Rice and Fiber Research Centre (NRFRC)). KALRO-Mwea is located in Mwea Division, Kirinyaga South District, Central Province, Kenya. The Centre is 21 km South West of Embu town and about 112 km North East of Nairobi. KALRO lies on Latitude 00^{o} 37’ S and Longitude 37^{o} 20’ E and is elevated at 1159 MASL (metres above sea level). The average rainfall is approximately 850 mm ranging from 500mm to 1250 mm which is divided into long rains between March and June averaging 450 mm and short rains between mid-October and December averaging 350 mm. This rainfall is defined by unequal distribution in terms of space, time and total amounts. The temperature mean is approximately 22º C (ranging: 15.6^{0}cto 28.6º C). The soil characteristics are: well-drained dusky-red to dark reddish-brown, nitosol and friable clay. This soil also has low fertility (Jaetzold and Schmidt, 1983).

3.2: Germplasm

A set of 30 rice breeding materials of advanced lines which included 19 crosses, 6 parents and 5 check varieties were obtained from Kenya Agricultural and Livestock Research Organization (KALRO) -Mwea and grown at KALRO-Mwea centre during the season 2016/ 2017. The 30 breeding materials are as shown in Table 2

Table 3: Thirty lines (19 generation of crosses, 6 parental and 5 check varieties) selected for evaluation

Genotype/ generation of cross	Generation	Description	Origin
NERICA.1 XNERICA.2	F3 population	Generation of crosses	KALRO-Mwea
NERICA1XNERICA11	F3 population	Generation of crosses	KALRO-Mwea
NERICA1XNERICA15	F3 population	Generation of crosses	KALRO-Mwea
NERICA1XSARO5	F3 population	Generation of crosses	KALRO-Mwea
NERICA2XNERICA1	F3 population	Generation of crosses	KALRO-Mwea
NERICA2XNERICA11	F3 population	Generation of crosses	KALRO-Mwea
NERICA2XKomboka	F3 population	Generation of crosses	KALRO-Mwea
NERICA2XSARO5	F3 population	Generation of crosses	KALRO-Mwea
NERICA11XNERICA2	F3 population	Generation of crosses	KALRO-Mwea
NERICA11XNERICA15	F3 population	Generation of crosses	KALRO-Mwea
NERICA15XNERICA2	F3 population	Generation of crosses	KALRO-Mwea
NERICA15XNERICA11	F3 population	Generation of crosses	KALRO-Mwea
NERICA15XSARO5	F3 population	Generation of crosses	KALRO-Mwea
KombokaXNERICA11	F3 population	Generation of crosses	KALRO-Mwea
KombokaXNERICA15	F3 population	Generation of crosses	KALRO-Mwea
SARO5XNERICA1	F3 population	Generation of crosses	KALRO-Mwea
SARO5XNERICA11	F3 population	Generation of crosses	KALRO-Mwea
SARO 5XNERICA15	F3 population	Generation of crosses	KALRO-Mwea
SARO5XKomboka	F3 population	Generation of crosses	KALRO-Mwea
NERICA 1(Parent)	Pure line	Aromatic, Blast tolerant, Long grains, Susceptible to	KALRO-Mwea

		drought.	
NERICA 2(Parent)	Pure line	Non-aromatic and Drought tolerant	KALRO-Mwea
NERICA 11(Parent)	Pure line	Non-aromatic, Long grains, Tolerance to blast and susceptible to drought.	KALRO-Mwea
NERICA 15(Parent)	Pure line	Drought tolerant and Non-aromatic,	KALRO-Mwea
Komboka (Parent)	Pure line	High yielding, mild aroma, tolerant to most diseases, good grain quality and drought tolerant.	KALRO-Mwea
SARO5(Parent)	Pure line	Aromatic, high yield, Susceptible to drought	KALRO-Mwea
NERICA 4(Check)	Pure line	Drought susceptible	KALRO-Mwea
NERICA 10(Check)	Pure line	Drought susceptible	KALRO-Mwea
Duorado precoce (Check)	Pure line	Drought tolerant	KALRO-Mwea
IRAT 109(Check)	Pure line	Drought susceptible	KALRO-Mwea
MWUR 4(Check)	Pure line	Drought tolerant	KALRO-Mwea

Source: National crop variety list (KEPHIS, 2015). The generation of crosses were obtained from a student who developed crosses and evaluated them up to F_3 seed.

3.3: Methods

3.3.1: Evaluation of the 19 generation of crosses at F_3, 6 parental and 5 checks under well-watered and drought stressed environments.

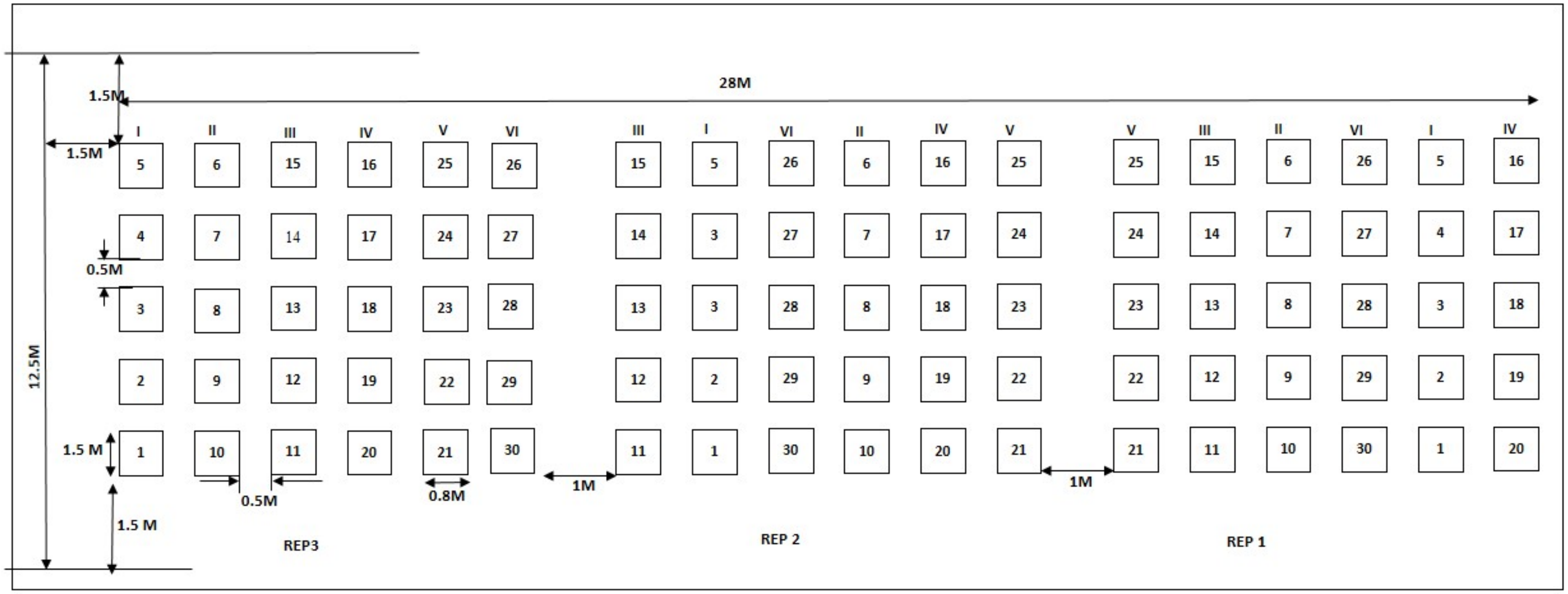
19 F_3 genotypes, 6 parental and 5 checks were evaluated for response to drought at KALRO-Mwea Centre field between October 2016 and February 2017 in the first season. The two environments: drought stressed and well-watered each sized 12.5 X 28M were constructed by erecting poles and covering with a polythene paper to create a rain-free area. In both plots, the field was ploughed, harrowed and raked to obtain a good seedbed for sowing and three seeds per hill were planted on dry land in an alpha-lattice design with a between crops spacing of 15cm and between row spacing of 20 cm.

The 19 F_3 genotypes, 6 parental and 5 checks were randomized in an Alpha Lattice design of three replications in both environments. In each plot, standard agronomic practices and plant protection measures were followed in order to maintain healthy crops. Di-Ammonium Phosphate (DAP, 18:46: 0) fertilizer 125kgs/ha was applied to each plot at planting with first irrigation regime while Calcium Ammonium Nitrate (CAN, 26%N) fertilizer (125kgs/ha) was applied at vegetative phase for top-dressing. Guard rows of 3 rows were used to surround the plots in order to protect the experimental lines.

In both environments, irrigation was applied using overhead sprinkler with the pump at medium speed. In both environments, irrigation was applied for six hours. In the well-watered environment, the plants were irrigated from planting to physiological maturity of 150 days after germination. In the drought stressed environment, the plants were irrigated from sowing to panicle initiation stage but at 84 days after germination, irrigation was discontinued for the rest of the crop cycle.

The 19 F3 genotypes, 6 parental and 5 checks lines were randomized in an alpha lattice design with three replications in both environments as shown in the figure below:

Field layout: Alpha lattice For Evaluation of F3 populations for drought tolerance



Four rows per entry, inter-row space = 15cm, and inter-crop space = 20cm, 5 plots in each block (5X6)

Figure 1: An alpha lattice layout in which the lines were randomized

Full plot size was 28Mx12.5M and each sub-plot sized 1.5Mx0.8M. Inter-crop spacing was 15cm and inter-row spacing was 20cm. Distance between one replication to another was 1M and the distance from one environment to another environment was 3M.

3.3.2: Evaluation of F_4 generation of crosses, parental and checks under well-watered and drought stressed environment.

19 generation of crosses at F_4, 6 parental and 5 checks were evaluated for response to drought for the second season at KALRO-Mwea centre in between June 2017 and December 2017 as described in section 3.3.1.

3.4: Data scoring

Both growth and reproductive data were collected. Five plants were sampled per plot and tagged for the following:

a) Plant height - This measured in centimeters from the ground up to the tallest panicles.

b) Number of tillers - Tillers for the sampled plants were counted in number.

c) Days to flowering (Days to heading) - Dates of flowering of 50% of the plants per plot were recorded to give number of days.

d) Leaf rolling- A scale of 0-9 was used. According to IRRI, 2014 the scale that was used to score the degree of leaf rolling as:

   i. 0-Leaves healthy.
   ii. 1-Leaves start to fold
   iii. 3-Leaves folding (deep V-shaped)
   iv. 5- Leaves fully cupped (U-shaped).
   v. 7- Leaves margins touching (O-shaped)
   vi. 9-Leaves tightly rolled

e) Number of filled and unfilled spikelets- After each sample was threshed, filled and unfilled spikelets were separated and counted. The number of filled and unfilled spikelets was used to obtain percentage spikelet fertility.

$$\text{Percentage spikelet fertility} = \frac{\text{No. of filled grains in the sample}}{\text{No. of filled and no. of unfilled spikelets}} * 100\%$$

f) Flag leaf length- The length of the flag leaf was measured in centimeters at maturity of the plants (before harvesting).

g) Panicle length- For the harvested samples, panicle length per plant was measured in centimeters.

h) 1000 grain weight- 1000 whole grains from the threshed samples were weighed using a precision balance in grams.

i) Biomass- This is the shoot biomass; the top part of rice that has been harvested and threshed was weighed in grams.

j) Yield/m^2- The threshed grains were bulked and weighed to obtain the plot yield in grams and converted to the total grain yield in tons per hectare.

3.4: Data analysis

All data collected were subjected to GENSTAT version 15 for Analysis of Variance (ANOVA) and combined ANOVA at $p<0.05$. GENSTAT version 15 was also used to obtain mean performance of agronomic, yield and yield related traits for the thirty rice lines.

Statistix software was used to obtain correlation of the various traits at $p<0.05$ with the aim of identifying if there is an association or the absence of the relationship between two traits under the well-watered and drought stressed conditions. GENSTAT version 15 was also used to obtain AMMI analysis. AMMI were obtained under meta-Analysis in GENSTATv15. From AMMI analysis IPCA 1 and 2 values were derived. In order to measure stability, ASV was calculated using the following equation that was proposed by Purchase, (1997) was used:

$$\mathrm{ASV} = \sqrt{\left[\frac{\mathrm{SS\ IPCA\ 1}}{\mathrm{SS\ IPCA\ 2}}(\mathrm{IPCA\ 1\ Score})\right]^2 + (\mathrm{IPCA\ 2\ Score})^2}$$

Where ASV and IPCA are AMMI Stability Value and Interaction Principal Component.

Genotype by Environment Analysis for R windows (GEA-R) was used to analyze effect of genotype and genotype by environment (GGE) interaction under well-watered and drought stressed environments through two seasons to obtain GGE biplots.

CHAPTER 4:

4.0: RESULTS AND DISCUSSION

4.1: Performance of agronomic, yield and yield related parameters of the 19 generation of crosses, 6 parental and 5 checks under well-watered and drought stressed environment

Combined ANOVA in Tables 4 and 5 show that there were highly significant differences among the rice genotypes for most the traits including biomass, panicle length per plant, days to flowering, number of panicles per plant, number of tillers, spikelet fertility, 1000-grain weight and grain yield. Significant differences at $p<0.05$ between seasons were observed for the following parameters: flag leaf length, panicle length per plant, spikelet fertility and days to flowering. These results also show significant variations in biomass, flag leaf length, panicle length per plant, days to flowering, number of panicles per plant, number of tillers, percentage spikelet fertility, 1000-grain weight and grain yield between the environments (conditions). This implies that there was a significant effect of drought on the thirty rice genotypes. Significant difference at $p<0.05$ for season x genotype x condition was noted for days to flowering and 1000-grain weight.

Table 4: Combined analysis of variance (ANOVA) for agronomic parameters of 30 rice genotypes in drought stressed and well-watered environments in Mwea over two seasons in 2016/2017

	DF	**MS**			
		PH	**NT**	**FLL**	**DTF**
Rep	2	2590ns	62.385	12.69	6.19
Season	1	1993ns	0.870ns	230.00***	423.47***
Genotype	29	3977*	167.907***	1361.76***	467.96***
Condition	1	287ns	3179.683***	2.53ns	709.00***
Season x genotype	29	2231ns	1.548ns	29.13ns	37.67ns
Season x condition	1	3877ns	1.308ns	24.93*	22.59***
Genotype x condition	29	2446ns	30.595***	19.32ns	31.57***
Season x genotype x condition	29	2269ns	0.814ns	8.90ns	30.84***
Residual	238	2288	6.782	15.34	10.26

Key: ***= Very highly significant, **= highly significant, *= Significant and ns=not significant, DF=Degrees of freedom; MS=Mean sum of squares. PH=Plant height; NT=Number of tillers; FLL=Flag leaf length, DTF= Days to flowering**.**

Table 5: Combined analysis of variance (ANOVA) for yield and yield related parameters of 30 rice genotypes in drought stressed and well-watered environments in Mwea over two seasons in 2016/2017

	DF	PL/P(cm)	NP/P	Biomass (g)	SF%	1000-GW (g)	GY (g)
Rep	2	0.768	27.912	25.68	0.032501	4.556	0.2655
Season	1	198.094***	13.379ns	23.28ns	0.096865***	8.837ns	0.0339ns
Genotype	29	547.189***	30.266***	313.31***	0.014744**	32.182***	12.5236***
Condition	1	31.049***	2882.072***	33498.24***	6.174***	2632.328***	1274.7978***
Season x genotype	29	1.465ns	1.445ns	5.89ns	0.007278ns	11.141***	0.5103ns
Season x condition	1	8.046**	18.860ns	2.96ns	0.000037ns	14.886*	2.4105*
Genotype x condition	29	10.224***	13.379***	55.27***	0.012313*	11.686***	7.8485***
Season x genotype x condition	29	4.239ns	1.734ns	8.860ns	0.005ns	12.773***	0.389ns
Residual	238	4.006ns	5.925	10.97	0.006905	2.516	0.4081

Key: ***= Very highly significant, **= Highly significant, *= Significant and ns=not significant. PL/P= Panicle length per plant in cm; 1000-GW= 1000 grain weight; SF%=Spikelet fertility, GY=Grain yield and NP/P=Number of panicles per plant

Table 6: Mean performance of agronomic parameters of the 30 rice lines in both well-watered and drought stress environments in Mwea over two seasons in 2016/2017

Ser.	Trait	PH (cm)		NT		FLL (cm)		LRS		DTF	
No.	Genotype	DS	WW	DS	WW	DS	WW	WW	DS	DS	WW
1	NERICA.1 XNERICA.2	83.3	95.8	8.6	12.7	22.3	23.9	0	3	101.3	103.2
2	NERICA1XNERICA11	84.2	85.5	10.3	20.8	23.4	25.7	0	3	99.5	98.5
3	NERICA1XNERICA15	97.2	96.3	8.8	13.3	29.3	24.6	0	3	98.7	98.0
4	NERICA1XSARO5	95.3	93.7	10.3	14.6	28.1	26.5	0	2	93.3	94.5
5	NERICA2XNERICA1	93.4	93.2	9.2	11.2	31.5	32.3	0	2	95.2	97.0
6	NERICA2XNERICA11	56.9	58.6	18.1	33.0	27.8	24.2	0	9	113.5	125.2
7	NERICA2XKomboka	87.8	96.0	8.5	13.9	24.5	29.5	0	0	95.2	95.7
8	NERICA2XSARO5	86.2	87.6	6.9	15.4	29.1	28.2	0	1	98.3	95.8
9	NERICA11XNERICA2	82.6	86.4	10.6	13.9	25.4	26.1	0	3	93.3	98.2
19	NERICA11XNERICA15	89.4	89.3	8.3	13.7	26.2	23.8	0	0	99.3	101.8
11	NERICA15XNERICA2	86.7	97.7	9.4	20.1	24.4	29.2	0	5	97.8	104.2
12	NERICA15XNERICA11	87.1	101.1	9.7	15.9	25.5	28.3	0	3	96.5	98.7
13	NERICA15XSARO5	96.0	101.7	7.2	16.6	28.3	28.8	0	4	97.3	102.2
14	KombokaXNERICA11	96.3	99.3	7.0	11.3	29.4	27.9	0	3	99.7	95.2
15	KombokaXNERICA15	89.2	92.5	9.7	13.6	26.6	27.5	0	0	98.3	98.8
16	SARO5XNERICA1	98.6	98.8	10.4	12.7	27.0	25.6	0	1	96.2	98.8
17	SARO5XNERICA11	88.9	103.7	7.3	14.1	27.7	27.7	0	3	96.7	101.3
18	SARO 5XNERICA15	81.8	95.6	6.5	15.9	26.7	24.9	0	5	100.7	99.0
19	SARO5XKomboka	89.2	107.1	9.3	14.1	25.5	24.2	0	5	100.5	99.0
20	NERICA 1(Parent)	79.5	96.9	6.3	16.9	26.1	27.5	0	1	100.8	102.3

21	NERICA 2(Parent)	80.4	81.2	7.6	13.5	26.6	23.1	0	1	98.2	101.7
22	NERICA 11(Parent)	84.9	86.8	11.8	10.7	25.3	24.9	0	3	98.3	103.8
23	NERICA 15(Parent)	78.7	87.5	9.7	14.4	30.3	27.7	0	3	95.7	97.0
24	Komboka(Parent)	87.7	103.9	7.9	14.9	27.2	29.1	0	5	97.4	96.8
25	SARO5(Parent)	81.3	86.1	8.3	11.8	28.1	25.9	0	3	97.2	98.7
26	NERICA 4(Check)	87.5	97.2	8.5	12.8	25.8	25.5	0	5	97.7	100.5
27	NERICA 10(Check)	89.8	94.0	9.0	13.8	28.0	28.7	0	3	96.8	100.3
28	Duorado precoce(Check)	62.8	71.7	16.9	22.1	28.9	25.5	0	7	115.2	121.0
29	IRAT 109(Check)	57.3	68.2	17.4	23.7	22.8	21.2	0	9	118.0	121.3
30	MWUR 4(Check)	59.3	65.2	17.1	23.2	21.4	26.1	0	9	119.5	126.0
	Grand mean	88.8	90.6	9.9	15.8	26.6	26.47	0	3	100.2	102.5
LSD	S*G	9.3	10.2	3.7	4.6	6.0	6.6			4.7	5.4
	S*E	1.8		0.8		1.2				0.9	
	G*E	7.0		3.0		4.5				3.6	
	S*G*E	9.9		4.2		6.3				5.143	

L.S. D= Least Significant Difference, DS=Drought stressed, WW= Well-watered, DTF= Days to flowering, FLL=Flag leaf length(cm), NT=Number of tillers, LRS= Leaf rolling score, PH= plant height. S*G= season x genotype, S*E= season x environment, G*E= genotype x environment and S*G*E= season x genotype x environment.

