EVALUATION OF VARIETAL PURITY OF CERTIFIED BASMATI 370 AND BW 196 FROM TWO RICE SEED SOURCES IN MWEA AND THE RESPONSE OF RICE TO VARYING N, P AND K FERTILIZER REGIMES

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DECLARATION

This thesis is my original work and it has not been presented for award of a degree in any other university.

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DEDICATION

I dedicate this work to my mother Anne and my eldest sister Mercy for their great inspiration to take up this task and their support throughout the study period.

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EQUATIONS

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
Bs 370	Basmati 370
DAP	Di-ammonium phosphate
DUS	Distinct, Uniform and Stable
EPZA	Export Processing Zones Authority
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	The Food and Agriculture Organization Corporate Statistical Database
IRRI	International Rice Research Institute
K	Potassium
KALRO	Kenya Agricultural and Livestock Research Organization
LSD	Least Significant Difference
MIAD	Mwea Irrigation Agricultural Development Centre
MIS	Mwea Irrigation Scheme
MOA	Ministry of Agriculture
MOP	Muriate of Potash
MRGM	Mwea Rice Growers Multipurpose
N	Nitrogen
NIB	National Irrigation Board
P	Phosphorus
RCBD	Randomized Complete Block Design
SA	Sulphate of Ammonia
SAS	Statistical Analysis System
SPSS	Special package for social sciences
TSP	Triple superphosphate
UPOV	International Union for the Protection of New Varieties of Plants
WARDA	West Africa Rice Development Association
KEPHIS	Kenya Plant Health Inspectorate Services

GENERAL ABSTRACT

Cultivating good quality seed and using appropriate nutrient levels are critical in reducing the current rice yield gap (8.5 t/ha) in Kenya. Planting good quality seed reduces the susceptibility of crops to diseases, improves response to management, results in uniform crop maturity and increases grain yield. Using suitable fertilizer regimes can increase rice crop yields by up to 70%. Currently, the genetic purity of Variety Basmati 370 and BW 196 rice sourced from the National Irrigation Board (NIB) and Mwea Rice growers multipurpose (MRGM) is unknown. The response of the two varieties to varying fertilizer regimes has not been determined. The objectives of this study were: 1. To determine the genetic purity of two rice varieties obtained from different seed sources in Mwea and 2. To determine the response of selected paddy rice varieties to varying levels of inorganic fertilizers. Field experiments were set up between August 2016 and January 2017 and between August 2017 and January 2018, at MIAD, Mwea division, Kirinyaga County. A sample size of 30 plants was taken per treatment. In the first objective, 40 agro-morphological rice characteristics were examined based on UPOV standards of evaluation. In the second objective, a randomized complete block design, was laid-out in split-plots having 13 N kg/ha: P_2O_5 kg/ha: K_2O kg/ha fertilizer ratios as the main plots and two rice varieties (Basmati 370 and BW 196) as the sub-plots. The 13 N, P and K fertilizer regimes were as follows: 00:00:00, 60:40:40, 80:60:60, 100:80:80, 60:40:00, 80:60:00, 100:80:00, 60:00:40, 80:00:60, 100:00:80, 00:40:40, 00:60:60 and 00:80:80. The presence of anthocyanin pigmentation, shape of the ligule, the coloration of stigma, lemma, basal leaf sheath and ligule, did not show any variation for both seasons for plants generated from nuclear, MRGM and NIB seeds, of Variety BW 196 and Basmati 370. Variety Basmati 370 plants generated from NIB seed exhibited a diversity index (0.14) which is higher than that of nuclear and MRGM (0.00) seeds. Variety BW 196 expressed higher diversities than Variety Basmati 370. Plants generated from the nuclear seed had the highest diversity index in the first (0.17) and in the second (0.25) season. Except for leaf blade width in the first season, all the quantitative traits studied revealed insignificant differences ($p \leq 0.05$). Variety BW 196 from NIB had significantly wider blades than those from MRGM. Variety Basmati 370 seeds exhibited less genetic diversity than BW 196. Variety BW 196 had more than four off-types in 1500 hundred plants, rendering the seed impure when checked against the UPOV's, DUS test guidelines. Fertilizer application significantly ($p \leq 0.05$) increased plant height, number of tillers per hill, panicle length and grain yield, but had no significant ($p \leq 0.05$) effect on the one thousand grain weight. Fertilizer regimes 100:00:80 and 100:80:00 delayed heading and maturity only in the second season. The highest yields were recorded in 80:60:60, 80:00:60, 100:80:80 and 100:00:80 in both seasons. The study has demonstrated that unlike variety Basmati 370, BW 196 was not genetically pure. Further, fertilizer regimes containing N and K elicited higher responses than fertilizer regime containing P. The highest yielding and most cost-effective fertilizer regime for rice production in Mwea is 80:00:60.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Rice (*Oryza sativa L.)* is the second most produced cereal in the world after wheat (Abodolereza *et al*., 2009). It is a staple food for more than half of the world's population. In 2011, the area under rice cultivation globally was 164 million hectares, with China covering about 143.4 million hectares, and Africa covering 10.5 million hectares (FAOSTAT, 2013). Apart from being a source of dietary energy and protein, rice is also a major commodity in world trade. It generates income and provides employment, in millions of households. The global rice consumption rates have been on the rise within the last 20 years, with sub-Saharan Africa experiencing an increase of more than 50% (Samarendu, 2013). The current global rice consumption is 408 million metric tons with China and India consuming more than 50% of this (FAO, 2013). The national rice consumption estimated at 540, 000 tonnes has been rising steadily at an average rate of 12% compared to wheat 4% and maize 1% per year (Onyango, 2014; GAIN Report, 2015). The upward trend has been attributed to population growth and changing feeding habits.

Rice was introduced to Kenya from Asia in 1907. Currently, it is the third most important cereal crop after maize and wheat (MOA, 2009). It was initially cultivated for commercial purposes but over time, in addition to being a cash crop, it has also been adopted as a crop for domestic consumption (Short *et al*., 2013). The local rice production stands at 101,510 tonnes (KNBS, 2017). This can barely cope with increased demand culminating in a high import dependency ratio (GAIN Report, 2015). In 2014, Kenya imported 420, 000 tonnes of milled rice to offset the deficit (GAIN Report, 2015). Import of rice into Kenya was estimated at over USD 168 million in the year 2014 (GAIN Report, 2015). Between the year 2005 and 2009, the average rice yields in Kenya was 2.5 t/ha (Onyango, 2014). Trial experiments have shown that Kenya has the potential of producing more than 11 t/ha (Saito *et al.*, 2013). This translates to a yield gap of approximately 8.5 t/ha.

The rice sector in Kenya is plagued by several challenges. These include: land degradation, damages by rice pests, destructive diseases, thin profit margins, poor access to extension and credit services and poor seed delivery systems. Middle men are prone to over-pricing or delivering poor quality seed (Onyango, 2014). In Kenya, it is not mandatory to certify rice under the seed act, therefore, it risks being produced informally (Muhunyu, 2012), resulting in seed that has more than one cultivar. A mixture of cultivars in the field can significantly reduce the value of a rice crop because of reduced yields, downgrading and decreased milling yield (Muhammad and Begum 2015). In Kenya farmers apply blanket fertilizer rates across their farms.

Varieties Basmati 370 and BW 196 are amongst the lowland rice varieties that dominate the Mwea Irrigation Scheme. Variety Basmati 370 is commonly cultivated due to its consumption traits which include aroma, marketability, good taste, milling quality, grain size and good color. Basmati 370 yields approximately 2.2 t/acre (Vincent, 2016). Variety BW 196 is glutinous, non-aromatic with medium sized grains, maturing in 135 days and yields approximately 3.2 t/acre. It is mainly cultivated for family consumption due to its better yields (Vincent, 2016).

1.2 Problem statement

Previously, there have been speculations that locally produced rice that is supplied in the Kenyan markets have a mixture of more than one rice variety (Muhunyu, 2012). It is hard to tell whether the seeds that are planted are impure or the mixing happens during harvesting, milling, or in market stalls. Under the seed Act, rice is categorized as a crop for voluntary seed certification because it is a self-pollinated crop. Some of its handling is therefore done informally, and some of the commercial rice seeds on sale may not meet the required standards for seed production. Farmers risk planting rice seeds that are genetically impure. This could translate to increased susceptibility to diseases, reduced grain quality, poor response to improved management, uneven plant maturity, and a consequent increase in yield gaps.

Fertilizer application is critical in rice production. The findings of a nutrient trial that was carried out over 20 years ago showed that 80:60:60 (N kg/ha: P_2O_5 kg/ha: K_2O kg/ha) fertilizer ratios were the recommended fertilizer treatment for rice production in Mwea (Wanjogu *et al.,* 1995). Studies show that despite the recommendation, most farmers apply 50 kg/acre of either di-ammonium phosphate or sulphate of ammonia to their farms (Muhunyu, 2012). The poor nutrient management, coupled with poor management of crop residues, repeated rice mono-cropping, continuous cultivation of improved high yielding rice varieties, and soil degradation have resulted in soils deficient of nutrients. Poor soil nutrition has a substantial negative effect on crop performance, which could result in increasing the already high rice yield gaps in Kenya.

1.3 Justification

To keep pace with the growing population, and increased rice consumption rates, it is imperative to increase rice production. Planting quality seed, use of appropriate nutrient levels and good soil and crop management practices are crucial in reducing the current yield gap in rice production in Kenya. Due to the wide variation of nutrient requirements by different plant varieties, it is critical to establish a best-fit between the nutrient supply and crop nutrient demand, by determining the suitable site- and variety specific balanced nutrient application rates. Based on a simple model by Dobbermann *et al*., (2000), attainable crop yield is often lower than the maximum yield due to water and nutrient stresses. In an irrigated field, water stress is eliminated, making the attainable yield, the maximum crop yield, in limited supply of nutrients (N, P and K). With good crop and nutrient management practices, the yield gap can be reduced by up to 80%. To be able to achieve a 70% rise in rice yield, use of good quality seeds of the preferred varieties and appropriate nutrient management practices for the different rice varieties is imperative (Fan *et al*., 2005).

1.4 Objectives

1.4.1 General objective

To contribute to the reduction of the current rice yield gap (8.5 t/ha) in Kenya.

1.4.2 Specific objectives

1. To determine the genetic purity of two rice varieties obtained from different seed sources in Mwea
2. To determine the response of selected irrigated rice varieties to varying levels of inorganic fertilizers

1.5 Hypotheses

1. The seed sources in Mwea produce varieties that are not pure genetically
2. Increasing the doses of N, P and K fertilizers enhances crop yield of selected rice varieties

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany, ecology and importance of rice

Rice (*Oryza sativa* L.) is an annual, sub-aquatic grass belonging to the genus *Oryza* and the tribe *Oryzeae* of the family poaceae. The genus *Oryza* has 25 species comprising 23 wild and 2 cultivated (*O. sativa* L and *O. glaberrima* Steud) with a pan-tropical and sub-tropical distribution (Brar and Khush, 2003). Rice is adapted to a wide range of environmental condition in terms of climate, soil types and hydrological situations. It does well in areas with high humidity, prolonged sunshine and sufficient water supply. It is a short day plant although some are not photo-periodic sensitive. Rice requires an average temperature of between 20^0C and 38^0C. Sandy loams to heavy clays are appropriate for its production. In dry soils, the optimum pH is between 5.5 - 6.5 and 7 - 7.2 in flooded conditions (Mambala, 2007).

According to Export Processing Zone Authority (2005), 95% of Kenya's rice is cultivated under irrigation and the remaining 5% is rain fed. Rice production is done by government-managed schemes, small-scale farmers, and private commercial schemes. It is grown on a total area of 21,829 ha (MOA, 2010). The National Irrigation Board has four irrigation schemes: one in central Kenya (Mwea) and three in the western region (Ahero, Bunyala and West Kano) (Short *et al*., 2013). Promoting the production of rice will cut down over reliance on Kenya's staple food (maize), improve income at household level, enhance food security, reduce the import bill for rice and create employment (Ntiritu and Odhiambo, 2002).

2.2 Constraints to rice production

Based on a report by the Ministry of Agriculture (2009), the rice production sector in Kenya is faced with several setbacks. These setbacks include inadequate skills on rice crop management, high costs of farm inputs and machinery, poor infrastructure, poor access to credit, uncoordinated marketing, biotic and abiotic stresses, land degradation and nutrient loss (Onyango, 2014).

Soil erosion and continuous cultivation have resulted in loss of soil nutrients and land degradation, consequently resulting in yield reduction. Permanent waterlogging and rice monoculture results in the deficiency of microelements such as zinc and sulfur, and often results in iron toxicities (Chataigner, 1997). Correcting soil toxicities is usually an expensive venture. For production to remain high in such areas, farmers have to increase inputs that enhance soil fertility. Such extra expenses have caused farmers to retreat from rice production to other income generating activities or they risk incurring heavy losses (Onyango, 2014).

Annually, pests and diseases contribute to yield losses of up to 25% (FAO, 1996). The most wide spread diseases in rice production are *Pyricularia oryzae* caused by fungus and bacterial wilt caused by *Xanthomonas oryzae.* Other destructive diseases include sheath rot, rice yellow mottle virus, bacterial blight, and rice blast. Quelea birds, rice gall midge, rats, and brown plant hoppers, are pests known to cause huge losses in rice fields (Onyango, 2014). Quelea and weaverbirds pose a major challenge to farmers. They move around in large flocks and they migrate to areas with large farms of cereal crops. When they invade such areas, they cause devastating grain losses (Muhunyu, 2012). Too much weeds in the field could result in total crop failure. The two main common weeds in paddy rice production are Barnyard grass (*Echinochloacrus-galli) and* weedy rice (*Oryza* sp.) (Ferrero, 2003).

2.3 Rice seed systems

Rice research in Kenya was constituted in 1969. It began with the establishment of Ahero irrigation scheme and its subsidiary station, the Mwea irrigation scheme. By 2005, the NIB led research (in both of these stations), had released 13 rice varieties; eight irrigated varieties namely: Basmati 370, Basmati 217, BW 196, ITA 310, BR 51- 74-6, BG-90-2, and IR 2793-80-1, and five rain-fed varieties namely: Dourado Precoce and NERICA 1, 4, 10, and 11 (Muhunyu, 2012).