Tables 4 and 5 show significant variations in genotypes, seasons, conditions, and interaction of season x condition x genotype for agronomic, yield and yield related parameters at p<0.05.

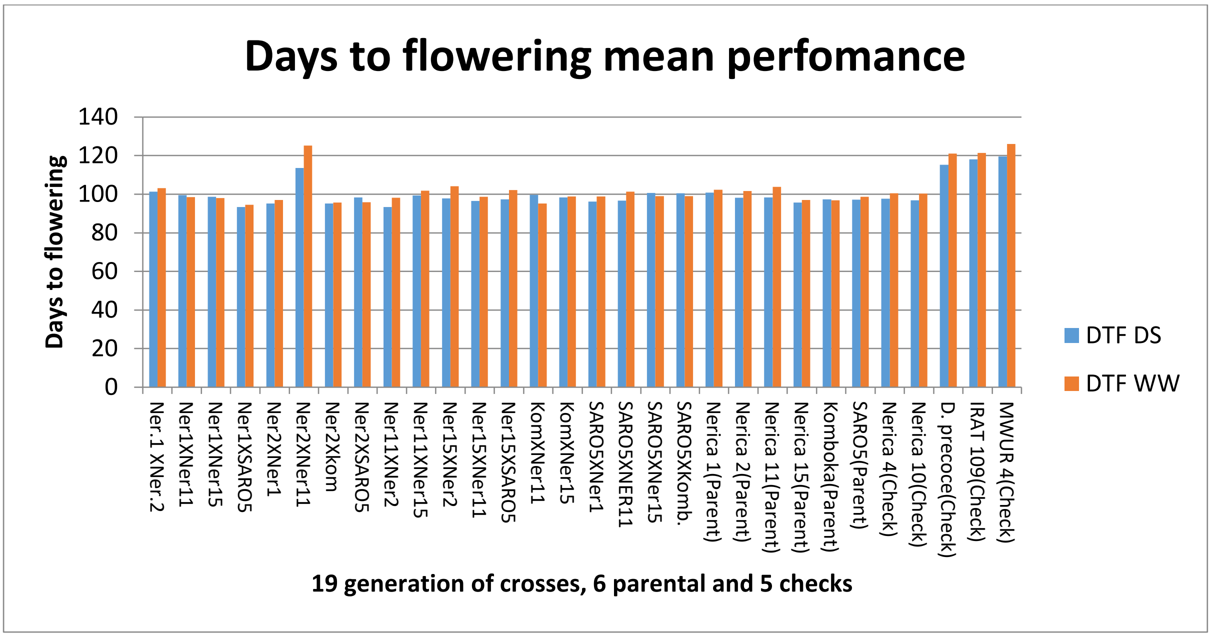


Figure 2: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for days to flowering. Blue bars: drought stressed environment and red bars: well-watered environment

Days to flowering varied from one genotype to another and also between the conditions. As for the drought stressed environment the variation was between 93 days to 120 days while in the well-watered environment variation was 94 days to 126 days. The grand mean of the genotypes in the drought stressed environment was 100.2 days while those in the well-watered environment was 102.5 days (Table 6).

There was a significant difference among genotypes, between the seasons and environments at P<0.05 for days to flowering (Table 4). Most of the lines in the drought stressed environment flowered earlier than those in the well-watered environment. In the well-watered environment, genotypes such as NERICA 1 x SARO5, Komboka x NERICA 11, NERICA 2 x Komboka, NERICA 2 x SARO5 and Komboka were the earliest in flowering but expressed an increase in the number of days to flowering under the drought stressed environment except for NERICA 1 x SARO5 showed a decrease in the number of days to flowering from 95 days to 93 days (Figure 2). Genotypes, MWUR4, NERICA 2 x NERICA 11, IRAT109, Dorado precoce and NERICA 15 x NERICA 2 flowered the latest in the well-watered environment and for these genotypes number of days to flowering showed a decrease with drought stress. For the genotypes in the drought stressed environment, NERICA 1 x SARO5, NERICA 11 xNERICA 2, NERICA 2 x NERICA 1, NERICA 2 x Komboka and NERICA 15 flowered earliest. These lines delayed in flowering under well-watered environment (Figure 2) while NERICA 1 x NERICA2, NERICA 2 x NERICA 11, Dorado precoce, IRAT 109 and MWUR4 flowered the latest.

NERICA 1 x SARO5 expressed early flowering characteristic of 93.33 days in drought stressed environment and 94.50 days in the well-watered environment (Figure 2). Most lines in the drought stressed environment expressed reduced number of days to flower as compared to those in the well-watered environment, variation was up to 12 days. As for medium maturing genotypes like Komboka x NERICA11, SARO5 x NERICA 15, Komboka and SARO5 x Komboka, they had reduced days to flowering in the well-watered environment than in the drought stressed environment.

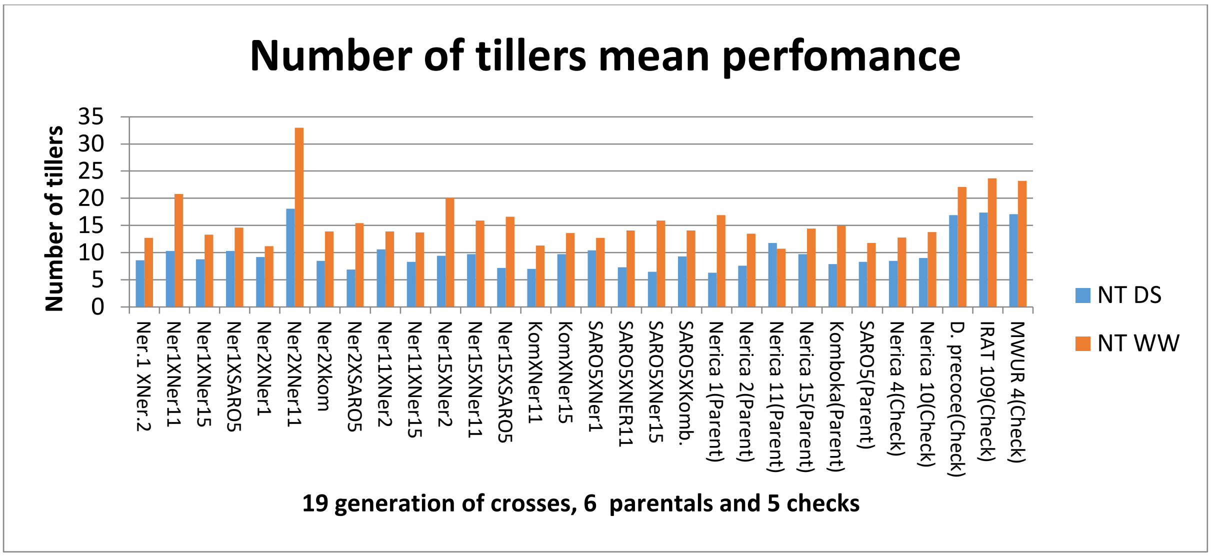


Figure 3: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for number of tillers. Blue bars: drought stressed environment and red bars: well-watered environment

Number of tillers showed significant variation ranging from 18.1 to 6.3 in the drought stressed environment and 11.2 to 33.0 in the well-watered environment (Table 6). There was a significant variation in number of tillers (Table 6). Table 3 show that there were significant variations among genotypes and between the two environments at p<0.05 for number of tillers per hill. Significant reduction in the number of tillers per hill by all the 30 rice lines was observed in the drought stressed environment as compared to the well-watered environment. Genotypes, NERICA 2 x NERICA 11, IRAT109, MWUR4 and Duorado precoce recorded 45.3, 42.1, 42.3 and 46.8 number of tillers per hill respectively in the well-watered environment but recorded 22.9, 23.8, 24.1 and 22.6 number of tillers per hill respectively in the drought stressed environment (Figure 3). Genotype NERICA 1 x NERICA 2 also showed reduction in number of tillers per hill with drought stress from 12.7 to 8.6 (Figure 3).

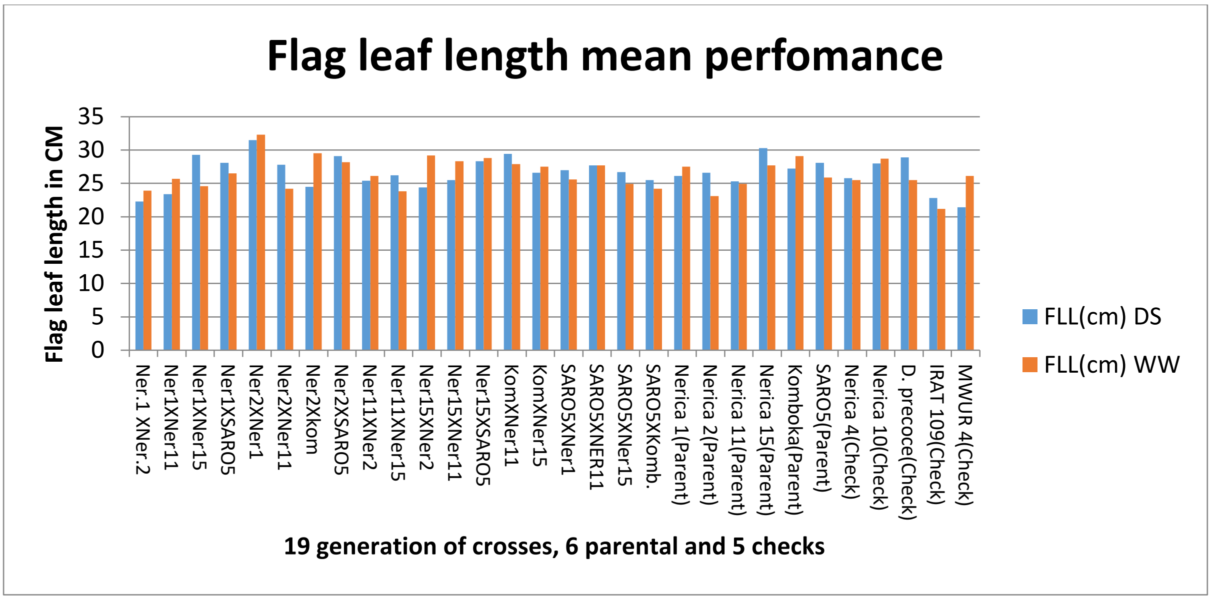


Figure 4: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for flag leaf length. Blue bars: drought stressed environment and red bars: well-watered environment

Flag leaf length varied between 21.4 cm and 31.5cm in the drought stressed environment and 21.2cm and 32.3 cm in the well-watered environment (Table 6). There was no significant difference in flag leaf length between the two conditions but significant differences were noted between seasons and among genotypes at p<0.05 (Table 4). In the well-watered environment, the genotypes with the longest flag leaf length were: NERICA 2 x NERICA 1, NERICA 2 x Komboka, NERICA 15 x NERICA 2, Komboka and NERICA 15 x SARO5 (Table 5). Those with the shortest flag leaf length were IRAT 109, NERICA 2, NERICA 1, NERICA1 x NERICA2 and SARO5 x Komboka. In the drought stressed environment, NERICA 2 x NERICA1, NERICA15, Komboka x NERICA11, NERICA1 x NERICA15 and NERICA 2 x SARO5 had the longest flag leaf length while MWUR4, NERICA 1XNERICA 2, IRAT109, NERICA 1 x NERICA 11 and NERICA 15 x NERICA 2 had the shortest flag leaf length (Figure 4). There were genotypes that had longer flag leaf length in drought stress environment than their counterparts in the well-watered environment these include: NERICA

1 x NERICA 15, NERICA 2 x NERICA 11, NERICA 2, Dorado precoce and NERICA 15 (Figure 4).

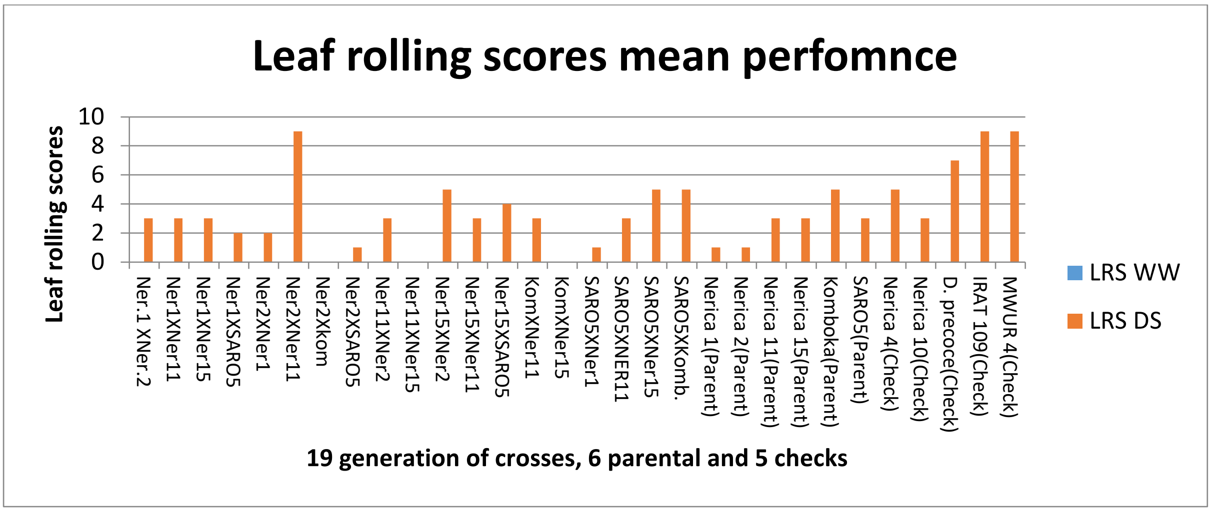


Figure 5: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for leaf rolling score. Blue bars: drought stressed environment and red bars: well-watered environment which the scores were zero

Leaf rolling scores varied among genotypes in the drought stressed environment. These scores were spread between 0 and 9 with a grand mean of 3.4 (Table 6). Leaf rolling scores showed a significant variation among the genotypes in the drought stressed environment. From field observation, the rice lines expressed healthy leaves in the well-watered environment while in the drought stressed environment there was varying leaf rolling scores. Leaf rolling scores ranged from 0-9, with 0 being healthy leaves and 9 being leaves that were tightly rolled. Leaf rolling scores reveal leaf water status and ability to maintain turgor during drought stress. Genotypes, NERICA 2 x NERICA 11, IRAT109, MWUR4 and Dorado Precoce had 9,9,9 and 7 leaf rolling scores respectively (Figure 5). It was observed that Dorado Precoce, IRAT 109, MWUR4 and NERICA 2 x NERICA 6 were the late maturing genotypes in both drought-stressed and well-watered environments. Genotypes, NERICA 11 x NERICA 15, Komboka x NERICA15, NERICA 2 x Komboka and NERICA 2 x SARO5 had 0,0, 0 and 0.5 leaf rolling scores respectively (Figure 5). These lines expressed drought tolerance since their leaves were healthy under drought stress conditions.