The Kenya Plant Health Inspectorate (KEPHIS) classifies rice as a voluntary crop in seed certification, because it is self-pollinated. This has encouraged informal handling of its seed resulting to the sale of poor quality rice seeds. So far, none of the commercial seed companies has shown interest in producing inbred rice seed for farmers. In Mwea, for example, rice seed is produced by MIAD (Mwea Irrigation Agricultural Development Centre), Mwea Rice Growers Multipurpose Co-operative Society (MRGM), and The Kenya Agricultural and Livestock Research Organization (KALRO). Kenya Agricultural and Livestock Research Organization is a corporate body created with the mandate of coordinating agricultural research in Kenya (KALRO Website) and it produces seed, only for the upland rice varieties. The NIB is managed by the Government of Kenya. It has been mandated to supervise all public irrigation schemes countrywide (MOA, 2009). Mwea Rice Growers Multipurpose Co-operative Society is a farmer association that runs part of the irrigation schemes in Mwea, with and on behalf of the farmers.

According to Muhunyu, (2012), 61% of farmers buy their seed from the NIB, and 7% buy from the other seed producing companies. The remaining 32% use either their own saved seed, seed from neighbors or obtain seed from the local market. In a similar study, Kihoro *et al.*, (2013), had findings that deviated slightly from the above. They reported that 83% of farmers source their seed from NIB-MIAD, 9% source them from MRGM, 6% use their own seed and 1% purchase it from private seed companies. Farmers do not source their seed from the local market.

2.4 Evaluation of rice varietal purity

Genetic purity, also referred to as varietal purity, is a key aspect in quality control. For varietal purity to be achieved, quality seeds should be used. Aspects of quality seeds involve seed purity, vigor, germination and health (Venkata, 2014). Genetic purity tests must be done during seed certification procedures to rid crops of ambiguous crop varieties and misuse of brand names by the sale of spurious seeds. Genetic purity of seed can be assessed by carrying out grow-out-tests that involve representative samples to be checked. Qualitative and quantitative characteristics (descriptors), related to seed quality are used for varietal identification (Anjana *et al*., 2016). For a variety to be considered true to type, it must meet the requirements for the DUS (Distinctness, Uniformity, and Stability) tests. A variety is said to be distinct if it is clearly different from any other variety that is known at the time of filling application for protection. It is said to be uniform if it is sufficiently identical in its relevant characteristics. Its stability is gauged by its relevant characteristics remaining unchanged over several propagations (UPOV, 2004). Apart from the use of morphological characteristics, methods such as molecular markers, biochemical markers, and chemical methods can be applied (Venkata, 2014).

Some of the molecular markers used include the Random Amplification of Polymorphic DNA (RAPD), Sequence Characterized Amplified Region (SCAR), Short Sequence Repeats (SSR) and Sequence Tagged Site (STS). Other molecular techniques involve the use of biochemical markers, and peroxidase test. Some chemical methods like the potassium hydroxide test, sodium hydroxide test, and ferrous sulphate color test have also been used (Venkata, 2014; Central Institute for Cotton Research, 2005).

In agricultural production, seed is a very critical input. It is an agronomic base, which has a huge economic value and it determines crop productivity. The quality of seed used determines the total yield output of a crop (Diaz *et al*., 1998 and Krishnan, 2005). Poor seed quality could result in poorly developed grains with relatively higher moisture content, low specific weights, discoloration, prolonged harvesting period and shortened storage life (Krishnan, 2005). Varietal purity is a key indicator of seed quality. Despite affecting yield, it also influences the crop production practices (Diaz *et al*., 1998). Good crop management practices combined with good quality seed translates to high crop productivity.

Globally and locally, studies on the determination of the genetic purity of crops have been conducted on several crops such as sunflower, maize, castor, horticultural crops and rice (Shankar *et al.*, 2013). Genetic purity tests, which have been done on NERICA (upland) varieties, involved the assessment of agronomic traits and use of microsatellites, to establish the relationships between the first 18 NERICA varieties. Results showed that there were no differences between NERICA 8 and 9. There was a clear distinction between NERICA 1 to 7 and NERICA 8 to 18 (Africa Rice Center, 2008).

A study done in Kenya to check for the agronomic variability within several rice lines: Basmati 217, Basmati 370, Pishori, NERICA and Sindano showed great genetic diversities within the various varieties analyzed (Mwangi *et al*., 2005). This expressed distinctiveness of the varieties with respect to the rest that are known to common knowledge.

2.5 Nitrogen, phosphorus and potassium nutrition in rice

Sixty seven percent of rice soils in East Africa are considered to be problem soils (highly saline) and very poor (Haefele *et al*., 2014). Proper crop and nutrient management practices must be instituted to improve this situation. Nitrogen, phosphorus and potassium are the three main elements that determine yield in rice production.

Nitrogen plays critical roles in the effective use of absorbed radiation from the sun and carbon metabolism in various biochemical and physiological processes of the plant (Huang *et al*., 2004). Rice plants take up most nitrogen in form of NH_4^+. The most commonly used nitrogen source is urea, which has an efficiency of 30-40%. Nitrogen is often lost through volatilization, de-nitrification, leaching and run-off. The intensity of these losses varies in various environments and management practices. Split application and deep placement of nitrogen fertilizers are major methods applied by farmers to minimize the losses. For the production of one tonne of rice (inclusive of straw), a rice crop takes up approximately 16-17 kilograms of nitrogen (Sahrawat, 2000). The critical stages for nitrogen application are during early stages, mid-tillering stages and the reproductive phase (Shukla *et al*., 2015). Application of nitrogen fertilizer increases the concentration and uptake of nutrients such as K, P, Zn, Fe, Cu, and Mn in rice (Romeo *et al*., 2004 and Lakshmanan *et al*., 2005). Increased root biomass and above ground biomass, is attributed to the increased uptake of the micronutrients (Lakshmanan *et al*., 2005). Rice fields with applied nitrogen fertilizer exhibit improved rates of decomposition of organic matter, because of the high concentration of organic carbon and nitrogen (Chantigny *et al*., 1999).

Rice requires less P as compared to N but depletion of P in the soil could result in a reduction of yields. For one milligram of rice grain produced, rice uses two- three kilograms of P (Saleque *et al*., 2001). Phosphorus is highly mobile within the plant. It is a major component of adenosine triphosphate, phospholipids and nucleic acids. It is essential in the transfer and storage of energy and preservation of membrane integrity. It promotes root development, tillering, early flowering and crop ripening. Deficiency of P is characterized by delayed crop maturity, low specific grain weight and poor grain quality (Dobbermann *et al*., 2000).

Potassium is often referred to as a quality nutrient because it determines the grain size, shape, color as well as the seed vigor. Plants deficient of K are highly susceptible to effects of both high and low temperatures, excess and inadequate water availability, attacks by nematodes, pests and diseases. It increases root growth, reduces lodging, activates several enzymes, translocate plant sugars, and increases concentration of starch in grains. It also maintains the turgidity of the plant (Dobbermann *et al*., 2000 and Fairhurst *et al*., 2007). Potassium increases the leaf area index, leaf chlorophyll and reduces the rate of leaf senescence therefore increasing canopy for photosynthesis. It affects the number of spikelets per panicle, number of filled grains and the grain's specific weight (Dobbermann *et al*., 2000).

Nitrogen, P and K nutrients affect the rate of photosynthesis in rice. Nitrogen nutrition determines the amount of chlorophyll present in the plant leaves whereas potassium and phosphorus determine the photosynthetic efficiency of the chlorophyll (Watanabe *et al*., 1970). Nitrogen deficiencies can be managed within a shorter time as compared to P and K, because of the presence of chemical and biological processes that could contribute to its availability. Both P and K require long-term remedies to ensure that they are available in the required quantities in the soil colloids.

2.6 Effects of inorganic fertilizer on growth and yield of rice

Increasing the levels of nitrogen significantly increases the effective number of tillers per hill, number of filled panicles, and 1000-grain weight (Hasanuzzaman *et al*., 2012). Raising the number of nitrogen split applications (up to four or six times) and applying late season nitrogen supply (instead of excessive application during early vegetative phase) results in increased apparent nitrogen recovery (ANR) and N uptake, but has no significant increase on the yield. Fields where additional N are added exhibit increased P and K uptake hence expressing a direct relationship between the concentration of N, P, and K and various yield attributes (Hasanuzzaman *et al*., 2012, Romeo *et al*., 2004 and Wang *et al*., 2001).

Different rice varieties respond differently to different levels of P. Increasing the levels of P in the soil expresses a linear increase of rice yield and straw. The higher the concentration of P_20_5 applied per variety, the higher the number of effective tillers per hill. Increase in the panicle lengths of rice is not directly proportional to the increase in the levels of P applied but has a direct relationship with the amount of N applied (Fageria *et al*., 2002). The number of filled grains per panicle increases with the increase in P concentrations. Results from treatments that exhibit a minimal number of filled panicles (having low concentrations of (P_20_5) also exhibit high levels of spikelet sterility. 1000- grain weight varies significantly with varying phosphorus levels (Fageria *et al*., 2002 and Sanjivkumar *et al*., 2014). Using 72 kg $ha^{-1}$of P_20_5 can increase crop yield by 45% relative to the control which lacks phosphorus. With respect to the straw yield, there is a direct correlation between variety and levels of P applied. The harvest index of rice is directly proportional to the amount of P applied (Alam *et al*., 2009a). The application of 100% of P, accompanied by the application of N and K results in increased production of dry matter at all stages of growth (Sanjivkumar *et al*., 2014).

Different rice varieties respond differently to different levels of K (Zou *et al.,* 2006). Increasing the concentration of K applied increases the number of panicles per m^2 and 1000- grain weight and results in a decrease of unfilled grains (Tran *et al*., 2012). Increasing K levels in the soil has a significant effect on the plant height, number and length of panicles, 1000-grain weight and crop yield. The addition of K increases the crop yield by 50% over the control (Rahmatullah *et al*., 2007).

2.7 Use of inorganic fertilizer in Mwea

According to Wanjogu *et al.,* (1995), the recommended fertilizer rate for rice production in Mwea is 80:60:60 (N kg/ha: P_2O_5 kg/ha: K_2O kg/ha) fertilizer ratios. Despite the recommendation, farmers in the Mwea Irrigation Scheme (MIS) mostly use two macronutrients (N and P) instead of the recommended three (N, P and K) (Kihoro *et al*., 2013). According to Muhunyu, (2012), none of the farmers apply organic fertilizer, 86% of farmers apply DAP basally, and 93% apply SA as a top dresser, though the quantity applied varies from farmer to farmer. Only 2% of farmers apply potassium chloride (MOP) as a basal fertilizer (Muhunyu, 2012). Kihoro *et al.,* (2013), on the other hand, reported that most farmers apply either dry or fresh animal manure during field preparation, while Onderi, (2016) reported that 52.1% of farmers used Diammonium phosphate (DAP), 2.5% used MOP, and 31.9% used triple superphosphate (TSP) as basal fertilizer. About 85.3% apply Sulphate of ammonia (SA) as a top dresser.

Continuous mono-cropping, loss of soil nutrients, and land degradation have resulted in reduced rice production. Famers are forced to spend a lot on fertilizer enhancement (Onyango, 2014). On average, each farmer applies 50 kg/ha of DAP basally and 50 kg/ha of SA as a top dresser, therefore the total value of fertilizer per acre is approximately Ksh. 5000 (Kihoro *et al.,* 2013). Some farmers have opted out of rice farming, because they are not able to purchase sufficient fertilizer for their fields (Onyango, 2014). The MRGM purchases fertilizer on behalf of most farmers. Those farmers who opt not to purchase fertilizer through MRGM end up buying fertilizer at a more expensive price (Muhunyu, 2012). The government also subsidizes prices for DAP fertilizer, which is generally more expensive than MOP. Farmers therefore prefer to take the subsidized DAP fertilizer, in the pretense that it would be used for maize production, even though it is not approved for rice production.

CHAPTER THREE: EVALUATION OF VARIETAL PURITY OF BREEDER SEED AND CERTIFIED RICE SEED FROM DIFFERENT SOURCES IN MWEA USING AGRO-MORPHOLOGICAL TRAITS

3.1 Abstract

Rice is a self-pollinated crop; hence, it is classified as a crop for voluntary seed certification. Farmers in Mwea use both certified and uncertified seed in their rice production. This has provided loopholes for cultivation of poor quality seed. The current study was carried out at MIAD, Mwea division, Kirinyaga County, to determine the genetic purity of certified seed from the National Irrigation Board (NIB) and Mwea Rice Growers Multipurpose (MRGM). The field experiment was set up in a randomized complete block design; replicated three times. Fourty agro-morphological rice parameters were evaluated based on UPOV standards of evaluation, during the main rice-growing seasons in Mwea (August-January between 2016 and 2018). The coloration of basal leaf sheath, ligule, lemma and stigma, presence of anthocyanin pigmentation and ligule shape, did not exhibit any variation in both seasons, for nuclear, NIB and MRGM seeds of Variety Basmati 370 and BW 196. The NIB certified seeds exhibited a higher diversity index (*H'* = 0.14) for Basmati 370, against (*H'*= 0.00) for the MRGM certified and breeder seeds. For BW 196, the highest diversity was registered in the nuclear seed, in both the first (*H'*=0.17) and the second season (*H'*= 0.25). Analysis of variance revealed insignificant differences ($p \leq 0.05$) for all the quantitative parameters studied, except for leaf blade width, in season one. Variety BW 196 from MRGM had significantly narrower blades than those from NIB. Minimal phenotypic variability within varieties from different seed sources were reported in this study. Seeds for variety Basmati 370 were genetically pure, but those of variety BW 196 had more than four off-types hence classifying the seeds as impure when evaluated against the DUS test guidelines, as provided by UPOV.

Key words: Basmati 370, BW 196, diversity, DUS test, nuclear seed

3.2 Introduction

Rice (*Oryza sativa*) was first introduced to Kenya in 1907. It has constantly gained prominence in Kenya's diet due to the changing eating habits in the population. Initially it was consumed mainly by urban dwellers, but, currently, consumption by the rural population is steadily on the rise (Rodenburg and Johnson, 2013). Presently, the consumption rates (400,000 t) surpass the production (80,000 t). The deficit is met via imports from Egypt, India and Pakistan. Promotion of rice production and consumption in Kenya will reduce over-reliance on maize, which is Kenya's staple food, and enhance income at household level, improve food security, create employment in rural areas and reduce the import bill for rice (Ntiritu and Odhiambo, 2002). Planting genetically pure seed is a prerequisite for increased rice production and improved food security. It results in crops with uniform agronomic performance and appearance (Smith and Register, 1998), better response to improved crop management, reduced susceptibility to diseases and consequently, better crop yields (Krishnan, 2005; Diaz *et al*., 1998).

Globally, UPOV is responsible for generating proper guidelines for distinctiveness, uniformity and stability (DUS) tests, detailing the specific characteristics to be examined in various crops. In Kenya this mandate has been given to Kenya Plant Health Inspectorate Service (KEPHIS), which classifies rice as a voluntary crop in seed certification. Farmers in Mwea plant either farmer sourced or certified seed, thus farmers risk planting rice varieties that are genetically impure. Previously, there have been speculations that middlemen often mix aromatic rice varieties with non-aromatic and sell the product at the price of pure aromatic rice; which is higher (Muhunyu, 2012). It's possible that this mixing could have begun at farm level, due to planting of impure rice seed.

Rice seed is produced by the National Irrigation Board (NIB), Mwea Rice Growers Multipurpose Co-operative Society (MRGM), and Kenya Agricultural and Livestock Research Organization (KALRO). KALRO, a corporate body created with the mandate of coordinating agricultural research in Kenya, produces seed for upland rice varieties and works in collaboration with International Rice Research Institute (IRRI) to develop better yielding varieties (GAIN Report, 2015). The MRGM is a farmer association that runs part of the irrigation scheme in Mwea, with and on behalf of the farmers. The NIB is managed by the Government of Kenya, and it is mandated to supervise public irrigation schemes countrywide (MOA, 2009) and to do research. By 2005 it had released 13 rice varieties, eight irrigated and five rain fed varieties, from Ahero and Mwea irrigation scheme (Muhunyu, 2012).

Genetic purity tests are usually done to assess the genuineness of a variety with respect to its type. These tests must be done during seed certification procedures to rid crops of ambiguous crop varieties and misuse of brand names by the sale of spurious seeds. One of the methods employed in the assessment of genetic purity and identification of cultivars is the use of agro-morphological characterization (Anjana *et al*., 2016). Because of their high efficiency (Rajanna *et al.,* 2011), these tests are suitable for determining varietal purity of seed lots from the NIB and MRGM. Several phenotypic characterization studies have been done in Kenya, with some focusing on sorghum, cowpea and rice (Muui, 2014; Max, 2017; Wambua, 2016). None of these studies have focused on comparing the genetic variability of similar rice varieties sourced from different rice seed sources in Mwea. In this view, this study was set up to examine the genetic purity of varieties Basmati 370 and BW 196 sourced from MRGM and NIB.

3.3 Materials and methods

3.3.1 Site description

The study was conducted at Mwea Irrigation Agricultural Development (MIAD) Center. Mwea Irrigation Agricultural Development Center is located within the National Irrigation Scheme in Mwea division, Kirinyaga County, which is situated at the foothills of Mt. Kenya, 100 km North East of Nairobi city (NIB, 1996). Its location is latitude $0^0$41’ S and longitude 37^0 20’ E at an attitude of 1195 m above sea level. It is situated near Kandongu Village, 16 km from Mwea town (NIB, 1996). Most of MIAD’s research is focused on rice, although it also conducts research on onions and tomatoes.

The total gazetted area for Mwea irrigation scheme is 30,350 acres. Approximately 52.4% of the area is used in rice production and the remaining is used for horticultural crops, subsistence farming and for public amenities. The scheme is divided into five sections: Mwea, Tebere (MIAD is located here), Thiba, Karaba and Wamumu. The scheme covers three agro-ecological zones with the highest moisture ratios (0.65) being recorded in agro-ecological zone III, followed by agro-ecological zone IV (0.5), and then agro-ecological zone V (0.4) (Sombroek *et al*., 1982). The soil comprises dark deep vertisols with an average pH of 6.8. The site receives an annual rainfall of between 950 and 1500 mm (FAO, 1996), with a temperature range of 15.6 ^{0}C – 28.6 ^{0}C and a mean temperature of 22 ^{0}C (Jaetzold *et al*., 2005). The long rains occur between March and May, while the short rains occur between October and December. Planting rice between the month of August and December is good because it allows for maximum grain filling and minimizes the incidence of diseases (Mukiama and Mwangi, 1989). The main sources of water for the scheme are Nyamindi and Thiba rivers. The Government legally owns the scheme and farmers have been allocated 1.6 ha per household.

The soils (15 cm depth) at the experimental plots were analyzed for various physico-chemical characteristics. The soil pH, organic carbon, electrical conductivity (EC), total N, available Olsen P and available K, were 5.12, 2.46%, 0.37 dS/m, 0.29%, 3.06 ppm and 68 ppm, respectively (Table 3.1).

Table 3.1: Chemical characteristics of the soil at Mwea experimental site

Soil parameters	Soil depth (0- 15 cm)	Soil parameters	Soil depth (0- 15 cm)
pH	5.12	Zinc ppm	1.02
*EC (salts) dS/m	0.37	*Sodium ppm	204
Phosphorus ppm	3.06	Iron ppm	249
Potassium ppm	68	*C.E.C meq/100g	52.8
Calcium ppm	3100	*Organic Carbon %	2.46
Magnesium ppm	1270	*Total Nitrogen %	0.29
Manganese ppm	98.4	Sodium % (ESP)	1.68
Sulphur ppm	24.6	Ca: Mg Ratio %	1.46
Copper ppm	1.04	Other Bases %	7.16
Boron ppm	0.21		

ppm- parts per million, meq/100g- milligram equivalents per 100 g soil, dS/m- deciSiemens per centimeter, ESP-Exchangeable Sodium Percentage

The field trials were established in August 2016 to January 2017 and in August 2017 to January 2018. During this period, meteorological data was collected from MIAD meteorological unit. The total rainfall ranged from 11.60 mm to 141.10 mm in the first season and 0.00 to 418.8 mm in the second. The mean temperature range was 21.75 to 28.79 ^{0}C and the average relative humidity was 78.03%.

3.3.2 Plant material

Varieties Basmati 370 and BW 196 were each collected from Mwea Rice Growers Multipurpose (MRGM) and the National Irrigation Board (NIB). Each of the variety’s nuclear seed (NS) material was collected from the National Irrigation Board, the custodian of these varieties in the country.

3.3.3 Experimental design and treatments

A field experiment was laid-out in a randomized complete block design. The blocks were replicated three times. Each block consisted of six treatments: Basmati 370 (nuclear seed), Basmati 370 (from MRGM), Basmati 370 (from NIB), BW 196 (nuclear seed), BW 196 (from MRGM), and BW 196 (from NIB). The total area covered by the experiment was 1352.8 m^2. Each plot was 6 × 4.8 m having a minimum of 500 plants each. Plant spacing was 20 cm and 30 cm within and between rows; respectively. The isolation distance between plots was 3 m.

3.3.4 Data collection

To determine the genetic purity of seed from different sources, 30 plants were sampled per treatment. Forty (40) agro-morphological traits were checked against specific descriptors as provided by the UPOV code (UPOV, 2004), the national test guidelines for DUS test in rice (Shobha *et al*., 2004), Standard Evaluation System for rice (SES) (IRRI, 2014) and Bioversity International, IRRI and WARDA, 2007. Data was collected by visual assessment, through single observation of individual (Table 3.2) and groups (Table 3.3) of plants or parts of plants, and by measuring a number parameters of individual plants or parts of plants (Table 3.4).

Table 3.2: Data collected by visually assessing individual plants or parts

Stage of development	Descriptors /Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)		Additional information on the method of data collection (source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
Booting stage		**Basal leaf sheath color**	The outer surface of the basal leaf sheath is checked
	1 [ ]	Green	
	2 [ ]	Green with purple lines	
	3 [ ]	Light purple	
	4 [ ]	Purple	
Booting stage		**Leaf blade: pubescence of surface**	Ocular inspection On the leaf surface, fingers were rubbed from the tips downwards
	1 [ ]	Absent or very weak	
	3 [ ]	Weak	
	5 [ ]	Medium	
	7 [ ]	Strong	

Table 3.2: Data collected by visually assessing individual plants or parts

Stage of development		Descriptors /Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)	Additional information on the method of data collection (source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
Booting stage		**Leaf: anthocyanin coloration of collar**	
	1 [ ]	Absent	
	9 [ ]	Present	
Booting stage		**Leaf: shape of ligule**	
	1 [ ]	Truncate	
	2 [ ]	Acute	
	3 [ ]	Cleft	
Booting stage		**Leaf: color of ligule**	
	1 [ ]	Colorless	
	2 [ ]	Green	
	3 [ ]	Green with purple lines	
	4 [ ]	Light purple violet	
	5 [ ]	Purple	
Booting stage		**Leaf: Anthocyanin coloration of auricles**	
	1 [ ]	Absent	
	9 [ ]	Present	
Anthesis to milk development stage		**Spikelet: Pubescence of the lemma**	Ocular inspection On the lemma surface, fingers were rubbed from the tip downwards
	1 [ ]	Absent	
	3 [ ]	Weak	
	5 [ ]	Medium	
	7 [ ]	Strong	
	9 [ ]	Very strong	
Anthesis half way		**Spikelet: Color of stigma**	Using a hand lens, the blooming spikelets, were looked at closely, between 9 am and 2 pm
	1 [ ]	White	
	2 [ ]	Light green	
	3 [ ]	Yellow	
	4 [ ]	Light purple	
	5 [ ]	Purple	
Anthesis half way		**Lemma: anthocyanin coloration of keel (early observation)**	
	1 [ ]	Absent or very weak	
	3 [ ]	Weak	
	5 [ ]	Medium	
	7 [ ]	Strong	
Anthesis half way		**Lemma: anthocyanin coloration of apex (early observation)**	
	1 [ ]	Absent or very weak	
	3 [ ]	Weak	
	5 [ ]	Medium	
	7 [ ]	Strong	
	9 [ ]	Very strong	
Milk stage		**Non-prostrate varieties only-Stem length (excluding Panicle)**	Measurements were taken from the ground level to the base of the panicle
	1 [ ]	Very short (<91 cm)	

Table 3.2: Data collected by visually assessing individual plants or parts

Stage of development	Descriptors /Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)		Additional information on the method of data collection (source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
	3 [ ]	Short (91-110 cm)	
	5 [ ]	Medium (111-130 cm)	
	7 [ ]	Long (131-150 cm)	
	9 [ ]	Very long (>150 cm)	
Milk stage		**Stem: Anthocyanin coloration of nodes**	
	1 [ ]	Absent	
	9 [ ]	Present	
Milk stage		**Stem: intensity of anthocyanin coloration of internodes**	Ocular inspection of the outer surface of the culm
	1 [ ]	Absent	
	9 [ ]	Present	
Milk stage		**Stem: thickness**	
	3 [ ]	Thin (<0.40 cm)	
	5 [ ]	Medium (0.40-0.55 cm)	
	7 [ ]	Thick (>0.55 cm)	
Beginning of anthesis		**Panicle : color of awns (early observation)**	
	1 [ ]	Light gold	
	2 [ ]	Gold	
	3 [ ]	Brown	
	4 [ ]	Reddish brown	
	5 [ ]	Light red	
	6 [ ]	Red	
	7 [ ]	Light purple	
	8 [ ]	Purple	
	9 [ ]	Black	
Between milk stage and dough development stage		**Panicle: Distribution of awns**	Along the panicle, presence and distribution of awns is checked
	1 [ ]	Tip only	
	2 [ ]	Upper quarter only	
	3 [ ]	Upper half only	
	4 [ ]	Upper three quarters	
	5 [ ]	Only Whole length	
Between milk stage and dough development stage		**Panicle: length of longest awns**	A minimum of 10 spikelets should be evaluated
	1 [ ]	very short (<5 mm)	
	3 [ ]	Short (~8 mm)	
	5 [ ]	Medium (~15 mm)	
	7 [ ]	Long (~30 mm)	
	9 [ ]	very long (>40 mm)	
Between dough development stage and ripening stage		**Spikelet: color of tip of lemma**	
	1 [ ]	White	
	2 [ ]	Yellowish	
	3 [ ]	Brown	
	4 [ ]	Red	
	5 [ ]	Purple	
	6 [ ]	Black	
Ripening stage		**Panicle: Attitude of branches**	Panicle compactness is checked. Classification is based on angle
	1 [ ]	Erect	

Table 3.2: Data collected by visually assessing individual plants or parts

Stage of development	Descriptors /Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)	Additional information on the method of data collection (source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
	3 [ ] Semi-erect 5 [ ] Spreading	of primary branches, density of the spikelet and the mode of branching
Ripening stage	**Panicle: type of secondary branching** 1 [ ] Type 1 2 [ ] Type 2 3 [ ] Type 2	Classification was done based on spikelet density, mode of branching and the angle of primary branches
Ripening stage	**Panicle: color of awns (late observation)** 1 [ ] Light gold 2 [ ] Gold 3 [ ] Brown 4 [ ] Reddish brown 5 [ ] Light red 6 [ ] Red 7 [ ] Light purple 8 [ ] Purple 9 [ ] Black	
Hardened caryopsis	**Decorticated grain: Shape (lateral View)** 1 [ ] Round (< 1.50) 2 [ ] Semi-round (1.50-1.99) 3 [ ] Half spindle-shaped (2.00-2.49) 4 [ ] Spindle-shaped (2.50-2.99) 5 [ ] Long spindle-shaped (≥ 3.00)	Using a caliper, the width and the length of the decorticated grain was measured. The length to width ratio was determined and categorized.
Hardened caryopsis	**Decorticated grain: color** 1 [ ] White 2 [ ] Light brown 3 [ ] Variegated brown 4 [ ] Dark brown 5 [ ] Light red 6 [ ] Red 7 [ ] Variegated purple 8 [ ] Purple 9 [ ] Dark purple/black	