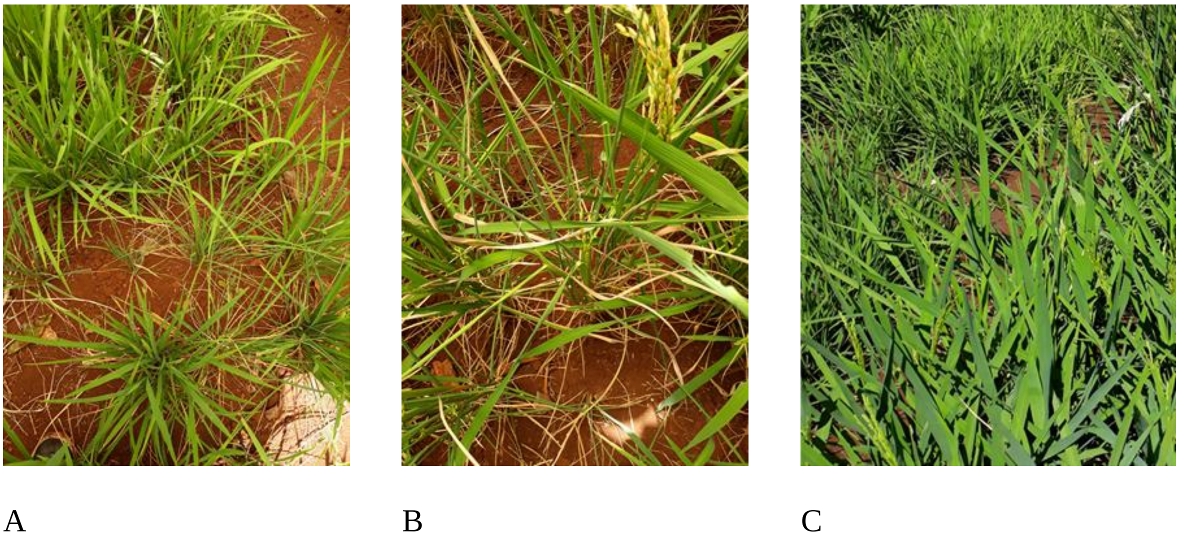


Figure 6: Images of rice crops under drought stressed environment (A and B) and well-watered environment (C)

A and B: The rice crops were weak, less populated and the leaves were rolling. C: The rice crops were very healthy, very green, densely populated and there was no leaf rolling exhibited.

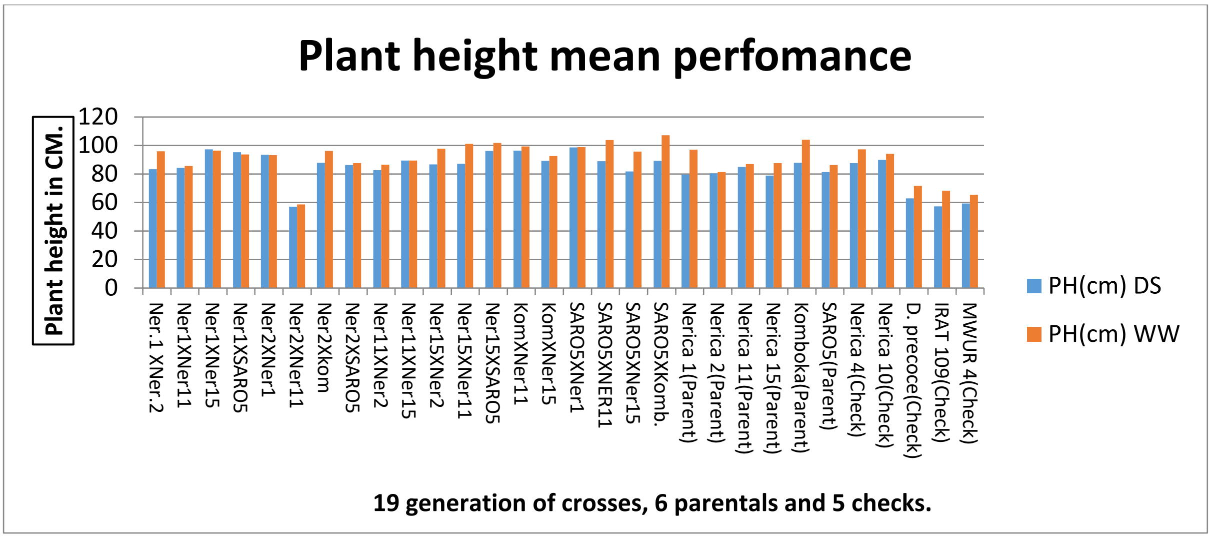


Figure 7: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for plant height. Blue bars: drought stressed environment and red bars: well-watered environment

Plant height varied between 56.9cm and 97.2 cm in the drought stressed environment and between 58.6 cm and 107.1 cm in the well-watered environment (Table 6). Table 3 show that there were significant differences in plant height at p<0.05**,** this could be due to genetic factors. There was an effect of drought stress on plant height of the genotypes but the effect was not significant. In the well-watered environment, the tallest genotypes were SARO5 x Komboka, Komboka, SARO5 x Ner11, Ner15 x SARO5 and Ner15 x Ner11. These genotypes had reduced plant height in the drought stressed conditions (89.2cm, 87.7cm, 88.9cm, 96.0cm and 87.1cm respectively). Figure 6 shows that the shortest genotypes were Ner2 x Ner11, MWUR4, IRAT 109, Dorado precoce and NERICA 2 which also showed a reduction in plant height in the drought stressed environment (56.9, 59.3cm, 57.3cm, 62.8 and 80.4 cm respectively).

The genotypes in the drought stressed environment also had a significant variation. The tallest genotypes were SARO5 x NERICA 1, NERICA 1 x NERICA 15, Komboka x NERICA 11, NERICA 15 x SARO5 and NERICA 1 x SARO5, these genotypes were taller in the well-watered environment as shown in Figure 6. The shortest genotypes were NERICA 2 x NERICA 11, IRAT109, MWUR4, Duorado precoce and NERICA 15 which were also the shortest in the well-watered environment (Figure 6). Variations between the genotypes in the well-watered and drought stressed environment ranged from 0.2cm to 17.9 cm.

Table 7: Mean performance of yield related parameters of the 30 rice lines under drought stressed and well-watered environments in 2016/2017

Ser. No.	Trait	Biomass (grams)		PL/P (centimetres)		NP/P		SF%		1000-GW (grams)	
	Genotype	DS	WW	DS	WW	DS	WW	DS	WW	WW	DS
1	NERICA.1 XNERICA.2	8.6	25.9	19.4	20.2	8.9	18.3	41.0	76.4	27.7	26.8
2	NERICA1XNERICA11	9.3	20.3	19.8	20.3	10.6	22.6	55.5	79.2	25.1	17.9
3	NERICA1XNERICA15	17.1	35.6	20.2	22.1	9.2	11.2	52.1	79.6	27.4	18.9
4	NERICA1XSARO5	9.8	25.5	21.6	23.4	10.6	13.6	52.9	76.1	26.8	24.6
5	NERICA2XNERICA1	15.4	36.4	17.3	22.2	9.5	15.2	44.7	74.3	25.2	22.2
6	NERICA2XNERICA11	22.9	45.3	21.0	24.7	10.1	14.6	47.7	82.9	28.4	19.4
7	NERICA2XKomboka	11.5	25.9	23.7	21.7	9.5	12.9	56.4	75.5	27.4	23.4
8	NERICA2XSARO5	11.9	32.5	21.6	21.6	7.2	16.7	46.3	71.9	27.5	21.7
9	NERICA11XNERICA2	8.4	25.4	20.4	21.8	9.8	15.5	53.7	79.6	30.1	24.4
10	NERICA11XNERICA15	7.2	31.9	19.4	24.7	10.1	15.9	54.2	79.2	26.9	22.9
11	NERICA15XNERICA2	11.4	36.5	19.1	19.4	9.7	15.7	44.7	78.9	27.3	22.3
12	NERICA15XNERICA11	15.7	34.8	19.4	21.1	8.1	13.8	51.7	82.3	26.8	19.8
13	NERICA15XSARO5	15.8	35.3	18.4	22.8	8.2	14.3	53.0	76.3	27.9	20.5
14	KombokaXNERICA11	11.3	35.2	19.2	22.3	7.3	12.2	38.3	78.2	27.4	24.5
15	KombokaXNERICA15	14.8	26.1	20.8	19.1	8.4	12.5	51.6	81.4	27.7	23.2
16	SARO5XNERICA1	9.3	36.4	19.5	25.3	9.0	12.7	61.1	76.7	28.0	23.2
17	SARO5XNERICA11	15.1	34.8	21.0	23.5	8.2	12.7	61.9	82.8	27.7	23.7
18	SARO 5XNERICA15	12.5	34.0	20.8	22.9	9.2	14.2	53.5	78.5	29.2	23.3

19	SARO5XKomboka	15.8	43.7	19.5	21.9	9.6	13.9	53.0	70.1	27.6	22.9
20	NERICA 1(Parent)	19.0	33.6	16.4	21.6	6.5	12.9	49.4	82.0	25.9	16.9
21	NERICA 2(Parent)	15.8	36.4	15.3	18.5	7.7	16.4	57.3	76.6	29.7	22.9
22	NERICA 11(Parent)	15.1	29.9	16.9	18.4	8.4	13.2	61.3	78.8	30.9	25.3
23	NERICA 15(Parent)	14.0	28.1	17.6	20.6	8.2	13.3	54.9	78.4	27.9	24.7
24	Komboka(Parent)	12.5	31.5	20.6	23.2	7.7	14.6	50.2	80.6	26.4	20.9
25	SARO5(Parent)	12.1	27.9	17.5	20.9	10.5	15.7	53.4	79.9	26.3	21.3
26	NERICA 4(Check)	15.0	35.2	20.3	25.2	7.4	10.3	55.8	82.4	29.1	21.7
27	NERICA 10(Check)	13.7	35.2	20.6	23.5	7.8	15.2	51.3	77.9	30.0	24.7
28	Duorado precoce(Check)	22.6	46.8	16.9	19.9	7.6	14.5	52.1	71.2	26.9	20.5
29	IRAT 109(Check)	23.8	42.1	17.6	19.2	11.3	17.3	40.4	78.5	25.2	21.1
30	MWUR 4(Check)	24.1	42.3	18.8	20.0	12.4	16.3	55.9	75.5	27.8	20.1
	GRAND MEAN	23.78	24.29	19.4	21.7	8.9	14.6	51.9	78.1		
LSD	S*G	5.6	5.1	2.8	3.6	2.9	4.7				
	S*E	0.9		0.6		0.7		2.4		0.5	
	G*E	3.8		2.3		2.8		9.5		1.8	
	S*G*E	5.3		3.2		3.9		13.4		2.6	

L.S. D= Least Significant Difference, DS=Drought stressed, WW= Well-watered, PL/P=Panicle length per plant (centimeters), NP/P=Number of Panicles per plant, SF= Spikelet fertility (%), 1000-GW=1000 Grain Weight (grams). S*G= season x genotype, S*E= season x environment, G*E= genotype x environment and S*G*E= season x genotype x environment

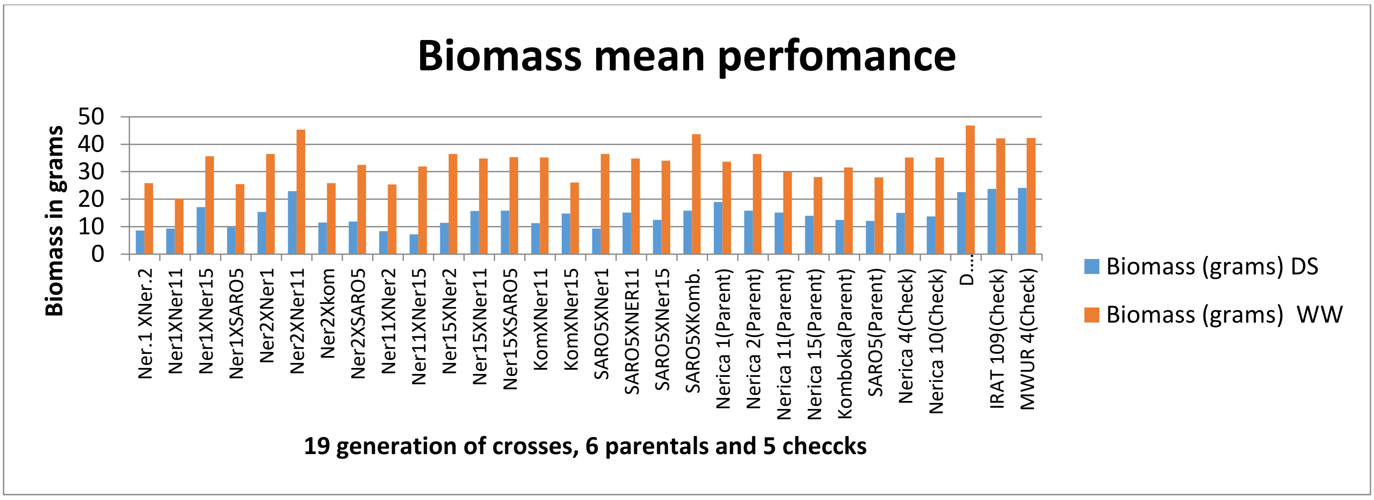


Figure 8: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for biomass. Blue bars: drought stressed environment and red bars: well-watered environment

There was a significant variation in biomass in the two environments as seen in Table 6. The highest biomass in the drought stressed environment obtained was 24.1g and the lowest being 8.4 g (Table 7). As for the drought stressed environment biomass differed ranged from 20.3g to 46.8g. This implies reduced biomass for the genotypes under drought stress as compared to those that were in the well-watered environment.

Biomass recorded significant differences among the genotypes and between the conditions at $p<0.05$ (Table 5). The results in this study shows a reduction in the weight of the dry matter by the lines in the drought stressed environment. For example, in the well-watered environment genotypes, IRAT 109, MWUR4, SARO5 x Komboka, NERICA 2 x NERICA11 and Dorado precoce recorded the highest biomass and in the drought stressed environment these lines expressed a reduction in biomass to 23.8g, 24.1g, 15.8g 22.9g and 22.6g respectively. Genotypes, NERICA 1 x NERICA 11, NERICA 11 x NERICA 2, NERICA 1XSARO5, NERICA 1 x NERICA 2 and NERICA 2 x Komboka (Figure 7) had the least biomass which also reduced in the drought stressed environment.

In the drought stressed environment (Figure 7), genotypes, NERICA 1, Dorado precoce, NERICA 2 x NERICA 11, IRAT 109 and MWUR 4 recorded the highest biomass while genotypes, NERICA 11 x NERICA 15, NERICA 11 x NERICA 2, NERICA 1 x NERICA 2, NERICA 1 x NERICA 11 and SARO5 x NERICA 1 recorded the least. Dorado precoce, IRAT 109, MWUR4 and NERICA 2 x NERICA 11 (46.8g, 42.1g, 42.3g, 45.3g respectively) expressed very high biomass in the well-watered environment and also had the highest biomass (22.6, 23.8, 24.8 and 22.9g respectively) in the drought stressed environment.

SARO5 x Komboka also expressed high biomass of 43.7 grams in the well-watered environment and this could be due to its height of 100.5cm, it recorded a decrease in biomass to 15.8g under drought stress (Figure 7).

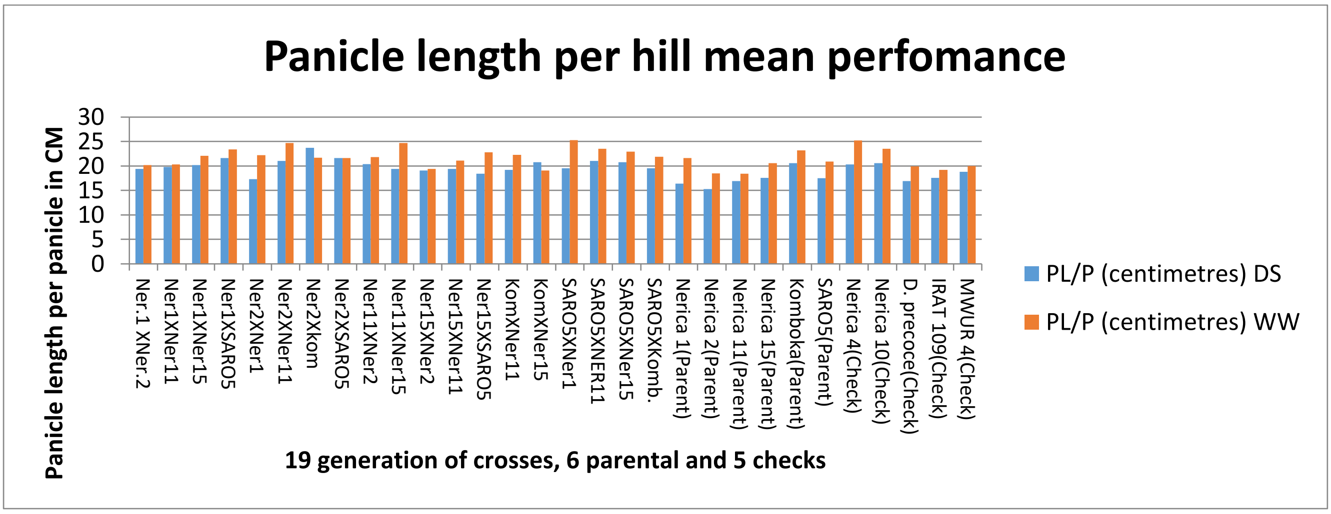


Figure 9: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for panicle length per hill. Blue bars: drought stressed environment and red bars: well-watered environment

Panicle length per hill of the genotypes in the drought stressed environment had a mean of 18.8 cm ranging between 15.3cm- 23.7cm while those in the well-watered environment had a mean of 20.0cm ranging between 18.4 and 25.3 (Table 7). Table 4 shows significant differences in panicle length in seasons, genotypes and conditions. The genotypes in the drought stressed environment expressed shorter panicle length than their counterparts in the well-watered environment. In the well-watered environment, genotypes, SARO5 x NERICA1, NERICA4, NERICA 2 x NERICA 11, NERICA 11 x NERICA 15 and SARO5 x NERICA 11 had the longest panicle length. As for these genotypes their panicles reduced to 19.53cm, 20.32cm, 21.00 cm, 19.42 cm and 21.04cm respectively in the drought stressed environment. The genotypes that exhibited short panicle length in the well-watered environment included: NERICA11, NERICA2, Komboka x NERICA 15, IRAT 109 and NERICA 15x NERICA 2 (Figure 8).

In the drought stressed environment, genotypes, NERICA 2x Komboka, NERICA 1 x SARO5, NERICA2 x SARO5, SARO5 x NERICA 11 and NERICA 2 x NERICA 11 recorded the longest panicle length while genotypes, NERICA 2, NERICA1, Dorado precoce, NERICA 11 and NERICA 2 x NERICA1 recorded the shortest panicle length (Figure 8). Genotypes, NERICA 2 x Komboka and Komboka x NERICA 15 expressed longer panicle length in the drought stressed environment than in the well-watered environment.

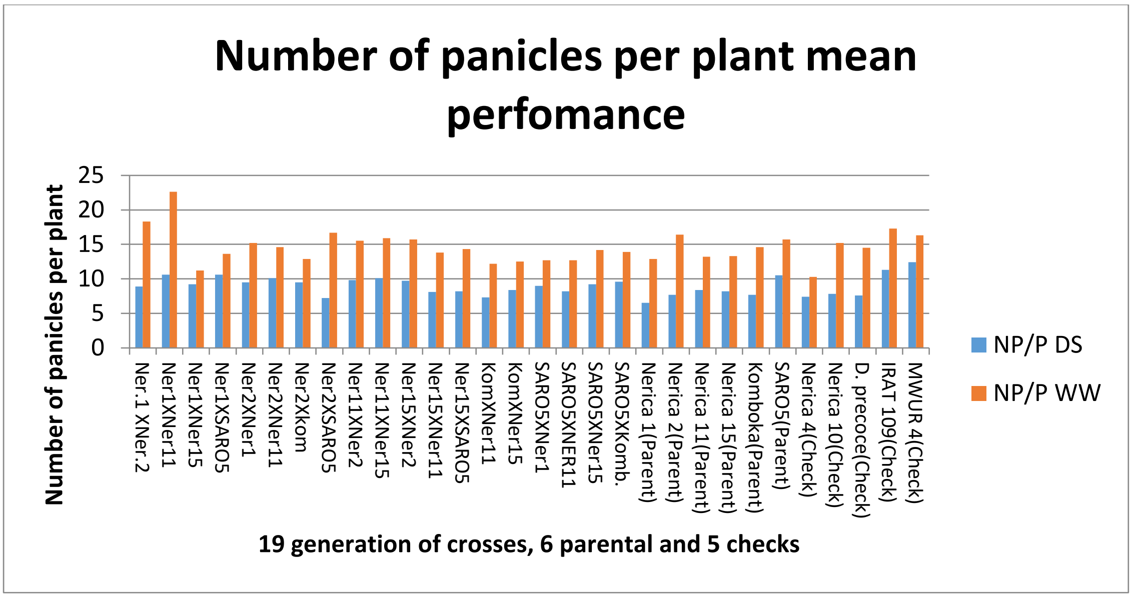


Figure 10: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for flag leaf length. Blue bars: drought stressed environment and red bars: well-watered environment

Number of panicles per plant varied between the two environments with those in the drought stressed environment ranging between 6.5 and 12.4 while those in the well-watered environment was between 10.3 and 22.6 (Table 7). Significant variation in the number of panicles per plant was exhibited among genotypes and between conditions at p<0.05 (Table 5). Reduced number of panicles per plant was recorded among genotypes in the drought stressed environment as compared to those in the well-watered environment. In the well-watered environment, genotypes, NERICA 2, NERICA 2 x SARO5, IRAT109, NERICA1 x NERICA 2 and NERICA 1 x NERICA11 recorded the highest number of panicles per plant. These genotypes a reduction to 7.73, 7.17, 11.28, 10.60 and 9.17 respectively in the drought stressed environment (Figure 9). Genotypes, NERICA 4, NERICA 1 x NERICA 15, Komboka x NERICA 11, Komboka x NERICA 15 and SARO5 x NERICA 11 recorded the least number of panicles per plant in the well-watered environment which also were decreased with drought stress.

In the drought stressed environment, genotypes, SARO5, NERICA 1 x NERICA11, NERICA 1 x SARO5, IRAT 109 and MWUR4 recorded the highest number of panicles per plant while genotypes, NERICA 1, NERICA 2 x SARO5, Komboka x NERICA 11, NERICA4 and Dorado precoce recorded the least number of panicles per hill (Figure 9).

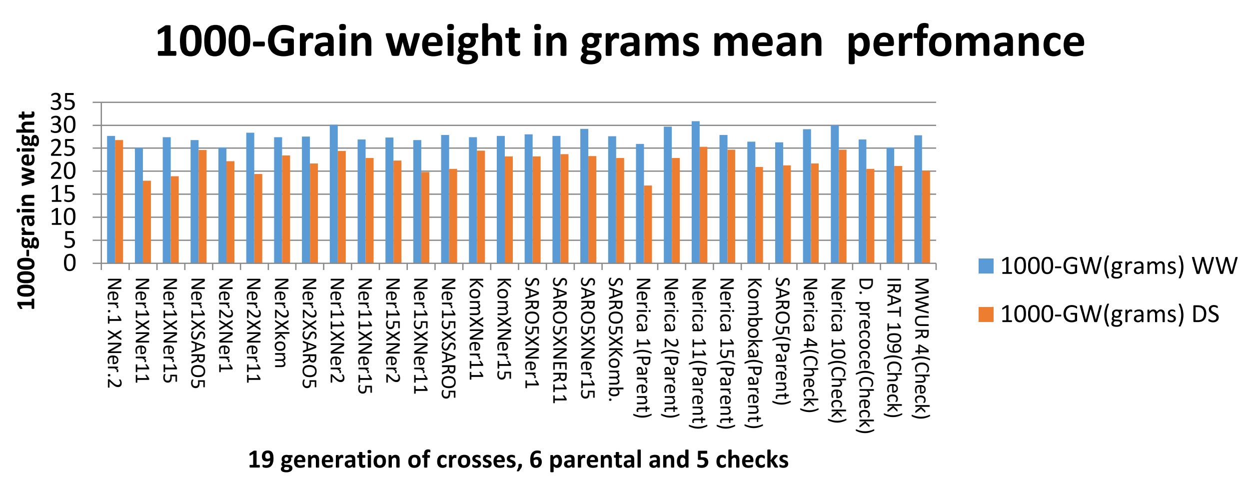


Figure 11: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for 1000-grain weight. Blue bars: drought stressed environment and red bars: well-watered environment

There was a significant reduction of 1000-grain weight of the 30 rice genotypes in the drought stressed environment as compared to those that were in the well-watered environment (Table 7). The weight of 1000 grains of the genotypes in the well-watered environment varied from 16.9 grams to 26.8 grams while those in the well-watered environment varied from 25.07grams to 30.97grams (Table 7). Significant differences among genotypes, between the conditions and in the interaction Season x genotype x condition was observed for 1000-grain weight (Table 5). There was a significant effect of drought stress on the weight of the grains negatively in all the grains. In the well-watered environment, genotypes, NERICA11, NERICA 11 x NERICA 2, NERICA 10, NERICA 2 and SARO5 x Ner15 recorded the highest 1000-grain weight which was significantly decreased in drought stressed environment as shown in Table 6. Progenies of NERICA1 x

NERICA 11, NERICA 2 x NERICA 1, IRAT 109, NERICA1 and SARO5 recorded the least 1000-grain weight which also recorded a decrease with drought stress (Figure 10). In the drought stressed environment, genotypes, NERICA 1 x NERICA 2, NERICA 11, NERICA 15, NERICA 10 and NERICA 1 x SARO5 had the highest 1000-grain weight and genotypes, NERICA 1, NERICA 1 x NERICA 11, NERICA 1 x Ner15, NERICA 2 x NERICA 11 and NERICA 15 x NERICA11 recorded the least.

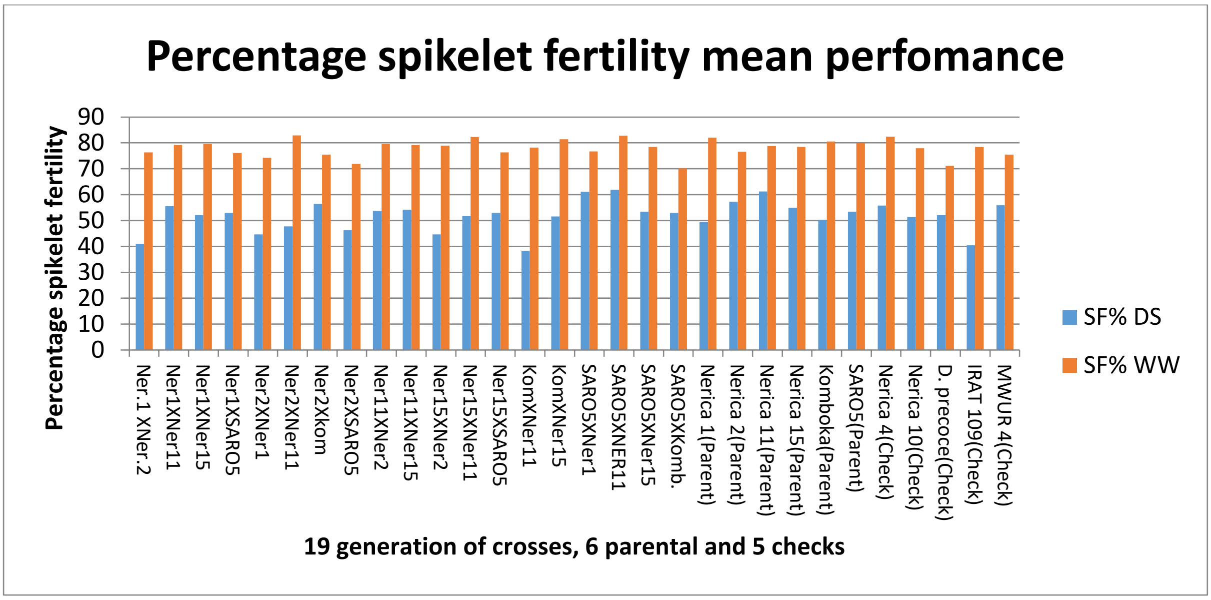


Figure 12: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for percentage spikelet fertility. Blue bars: drought stressed environment and red bars: well-watered environment

Percentage spikelet fertility varied between the two environments, in that there was a reduced spikelet fertility of the genotypes in the drought stressed environment (38.3%-61.9%) as compared to those in the well-watered environment (70.1%-82.8%) (Table 7). In well-watered environment (Figure 11), genotypes, NERICA 2 x NERICA 11, SARO5 x NERICA 11, NERICA 4, NERICA 15 x NERICA 11 and NERICA 1 had the highest percentage spikelet fertility. The lines recorded a reduction in percentage spikelet fertility under drought stress conditions. The least spikelet fertility in the well-watered environment were by genotypes, SARO5 x Komboka, SARO5 x NERICA 15, NERICA 2 x SARO5, NERICA 2 x

NERICA 1 and NERICA 2 x Komboka which also recorded a reduction in percentage spikelet fertility in the drought stressed environment. Progenies from generation of crosses of NERICA 2 x Komboka, NERICA 2, SARO5 x NERICA 1, NERICA 11 and SARO5 x Ner11 recorded the highest percentage spikelet fertility in the drought stressed environment while genotypes, Komboka x NERICA11, IRAT 109, NERICA 1 x NERICA 2, NERICA 15 x NERICA 2 and Komboka x NERICA15 (Figure 11) recorded the least.

Table 8: Mean performance in yield and the percentage yield reduction of the 30 rice genotypes in drought stressed and well-watered in Mwea over two seasons in 2016/2017

		Grain yield(t/ha)		**Yield reduction (Percentage)**
Ser.No.	**Genotype**	**DS**	**WW**	
1	NERICA.1 XNERICA.2	1.4	3.5	60
2	NERICA1XNERICA11	1.0	7.3	85
3	NERICA1XNERICA15	1.7	6.4	73
4	NERICA1XSARO5	2.2	7.5	71
5	NERICA2XNERICA1	1.4	2.4	43
6	NERICA2XNERICA11	1.3	4.8	73
7	NERICA2XKom	2.1	7.0	70
8	NERICA2XSARO5	1.7	8.9	81
9	NERICA11XNERICA2	1.9	5.9	67
10	NERICA11XNERICA15	1.4	3.2	56
11	NERICA15XNERICA2	1.5	3.0	52
12	NERICA15XNERICA11	1.9	7.6	75
13	NERICA15XSARO5	2.3	8.1	71
14	KombokaXNERICA11	1.7	7.0	75
15	KombokaXNERICA15	1.5	3.0	51
16	SARO5XNERICA1	1.8	6.4	71
17	SARO5XNERICA11	2.5	8.4	70
18	SARO 5XNERICA15	1.8	5.1	65
19	SARO5XKomboka	1.6	5.1	69
20	NERICA 1(Parent)	1.0	3.5	71
21	NERICA 2(Parent)	0.9	3.0	72
22	NERICA 11(Parent)	2.1	4.9	57
23	NERICA 15(Parent)	1.5	5.2	71
24	Komboka(Parent)	1.8	4.2	57
25	SARO5(Parent)	1.4	5.9	76

26	NERICA 4(Check)	2.3	4.5	50
27	NERICA 10(Check)	1.3	6.5	80
28	Duorado precoce(Check)	1.2	5.1	77
29	IRAT 109(Check)	1.2	3.9	70
30	MWUR 4(Check)	1.8	4.5	59
	Grand mean	1.6	5.4	70
LSD	S*G	0.7		
	S*E	0.2		
	G*E	0.7		
	S*G*E	1.0		

DS=Drought Stressed, WW=Well-watered. S*G= season x genotype, S*E= season x environment, G*E= genotype x environment and S*G*E= season x genotype x environment.

Significant variation among genotypes was noted in between the two environments at $p<0.05$ (Table 5). The yield varied from 3.0t/ha to 8.9 t/ha in the well-watered environment and between 0.9t/ha to 2.5 t/ha in the drought stressed environment. The genotypes in the drought stressed environment showed significant reduction in yield as compared to the genotypes in the well-watered environment. The percentage mean reduction of all genotypes was at 70%. The percentage yield reduction varied between 43% and 85% (Table 8).

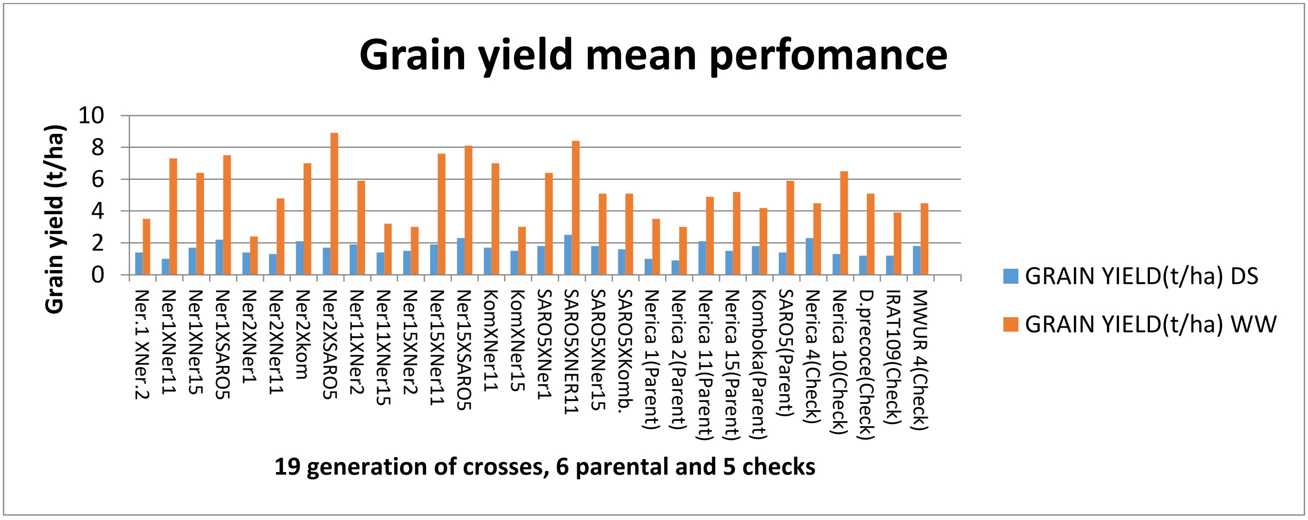


Figure 13: A chart showing the mean performance of the 19 generation of crosses, 6 parental and 5 checks for grain yield. Blue bars: drought stressed environment and red bars: well-watered environment

The effects varied from one genotype to the other depending on the ability to tolerate drought stress for instance, genotypes, NERICA 2 x SARO5, SARO5 x NERICA 11, NERICA 15 x SARO5, NERICA 15 x NERICA 11 and NERICA 1 x SARO5 which yielded very well in the well-watered environment had a yield reduction of 81%, 71%, 71%, 75% and 71% respectively with drought stress. Progenies of NERICA 2 x NERICA 1, Komboka x NERICA 15, NERICA 15 x NERICA 2, NERICA2 and NERICA 11 x NERICA15 yielded the least in the well-watered environment and also recorded a yield reduction of 43%, 51%, 52%, 72% and 56% respectively (Figure 12).

Genetic control of grain yield is made up of chains of biochemical processes. There was significant difference at $p<0.05$ between the conditions, among the genotypes and at genotype x condition interaction for grain yield (Table 4). Table 4 shows that there was a significant effect of drought stress on the grain yield of the thirty rice lines. For example, genotypes, NERICA 2 x SARO5, SARO5 x NERICA 11, NERICA 15 x SARO5, NERICA 15 x NERICA 11 and NERICA 1 x SARO5 which yielded very well in the well-watered environment but recorded decreased yields (1.68t/ha, 2.49t/ha, 2.31t/ha, 1.91t/ha and 2.17 respectively) in the drought stress environment. Progenies of NERICA 2 x NERICA 1, Komboka x NERICA 15, NERICA 15 x NERICA 2, NERICA2 and NERICA 11 x NERICA 15 were the least in yield in the well-watered environment and also recorded a yield reduction with drought stress (Figure 12). The best performing lines in terms of grain yield were genotypes of NERICA 1 and NERICA 2 x SARO5 in both drought stress and well-watered environment respectively.