Table 3.3: Data collection by visually assessing, by a single observation of a group of plants or parts of plants

Stage of development		Descriptors /Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)	Additional information on the method of data collection (source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
Booting stage		**Leaf: intensity of green color**	
	3 [ ]	Light	
	5 [ ]	Medium	
	7 [ ]	Dark	
Booting stage		**Leaf: anthocyanin coloration**	
	1 [ ]	Present	
	9 [ ]	Absent	
50 % inflorescence emerged		**Time of heading: (50% of plants with heads)**	It is recorded once 50% of the inflorescence emerges
	1 [ ]	Very early (<71)	
	3 [ ]	Early (71-90)	
	5 [ ]	Medium (91-110)	
	7 [ ]	Late (111-130)	
Beginning of anthesis		**Flag leaf: Attitude of blade (early observation)**	The angle of openness between the culm of the leaf below the flag leaf and the blade tip is assessed
	1 [ ]	Erect	
	3 [ ]	Semi-erect	
	5 [ ]	Horizontal	
	7 [ ]	Recurved	
Ripening stage		**Panicle: Attitude in relation to stem**	
	1 [ ]	Upright	
	2 [ ]	Semi-upright	
	3 [ ]	Slightly drooping	
	4 [ ]	Strongly drooping	
Ripening stage		**Panicle: exsertion(IRRI, 2004)**	The degree to which the panicle is exserted above the flag leaf sheath is observed.
	1 [ ]	Enclosed (panicle is partly or entirely enclosed within the leaf)	
	3 [ ]	Partly-exserted (panicle base is slightly beneath the collar of the flag leaf blade)	
	5 [ ]	Just-exserted (panicle base coincides with the collar of the flag leaf blade)	
	7 [ ]	Moderately well-exserted (panicle base is above the collar of the flag leaf blade)	
	9 [ ]	Well-exserted (panicle base appears well above the collar of the flag leaf blade)	
Ripening stage		**Time of maturity**	The number of days from seeding to 85% of the grains reaching maturity is recorded
	1 [ ]	Very early (<100)	
	3 [ ]	Early (101-120)	
	5 [ ]	Intermediate (121-140)	
	7 [ ]	Late (141-160)	

Table 3.3: Data collection by visually assessing, by a single observation of a group of plants or parts of plants

Stage of development		Descriptors /Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)	Additional information on the method of data collection (source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
	9 [ ]	Very late (>160)	
Hardened caryopsis		**Decorticated grain: Length**	Using a caliper, the length of 10 de-hulled grains was determined. Measurements were recorded in millimeters, to 2 decimal places
	3 [ ]	Short	
	5 [ ]	Medium	
	7 [ ]	Long	
Ripening stage		**Flag leaf: Attitude of blade (late observation)**	The angle of openness between the culm of the leaf below the flag leaf and the blade tip was determined.
	1 [ ]	Erect	
	3 [ ]	Semi-erect	
	5 [ ]	Horizontal	
	7 [ ]	Recurved	

Table 3.4: Data collection by measuring a number of individual plants or parts of plants

Stage of development		Descriptors/Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)	Additional information on the method of data collection(source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
Booting stage		**Leaf blade: length**	Actual measurements, in centimeters, of the leaf below the flag leaf was recorded.
	3 [ ]	Short (<30 cm)	
	5 [ ]	Medium (30-45 cm)	
	7 [ ]	Long (>45 cm)	
Booting stage		**Leaf blade: width**	Actual measurements of the widest section, of the blade below the flag leaf was recorded.
	3 [ ]	Narrow (<1 cm)	
	5 [ ]	Medium (1-2 cm)	
	7 [ ]	Broad (>2 cm)	
Milk stage to ripening stage		**Panicle: Length of main axis**	The base of the panicle to its tip was measured and the actual figures recorded
	3 [ ]	Short (16-20 cm)	
	5 [ ]	Medium (21-25cm)	
	7 [ ]	Long (26-30 cm)	
Hardened caryopsis		Decorticated grain: width	Using a caliper, the widest parts of 10 grains of fertile lemma and palea were measured and the actual measurements recorded in millimeters
	3 [ ]	Narrow (<2.0 mm)	
	5 [ ]	Medium (2.0-2.5 mm)	
	7 [ ]	Broad (>2.5 mm)	
Hardened caryopsis		**Grain: Width**	Without including the awns, the distance between the apiculus and the lower most sterile lemma was measured and recorded in millimeters.
	3 [ ]	Narrow (2.1-2.5 mm)	
	5 [ ]	Medium (2.6-3.0 mm)	
	7 [ ]	Broad (3.1-3.5 mm)	
		Grain: Length	

Table 3.4: Data collection by measuring a number of individual plants or parts of plants

Stage of development	Descriptors/Characteristic (source : UPOV, 2004; Shobha *et al*., 2004)		Additional information on the method of data collection(source: IRRI, 2004 and Bioversity International, IRRI and WARDA, 2007)
Hardened caryopsis	3 [ ] 5 [ ] 7 [ ]	Short (6.1-8.5 mm) Medium 8.6-10.5 mm) Long (10.6-12.5 mm)	An average of 10 plants should be measured using a caliper. The distance between the base of the lowest glume to the apiculus, awns should be excluded.
Hardened caryopsis	 3 [ ] 5 [ ] 7 [ ]	**Grain: Weight of 1000 fully developed grains** Low| (15-20 g) Medium (21-25 g) High (26-30)	After drying the grains to 14% moisture content, 1000 well-developed whole grains were weighed to precision and the values recorded in millimeters

3.3.5 Data analysis

Analysis of variance (ANOVA) was done to check for the differences between the means for quantitative data. The variances were calculated based on the standard procedure as proposed by Gomez and Gomez (1984), using Genstat 15th edition software.

Qualitative rice crop traits were encoded into 1 to 9 classes as provided by the UPOV code (UPOV, 2004) and the national test guidelines for DUS test in rice (Shobha *et al*., 2004). Frequency distribution for these characters was carried out, then used to calculate diversity for each of the traits. Shannon-Weiner diversity index (*H*') was calculated using the formula 1, described by Hutcheson, 1970.

Equation 1:

$$H' = -\sum_{I-1}^{n} pi \ln(pi)$$

Where n is the number of phenotypic classes of characteristics and *p*i the frequency of the observations in the *i*th class.

3.4 Results

3.4.1 Effect of seed source on the qualitative characteristics of different rice varieties

Minimal genetic variations were reported in different varieties, whose seeds were sourced from nuclear seed, NIB and MRGM. In the first season, for Basmati 370 plants, 97% of the plant sample from NIB, and 100% from MRGM and nuclear seeds, had medium-green colored leaves, weak pubescence of the leaf blade, horizontal flag leaves and reddish brown awns at ripening stage. Three percent of the sampled plants, generated from NIB had dark green leaves, very weak leaf blade pubescence, no awns and erect flag leaves at ripening stage. Similar results were reported in the second season (Table 3.5a).

For variety BW 196 seeds, in the first season, 97% of seed from nuclear material and a 100% of the sampled plants that were generated from MRGM and NIB certified seed had dark green leaves, medium leaf blade pubescence, erect flag leaf and light gold awns at ripening stage. Three percent of crops sampled from the nuclear seed material had medium green leaves, very weak leaf blade pubescence, horizontal flag leaf and reddish brown awns at ripening stage. For the second season, 93% of crops sampled from nuclear seed material and 97% of plants sampled, from certified seed of MRGM and NIB treatments, had dark green leaves, medium leaf blade pubescence, horizontal flag leaf and light gold awns at ripening stage. Seven percent of the sample from nuclear seed and 3% of the sample from certified seed of NIB and MRGM had medium green leaves, very weak leaf blade pubescence, horizontal flag leaf and light gold awns at ripening stage (Table 3.5b).

Both varieties BW 196 and Basmati 370 rice seed, from all the seed sources under study, expressed green basal leaf sheath colors, 2-cleft colorless ligules, white stigma color, semi-erect flag leaf attitude at the beginning of anthesis and lacked anthocyanin coloration on the leaf and stem parts (leaf blade, collar, auricles, nodes and internodes) under consideration, irrespective of the source of the seed planted. Except for the awn-less plants in NIB plots, awns appeared at the tip only and light gold awn color was prominent at the beginning of anthesis, in all the other plots (Table 3.5a and b).

Ninety seven percent of the sample of variety Basmati 370 plants generated from NIB seeds, and a 100% of the sample generated from MRGM and nuclear seeds, expressed slightly drooping panicle attitude (in relation to the stem) at ripening stage, type 1 secondary branching panicles and had well-exserted panicles. Three percent of the sample from NIB plants had upright panicles at ripening stage, type 1 secondary branching panicles and moderately well-exserted panicles. Similar results were reported in the second season (Table 3.5a).

For BW 196 seeds, in the first season, 97% of the sample from nuclear seed material and 100% of the plants generated from MRGM and NIB certified seed had partly-exserted, semi-erect, type 3 secondary branching panicles. 3% of the sample from nuclear seed material had slightly drooping panicles, type 1 secondary branching panicles. In the second season, 97% of plants generated from certified seed of MRGM and NIB, and 93% of the sample from nuclear seed material had partly well-exserted, semi-erect, type 3 secondary branching panicles, against 3% and 7%; respectively, that had well-exserted, slightly drooping, type 1 secondary branching panicles (Table 3.5b).

In both varieties, irrespective of the seed source, the decorticated grains were brown, the pubescence of the lemma was weak, and its tips were yellowish. There was no anthocyanin coloration on the apex, keel and the area below the apex (Table 3.5a and b).

Table 3.5 a : Summary of the distribution of qualitative plant traits in Basmati 370 plants generated from nuclear and certified seed from MRGM and NIB, in Mwea, between August 2016 and February 2018

GRAIN AND PLANT	FIRST SEASON			SECOND SEASON		
GROWTH TRAITS	**MRGM**	**NS**	**NIB**	**MRGM**	**NIB**	**NS**
Basal leaf: sheath color	Green (1)	Green (1)	Green (1)	Green (1)	Green (1)	Green (1)
Leaf: intensity of green color	Medium (1)	Medium (1)	**Medium (0.97)** **Dark (0.03)**	Medium (1)	**Medium (0.97)** **Dark (0.03)**	Medium (1)
Leaf: anthocyanin coloration	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Leaf blade: pubescence of surface	Weak (1)	Weak (1)	**Weak (0.97)** **Very weak (0.03)**	Weak (1)	**Weak (0.97)** **Very weak (0.03)**	Weak (1)
Leaf: anthocyanin coloration of collar	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Leaf: shape of ligule	Cleft (1)	Cleft (1)	Cleft (1)	Cleft (1)	Cleft (1)	Cleft (1)
Leaf: color of ligule	Colorless (1)	Colorless (1)	Colorless (1)	Colorless (1)	Colorless (1)	Colorless (1)
Leaf: Anthocyanin coloration of auricles	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Panicle : color of awns (early observation)	Light gold (1)	Light gold (1)	Light gold (1)	Light gold (1)	Light gold (1)	Light gold (1)
Flag leaf: Attitude of blade (early observation)	Semi-erect (1)	Semi-erect (1)	Semi-erect (1)	Semi-erect (1)	Semi-erect (1)	Semi-erect (1)
Spikelet: Pubescence of lemma	Weak (1)	Weak (1)	Weak (1)	Weak (1)	Weak (1)	Weak (1)
Spikelet: Color of stigma	White (1)	White (1)	White (1)	White (1)	White (1)	White (1)
Lemma: anthocyanin coloration of keel (early observation)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Lemma: anthocyanin coloration of apex (early observation)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Lemma color	Brown (1)	Brown (1)	Brown (1)	Brown (1)	Brown (1)	Brown (1)
Stem: Anthocyanin coloration of nodes	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Stem: intensity of anthocyanin coloration of internodes	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Panicle: Distribution of awns	Tip only (1)	Tip only (1)	Tip only (1)	Tip only (1)	Tip only (1)	Tip only (1)

Table 3.5 a : Summary of the distribution of qualitative plant traits in Basmati 370 plants generated from nuclear and certified seed from MRGM and NIB, in Mwea, between August 2016 and February 2018

GRAIN AND PLANT	FIRST SEASON			SECOND SEASON		
GROWTH TRAITS	**MRGM**	**NS**	**NIB**	**MRGM**	**NIB**	**NS**
Spikelet: color of tip of lemma	Yellowish	Yellowish	Yellowish	Yellowish	Yellowish	Yellowish
Flag leaf: Attitude of blade (late observation)	Horizontal (1)	Horizontal (1)	**Horizontal (0.97)** **Erect (0.03)**	Horizontal (1)	**Horizontal (0.97)** **Erect (0.03)**	Horizontal (1)
Panicle: color of awns (late observation)	Reddish brown (1)	Reddish brown (1)	**Reddish brown (0.97)** **Absent (0.03)**	Reddish brown (1)	**Reddish brown (0.97)** **Absent (0.03)**	Reddish brown (1)
Panicle: Attitude in relation to stem	Slightly drooping (1)	Slightly drooping (1)	**Slightly drooping (0.97)** **Upright (0.03)**	Slightly drooping (1)	**Slightly drooping (0.97)** **Upright (0.03)**	Slightly drooping (1)
Panicle: Attitude of branches	Spreading (1)	Spreading (1)	Spreading (1)	Spreading (1)	Spreading (1)	Spreading (1)
Panicle: type of secondary branching	Type 1 (1)	Type 1 (1)	**Type 1 (0.97)** **Type 2 (0.03)**	Type 1 (1)	**Type 1 (0.97)** **Type 2 (0.03)**	Type 1 (1)
Panicle: exsertion	Well-exserted (1)	Well-exserted (1)	**Well-exserted (0.97)** **Moderately well-exserted (0.03)**	Well-exserted (1)	**Well-exserted (0.97)** **Moderately well-exserted (0.03)**	Well-exserted (1)
Decorticated grain: color	Light brown (1)	Light brown (1)	Light brown (1)	Light brown (1)	Light brown (1)	Light brown (1)