4.2: Phenotypic correlations coefficients of the measured traits under drought stressed and well-watered environments

Table 8 shows that there was a significant negative correlation between plant height and number of tillers (r= -0.607), days to flowering (r=-0.678), number of panicles (r=-0.234) and biomass (r= -0.273) but a significant positive correlation was observed between plant height and panicle length (r= 0.243), flag leaf length (r=0.263) and grain yield (r = 0.220).

The results showed that there was a significant negative correlation between grain yield and days to flowering (r=-0.250) but there were no significant correlations with number of tillers (r=-0.072), number of panicles (r=-0.032), percentage spikelet fertility (r=0.045) and biomass (r=-0.174). A significant positive correlation was observed between grain yield and plant height (r=0.220) but no significant positive correlation was found between grain yield and panicle length (r=0.111), 1000- grain weight (r=0.040) and flag leaf length (r=0.084) (Table 9)

Table 9: Phenotypic coefficient correlations for traits of the 30 rice genotypes in the well-watered environment at Mwea over two seasons in 2016/2017

	PH	**NT**	**PL**	**DTF**	**NP/P**	**FLL**	**Biomass**	**SF%**	**1000GW**
NT	-0.6073***								
PL	0.2436***	-0.0460ns							
DTF	-0.6784***	0.6610***	-0.1220ns						
NP/P	-0.2348**	0.2693***	-0.1075ns	0.0998ns					
FLL	0.2636***	-0.1468*	0.2148**	-0.2541***	0.0194ns				
Biomass	-0.2737***	0.4129***	0.0938ns	0.5681***	-0.1089ns	-0.0412ns			
SF%	-0.0335ns	0.0710ns	0.0644ns	-0.0053ns	-0.0240ns	0.0002ns	-0.0730ns		
1000GW	0.0300 ns	-0.1039ns	-0.0587ns	-0.0520ns	-0.1449 ns	-0.0096ns	0.0060 ns	0.0005ns	
GY	0.2201**	-0.0720ns	0.1114ns	-0.2504***	-0.0325ns	0.0836ns	-0.1741ns	-0.0452ns	0.0402ns

Key: ***= Very highly significant, **= Highly significant, *= Significant and ns=not significant. PH= plant height; NT= Number of tillers, PL= Panicle length, DTF= Days to flowering, NP/P=Number of panicles per plant; FLL= Flag leaf length; 1000-GW= 1000 grain weight, SF%=Percentage spikelet Fertility and GY=Grain yield.

Table 10: Phenotypic correlations coefficients for agronomic traits of the 30 rice genotypes under drought stressed environment in Mwea over two seasons in 2016/2017

	PH	**NT**	**PL.**	**DTF**	**NP/P**	**FLL**	**Biomass**	**%SF**	**1000-GW**
NT	-0.5445***								
PL	0.2210**	-0.0654ns							
DTF	-0.724***	0.5985***	-0.1674*						
NP/P	-0.0985ns	0.3491***	0.0796	0.2294**					
FLL	0.1957**	-0.0765ns	0.1335ns	-0.1998**	-0.1768*				
Biomass	-0.5***	0.4541***	-0.1979**	0.5814***	0.1305ns	-0.0018ns			
%SF	0.0810ns	-0.0698ns	-0.0032ns	-0.0830ns	0.0275ns	-0.0227ns	-0.0651ns		
1000-GW	0.2095**	-0.1141ns	0.0142ns	-0.2546***	-0.1160ns	0.0713ns	-0.3280***	0.0557ns	
GY	0.3036***	-0.0353ns	0.1974**	-0.2348**	0.1695*	0.080ns	-0.057ns	0.2208**	0.0692ns

Key: ***= Very High Significant, **= High Significant, *= Significant and ns=no significant differences. PH= plant height, NT= Number of Tillers, PL= Panicle Length, DTF= Days to Flowering, NP/P=Number of Panicles per plant, FLL= Flag Leaf Length1000-GW= 1000 grain weight, SF%=Spikelet Fertility and GY=Grain yield

Under drought stress, a significant negative correlation between plant height with number of tillers (r=-0.544), biomass (r=-0.5) and days to flowering (r=-0.72) but plant height was significantly positively correlated to panicle length (r=0.221) and flag length (r=0.195). Plant height and number of panicles per plant (r=0.009) were not significantly negatively correlated (Table 10).

A significant negative correlation was shown between grain yield and days to flowering (r=-0.234) but grain yield was not significantly correlated to number of tillers (r=-0.035) and biomass (r=-0.057). A significant positive correlation was noted between grain yield and plant height (r=0.306) and spikelet fertility (r=0.220) but grain yield was not significantly correlated with flag leaf length, number of panicles, 1000-grain weight and panicle length (Table 10).

Table 11: Combined correlation coefficients in agronomic traits of the thirty rice genotypes in two seasons under drought stress environment and well –watered environment at Mwea through two seasons in 2016/2017

	PH	NT	PL	DTF	NP/P	FLL	Biomass	SF%	1000GW
NT	-0.1296*								
PL	0.0219ns	0.1791***							
DTF	-0.1768***	0.6038***	-0.0723ns						
NP/P	-0.0303ns	0.5618***	0.2600***	0.1969***					
FLL	0.1986***	-0.1087*	0.1540**	-0.2299***	-0.0516ns				
Biomass	-0.0374ns	0.6535***	0.3236***	0.4238***	0.5863***	-0.0296ns			
SF%	0.0180ns	0.4488***	0.3442***	0.0820ns	0.5841***	-0.0226ns	0.6694***		
1000GW	0.0129ns	0.3246***	0.2704***	-0.0356ns	0.5075***	0.0311ns	0.6237***	0.596***	
GY	0.0320ns	0.4048***	0.3897***	-0.0318ns	0.5707***	0.0306ns	0.6236***	0.6705***	0.5846***

Key: ***= Very highly Significant, **= Highly Significant, *= Significant and ns=not significant. PH= Plant height, NT= Number of tillers, PL= Panicle length, DTF= Days to flowering, NP/P=Number of panicles per plant, FLL= Flag leaf length, 1000-GW= 1000 grain weight, SF%=Spikelet fertility and GY=Grain yield.

Combined phenotypic correlation coefficients of the traits for the 30 rice lines showed that there was a significant negative correlation between plant height and number of tillers (r=-0.129), days to flowering (r=-0.176) and number of panicles per plant (r=-0.030) but not significantly correlated with biomass (r=-0.037) (Table 8). There were positive correlations between plant height with panicle length and grain yield with r= 0.022 and r=0.032 respectively under well-watered environment (Table 11).

Grain yield was significantly positively correlated with the number of tillers (r=0.405), panicle length (r=0.387), number of panicles per plant (r=0.571), percentage spikelet fertility (r=0.670), 1000-Grain Weight (r=0.585) and biomass (r=0.624) but grain yield was not significantly correlated with plant height (r=0.032), flag leaf length (r=0.031) and days to flowering (Table 11).

4.3: Additive Main Effects and Multiplicative Interaction (AMMI) and (Interactive Principal Component Analysis (IPCA) analysis

The analysis of variance of AMMI model for the 30 rice lines over two seasons under two environments showed that genotypes accounted for 18.2% of the total treatment sum of squares, environment explained 64.12% and Genotype x Environment (GXE) interaction accounted for 12.73% at $p<0.05$ (Table 12). GEI sum of squares were partitioned into IPCA 1 and IPCA 2. From this study, IPCA 1 explained 90.34% of the GEI sum of square while IPCA 2 explained only 9.66%. These results depict that IPCA1 was sufficient for evaluation of variation in grain yield as explained by GEI

Table 12: ANOVA for AMMI and IPCA analysis for grain yield in t/ha of the 30 rice lines in drought stressed and well-watered environments through two seasons in 2016/2017 at KALRO-Mwea

Source of variation	Df	SS	%SS	MS	GEI SS%
Treatments	119	1894.1		15.92***	
Genotypes	29	363.2	18.2	12.52***	
Environments	3	1277.2	64.12	425.75***	
Block	8	6.2		0.78*	
Interactions (GEI)	87	253.7	12.73	2.92***	
IPCA1	31	229.2		7.39***	90.34
IPCA2	29	16.8		0.58ns	9.66
Residuals (noise)	27	7.8		0.29ns	
Error	232	91.4		0.39	
Total	359	1991.8		5.55	

Key: ***= very highly significant, **= highly significant, *= significant and ns=not significant. GEI=Genotype by Environment Interaction.

Table 12 shows the mean yield of the genotypes varied between environments and seasons. The mean yield of the drought stressed environment varied between 1.0 t/ha and 2.8 t/ha in season 1 and between 0.4t/ha and 3.0 t/ha in season 2 (Table 13). The average grain yield ranged from in the four environments ranged from 1.9t/ha to 5.4 t/ ha (Table 13). The IPCA for yield of the 30 rice genotypes were also presented in table 13. Lowest score of IPCA 1 was –0.8 while the highest score was 0.9. IPCA2 ranged from -0.3 to 0.5 (Table 13).

Table 13: IPCA scores, ASV (AMMI Stability Variance) and mean performance in tons per hectare of the 30 rice lines grown under well-watered and drought stressed environment through two seasons in 2016/ 2017 at KALRO-Mwea

Ser. No.	Genotypes	MEANS					IPCA Score		ASV
		Drought1	**Drought2**	**WW1**	**WW2**	**GM**	**IPCA1**	**IPCA2**	
1	NERICA.1 XNERICA.2	1.6	1.2	3.4	3.5	2.4	0.58217	0.03476	7.9
2	NERICA1XNERICA11	1.0	1.1	7.1	7.4	4.2	-0.82146	-0.00619	11.2
3	NERICA1XNERICA15	1.9	1.5	6.4	6.5	4.1	-0.31239	0.18865	4.3
4	NERICA1XSARO5	1.8	2.6	7.4	7.7	4.9	-0.55842	-0.35142	7.6
5	NERICA2XNERICA1	1.2	1.5	2.3	2.5	1.9	0.91225	-0.34524	12.5
6	NERICA2XNERICA11	1.4	1.2	4.7	4.9	3.0	0.09969	0.00107	1.4
7	NERICA2XKomboka	1.2	3.0	6.8	7.3	4.6	-0.43041	-0.85482	5.9
8	NERICA2XSARO5	1.1	2.2	8.6	9.1	5.3	-1.18555	-0.39368	16.2
9	NERICA11XNERICA2	2.2	1.8	5.9	6.1	3.9	-0.07967	0.13272	1.1
10	NERICA11XNERICA15	1.5	1.3	3.2	3.3	2.3	0.65798	-0.05108	8.9
11	NERICA15XNERICA2	1.5	1.4	2.9	3.1	2.3	0.74355	-0.11801	10.1
12	NERICA15XNERICA11	2.3	1.5	7.5	7.7	4.7	-0.63006	0.36190	8.6
13	NERICA15XSARO5	2.8	1.9	7.9	8.2	5.2	-0.65580	0.43780	8.9
14	KombokaXNERICA11	1.5	1.9	6.9	7.2	4.4	-0.52526	-0.18088	7.2
15	KombokaXNERICA15	1.5	1.4	2.9	3.0	2.2	0.75454	-0.15250	10.3
16	SARO5XNERICA1	1.8	1.8	6.3	6.5	4.1	-0.27617	0.01432	3.88

17	SARO5XNERICA11	2.8	2.1	8.2	8.5	5.4	-0.70676	0.36049	9.6
18	SARO 5XNERICA15	2.5	1.1	5.1	5.1	3.5	0.17252	0.53777	2.4
19	SARO5XKomboka	1.7	1.5	5.0	5.2	3.4	0.09165	-0.00372	1.3
20	NERICA 1(Parent)	1.4	0.6	3.5	3.6	2.3	0.42588	0.22999	5.8
21	NERICA 2(Parent)	1.2	0.4	3.1	3.1	1.9	0.53135	0.18492	7.3
22	NERICA 11(Parent)	1.8	2.4	4.8	5.0	3.5	0.30398	-0.35306	4.2
23	NERICA 15(Parent)	1.7	1.3	5.2	5.3	3.4	0.01635	0.12664	0.3
24	Komboka(Parent)	1.9	1.6	4.1	4.2	2.9	0.46567	0.01530	6.4
25	SARO5(Parent)	1.4	1.4	5.8	6.0	3.7	-0.24637	-0.04913	3.4
26	NERICA 4(Check)	2.7	1.8	4.5	4.6	3.4	0.51947	0.23436	7.1
27	NERICA 10(Check)	1.2	1.3	6.4	6.6	3.9	-0.49632	-0.02067	6.7
28	Duorado precoce(Check)	1.5	0.8	5.1	5.2	3.2	-0.05987	0.23092	0.8
29	IRAT 109(Check)	1.2	1.1	3.9	4.1	2.6	0.32593	-0.05774	4.4
30	MWUR 4(Check)	1.8	1.9	4.4	4.5	3.2	0.38155	-0.15345	5.2
	Mean	1.7	1.6	5.3	5.5	3.5			7.9

Key: Drought 1 and Drought 2= drought season 1 and drought season 2 respectively, WW1 and WW2=well-watered season 1 and well-watered season 2 respectively. GM= General mean, IPCA= Interaction Principal Component Analysis, ASV=AMMI stability variance.

The lowest ASV value obtained in this study was 0.2 while the highest ASV value was 16.2 (Table 13). Genotypes, SARO5 x NERICA 11 (5.4t/ha), NERICA 2XSARO5 (5.3t/ha), NERICA 15 x SARO5 (5.2t/ha), NERICA 1 x SARO5 (4.9 t/ha) and NERICA 15 x NERICA 11 (4.7t/ha) recorded the highest grain yield. These genotypes show the possibility of possessing traits that may have positive impact on yield. Genotypes, NERICA 2(1.9t/ha), Komboka x NERICA15 (2.2t/ha) and NERICA 2 x NERICA 1 (1.8t/ha) had the lowest grain yield. These genotypes could possess traits that have negative impact on yield.

According to ASV (Table 13), the genotypes with the least score is the most stable. From this study, the ASV ranked genotypes, NERICA 15 <Dorado Precoce <NERICA 11 x NERICA 2 < SARO5 x Komboka < NERICA 2 x NERICA 11 as the most stable and NERICA 2 x SARO5 < NERICA 2 x NERICA 1 < NERICA 1 x NERICA 11 < Komboka x NERICA 15 <NERICA 15 x NERICA 2 as the most unstable (Table 12). This is in agreement with studies which have used ASVs to evaluate stability of grain yield of various bread wheat varieties.

From this study, the highest IPCA1 scores were expressed by genotypes NERICA 1 x NERICA 2, NERICA 11 x NERICA 15, NERICA 15 x NERICA 2, Komboka x NERICA 15 and NERICA 2 x NERICA 1. Lowest IPCA1 scores were exhibited by NERICA 2 x SARO5, NERICA 1 x NERICA 11, SARO5 x NERICA 11, NERICA 15 x SARO5 and NERICA 15 x NERICA 11.

4.4: GGE Biplot Analysis

GGE biplots were constructed using two principal components (principal component 1 and principal component 2). GGE biplots graphically displays patterns of genotypes across environments in a multi-locational trial. The goodness of fit of GGE biplot is 100% with PC1 accounting for 96.44% and PC2 accounting for 3.56% (Figure 13).

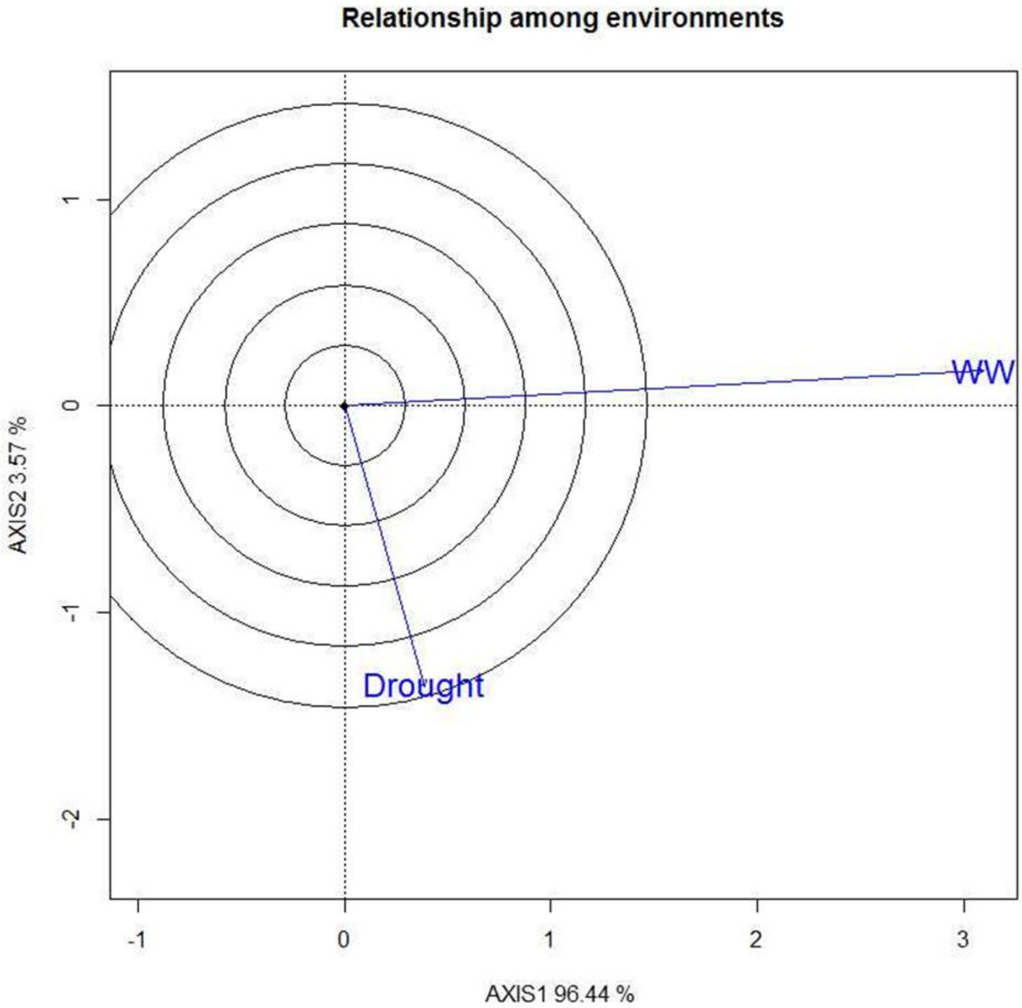


Figure 14: Relationship among environments. WW-well-watered environment and Drought-Drought stressed environment.