Table 3.5 b: Summary of the distribution of qualitative plant traits in BW 196 plants generated from nuclear and certified seed from MRGM and NIB, in Mwea, between August 2016 and February 2018

GRAIN AND PLANT	FIRST SEASON			SECOND SEASON		
GROWTH TRAITS	**MRGM**	**NIB**	**NS**	**MRGM**	**NIB**	**NS**
Basal leaf: sheath color	Green (1)	Green (1)	Green (1)	Green (1)	Green (1)	Green (1)
Leaf: intensity of green color	Dark (1)	Dark (1	**Dark (0.97)** **Medium (0.03)**	**Dark (0.97)** **Medium (0.03)**	**Dark (0.97)** **Medium (0.03)**	**Dark (0.93)** **Medium (0.07)**
Leaf: anthocyanin coloration	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Leaf blade: pubescence of surface	Medium (1)	Medium (1)	**Medium (0.97)** **Weak (0.03)**	**Medium (0.97)** **Weak (0.03)**	**Medium (0.97)** **Weak (0.03)**	**Medium (0.93)** **Weak (0.07)**

Table 3.5 a : Summary of the distribution of qualitative plant traits in Basmati 370 plants generated from nuclear and certified seed from MRGM and NIB, in Mwea, between August 2016 and February 2018

GRAIN AND PLANT	FIRST SEASON			SECOND SEASON		
GROWTH TRAITS	**MRGM**	**NS**	**NIB**	**MRGM**	**NIB**	**NS**
Leaf: anthocyanin coloration of collar	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Leaf: shape of ligule	Cleft (1)	Cleft (1)	Cleft (1)	Cleft (1)	Cleft (1)	Cleft (1)
Leaf: color of ligule	Colorless (1)	Colorless (1)	Colorless (1)	Colorless (1)	Colorless (1)	Colorless (1)
Leaf: Anthocyanin coloration of auricles	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Panicle : color of awns (early observation)	Light gold (1)	Light gold (1)	**Light gold (0.97)** **Awn less (0.03)**	Light gold (1) Light gold (1)	**Light gold (0.97)** **Awn less (0.03)**	Light gold (1) Light gold (1)
Flag leaf: Attitude of blade (early observation)	Erect(1)	Erect(1)	**Erect (0.97)** **Horizontal (0.03)**	**Erect (0.97)** **Horizontal (0.03)**	**Erect (0.97)** **Horizontal (0.03)**	**Erect (0.93)** **Horizontal (0.07)**
Spikelet: Pubescence of lemma	Weak (1)	Weak (1)	Weak (1)	Weak (1)	Weak (1)	Weak (1)
Spikelet: Color of stigma	White (1)	White (1)	White (1)	White (1)	White (1)	White (1)
Lemma: anthocyanin coloration of keel (early observation)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Lemma: anthocyanin coloration of apex (early observation)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Lemma color	Light gold (1)	Light gold (1)	**Light gold (0.97)** **Brown (0.03)**	**Light gold (0.97)** **Brown (0.03)**	**Light gold (0.97)** **Brown (0.03)**	**Light gold (0.93)** **Brown (0.07)**
Stem: Anthocyanin coloration of nodes	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Stem: intensity of anthocyanin coloration of internodes	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)	Absent (1)
Panicle: Distribution of awns	Tip only (1)	Tip only (1)	Tip only (1)	Tip only (1)	Tip only (1)	Tip only (1)
Spikelet: color of tip of lemma	Yellowish (1)	Yellowish (1)	Yellowish (1)	Yellowish (1)	Yellowish (1)	Yellowish (1)
Flag leaf: Attitude of blade (late observation)	Erect (1)	Erect (1)	**Erect (0.97)** **Horizontal (0.03)**	**Erect (0.97)** **Horizontal (0.03)**	**Erect (0.97)** **Horizontal (0.03)**	**Erect (0.93)** **Horizontal (0.07)**
Panicle: color of awns (late observation)	Light gold (1)	Light gold (1)	**Light gold (0.97)** **Reddish (0.03)**	**Light gold (0.97)** **Reddish (0.03)**	**Light gold (0.97)** **Reddish (0.03)**	**Light gold (0.93)** **Reddish (0.07)**

Table 3.5 a : Summary of the distribution of qualitative plant traits in Basmati 370 plants generated from nuclear and certified seed from MRGM and NIB, in Mwea, between August 2016 and February 2018

GRAIN AND PLANT GROWTH TRAITS	**FIRST SEASON**			**SECOND SEASON**		
	MRGM	**NS**	**NIB**	**MRGM**	**NIB**	**NS**
Panicle: Attitude in relation to stem	Slightly drooping (1)	Slightly drooping (1)	**Slightly drooping (0.03) Semi-upright (0.97)**	**Slightly drooping (0.03) Semi-upright (0.97)**	**Slightly drooping (0.03) Semi-upright (0.97)**	**Slightly drooping (0.07) Semi-upright (0.93)**
Panicle: Attitude of branches	Spreading (1)	Spreading (1)	Spreading (1)	Spreading (1)	Spreading (1)	Spreading (1)
Panicle: type of secondary branching	Type 3 (1)	Type 3 (1)	**Type 3 (0.97) Type 1 (0.03)**	**Type 3 (0.97) Type 1 (0.03)**	**Type 3 (0.97) Type 1 (0.03)**	**Type 3 (0.93) Type 1 (0.07)**
Panicle: exsertion	Partly-exserted (1)	Partly-exserted (1)	**Partly-exserted (0.97) Well-exserted (0.03)**	**Partly-exserted (0.97) Well-exserted (0.03)**	**Partly-exserted (0.97) Well-exserted (0.03)**	**Partly-exserted (0.93) Well-exserted (0.07)**
Decorticated grain: color	Light brown (1)	Light brown (1)	Light brown (1)	Light brown (1)	Light brown (1)	Light brown (1)

NIB- National Irrigation Board, MRGM- Mwea Rice Growers Multipurpose, NS-Nuclear seed

Observations in the experimental plots revealed genetic diversities. Basmati 370 had a lower number of off-types. When compared to its nuclear seed which had only one off-type in the first season, Basmati 370 certified seeds from MRGM had one and zero off-types in the first and second season; respectively. Those from NIB had 2 and 3 off-types in the first and second season; respectively. All the variety BW 196 seed sources had at least 2 off-types per plot (Figure 3.1, 3.2 and 3.3). Variety BW 196 seeds generated from nuclear material had 5 and 8 off-types in the first and second season, respectively. Certified seed from MRGM had 5 and 8 off-types in the first and second season; respectively. Certified seed from NIB had 6 and 8 off-types in the first and the second season; respectively. The Figure 3.4 G shows the most common off-type in variety Basmati 370 seed from NIB. Figure 3.4 H shows an off-type that ranks second in prominence, after variety Basmati 370, in variety BW 196 plots.

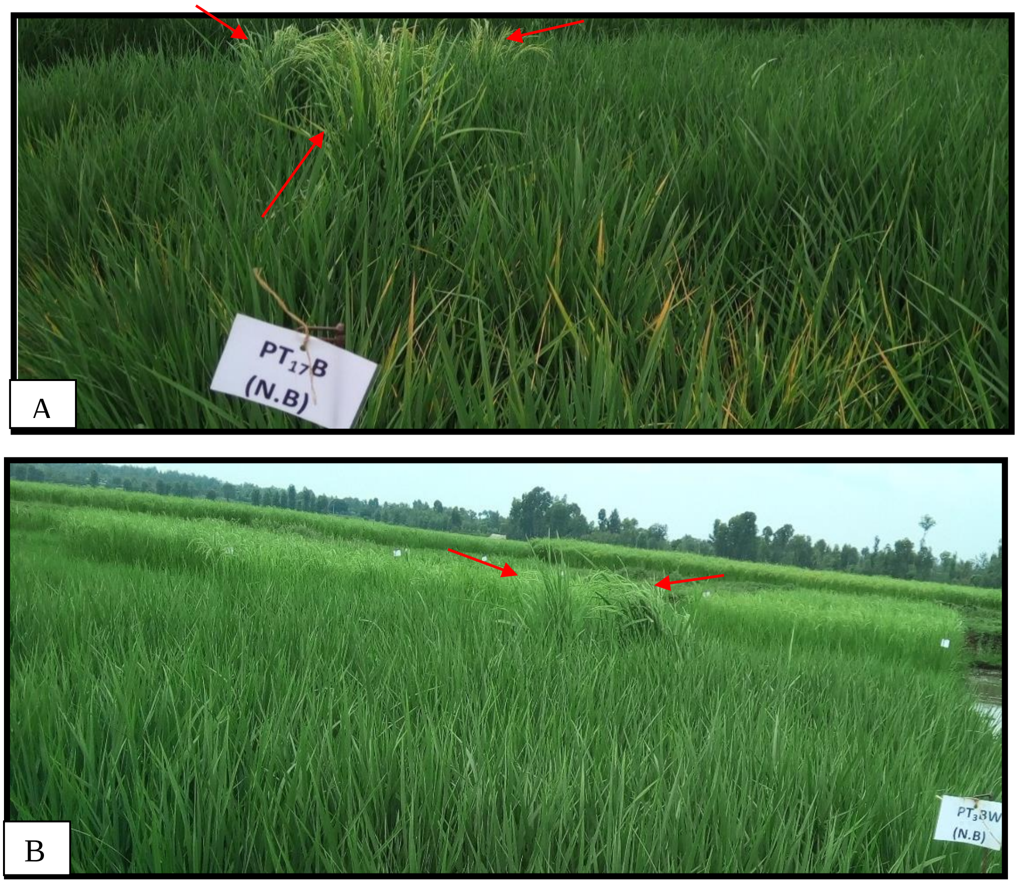

Figure 3.1: Plots of the NIB seed having three off-types in photograph A and two in photograph B, as indicated by the arrows

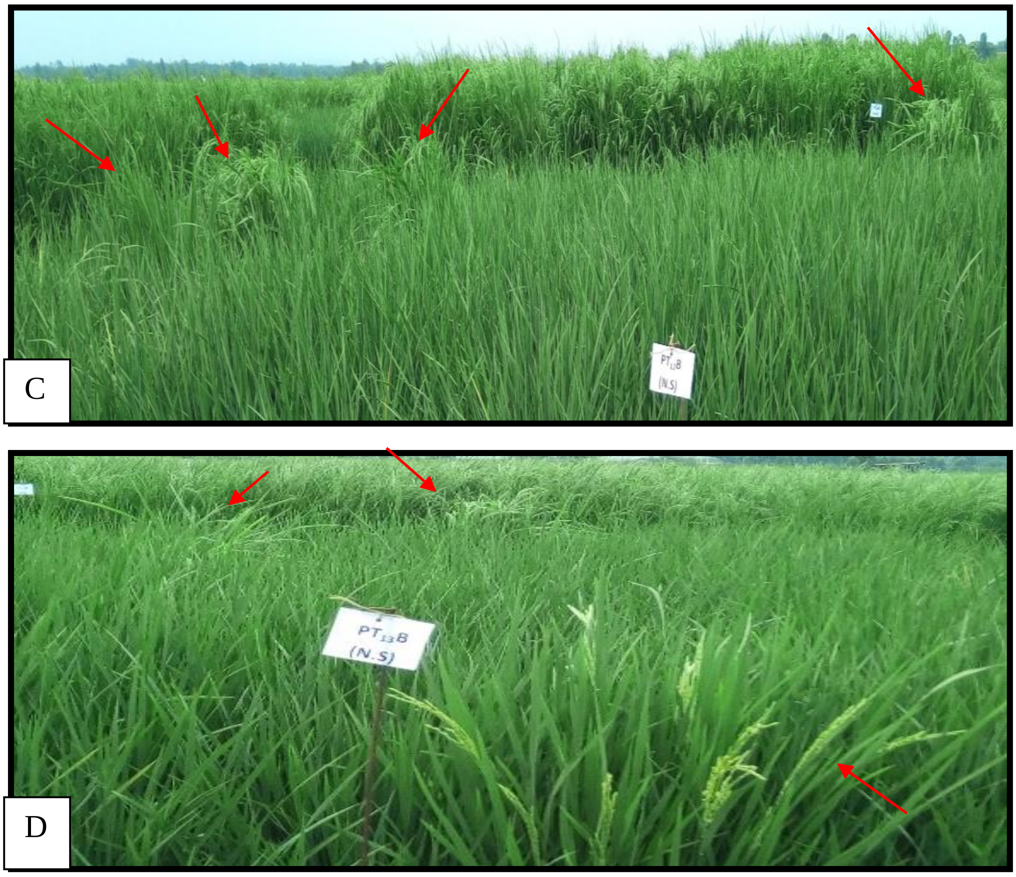

Figure 3.2: Plots of the nuclear seed having four off-types on plot C and three on plot D as indicated by the arrows

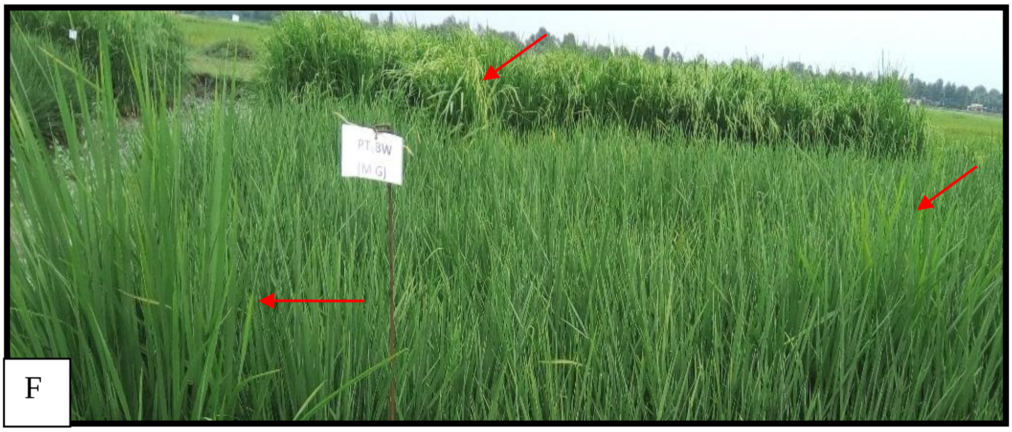

Figure 3.3: Plots of the MRGM seed having three off-types on plot E and three on plot F as shown by the arrows