Correlation coefficient is approximated by cosine of the angle between two vectors. Acute angles represent positive correlations, obtuse angles represent negative correlations and right angle represents no correlations. Figure 14 shows the angle between well-watered and drought stressed environment is an acute angle showing positive correlations between the two environments.

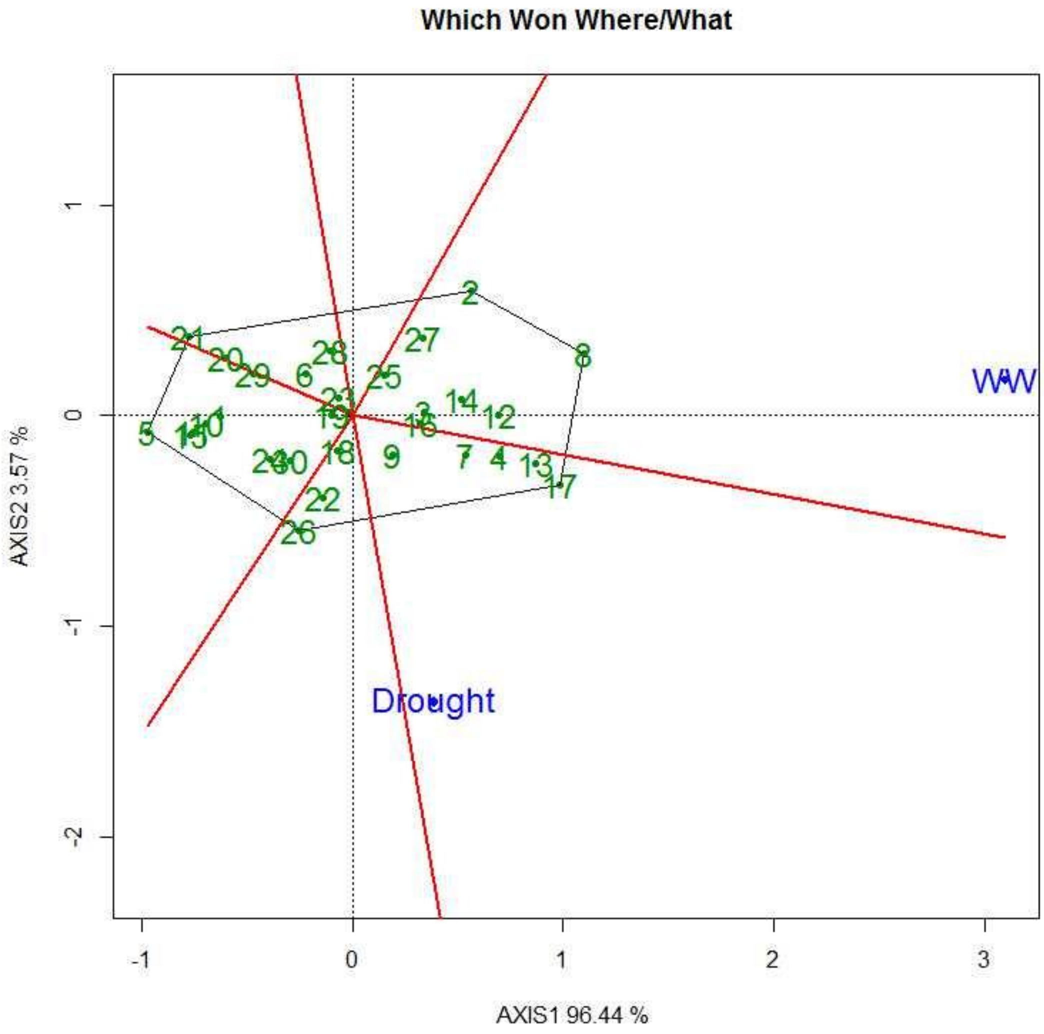


Figure 15: Polygon view of GGE biplot based on symmetrical scaling

Guide:1-NERICA1XNERICA2,2-NERICA1XNERICA11, 3- NERICA 1XNERICA15,4-NERICA1XSARO5,5-NERICA2XNERICA1,6-NERICA2XNERICA11,7-NERICA2XKomboka,8-NERICA2XSARO5,9-NERICA11XNERICA2,10-NERICA11XNERICA15,11-NERICA15XNERICA2,12-NERICA15XNERICA11,13-NERICA15XSARO5,14-KombokaXNERICA11,15-KombokaXNERICA15,16-SARO5XNERICA1,17-SARO5XNERICA11,18-SARO5XNERICA15,19-SARO5XKomboka, 20-NERICA1(Parent),21-NERICA2(Parent), 22-NERICA11(Parent), 23-NERICA15(Parent), 24-Komboka(Parent), 25-SARO5(Parent), 26-NERICA4(Check), 27-NERICA 10(Check), 28-Duorado precoce (Check), 29- IRAT109(Check) and 30- MWUR 4(Check).

The Which-Won-Where view of GGE biplot aids in visualizing mega-environments. This biplot is n form of an irregular polygon and a set of lines in red drawn from the point of the biplot origin. The set of lines intersects the sides at a right angle. The vertices of the polygon are genotype markers located furthest away from the biplot origin in various directions. The genotypes are in green numbers. The winning genotype for a sector is at the vertex of the sector at the intersection of the two polygon sides whose perpendicular lines form the boundary of that sector. From this biplot, the two environments fall into two sectors with different winning lines. Ray 1 is perpendicular to the sides that connect segregating genotype 2 and 8. In the well-watered environment, 1 and 8 (NERICA 2 x SARO5 and NERICA 1 x NERICA 11 respectively) were the winning lines while in the drought stressed environment 17 (SARO5 x NERICA 11) was the winning line (Figure 15).

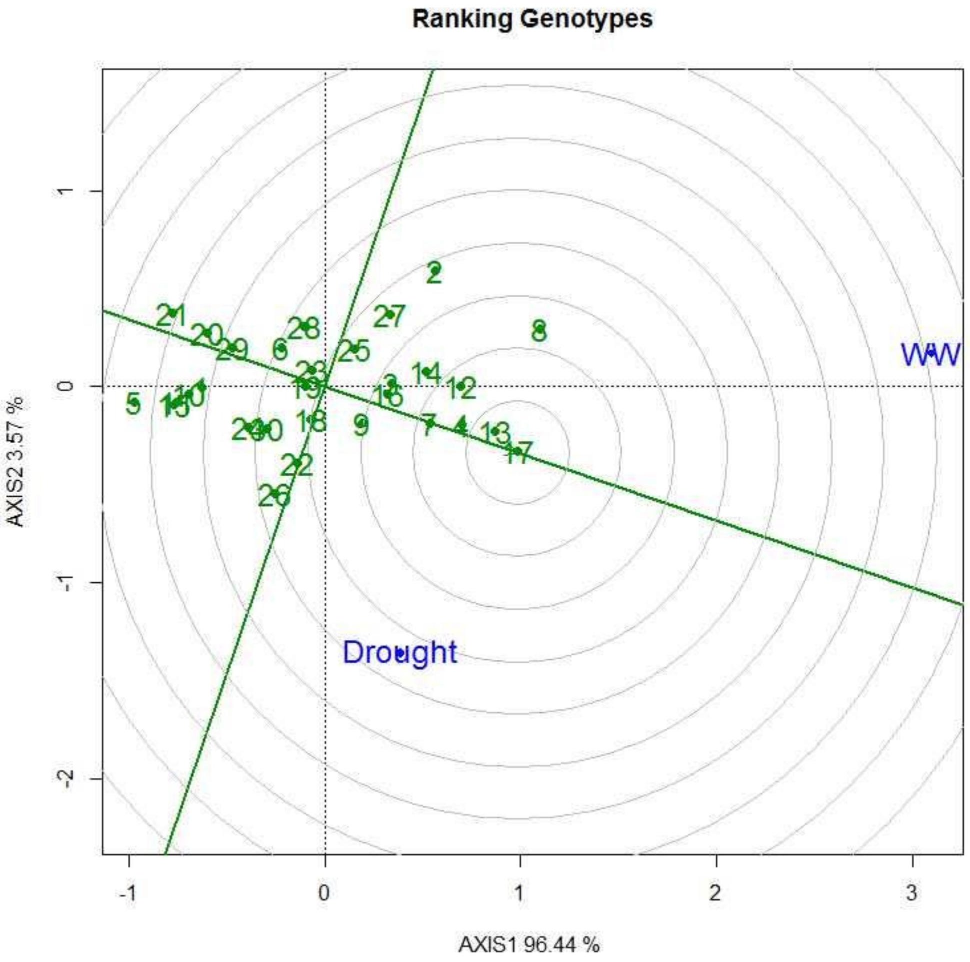


Figure 16: GGE-biplot based on genotype-focused scaling for comparison the genotypes with ideal genotypes.

Guide:1-NERICA1XNERICA2,2-NERICA1XNERICA11, 3- NERICA 1XNERICA15,4-NERICA1XSARO5,5-NERICA2XNERICA1,6-NERICA2XNERICA11,7-NERICA2XKomboka,8-NERICA2XSARO5,9-NERICA11XNERICA2,10-NERICA11XNERICA15,11-NERICA15XNERICA2,12-NERICA15XNERICA11,13-NERICA15XSARO5,14-KombokaXNERICA11,15-KombokaXNERICA15,16-SARO5XNERICA1,17-SARO5XNERICA11,18-SARO5XNERICA15,19-SARO5XKomboka,20-NERICA1(Parent),21-NERICA2(Parent),22-NERICA11(Parent),23-NERICA15(Parent), 24-Komboka(Parent), 25-SARO5(Parent), 26-NERICA4(Check), 27-NERICA 10(Check), 28-Duorado precoce (Check), 29-IRAT109(Check) and 30- MWUR 4(Check).

Ideal genotype must have the highest mean performance and be absolutely stable. Concentric lines are drawn to help visualize the distance between each genotype and the ideal genotype. The closer a genotype is to the ideal genotype the more desirable it is. Figure 15 ranks genotype with reference to ideal genotype. A genotype is desired if it’s closer to the ideal genotype (Farshadfar et al., 2012). From Figure 16, segregating genotypes SARO5 x

NERICA 11(17) and NERICA 15 x SARO 5 (13) fell within the innermost concentric circles and therefore ranked as the best in terms of yield and stability. NERICA 1 x SARO 5 was ranked as the next desirable genotype. NERICA 2x NERICA 1 was ranked as the most unfavorable since they were far from the ideal line.

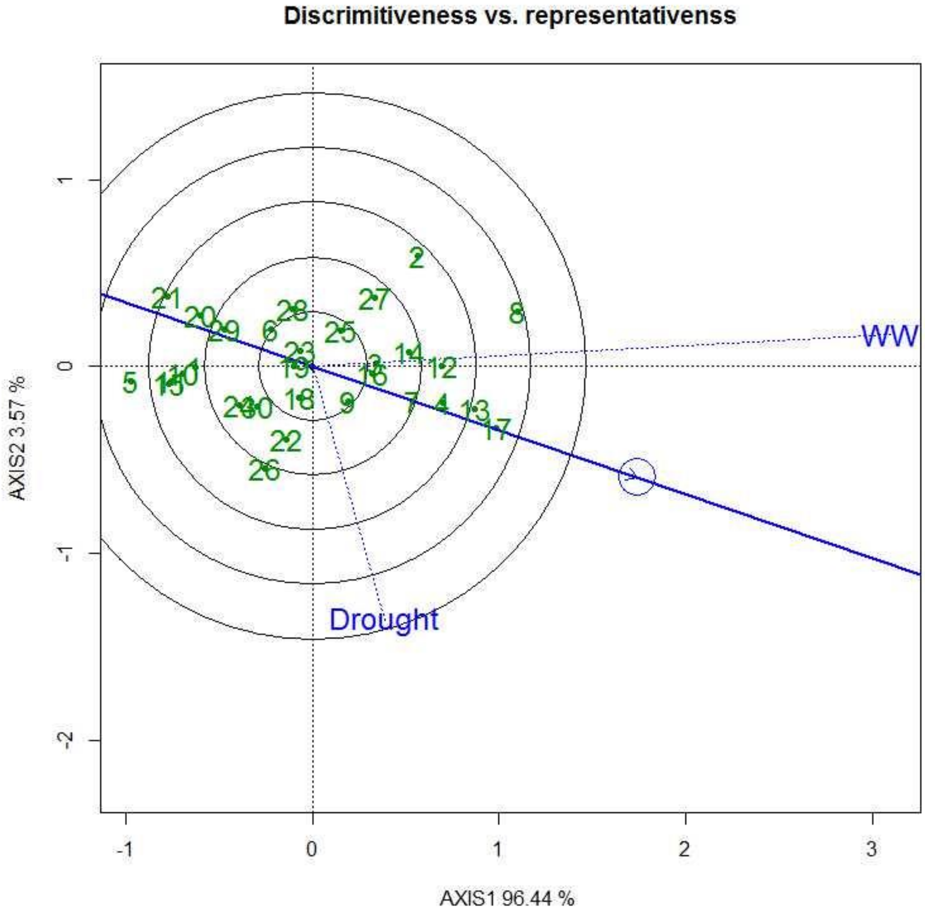


Figure 17: The discriminating and representative view showing the discriminating ability and representativeness of the test environments. Guide:1-NERICA1XNERICA2,2-NERICA1XNERICA11,3-NERICA1XNERICA15,4-NERICA1XSARO5,5-NERICA2XNERICA1,6-NERICA2XNERICA11,7-NERICA2XKomboka,8-NERICA2XSARO5,9-NERICA11XNERICA2,10-NERICA11XNERICA15,11-NERICA15XNERICA2,12-NERICA15XNERICA11,13-NERICA15XSARO5,14-KombokaXNERICA11,15-KombokaXNERICA15,16-SARO5XNERICA1,17-SARO5XNERICA11,18-SARO5XNERICA15,19-SARO5XKomboka,20-NERICA1(Parent),21-NERICA2(Parent),22-NERICA11(Parent), 23-NERICA15(Parent), 24-Komboka(Parent), 25-SARO5(Parent), 26-NERICA4(Check), 27-NERICA 10(Check), 28-Duorado precoce (Check), 29- IRAT109(Check) and 30- MWUR 4(Check).

The discriminative vs. representative biplot aids in evaluating each test-environment. This biplot provides answers for the following questions:

i) Is the test environment able to discriminate the genotypes that is does it provide much information about the differences among genotype?

ii) Is the test environment representative of the mega-environment?

iii) Does the test environment give unique information about the genotypes?

Test environment with a longer vector for instance the well-watered environment, are more discriminating of genotypes. For the drought stressed environment, it has a shorter vector from the biplot origin, all genotypes performed similarly in it and therefore it gives less information about the differences among genotypes. The shorter vector also depicts that the environment is not well represented by PC1 and PC2.

The discriminating and representativeness biplot show that the well-watered environment was discriminating and non-representative due to the long vector from the AEC. The shorter vector of the drought environment falls further from the average environment and therefore described as non-discriminating and non-representative of the target region (Figure 17).

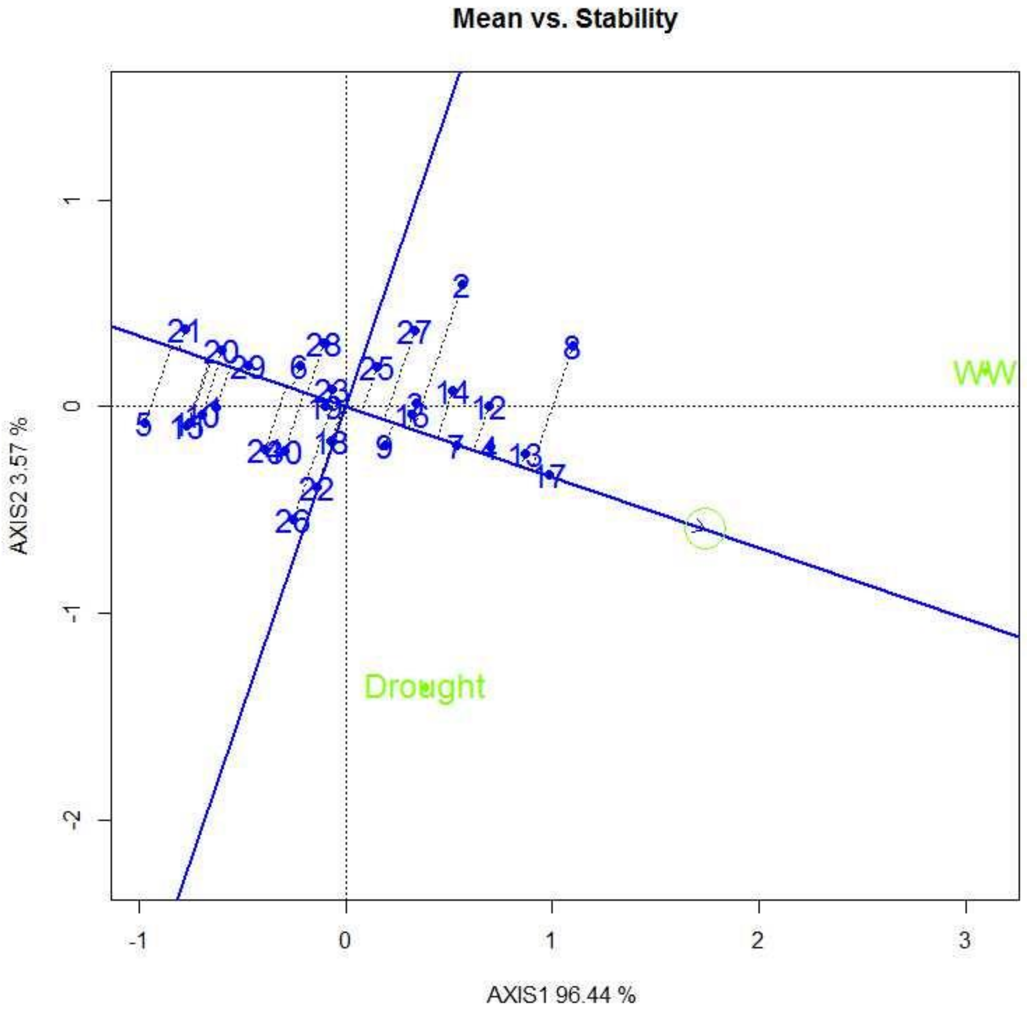


Figure 18: GGE biplot based on genotype focused singular value partitioning for comparison of the genotypes with the ideal genotype.

Guide:1-NERICA1XNERICA2,2-NERICA1XNERICA11, 3- NERICA 1XNERICA15,4-NERICA1XSARO5,5-NERICA2XNERICA1,6-NERICA2XNERICA11,7-NERICA2XKomboka,8-NERICA2XSARO5,9-NERICA11XNERICA2,10-NERICA11XNERICA15,11-NERICA15XNERICA2,12-NERICA15XNERICA11,13-NERICA15XSARO5,14-KombokaXNERICA11,15-KombokaXNERICA15,16-SARO5XNERICA1,17-SARO5XNERICA11,18-SARO5XNERICA15,19-SARO5XKomboka, 20-NERICA1(Parent),21-NERICA2(Parent), 22-NERICA11(Parent), 23-NERICA15(Parent), 24-Komboka(Parent), 25-SARO5(Parent), 26-NERICA4(Check), 27-NERICA 10(Check), 28-Duorado precoce (Check), 29- IRAT109(Check) and 30- MWUR 4(Check).

The mean vs. stability biplot is used to identify an ideal genotype which is characterized by both high mean performance and high stability. This biplot enabled visualization of genotype mean performance and their stability across the mega environment. The average environment axis is single-arrowed line passing through biplot origin and the average environment is at the center of the small circle which is the average environment.

Stability of grain yield of genotypes are evaluated by AEC (Average Environment Coordination), where principal components are used in all the environments. A line drawn through AEC and biplot origin is called average environment axis (AEA). AEA points in one direction pointing the genotype main effect. The AEC ordinate separates genotypes with below average means from those above average means. Figure 17 shows the performance of the lines were ranked as follows in this biplot 17>8>13>4>12>7>14>2>16>3>9>27>25 to be above average means.

The mean and stability biplot show that genotypes SARO 5x NERICA 11, NERICA 2 XSARO 5 and NERICA 15 x SARO 5 had the highest grain yield (Figure 18). Stability of the genotypes depend on their projection on to the line drawn through AEC.

17 was the most stable genotype as it is located close to the AEC and had almost zero projection onto the AEA. This was one of the highly consistent line across the environments. Lines 2 and 26 were least stable as they had long projections from the AEA (Figure 18).

4.5: DISCUSSION

4.5.1: Identification of variation of genotypes in drought stressed and well-watered environment

The study revealed that there was an effect of drought stress on plant height of the 19 generation of crosses, 6 parental and 5 checks. Plant height decreased by drought stress as a result of reduction in the number of nodes and the distance between internodes. Significant variations among the 19 generation of crosses, 6 parental and 5 checks and between the two environments for number of tillers were observed. This observation could be explained by the reduction in leaf initiation by the genotypes in the drought stressed environment unlike those in the well-watered environment that had no difficulty in leaf initiation. A further explanation could be the reduction in PAR (Photosynthetically Active Radiation) that leads to decreased number of tillers per hill. Decreased water content in the soil leads to decreased water uptake which reduces the ability of the plants to produce enough assimilates. This results in inhibition of both photosynthesis and cell division at meristematic tissues. The results obtained in this study were in tandem with that of Zubaer et al., (2007) who observed decreased tiller number per hill with drought stress among the rice genotypes. This observation of reduced number of tillers in the drought stressed environment is in line with the study done by Fen et al., (2015).

The study revealed no significant in flag leaf length between conditions but significant variations between seasons and among genotypes. This could be attributed to complete vegetative development of the crops and therefore there was no destruction of the flag leaf length. During reproduction and filling of the grains, the flag leaf acts as a source of photosynthetic energy (source of photosynthates to the grains). Direct intense effects on rice productivity could be felt in case of damages to the flag leaf length. Therefore, protecting flag leaf is crucial at the early stages of the leaf (Rahman et al., 2013)

From the study, the lines under drought stress flowered earlier than those under well-watered conditions. The early flowering genotypes adopted drought escape mechanism by flowering earlier in drought stressed environment in comparison with their counterparts in the well-watered environment. Drought escape allows short developmental duration and therefore the rice crops can adapt best to late or terminal drought resulting in higher yields (Allah et al., 2010.

Leaf rolling varied significantly among the crops under drought stress environment. The tightly rolled genotypes showed reduced drought tolerance**.** In that drought stress induced loss of turgor and poor osmotic adjustment. The lines that expressed high leaf rolling scores led to decreased interception of light with the rice leaves. This ultimately resulted in decreased grain yield in these crops. Decreased leaf rolling indicated the capacity to maintain turgor and avoid dehydration. These lines that express decreased leaf rolling were susceptible to drought stress but had superior yields due to the shorter days to flowering character. Leaf rolling has a negative effect on light use efficiency therefore reducing photosynthetic rate leading to decreased grain yields.

This study shows significant variations in panicle length among the lines with those under drought stress expressing shorter panicle length than those under well-watered environment. Chaum et al., (2010) notes that exposure of two tolerant genotypes to drought stress, panicle length and panicle grains were not affected but those of the susceptible genotypes decreased. The tolerant genotypes had a greater productivity. The decrease in panicle length is due to decrease photosynthates being transported from the source (flag leaf) to the sink (panicle) as a result of drought stress.

From this study, the number of panicles per plant were reduced in the drought stressed environment as compared to the lines in the well-watered environment. Number of panicles per plant is highly associated with the number of tillers and therefore reduction in the number of tillers leads to a reduction in the number of panicles. Panicles are also sink for the rice plants, and drought stress affect the translocation of photosynthates leading to reduced number of panicles. Under well-watered environment, photosynthesis is not affected and therefore more carbohydrates are transported to the panicles leading to filled grains and increased number of panicles and eventually increased grain yield. This can be explained by the fact that drought stress decreases the build-up of dry weight in all the organs of the crops. The decrease in biomass reduces the life cycle of plants resulting in decreased yields (Korres et al., 2016).

Grain filling differed among the genotypes in the two environments affecting the percentage spikelet fertility. Significant differences were noted with season, genotype and condition. The genotypes in the drought stressed environment had reduced number of filled spikelets as compared to those in the well-watered environment. The reduction in the number of filled spikelets led to a reduction in percentage spikelet fertility. When drought was introduced at booting stage, there was a reduction in fertilization of spikelets leading to decreased grain filling. Spikelet fertility decreased with drought stress in that the genotypes in the drought stressed environment expressed a lower spikelet fertility percentage compared to those in well-watered environment.

Decreased filling of the grains is as a result of water stress causing variation of the size of the glume in order to amass starch. Drought stress also affects division and expansion of endosperm cells and the rate of accumulation of dry matter per unit concentration of sucrose. According to Korres et al., (2016), when drought is introduced at flowering phase, pollen viability, seed set and stigma receptivity are drastically affected.

Percentage spikelet fertility is a crucial determinant of yield and is a very good indicator of the intensity of drought stress, (Guimaraes et al, 2010). Spikelet sterility is mostly due to water stress at meiosis phase but not due to panicle water status (Liu et al., 2007) Both anther dehiscence and panicle exsertion are very sensitive to drought. Panicle exsertion accounts for twenty-five to thirty percent of spikelet fertility majorly due to the inability of the unexserted spikelets to complete anthesis and shed pollen (Barnabas et al., 2008) during flowering under drought stress conditions. This ultimately leads to failure of spikelets to open up during anthesis or drying out of the spikelets. Decreased availability of water may also lead to shriveling of anthers leading to insufficient amount of pollen for fertilization. Decreased spikelet fertility can also be due to an increase in respiration during grain filling resulting increased utilization of carbohydrates by the crops hence decreased photosynthetic efficiency. These observations are in line with that of Zubaer et al., (2007) who observed decreased 1000-grain weight among the rice genotypes with drought stress. Grain filling is described by amassing of carbohydrates in the pistils of the flowers. The carbohydrates are majorly obtained from photosynthesis that takes place in the three to four uppermost leaves. Decrease in photosynthesis results in reduced production of assimilates that are meant for development of panicles and filling of grains. This ultimately leads to reduced grain yield.

Decreased 1000-grain weight and percentage spikelet fertility is as a result of reduced translocation of assimilates to the grains leading to reduced grain weight. These findings are in harmony with those of Moonmoon and Islam, (2017) who studied the effect of drought stress at different growth stages on yield and yield components of 6 rice genotypes. The degree of reduction of grain weight varies with the intensity of drought stress. Chaum et al., (2010) explains that drought stress disrupts most development stages of rice including both ovule and pollen abortion resulting in increased spikelet sterility, decreased grain weight and hence decreased yields.

Reduction in yield is dependent on the timing, duration and severity of the drought stress. Percentage yield reduction in this experiment is majorly due to drought occurring at flowering phase, it was terminal in terms of severity and it lasted through two growth phases of these genotypes (flowering and grain filling stage). Barnabas et al., (2008) explains that decreased grain set at flowering lead to decreased grain yield with drought stress. In this study, it was noted that drought stress led to decreased number of panicles per plant, biomass, 1000-grain weight, panicle length and percentage spikelet fertility leading to decreased grain yields. This reduction in grain yield is also as a result of drought stress interfering with translocation of carbohydrates, photosynthesis, growth and transpiration of the rice lines (Guimares, 2016).

4.5.2: Phenotypic correlation of the various traits under the well-watered and drought stressed environment.

In this study, a highly significant positive correlation between grain yield and plant height in both droughts stressed and well-watered environment was observed. This shows that the tall rice lines were higher yielding than the short varieties. There was also a significant negative correlation between plant height and number of tillers in both environments. This shows that in both conditions tall lines had fewer number of tillers while the shorter lines that had many number of tillers.

Babu et al., (2010) noted a high positive correlation between traits such as biomass, 1000-grain weight and number of tillers with grain yield in both droughts stressed and well-watered environment. They further noted a high positive correlation between panicle length and plant height in the drought stressed environment.

There was also significant positive correlation between plant height and panicle length in both well-watered and drought stressed environments respectively. Number of tillers also expressed positive correlations with biomass in both environments. There was a negative correlation between days to flowering and grain yield in both environments implying that the early maturing lines had higher yields than the late maturing lines. This is due to the ability of the early maturing lines to escape drought resulting in increased yields.

Under drought stressed environment, significant positive correlations were noted between percentage spikelet fertility with grain yield. Increased spikelet fertility may have led to increased grain yield. The lines that expressed increased spikelet fertility recorded increased yields. Significant negative correlations between 1000-grain weight with days to flowering and biomass was also recorded in the drought stressed environment. From this study, it was noted that grain yield by the genotypes were influenced by most parameters.

4.5.3: Genotype by Environment interaction of the 19 generation of crosses, 6 parental and 5 checks by AMMI analysis.

The large percentage sum of squares indicates significant differences in the averages between the environments leading to variations in yield. Similar results by Oliveria et al., (2013) have been seen in yellow passion fruit where a big percentage of SS is attributed to E and GXE interaction (95%). ASV is based on IPCA1 and IPCA 2 and has been used to rank stability of wheat and yellow passion fruit. The results from this study showed that there was variability in genotypes in that the 19 generation of crosses, 6 parental and 5 checks responded differently to water stress. This also indicate that there is possible genetic makeup that control yield and yield stability.

From these results, it is likely that the difference in yield among the thirty rice lines was due to the presence of Genotype x Environment Interaction (GEI). This implies that, selection process may be complicated since GEI decreased the importance of genotypes by affecting their yield performance by reducing the association between phenotypic and genotypic value (Amiri et al., 2013).

AMMI Stability Variance (ASV) is the distance from the co-ordinate point to origin in two-dimensional scatter-gram of IPCA1 scores against IPCA2 scores. IPCA 1 contributes largely to the GEI sum of squares and therefore it has to be weighted. Calculating weighted value enables compensation of relative contribution of IPCA1 to IPCA2 to the interaction sum of squares (Funga et al., 2017). The weighting is done by obtaining the proportional difference between IPCA1 and IPCA2. Genotypes with the least IPCA1 and ASV are the most stable.

4.5.4: GGE Biplot Analysis of Genotypes by Environment Interaction of 19 generation of crosses, 6 parental and 5 checks

The GGE biplots were able to rank the19 generation of crosses, 6 parental and 5 checks based on their performance in the two environments. They were ranked as follows: those above average, below average, stable, unstable and ideal genotypes. Those below average and unstable ones were not given much consideration in selection of rice lines that are high yielding and drought tolerant for a future breeding program. The stable and high yielding ones were important for selection and could be incorporated in a future breeding program SARO 5x NERICA 11 was selected for higher yield and stability across the mega-environments.

CHAPTER SIX:

CONCLUSIONS AND RECOMMENDATIONS

6.1: Conclusion

In this study, thirty segregating Kenyan rice lines were evaluated under drought stress and well-watered environment on the basis of agronomic traits, yield and yield related parameters. Among these segregating populations, generation of crosses NERICA 1 x SARO5, SARO5 x NERICA 11, NERICA 15 x SARO5 and Komboka x NERICA 15 had superior traits such as high yields in tonnes per hectare and also exhibited superiority in traits such as panicle length, plant height, flag leaf length and 1000-grainweight.

Most of the drought related traits were noted to be positively correlated with yield. These traits therefore impact positively on the performance of the genotypes in terms of yield. It was also noted that days to flowering was negatively correlated with grain yield under drought stress, meaning that the early flowering lines had higher grain yield due to their ability to escape drought.

In the genotype by environment study, AMMI analysis showed that SARO5 x Ner11 recorded a high grand mean yield and also a high ASV value of 9.649. This means that it is an unstable genotype despite the high mean yield. NERICA 2 x NERICA1 had very high ASV value of 12.450 and low yields therefore an unfavourable genotype. Stable genotypes included NERICA 15 and Dorado precoce which recorded low ASV values and medium yield of 3.4 t/ha and 3.1t/ha respectively. A stable genotype is suitable line for a breeding program.

GGE biplot show that there were positive correlations between well-watered and drought stressed environment. The mean and stability biplot show that genotypes SARO 5x NERICA 11, NERICA 2 XSARO 5 and NERICA 15 x SARO 5 had the highest grain yield. Segregating genotypes SARO5 x NERICA 11 and NERICA 15 x SARO 5 fell within the innermost concentric circles and therefore ranked as the best in terms of yield and stability. NERICA 1 x SARO 5 was ranked as the next desirable genotype. NERICA 2x NERICA 1 was ranked as the most unfavourable since they were far from the ideal line. The discriminating and representativeness biplot show that the well-watered environment was discriminating and non-representative due to the long vector from the AEC. In the polygon view of biplot, segregating lines, NERICA 2 x SARO5 and NERICA 1 x NERICA 11 were higher yielding in the well-watered environment while SARO5 x NERICA 11 was the best performing in the drought stressed environment.

6.2: Recommendations

In order to complete this study, the following research topics are recommended to be undertaken:

- Multi-location evaluation of genotypes SARO5 x NERICA11, NERICA 2 x SARO5 and NERICA 15 x SARO5, NERICA 15 and Duorado precoce under drought stress.
- Conduct studies on root characteristics on the thirty segregating populations for genotype identification.
- Generate crosses between the market preferred varieties especially Basmati with some drought tolerant upland varieties and evaluate them for drought tolerance.

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APPENDICES

Appendix 1: Analysis of variance (ANOVA) for agronomic parameters of 30 rice genotypes in drought stressed and well-watered environments in Mwea in season 1 in 2016.