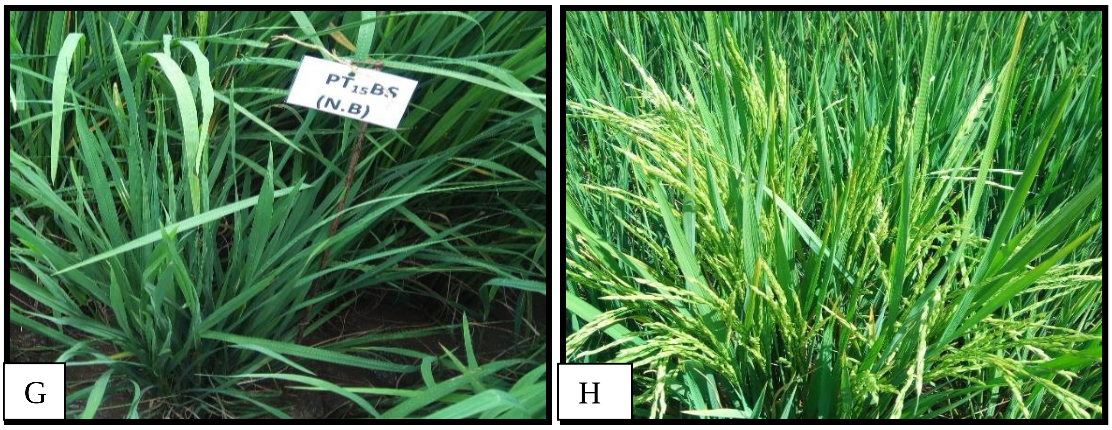

Figure 3.4: Photo G showing an off-type that is prominent in plots generated from NIB seeds of Basmati 370 and H showing the second most common off-type after Basmati 370 in BW 196 plots

For Basmati 370, in both seasons, the NIB had the highest diversity of *H'*= 0.14 while the nuclear seed and that from MRGM had a diversity index (*H'*) of 0.00 (Table 3.6). For variety BW 196, the nuclear seed had the highest diversity index in both the first (*H'*=0.17) and the second (*H'*= 0.25) season. Seeds from MRGM and NIB each had a diversity index of 0.00 in the first and 0.18 in the second season; respectively. BW 196, exhibited a higher diversity than Basmati 370 in both seasons (Table 3.6).

Table 3.6: Shannon Weiner diversity indices (*H'*) of rice parameters that exhibited variation within rice varieties from varying seed sources

Season	Variety	Seed sources	Crop parameters: Leaf: Intensity of green color	Leaf: Pubescence of blade surface	Flag leaf: Attitude of blade: Early observation	Flag leaf: Attitude of blade: Late observation	Panicle : color of awns: Early observation	Panicle : color of awns: Late observation	Panicle: Attitude in relation to stem	Panicle: Attitude of branches	Panicle: Type of secondary branching	Panicle: Exsertion	Panicle: Decorticated grain: Color	Average (*H'*)
First season	**Bs 370**	MRGM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		NIB	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
		NS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Total *H'*	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	BW 196	MRGM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		NIB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		NS	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
		Total *H'*	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Second season	**Bs 370**	MRGM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		NIB	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
		NS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Total *H'*	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	BW 196	MRGM	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
		NIB	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
		NS	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
		Total *H'*	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18

3.4.2 Effect of seed source on quantitative characteristics of rice varieties

There were significant ($p \leq 0.05$) differences between the two varieties with respect to leaf blade length, days to maturity, stem, panicle and grain characteristics (Table 3.7 and 3.8). Seed sources and the interaction of the variety and seed source did not significantly affect these plant attributes. Variety Basmati 370 had significantly longer leaf blades (49.74 vs. 33.84) cm, stems (107.71 vs. 64.91) cm, awns (2.05 vs. 0.36) cm, panicles (24.73 vs. 20.67) cm, and length to width ratios (3.58, vs. 4.01) cm than BW 196. Variety BW 196 and Basmati 370 had similar grain lengths though the former registered higher grain yield (2.23 vs. 3.74) kg/ha and grain widths (2.46 vs. 1.95), cm. Similar results were replicated in the second season (Table 3.7 and 3.8).

Table 3.7: Means of plant growth and grain characteristics of two rice varieties planted using seeds obtained from two different sources in Mwea in the first season in 2016

Grain and plant growth traits	Leaf blade length	Days taken to Heading	Maturity	Stem length	thickness	Panicle length longest awns	axis	Decorticated grain Length	width	shape	Grain width	length	weight	Yield
Variety Bs 370	49.74	69.89	112.44	107.71	5.27	2.05	24.73	6.97	1.95	3.58	2.25	9.17	20.38	-
Variety BW 196	33.84	93.67	132.22	64.91	5.93	0.36	20.67	6.57	2.46	2.71	2.94	9.08	30.18	-
P- Value (V)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.01	<.001	<.001	<.001	NS	<.001	-
P- value (S)	0.10	0.33	0.08	0.63	0.84	0.40	0.92	0.88	0.53	0.93	0.35	0.14	0.11	-
P- value (V*S)	0.52	0.33	0.17	0.85	0.18	0.37	0.60	0.26	0.15	0.78	0.48	0.06	0.56	-
LSD p≤ (0.05) (V)	1.77*	2.12*	2.14*	3.42*	0.30*	0.17*	0.79*	0.25*	0.09*	0.08*	0.12*	NS	1.12*	-
LSD p≤ (0.05) (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-
LSD p≤ (0.05) (V*S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-
CV %	4.00	2.50	1.90	3.80	5.10	13.50	3.30	3.50	3.80	5.20	4.60	2.50	4.20	-

Table 3.8: Means of plant growth and grain characteristics of two rice varieties planted using seeds obtained from two different sources in Mwea in the second season in 2017/2018

Grain and plant growth Characteristics	Leaf blade length	Days taken to		Stem		Panicle length		Decorticated grain			Grain			
		Heading	Maturity	length	thickness	longest awns	axis	length	width	shape	width	Length	weight	Yield
Variety Bs 370	55.51	77.52	116.3	106.33	4.51	1.58	24.69	7.97	2.00	4.01	2.26	9.20	20.43	2.23
Variety BW 196	40.86	103.19	131.90	65.40	6.02	0.24	20.29	7.47	2.61	2.89	2.91	8.90	28.52	3.74
P- Value (V)	<.001	<.001	<.001	<.001	<.001	<.001	0.001	<.001	<.001	<.001	<.001	NS	<.001	<.001
P- value (S)	0.77	0.26	0.74	0.84	0.6	0.82	0.85	0.72	0.30	0.17	0.88	0.68	0.18	0.16
P- value (V*S)	0.95	0.21	0.77	0.11	0.47	0.93	0.33	0.13	0.20	0.65	0.68	0.13	0.80	0.39
LSD p≤ (0.05) (V)	6.88*	2.12*	4.24*	3.42*	0.45*	0.18*	2.21 *	0.23*	0.07*	0.11*	0.14*	NS	3.25*	0.56*
LSD p≤ (0.05) (S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD p≤ (0.05) (V*S)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV %	7.17	1.20	3.27	4.69	7.77	17.42	6.99	2.77	2.95	3.03	5.01	2.98	11.03	16.74

V-variety, S-seed source, V*S- interaction between variety and source, NS- Not significant at $P_{0.05}$, * -significant at $P_{0.05}$, CV- co-efficient of variation, LSD- Least significant difference at $P_{0.05}$

Variety, seed source and the interaction of variety and seed source significantly affected the mean leaf blade width of rice, only in the first season. Only variety significantly affected the leaf blade width in the second season. In the first season, variety BW 196 plants had significantly wider leaf blades (1.08 cm) than Basmati 370 (0.77 cm) plants irrespective of the seed source. Seed of variety BW 196 from NIB produced plants with significantly wider leaf blades (1.09 cm) than seed from MRGM (1.04 cm). Plants raised from nuclear seeds were not significantly different in leaf blade from plants raised from seed from NIB. Among the three sources, for Basmati 370, there were no significant differences in leaf blade width. Across the two varieties, seeds obtained from MRGM had plants with significantly lower mean leaf blade width (0.90 cm) than plants raised from seeds obtained from NIB (0.93 cm) and nuclear seed (0.93 cm) which were not significantly different. Across the seed sources, Basmati 370 plants had a significantly lower overall mean leaf blade width than BW 196 plants (Table 3.9).

Table 3.9: Mean width of the leaf blade of two rice varieties with seeds obtained from varying sources in Mwea in the first and second season between August 2016 and February 2018

Variety	**Seed sources**							
	First season				**Second season**			
	MRGM	**NIB**	**Nuclear**	**Means**	**MRGM**	**NIB**	**Nuclear**	**Means**
Basmati 370	0.77	0.77	0.80	0.78	0.97	0.96	0.97	0.97
BW 196	1.04	1.09	1.06	1.06	1.05	1.05	1.04	1.05
Means	0.90	0.93	0.93	0.92	1.01	1.01	1.01	1.01
P-value (V)	<.001				0.00			
P-value (S)	0.05				0.95			
P-value (V*S)	0.05				0.86			
LSD≤0.05 (V)	0.02*				0.05*			
LSD≤0.05 (S)	0.02*				NS			
LSD≤0.05 (V*S)	0.04*				NS			
CV %	2.20				4.01			

V-variety, S-seed source, V*S- interaction between variety and source, NS- Not significant at $P_{0.05,}$ * - significant at $P_{0.05,}$ CV- co-efficient of variation, LSD- Least significant difference at $P_{0.05}$

3.5 Discussion

In the present study, seed source did not have a significant effect on phenological characteristics of rice. Phenological characteristics are important crop characteristics. Days taken to heading dictate the regional and seasonal adaptability of rice cultivars (Abo *et al.,* 2011). Time taken by crops to reach maturity has an effect on the grain yield (Ntanos and Koutroubas, 2002). The panicle exsertion varied with varying seed sources in the present study. In this study, 97% of Basmati 370 rice samples from NIB had well-exserted panicles, 3% had moderately well-exserted panicles. For variety BW 196, the variations ranged from partly-exserted to well-exserted. Hoan *et al.,* (1998), noted that panicle exsertion is greatly influenced by environmental conditions and cropping seasons. It is an important trait that affects grain production. The higher the panicle exerstion, the higher the chances of out-crossing (Yuan *et al.,* 1988; Sidharthan *et al.,* 2007). Leaf blade color also varied with varying seed sources. The highest variations in Basmati 370 seed sources were noted in NIB seeds. In variety BW 196, the highest variations were noted in nuclear seed. The intensity of green color varied from dark to medium green. This trait is an unreliable morphological characteristic in studying genetic variability within a population because it is affected by several aspects including but not limited to bleaching effect by the sun, environmental conditions and applied fertilizers (Ashwani *et al.,* 2013). In Basmati 370 seeds from NIB, 3% of the sampled plants didn’t have awns. All the other plots had awns at the tips only. The color of awns at ripening stage varied from light gold to reddish brown. Awns play a crucial role in seed dispersal and in protecting crops against predation (Takahashi *et al.,* 1986). From the sample examined in this study, all stigmas were white. Similarly, Shobha *et al.,* (2004) reported white stigmas in variety Basmati 370.

In this study, panicle length and grain weight were not significantly affected by seed source. These two crop parameters greatly influence grain yield, and they vary among varieties (Ashfaq, *et al.*, 2012; Sarma *et al.*, 2004). Panicle length of the main axis, presence of secondary branching, grain width, and decorticated grain length were not affected by the seed sources under consideration in this study. According to Zafar *et al*., (2004), grains that are long and slender tend to have lower grain weights than broader and shorter grains.

Among the quantitative traits covered in this study, only leaf blade width, in the first season, exhibited significant differences among seeds of similar varieties obtained from varying seed sources. Variety Basmati 370 seed from MRGM produced plants with a lower leaf blade width than seed from NIB. These results agree with those of UPOV, 2006 (TGP/10/1 Draft 5) which elucidate that minimal variations are expected from self-pollinated crops such as rice and wheat. Very little genetic variation is acceptable in self-pollinated crops. In a sample size of 1500 plants, the optimum number of off-types allowed in uniformity assessment tests is four (4). Once a variety has proven uniformity, it can also be considered stable (TG/16/8, 2004). On average all the variety BW 196 plots had a minimum of two off-types. This translates to at least six (6) off-types in 1500 plants (Fig. 3.1, 3.2 and 3.3). Variety Basmati 370 had minimal number of off-types (0 to 2) per plot. The total Shannon-Weiner diversity index (*H')* for variety Basmati 370 was low (*H'*= 0.06) it ranged from 0.00 for MRGM and the nuclear seed, to 0.14 in seed raised from NIB. Higher Shannon-Weiner diversity indexes (*H'*=0.17 and 0.18) were recorded in variety BW 196, in the first and second seasons; respectively. Nuclear seed had the highest diversity (*H'* = 0.25) while seed from MRGM and NIB recorded a lower diversity index (*H'*) of 0.14. Nuclear seed should be having the least genetic diversity, though this was not the case in the current study. Any seed that is submitted for genetic purity testing must have a physical purity of 98% and must exhibit the highest level of genetic purity (Shobha *et al*., 2004). This shows that certified seed of BW 196 seed from MRGM, NIB and their nuclear seed is genetically impure, while seeds of variety Basmati 370 from these sources are pure genetically. It's possible that genetic purity of BW 196 has been neglected because it is mainly planted for subsistence consumption in Mwea. A study done by Muhunyu, 2012 revealed that 61% of farmers buy their seed from the NIB, and 7% buy from the other seed producing companies. The remaining 32% use either their own saved seed, seed from neighbors or obtain seed from the local market. This means that 68% of farmers in Mwea risk planting impure seed of variety BW 196, which could result in rice yield reductions. There is need to identify gaps in the rice seed production processes in Mwea and come up with recommendations on how to avert this problem.

To better explore diversity between rice varieties from varying sources, molecular techniques could be exploited to ascertain the genetic purity of each source. Beyene *et al., (*2005) in their study identified that use of agro-morphological characterization is less efficient in distinguishing (genetically) between related landraces than AFLP (Amplified fragment length polymorphisms) and SSR (simple sequence repeats) techniques. This is because these morphological characters suffer from the limitations of number, interact with the environment and are subjective in decision making. Kole *et al.,* (2016) also preferred Simple Sequence Repeat (SSR) and Sequence Tagged Site (STS) to grow-out tests (GOT) for assessment of seed purity. The preferences could be explained by the fact that molecular markers are not affected by environmental conditions and crop management practices (Ovesna *et al.,* 2002).

3.6 Conclusion

The findings of this study have revealed minimal phenotypic variability within variety Basmati 370 obtained from NIB and MRGM and with their respective nuclear material. A higher diversity was recorded in variety BW 196. All the aforementioned seed sources produce Basmati 370 seed that is genetically pure, and BW 196 seed that is genetically impure. There is need to identify and rectify rice seed production gaps that could have resulted in production of genetically impure seed of variety BW 196.

CHAPTER FOUR: THE RESPONSE OF SELECTED IRRIGATED RICE VARIETIES TO VARYING N, P AND K FERTILIZERS REGIMES

4.1 Abstract

Rice production has been fluctuating in Mwea irrigation scheme because of poor crop management practices and reduced soil fertility. Proper rice nutrition increases crop yield and conserves the environment. A field experiment was conducted at MIAD Center, Mwea division, Kirinyaga County, in August 2016 to February 2017 and August 2017 to February 2018, to determine the response of two rice genotypes (Basmati 370 and BW 196) to varying N, P and K fertilizer regimes. A randomized complete block design, with three replications, was laid-out in split-plots consisting of 13 N, P and K fertilizer regimes as the main plots and two rice varieties as the sub-plot. The N kg/ha: P_2O_5 kg/ha: K_2O kg/ha fertilizer treatment ratios used were: 00:00:00, 60:40:40, 80:60:60, 100:80:80, 60:40:00, 80:60:00, 100:80:00, 60:00:40, 80:00:60, 100:00:80, 00:40:40, 00:60:60 and 00:80:80. Analyses of variance showed that fertilizer application significantly increased plant height, tiller numbers, panicle length, and yield, but had no significant effect on grain weight. Days to heading and to maturity were significantly increased only in the second season. Fertilizer regimes 100:80:00 and 100:00:80 took longer days to head and to mature. The highest grain yield was realized in fertilizer regime: 80:60:60, 80:00:60, 100:80:80 and 100:00:80. Owing to its cost-effectiveness, fertilizer regime 80:00:60 would be recommended for rice production in Mwea.

Key words: Basmati 370, BW 196, fertilizer regimes, Nitrogen (N), Phosphorus (P), Potassium (K), rice

4.2 Introduction

Traditionally, rice was a very prominent crop only in Asia, but over the years, it has gained prominence in Africa's farming systems and diet (Audebert *et al.,* 1999). In Africa, it is ranked fourth after maize, sorghum and millet, in terms of acreage grown. Its production is ranked second after maize (FAOSTAT, 2012). Trial experiments have shown that Kenya has the potential of producing more than 11 t/ha (Saito *et al.,* 2013). However, between the year 2005 and 2009, the average rice yields in Kenya was 2.5 t/ha (Onyango, 2014), translating to a yield gap of approximately 8.5 t/ha.

Based on a report by the Ministry of Agriculture (2009), the rice production sector in Kenya is faced with several setbacks. These setbacks include but not limited to, inadequate skills on rice crop management, high costs of farm inputs and machinery, poor infrastructure, poor access to credit, uncoordinated marketing, biotic and abiotic stresses, high disease incidences, land degradation and nutrient loss. In Mwea irrigation scheme, the mean crop production has been fluctuating due to reduced soil fertility which produces low yields, soil degradation due to continuous mono-cropping, and use of inappropriate crop management practices by farmers (Nyamai *et al.*, 2012). Previously, farmers in Mwea used to burn one part of their farm and spread ashes across the paddy fields. Due to the increasing demand for animal feed, straw is baled and sold, hence organic matter is transported to a different location. Husks are also disposed elsewhere after de-hulling (Muhunyu, 2012). The mass transportation of organic matter from the rice fields, combined with permanent waterlogging and rice monoculture reduces the inherent capacities of the soil to supply nutrients, and it could also result in iron toxicities (Chataigner, 1997). Loss of soil nutrients and land degradation, results in long term negative effects on crop production.

Proper application of fertilizer can increase rice quality (Alam *et al.*, 2009b), reduce plant diseases by 50% and increase yield by up to 12.5% (Buresh *et al.*, 2005). It also preserves soil health, minimizes environmental pollution (Dabnath, 2012), and increases profit to farmers (Fairhust *et al.,* 2007).

The three primary nutrients that influence rice production are nitrogen, phosphorus and potassium. Nitrogen is required in considerably higher amounts as compared to the other two. This is because plants require it in high quantities and it is easily lost because of its instability (Dabnath, 2012). Phosphorus is very important in plants because it plays critical roles in the plant's lifecycle. It has an impact on crucial physiological processes such as nitrogen fixation, photosynthesis, anthesis, heading and maturity (Dabnath, 2012). Potassium aids in essential physiological processes like protein synthesis, cell division and growth (Rao, *et al.*, 2006). Varying rice varieties require varying proportions of these plant nutrients (Kondo and Wanjogu; 2001 and Dobbermann *et al*., 2000). At least all farmers in Mwea use chemical fertilizers, with 86% using Di-ammonium Phosphate (DAP) as basal fertilizer, 93% using Sulphate of ammonia (SA) as a top dresser. Only 2% use Muriate of potash (MOP) as a basal fertilizer (Muhunyu, 2012). Irrespective of the soil nutrient status and rice variety planted, most farmers apply 50 kg/acre of either di-ammonium phosphate or Sulphate of ammonia, to their fields. Such blanket fertilizer application could have substantial negative effect on rice crop performance and yield. In view of these perspectives, the current study was carried out to determine the response of selected paddy rice varieties to varying N, P and K fertilizer regimes.

4.3 Materials and methods

4.3.1 Site description

The current study was conducted for two seasons; from August 2016 to February 2017, and between August 2017 and February 2018. It was carried out in MIAD, Mwea irrigation scheme, in Mwea Division, Kirinyaga County (NIB, 1996). The Mwea irrigation scheme has five sections namely: Karaba, Mwea, Kamumu, Tebere and Thiba (Sombroek *et al*., 1982). MIAD occurs in Tebere. It is located to the southeastern dry plains of Mount Kenya and to the northeastern region of Kenya's capital (Nairobi), which is approximately 100 km away from the scheme (NIB, 1996).

Out of the 30,350 acres of land gazetted for the Mwea irrigation scheme, approximately 16,000 acres is used for production of paddy rice, what remains is used for subsistence farming, production of horticultural crops and for public amenities. The water used for irrigation in this scheme is sourced from river Thiba and Nyamindi. Agro-ecological zone III, IV and V are the most prominent in the scheme, with agro-ecological zone III recording the highest moisture ratios of 0.65 and agro-ecological zone IV recording the lowest (0.4) (Sombroek *et al*., 1982). The dark vertisols found in this area have a pH of 6.8. The annual rainfall recorded within the scheme is between 950 and 1500 mm (FAO, 1996). The temperature ranges from 15.6 ^{0}C – 28.6 ^{0}C with its mean being 22 ^{0}C (Jaetzold *et al*., 2005). For minimal disease incidence and optimum grain filling, rice is best planted between August and December (Mukiama and Mwangi, 1989). Before planting the rice seed, soil at the experimental site was collected at two depths (0-15 and 15-30 cm), from different homogenous units and bulked into two samples. The soils were analyzed for pH, micronutrients, macronutrients, organic carbon and electrical conductivity (Table 4.1).

Table 4.1: Chemical characteristics of the soil at Mwea experimental site

Soil parameters	Soil depth (0- 15 cm)	Rating	Soil depth (16-30 cm)	Rating	Critical range**
pH	5.12	Strongly acidic	5.61	Moderately acidic	5.00-6.50
*EC (salts) dS/m	0.37	Moderate	0.16	Low	2.00-3.90
Phosphorus ppm	3.06	Very low	0.93	Very low	22-34
Potassium ppm	68	Low	37.1	Very low	131-175
Calcium ppm	3100	High	3260	High	1000-2000
Magnesium ppm	1270	Very high	1380	Very high	60-360
Manganese ppm	98.4	Very high	126	Very high	≤ 65
Sulphur ppm	24.6	High	15.1	High	16.00-24.00
Copper ppm	1.04	Medium	1.5	High	0.90-1.20
Boron ppm	0.21	Low	0.33	Low	0.50-1
Zinc ppm	1.02	Low	1.12	Medium	≥4.1
*Sodium ppm	204	High	222	High	69-161
Iron ppm	249	Very high	229	Very high	9.00-12.00
*C.E.C meq/100g	52.8	Very high	43	Very high	12.00-25.00
*Organic Carbon %	2.46	High	2.13	High	1.00-1.80
*Total Nitrogen %	0.29	High	0.26	High	0.15-0.25
Sodium % (ESP)	1.68	High	2.24	Very high	0.00-1.00
Ca: Mg Ratio %	1.46	Ca (low)	1.42	Ca (low)	4.00-6.00
Hydrogen %	41.4	-	26.7	-	-
Other Bases %	7.16	Very low	6.18	-very low	40-60

ppm- parts per million, meq/100g- milligram equivalents per 100 g soil, dS/m- deciSiemens per centimeter, ESP-Exchangeable Sodium Percentage. The sources of critical ranges are: Arkansas rice pocket guide; Bolsa analyticals; Hazelton and Murphy, 2007; Horneck *et al*., 2011 and University of Arkansas

Meteorological data (Table 4.2) was collected from MIAD meteorological station during the rice growing season between August 2016 and February 2018.

Table 4.2: Climatic conditions at MIAD during the main rice growing seasons between 2016 and 2017

Year	Month	Total rainfall / mm	Temperature/ 0C Max.	Min.	Mean	Relative humidity/ %	Evaporation /mm·d-1
2016	Sep.	51.2	28.06	16.05	22.06	81.07	4.70
	Oct.	11.6	30.53	17.10	23.82	75.55	6.17
	Nov.	141.1	28.61	17.40	23.01	84.40	4.72
	Dec.	35.00	28.51	15.00	21.75	78.61	5.23
2017	Jan.	0.00	30.62	13.67	22.15	69.74	6.65
	Sep.	48.10	28.52	16.62	22.57	77.83	5.37
	Oct.	161.7	39.44	18.14	28.79	74.10	6.61
	Nov.	418.8	27.37	17.26	22.32	86.47	5.36
	Dec.	24.50	28.56	15.11	21.83	74.55	5.41

4.3.2 Experimental design and treatments

The experiment was laid-out in a randomized complete block design, and replicated three times. Performance of the nuclear seed of two rice varieties Basmati 370 and BW 196 was evaluated against thirteen fertilizer regimes having varied fertilizer combinations of N, P and K fertilizers as indicated in Table 4.3. Urea, Muriate of potash (MOP) and Triple superphosphate (TSP) were used as sources of N, K and P, respectively.

Table 4.3: N, K_2O and P_2O_5 treatment combination applied in kg/ha

N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
00	00	00									
60	40	40	60	40	00	60	00	40	00	40	40
80	60	60	80	60	00	80	00	60	00	60	60
100	80	80	100	80	00	100	00	80	00	80	80

The plant spacing was 20 x 20 cm. The plot size was 3 x 3 m with a distance of 0.4 m between plots and 2 m between blocks. The experiment covered 1609.5 m^2. Each main plot (containing nutrient management treatments) was bunded and lined with a black polythene paper (gauge 500) at a depth of 1 m, to maintain a uniform water depth and to ensure that the fertilizer treatments did not mix.

4.3.3 Data collection

To examine the crop's response to different inorganic fertilizer regimes, data was collected from a sample size of 30 plants per treatment. Data on plant height and number of tillers per hill was collected at 30, 60 and 75 days after transplanting. Using a ruler, plant height measurements were taken from the soil surface to the apex of the tallest panicle, excluding awns. The recordings were then given in whole numbers (in centimeters). The actual count of the number of tillers per hill was taken on ten hills per plot. To determine days to heading, data was taken once 50% of heads become visible. At dough development stage, using a ruler, panicle measurements (in centimeters) were taken from the base to the apex of the panicle. Once 85% of the grains had attained maturity, days taken to maturity were recorded. At maturity, 1000 well-developed seeds were weighed to precision using a weighing scale, after the seed was dried to 14% moisture content. To determine the grain yield, two border rows were discarded per plot and grain was harvested from the middle rows. The paddy rice grains were sun dried and their moisture content adjusted to 14% using the formula 2, provided by Gomez, 1972.

Equation 2:

$$Adjusted\ grain\ weight = A \times W$$

Where A is the adjustment coefficient and W is the grain weight of the harvested rice grains. The coefficient A is computed as illustrated below:

Equation 3:

$A = \frac{100-M}{86}$, Where M is the moisture content of the harvested grain.

4.3.4 Data analysis

Data collected were subjected to analysis of variance and treatment means was compared using the Least Significant Difference (LSD) test at P ≤0.05 using Genstat software15th edition. Different crop parameters were subjected to multiple linear regression analysis to establish their relationships with crop yield.