	Df	**MS**				
		PH	DTF	FLL	NP/P	NT
Rep	2	16.16	4.36	90.37	19.717	25.175
Genotype	29	753.16***	375.97***	44.02***	15.410***	81.654***
Condition	1	2073.33***	384.27***	27.84ns	1683.612***	1526.0***
GenotypeXCondition	29	60.81*	38.39***	11.10ns	7.075ns	15.622***
Residual	118	38.75	13.54	19.11	6.274	6.180
Total	179					

*****=**very highly significant**, **=**Highly significant, ***=**significant, ns=not significant. Df= degrees of freedom, MS= mean sum of squares. PH= Plant height, DTF= days to flowering, FLL= Flag leaf length, NP/P=Number of Panicles per plant, NT= Number of tillers

Appendix 2: Analysis of variance (ANOVA) for yield and yield related parameters of 30 rice genotypes in drought stressed and well-watered environments in Mwea in season 1 in 2016

	Df	MS				
		PL	%SF	Biomass	1000-GW	GY
Rep	2	0.750	0.015	8.409	2.114	0.0135
Genotype	29	27.326***	0.01229***	173.657***	25.385***	5.7893***
Condition	1	302.642***	3.102***	17065.65***	1521.6***	583.17***
GenotypeXCondition	29	6.831*	0.008445*	27.056***	5.608*	4.2858***
Residual	118	3.658	0.00533	9.623	3.369	0.2390
Total	179					

*****=** Very Highly significant (p<0.005), **=Highly significant (p<0.05), *= Significant (p<0.05) and ns= not significant. Df= degress of freedom, MS= mean sum of squares. PL= Panicle length, %SF= Percentage spikelet fertility, 1000-GW= 1000-grain weight and GY=grain yield

Appendix 3: Mean performance of agronomic parameters of thirty rice lines evaluated under drought stress and well-watered environment in Mwea, season 1 in the year 2016

Ser. No.	**Traits**	**PH**		**DTF**		**FLL**		**NP/P**		**NT**	
	Genotype	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
1	Ner.1 XNer.2	83.6	96.4	100.3	104.3	23.4	23.2	8.7	17.6	8.7	12.7
2	Ner1XNer11	84.1	86.1	100.0	99.0	23.1	25.4	10.3	22.4	9.3	20.3
3	Ner1XNer15	98.1	96.5	96.3	97.3	26.7	22.5	8.6	11.0	8.7	13.0
4	Ner1XSARO5	94.7	94.4	93.3	93.3	27.5	25.7	10.7	13.3	10.0	14.8
5	Ner2XNer1	90.4	92.5	96.6	96.0	32.5	35.4	8.8	16.6	9.3	11.2
6	Ner2XNer11	56.2	58.5	111.3	122.6	27.8	27.2	9.3	15.0	18.0	32.8
7	Ner2XKom	86.3	97.4	95.3	95.6	30.3	32.1	9.6	13.0	8.0	13.8
8	Ner2XSARO5	86.6	87.3	98.0	96.3	27.7	28.0	7.3	17.5	7.0	15.1
9	Ner11XNer2	82.9	86.8	91.6	96.3	24.7	27.5	9.3	16.3	10.6	14.0
10	Ner11XNer15	89.2	88.9	97.3	99.6	26.7	22.9	10.1	15.5	8.6	14.0
11	Ner15XNer2	85.0	99.9	98.0	105.0	24.7	27.7	9.5	15.6	9.0	19.9
12	Ner15XNer11	84.9	100.3	92.3	96.3	24.4	28.2	7.6	13.1	9.6	15.9
13	Ner15XSARO5	94.8	102.3	92.6	101.6	30.0	31.3	7.1	13.9	7.6	15.9
14	KomXNer11	95.4	98.4	100.3	91.0	30.8	29.0	7.0	11.9	7.3	11.7
15	KomXNer15	91.5	92.2	99.3	96.3	28.2	29.0	7.8	12.8	10.0	13.6
16	SARO5XNer1	98.2	99.5	93.6	93.6	27.9	27.0	9.3	13.4	10.6	12.4
17	SARO5XNER11	87.4	102.6	94.0	102.0	28.8	28.2	8.1	12.7	7.3	13.8
18	SARO5XNer15	82.0	94.5	99.0	99.6	28.1	25.3	9.2	14.3	6.3	15.8
19	SARO5XKomb.	89.6	108.1	103.0	99.0	25.4	21.6	9.4	13.5	9.6	14.5
20	NERICA 1(Parent)	79.5	97.0	96.0	102.6	28.3	27.6	6.0	12.4	5.2	16.5
21	NERICA 2(Parent)	84.0	80.2	92.6	106.3	30.4	23.3	8.0	15.5	8.3	13.6
22	NERICA 11(Parent)	85.2	85.8	95.0	104.0	26.8	22.8	7.2	13.8	11.6	10.6
23	NERICA 15(Parent)	77.8	86.4	94.3	98.6	33.6	30.8	7.2	12.9	10.0	14.0
24	Komboka(Parent)	86.9	102.5	95.6	95.6	30.3	31.1	7.4	15.4	8.0	14.2
25	SARO5(Parent)	81.2	85.8	97.0	97.3	26.8	26.0	9.6	15.7	8.3	11.9
26	NERICA 4(Check)	87.4	97.1	96.0	94.0	28.3	25.0	6.8	9.9	8.3	13.2
27	NERICA 10(Check)	89.2	95.0	95.3	97.3	29.2	29.4	6.8	15.7	9.0	13.8
28	D. precoce(Check)	63.1	69.5	113.0	122.6	30.6	27.7	7.0	14.5	16.0	21.8
29	IRAT 109(Check)	56.8	67.8	117.3	124.0	24.9	20.8	10.3	16.5	17.3	22.3
30	MWUR 4(Check)	58.5	64.3	119.0	123.6	24.5	27.0	10.8	16.7	18.6	23.5
	GM	83.7	90.5			27.7	27.0	8.5	14.6	9.9	15.7
	LSD	10.0		5.9		7.0		4.0		4.0	

PH= Plant height, DTF= days to flowering, FLL= Flag leaf length, NP/P=Number of panicles per plant, NT= Number of tillers

Appendix 4: Mean performance of yield and yield related parameters of thirty rice lines evaluated under drought stress and well-watered environment in Mwea, season 1 in the year 2016

Ser. No.	Traits	PL		%SF		Biomass		1000-GW		GY	
	Genotype	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
1	Ner.1 XNer.2	19.5	20.4	39	70	8.0	24.1	26.4	30.0	1.5	3.6
2	Ner1XNer11	20.6	21.9	54	79	8.4	19.5	16.1	24.0	0.9	7.2
3	Ner1XNer15	20.0	22.6	55	76	17.1	34.7	19.0	25.1	2.0	6.1
4	Ner1XSARO5	21.9	23.3	51	77	8.7	26.4	24.4	29.1	1.7	7.2
5	Ner2XNer1	16.6	24.2	41	73	13.8	37.2	21.3	23.4	1.2	2.0
6	Ner2XNer11	21.6	26.0	53	86	24.8	45.0	19.3	27.4	1.3	4.8
7	Ner2XKom	27.6	23.6	55	75	11.0	25.8	23.3	30.5	1.1	7.0
8	Ner2XSARO5	23.2	24.0	41	72	11.3	31.8	22.0	24.3	1.1	8.4
9	Ner11XNer2	21.7	23.3	54	78	8.8	25.1	22.3	31.4	2.1	5.7
10	Ner11XNer15	19.3	24.5	52	78	6.1	31.3	22.7	28.7	1.5	3.3
11	Ner15XNer2	19.3	21.8	48	75	10.3	34.0	21.8	26.4	1.4	3.3
12	Ner15XNer11	19.2	20.9	43	81	12.4	36.4	20.0	29.0	2.2	7.3
13	Ner15XSARO5	17.8	22.7	51	75	15.8	33.3	20.9	27.0	2.7	8.2
14	KomXNer11	19.1	23.0	35	77	10.9	36.6	23.3	28.0	1.4	7.1
15	KomXNer15	21.2	22.6	51	79	14.0	27.0	22.2	26.9	1.4	3.0
16	SARO5XNer1	21.0	25.2	60	78	9.5	35.7	21.7	29.8	1.8	6.2
17	SARO5XNER11	24.4	24.8	57	82	13.7	34.4	22.5	26.8	2.8	8.3
18	SARO5XNer15	21.9	24.4	54	77	12.8	33.5	22.5	28.7	2.4	5.2
19	SARO5xKomboka	20.5	21.3	54	70	15.7	43.6	23.0	29.6	1.6	5.2
20	NERICA 1(Parent)	16.4	22.5	51	87	18.4	33.4	16.8	26.0	1.4	3.5
21	NERICA 2(Parent)	15.2	18.8	52	73	16.9	37.4	22.8	27.1	1.2	3.0
22	NERICA 11(Parent)	16.6	18.3	57	76	14.0	30.3	25.4	31.6	1.9	4.3
23	NERICA 15(Parent)	17.4	20.8	58	74	13.8	28.4	24.7	29.9	1.7	5.1
24	Komboka(Parent)	21.6	24.8	53	83	13.4	30.8	21.0	25.4	1.9	4.0
25	SARO5(Parent)	17.6	21.6	43	76	12.0	27.2	21.2	26.8	1.4	5.4
26	NERICA 4(Check)	22.4	25.3	56	77	14.0	34.6	21.0	26.2	2.7	4.2
27	NERICA 10(Check)	21.6	25.2	46	76	14.2	34.0	23.9	31.0	1.2	6.4
28	D. precoce(Check)	17.0	20.1	51	65	23.0	46.6	20.4	28.2	1.5	4.7
29	IRAT 109(Check)	18.3	19.2	33	75	26.6	42.8	21.3	26.4	1.2	3.8

30	MWUR 4(Check)	19.4	20.6	56	74	21.0	43.3	20.8	23.7	1.7	4.6
	GM	20.0	22.6	50	70	14.0	33.51	21.8	27.6	1.7	5.3
	LSD	3.092				5.016				0.7	

PL= Panicle Length, %SF= Percentage spikelet fertility, 1000-GW= 1000-grain weight and GY=grain yield. GM=Grand Mean LSD=Least Significant Difference

Appendix 5: Analysis of variance (ANOVA) for agronomic parameters of 30 rice genotypes in drought stressed and well-watered environments in Mwea in season 2 in 2017.

	Df	MS				
		PH	DTF	FLL	NP/P	NT
Rep	2	10.61	2.689	19.41	9.503	39.274
Genotype	29	726.03***	356.376***	26.95***	16.3***	87.802***
Condition	1	2044.58***	120.0***	6.66ns	1217.32***	1654.987***
GenotypeXCondition	29	50.75ns	24.061***	16.90ns	8.456ns	15.787*
Residual	118	37.66	7.067	10.41	5.655	7.464
Total	179					

*****=** Very Highly significant ($p<0.005$), **=Highly significant ($p<0.05$), *= Significant ($p<0.05$) and ns= not significant. Df= degress of freedom, MS= mean sum of squares. PH= Plant height, DTF= days to flowering, FLL= Flag leaf length, NP/P=Number of panicles per plant, NT= Number of tillers

Appendix 6: Analysis of variance (ANOVA) for yield and yield related parameters of 30 rice genotypes in drought stressed and well-watered environments in Mwea in season 2 in 2017

	Df	**MS**				
		PL	%SF	Biomass	1000-GW	GY
Rep	2	0.810	0.0150	8.409	2.114	0.3961
Genotype	29	11.769***	0.0123***	173.657***	25.385***	7.2445***
Condition	1	246.012***	3.102***	17065.65***	1521.56***	694.03***
GenotypeXCondition	29	7.631*	0.0084***	27.056***	5.608*	3.952***
Residual	118	4.408	0.0053	9.623	3.369	0.5816
Total	179					

*****=** Very High significant ($p<0.005$), **=High significant ($p<0.05$), *= Significant ($p<0.05$) and ns= not significant. Df= degress of freedom, MS= mean sum of squares. PL= Panicle length, %SF= Percentage spikelet fertility, 1000-GW= 1000-grain weight and GY=grain yield

Appendix 7: Mean Performance of agronomic parameters of thirty rice lines evaluated under drought stress and well-watered environment in Mwea, season 2 in the year 2017

Ser. No.	Traits	PH		DTF		FLL		NP/P		NT	
	Genotype	DS	WW	DS	WW	DS	WW	DS	WW	DS	WW
1	Ner.1 XNer.2	82.9	95.2	102.3	102.0	21.7	24.7	9.1	18.9	8.5	12.7
2	Ner1XNer11	84.2	84.8	99.0	98.0	23.6	25.9	10.8	22.8	11.2	21.2
3	Ner1XNer15	96.3	96.0	101.0	98.6	31.8	26.9	9.7	11.4	8.9	13.6
4	Ner1XSARO5	95.8	93.0	93.3	95.6	28.7	27.2	10.4	13.8	10.6	14.4
5	Ner2XNer1	89.8	93.9	93.6	98.0	30.4	29.1	10.1	13.6	9.0	11.2
6	Ner2XNer11	57.5	58.6	115.6	127.6	27.8	21.2	10.9	14.2	18.1	33.2
7	Ner2XKom	89.3	94.5	95.0	95.6	18.6	26.8	9.4	12.8	8.9	14.0
8	Ner2XSARO5	85.7	87.8	98.6	95.3	30.5	28.4	7.0	15.8	6.7	15.6
9	Ner11XNer2	82.3	86.0	95.00	100.0	26.0	24.7	10.2	14.6	10.6	13.7
10	Ner11XNer15	89.5	89.7	101.3	104.0	26.0	24.6	10.0	16.2	8.0	13.3
11	Ner15XNer2	88.2	95.5	97.6	103.3	24.3	30.6	9.8	15.8	9.7	20.2
12	Ner15XNer11	89.1	101.8	100.6	101.0	26.5	28.3	8.6	14.4	9.6	15.8
13	Ner15XSARO5	97.3	101.0	102.0	102.6	26.5	26.2	9.2	14.6	6.7	17.2
14	KomXNer11	97.3	100.1	99.0	99.3	27.8	26.7	7.6	12.4	6.6	10.9
15	KomXNer15	86.8	92.7	97.3	101.3	24.9	26.0	8.8	12.2	9.4	13.6
16	SARO5XNer1	98.9	98.0	98.6	104.0	26.1	24.1	8.6	12.0	10.1	12.8
17	SARO5XNER11	90.5	104.8	99.33	100.6	26.5	27.0	8.2	12.6	7.3	14.2
18	SARO5XNer15	81.7	96.6	102.3	98.3	25.3	24.5	9.2	14.1	6.6	15.9
19	SARO5XKomb.	88.8	106.1	98.0	99.0	25.4	26.7	9.8	14.2	8.8	13.7
20	NERICA 1(Parent)	79.5	96.8	105.6	102.0	24.1	27.4	6.9	13.4	7.2	17.4
21	NERICA 2(Parent)	76.7	82.2	103.6	97.0	23.0	22.8	7.4	17.2	6.9	13.4
22	NERICA 11(Parent)	84.5	87.7	101.6	103.6	23.8	27.0	9.5	12.6	11.9	10.7
23	NERICA 15(Parent)	79.7	88.6	97.0	95.3	27.0	24.4	9.0	13.6	9.4	14.8
24	Komboka(Parent)	88.4	105.2	99.3	98.0	24.0	27.0	7.8	13.7	7.9	15.6
25	SARO5(Parent)	81.3	86.3	97.3	100.0	29.4	25.8	11.3	15.6	8.3	11.7
26	NERICA 4(Check)	87.5	97.3	99.3	107.0	23.3	25.8	7.9	10.7	8.6	12.4
27	NERICA 10(Check)	90.4	92.9	98.3	103.3	26.8	28.0	8.7	14.7	9.0	13.8
28	D. precoce(Check)	62.5	73.9	117.3	119.3	27.1	23.2	8.1	14.4	17.7	22.3
29	IRAT 109(Check)	57.8	68.6	118.6	118.6	20.6	21.6	12.2	18.0	17.5	25.1

30	MWUR 4(Check)	60.1	66.0	120.0	128.3	18.5	25.1	13.8	15.9	15.4	22.7
	GM	84.0	90.7	101.6	103.2	25.5	25.9	9.3	14.5	9.8	15.9
	LSD	9.9		4.2		5.2		3.8		4.4	

PH= Plant height, DTF= days to flowering, FLL= Flag leaf length, NP/P=Number of Panicles per plant, NT= Number of tillers

Appendix 8: Mean Performance of yield and yield related parameters of thirty rice lines evaluated under drought stress and well-watered environment in Mwea, season 2 in the year 2017

Ser.		**PL**		**%SF**		**Biomass**		**1000-GW**		**GY**	
No.	**Genotype**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**
1	Ner.1 XNer.2	19.2	20.0	39	70	8.0	24.1	26.4	30.0	1.2	3.3
2	Ner1XNer11	18.9	18.7	54	79	8.4	19.5	16.1	24.0	1.1	7.2
3	Ner1XNer15	20.3	21.5	55	76	17.1	34.7	19.0	25.1	1.4	6.7
4	Ner1XSARO5	21.3	23.3	51	77	8.7	26.5	24.4	29.1	2.5	7.8
5	Ner2XNer1	17.9	20.1	41	73	13.8	37.2	21.4	23.4	1.4	2.6
6	Ner2XNer11	20.3	23.3	53	86	24.8	45.0	19.3	27.4	1.2	4.7
7	Ner2XKom	19.8	19.8	55	75	11.0	25.8	23.3	30.5	3.0	7.0
8	Ner2XSARO5	19.9	19.2	41	72	11.3	31.8	22.0	24.3	2.1	9.3
9	Ner11XNer2	19.1	20.2	54	78	8.8	25.1	22.3	31.4	1.7	6.2
10	Ner11XNer15	19.5	24.0	52	78	6.2	31.3	22.7	28.8	1.3	3.1
11	Ner15XNer2	18.9	23.2	48	75	10.4	34.0	21.8	26.4	1.4	2.7
12	Ner15XNer11	19.6	21.2	43	81	12.4	36.5	20.0	29.0	1.5	7.7
13	Ner15XSARO5	19.0	22.8	51	75	15.8	33.4	20.9	27.0	1.9	7.8
14	KomXNer11	19.3	21.5	35	77	10.9	36.7	23.3	28.2	1.9	6.9
15	KomXNer15	20.3	15.5	51	79	14.0	27.1	22.2	26.9	1.4	2.9
16	SARO5XNer1	18.1	25.2	60	78	9.5	35.7	21.7	29.8	1.7	6.5
17	SARO5XNER11	17.6	22.2	57	82	13.7	34.5	22.5	26.8	2.1	8.4
18	SARO5XNer15	19.7	21.4	54	77	12.8	33.5	22.5	28.7	1.1	4.9
19	SARO5XKomb.	18.5	22.5	54	70	15.7	43.6	23.0	29.6	1.5	4.9
20	NERICA 1(Parent)	16.5	20.6	51	87	18.4	33.4	16.8	26.0	0.6	3.6
21	NERICA 2(Parent)	15.3	18.0	52	73	16.9	37.4	22.8	27.1	0.4	3.1
22	NERICA 11(Parent)	17.1	18.4	57	76	14.0	30.4	25.4	31.6	2.3	5.5
23	NERICA 15(Parent)	17.7	20.3	58	74	13.8	28.4	24.7	29.9	1.3	5.3
24	Komboka(Parent)	19.6	21.6	53	83	13.4	30.8	21.0	25.4	1.6	4.3
25	SARO5(Parent)	17.4	20.1	43	76	12.0	27.3	21.2	26.8	1.4	6.3
26	NERICA 4(Check)	18.2	24.9	56	77	14.0	34.7	21.0	26.2	1.8	4.8
27	NERICA	19.5	21.7	46	76	14.3	34.1	23.9	31.0	1.3	6.5

	10(Check)										
28	D. precoce(Check)	16.7	19.7	51	65	23.0	46.6	20.4	28.2	0.8	5.5
29	IRAT 109(Check)	16.8	19.2	33	75	26.6	42.8	21.3	26.4	1.1	4.1
30	MWUR 4(Check)	18.3	19.4	56	74	21.1	43.4	20.8	23.7	1.9	4.3
	GM	18.7	21.0	50	76	14.0	33.5	21.8	27.6	1.5	5.5
	LSD	3.395		4.216		5.0		2.9		1.2	

PL= Panicle length, %SF= Percentage spikelet fertility, 1000-GW= 1000-grain weight and GY=grain yield.