4.4: Results

Plant height

The main effects of variety and fertilizer regimes on plant height at 30 days after transplanting were significant ($p \leq 0.05$), but the interaction effects between the two were not. Except N-omission treatments 00:40:40, 00:60:60 and 00:80:80, all the N, P and K fertilizer treatment combinations increased rice plant height relative to the no-fertilizer control, in the first season. Nitrogen, P and K fertilizer combinations 60:40:40, 80:60:60, 100:80:80, 80:60:00, 100:80:00 and 100:00:80 produced the tallest plants at 30-DAT. In the second season, only 80:60:60, 100:80:80 and 80:00:60 N, P and K treatment combinations increased plant height relative to the no-fertilizer control and they produced the tallest plants at 30-DAT (Table 4.4). Variety Basmati 370 plants were significantly taller than BW 196.

Table 4.4: Effect of varying fertilizer regimes on the average plant height (cm) of two rice varieties at 30 days after transplanting in first and second season at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Variety					
	First season			Second season		
	Basmati 370	BW 196	Mean	Basmati 370	BW 196	Mean
00:00:00	19.00	15.00	17.00	39.33	37.33	38.33
60:40:40	23.67	19.00	21.34	41.67	41.33	41.50
80:60:60	23.00	20.00	21.50	50.33	42.33	46.33
100:80:80	24.00	19.67	21.84	45.33	43.33	44.33
60:40:00	20.67	18.33	19.50	42.00	39.33	40.67
80:60:00	22.00	18.67	20.34	45.67	38.00	41.83
100:80:00	24.67	19.67	22.17	40.33	40.00	40.17
60:00:40	20.67	18.67	19.67	43.67	39.67	41.67
80:00:60	21.33	19.00	20.17	47.67	42.00	44.83
100:00:80	23.33	20.00	21.67	41.00	41.33	41.17
00:40:40	19.33	16.67	18.00	41.00	43.33	42.17
00:60:60	19.67	15.67	17.67	44.67	39.33	42.00
00:80:80	20.33	16.67	18.50	44.67	39.33	42.00
Mean	21.67	18.23	19.95	43.64	40.51	42.08
Fpr V	<.001			<.001		
Fpr F	<.001			0.02		

Table 4.4: Effect of varying fertilizer regimes on the average plant height (cm) of two rice varieties at 30 days after transplanting in first and second season at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Variety					
	First season			Second season		
	Basmati 370	BW 196	Mean	Basmati 370	BW 196	Mean
Fpr F*V	0.99			0.22		
LSD $_{0.05}$ V	0.73*			1.52*		
LSD $_{0.05}$ F	1.85*			3.88*		
LSD $_{0.05}$ F*V	NS			NS		
CV %	8.00			7.90		

Fpr- F probability, LSD- Least significant difference at P $_{0.05,}$ V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at P $_{0.05,}$ * -significant at P $_{0.05,,}$ CV-co-efficient of variation Ratio of $N: P_2O_5: K_2O$ refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

The effects of variety and fertilizer regimes on plant height were significant (p≤0.05) at 60-DAT, but the interaction effect between the two was insignificant. In the first season, all the fertilizer treatment combinations except N omission plots (00:40:40, 00:60:60 and 00:80:80) increased plant height relative to the no-fertilizer treatment. Fertilizer regimes 60:40:40, 80:60:60 and 100:80:80, 100:80:00, and 100:00:80 had the tallest plants. For the second season, all the fertilizer treatment combinations, with the exception of 60:40:40, 80:60:60, 100:80:80, 80:00:60 and 100:00:80, corresponded with the no-fertilizer treatment (Table 4.5). Variety Basmati 370 plants were taller than BW 196 plants.

Table 4.5: Effect of varying fertilizer regimes on the average plant height (cm) of two rice varieties at 60 days after transplanting in the first and second seasons at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Variety					
	First season			Second season		
	Basmati 370	BW 196	Mean	Basmati 370	BW 196	Mean
00:00:00	63.00	40.33	51.67	79.00	44.33	61.67
60:40:40	76.67	46.67	61.67	89.67	50.00	69.83
80:60:60	82.67	51.33	67.00	89.00	54.00	71.50
100:80:80	84.00	52.67	68.33	91.33	52.67	72.00
60:40:00	74.33	47.00	60.67	78.04	42.46	60.25
80:60:00	71.33	46.00	58.67	82.67	44.33	63.50
100:80:00	83.00	48.00	65.50	79.33	51.33	65.33
60:00:40	76.00	48.33	62.17	83.33	48.67	66.00
80:00:60	76.00	48.33	62.17	90.00	52.67	71.33
100:00:80	85.00	52.67	68.83	90.67	59.00	74.83

Table 4.5: Effect of varying fertilizer regimes on the average plant height (cm) of two rice varieties at 60 days after transplanting in the first and second seasons at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Variety					
	First season			Second season		
	Basmati 370	**BW 196**	**Mean**	**Basmati 370**	**BW 196**	**Mean**
00:40:40	67.33	45.00	56.17	83.00	49.00	66.00
00:60:60	69.33	43.33	56.33	79.00	47.00	63.00
00:80:80	64.00	43.33	53.67	84.00	49.00	66.50
Mean	74.82	47.15	60.99	84.54	49.57	67.06
Fpr V	<.001			<.001		
Fpr F	<.001			<.001		
Fpr F*V	0.12			0.62		
$LSD_{0.05}$ V	1.88*			1.95*		
$LSD_{0.05}$ F	4.78*			4.98*		
$LSD_{0.05}$ F*V	NS			NS		
CV %	6.80			6.40		

Fpr- F probability, LSD- Least significant difference at $P_{0.05,}$ V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at $P_{0.05,}$ * -significant at $P_{0.05,}$, CV-co-efficient of variation Ratio of $N: P_2O_5: K_2O$ refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

At 75-DAT, the effects of variety and fertilizer regimes on plant height were significant ($p \leq 0.05$), although there was no interaction between the two. Except 00:40:40, 00:60:60 and 00:80:80, all the other N, P and K fertilizer treatments increased plant height in the first season, relative to the no-fertilizer control. In contrast, in the second season, all the fertilizer combination treatments increased plant height relative to the control, except for the K omission treatment combinations (60:40:00, 80:60:00, and 100:80:00) (Table 4.6). Nitrogen, P, and K treatment combinations of 60:40:40, 80:60:60, 100:80:80, 100:80:00 and 100:00:80 had the tallest plant height at 75-DAT, in the first season. In the second season, 60:40:40, 80:60:60, 100:80:80, and 100:00:80, 80:00:60 and 00:80:80 N, P and K fertilizer regimes had the highest plant height. Variety Basmati 370 plants were taller than variety BW 196 plants.

Table 4.6: Effect of varying fertilizer regimes on the average plant height (cm) of two rice varieties at 75 days after transplanting in the first and second season at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Variety					
	First season			Second season		
	Basmati 370	BW 196	Mean	Basmati 370	BW 196	Mean
00:00:00	86.33	40.00	63.17	103.00	46.00	74.50
60:40:40	101.67	47.00	74.33	109.00	61.00	85.00
80:60:60	99.67	52.67	76.17	117.00	58.00	87.50
100:80:80	102.33	54.00	78.17	114.00	59.33	86.67
60:40:00	95.33	46.67	71.00	97.87	49.07	73.47
80:60:00	93.33	46.67	70.00	107.33	51.33	79.33
100:80:00	101.67	49.00	75.33	101.67	57.00	79.33
60:00:40	94.00	49.00	71.50	109.67	52.67	81.17
80:00:60	93.67	49.67	71.67	115.00	59.67	87.33
100:00:80	104.67	53.00	78.83	113.33	64.00	88.67
00:40:40	93.33	43.00	68.17	110.33	54.33	82.33
00:60:60	94.33	43.67	69.00	108.67	51.33	80.00
00:80:80	88.67	43.67	66.17	113.00	53.67	83.33
Mean	96.08	47.54	71.81	109.22	55.18	82.20
Fpr V	<.001			<.001		
Fpr F	<.001			<.001		
Fpr F*V	0.90			0.16		
LSD $_{0.05}$ V	2.56*			2.14*		
LSD $_{0.05}$ F	6.52*			5.46*		
LSD $_{0.05}$ F*V	NS			NS		
CV %	7.80			5.70		

Fpr- F probability, LSD- Least significant difference at P $_{0.05,}$ V-variety, F-fertilizer regimes, F*V- interaction between Variety and Fertilizer regimes, NS- Not significant at P $_{0.05,}$ * -significant at P $_{0.05,,}$ CV- co-efficient of variation Ratio of $N: P_2O_5: K_2O$ refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Tillers

Variety and fertilizer regimes had significant effects on the number of tillers at 30-DAT, but their interaction had no significant effect on this parameter. Except 60:00:40, 100:00:80 and 00:40:40, in the first season, all other fertilizer treatments were significantly different from the no fertilizer control, in the number of tillers. Fertilizer treatments 80:60:60, 100:80:80, 80:60:00, 100:80:00, 00:60:60 and 00:80:80 out-performed the rest in number of tillers (Table 4.7). In the second season, fertilizer regime 80:60:60, produced the highest number of tillers, while fertilizer regime

60:40:40, 60:40:00, 100:80:00, 100:00:80, 00:80:80 and 00:00:00 performed as poorly. Variety BW 196, had significantly higher tiller number per hill than Variety Basmati 370.

Table 4.7: Effects of varying fertilizer regimes on the mean of tiller numbers per hill of two rice varieties at 30 days after transplanting in the first and the second season at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Variety					
	First season			Second season		
	Basmati 370	**BW 196**	**Mean**	**Basmati 370**	**BW 196**	**Mean**
00:00:00	3.57	4.80	4.19	4.79	6.87	5.83
60:40:40	4.57	6.13	5.35	5.50	6.72	6.11
80:60:60	5.03	6.90	5.97	8.87	9.73	9.30
100:80:80	5.70	7.67	6.69	7.30	7.43	7.37
60:40:00	4.20	6.70	5.45	5.40	7.12	6.26
80:60:00	4.90	8.73	6.82	6.53	7.17	6.85
100:80:00	5.73	7.60	6.67	4.43	6.93	5.68
60:00:40	3.67	5.73	4.70	6.21	8.13	7.17
80:00:60	4.07	6.67	5.37	7.13	7.53	7.33
100:00:80	4.70	5.90	5.30	4.29	5.70	4.99
00:40:40	3.67	5.20	4.44	5.23	7.87	6.55
00:60:60	4.80	6.63	5.72	6.40	6.70	6.55
00:80:80	5.50	6.83	6.17	5.90	6.20	6.05
Mean	4.63	6.58	5.61	6.00	7.24	6.62
Fpr V	<.001			<.001		
Fpr F	<.001			<.001		
Fpr F*V	0.65			0.80		
$LSD_{0.05}$ V	0.45*			0.61*		
$LSD_{0.05}$ F	1.14*			1.55*		
$LSD_{0.05}$ F*V	NS			NS		
CV %	17.5			20.2		

Fpr- F probability, LSD- Least significant difference at $P_{0.05,}$ V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at $P_{0.05,}$ * -significant at $P_{0.05,,}$ CV-co-efficient of variation Ratio of $N: P_2O_5: K_2O$ refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Variety and fertilizer regime had significant ($p\leq0.05$) influence on the tiller count per hill at 60-DAT, but there was no interaction effect between the two (Table 4.8). In both seasons, 60:40:00, 60:00:40, and the N omission treatments combinations (00:40:40, 00:60:60, 00:80:80) were statistically similar in tiller number to the no-fertilizer control, and N, P, K treatment combinations (60:40:40, 80:60:60, 100:80:80), 80:60:00, 100:80:00, 80:00:60 and 100:00:80 out-performed the rest in tiller number (Table 4.8). Variety BW 196 had significantly higher tiller numbers than Variety Basmati 370.

Table 4.8: Effects of varying fertilizer regimes on the mean tiller number per hill of two rice varieties at 60 days after transplanting in the first and the second seasons at MIAD

Fertilizer regimes	Variety					
	First season			Second season		
($N: P_2O_5: K_2O$)	Basmati 370	BW 196	Mean	Basmati 370	BW 196	Mean
00:00:00	17.37	27.33	22.35	14.57	21.45	18.01
60:40:40	24.22	35.85	30.04	19.09	27.77	23.43
80:60:60	29.53	30.08	29.80	17.45	26.75	22.10
100:80:80	23.69	39.87	31.78	20.40	26.05	23.23
60:40:00	21.46	28.81	25.14	18.18	23.21	20.70
80:60:00	22.46	40.69	31.58	16.45	27.43	21.94
100:80:00	22.70	36.62	29.66	15.86	27.26	21.56
60:00:40	20.19	31.64	25.92	15.56	25.57	20.57
80:00:60	24.17	36.56	30.36	17.43	26.52	21.97
100:00:80	27.88	30.61	29.25	18.26	29.41	23.84
00:40:40	17.55	27.70	22.63	13.62	20.93	17.28
00:60:60	18.61	24.45	21.53	14.12	24.27	19.20
00:80:80	18.41	27.33	22.87	14.94	21.98	18.46
Mean	22.17	32.12	27.15	16.61	25.28	20.95
Fpr V	<.001			<.001		
Fpr F	<.001			<.001		
Fpr F*V	0.11			0.53		
$LSD_{0.05}$ V	2.17*			1.22*		
$LSD_{0.05}$ F	5.52*			3.12*		
$LSD_{0.05}$ F*V	NS			NS		
CV %	17.50			12.80		

Fpr- F probability, LSD- Least significant difference at $P_{0.05,}$ V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at $P_{0.05,}$ * -significant at $P_{0.05,,}$ CV-co-efficient of variation Ratio of $N: P_2O_5: K_2O$ refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Both variety and fertilizer regime had a significant ($p \leq 0.05$) influence on the number of tillers per hill at 75-DAT but there was no interaction effect between the two (Table 4.9). In both seasons, N omission (00:40:40, 00:60:60, 00:80:80) and 60:40:00 N, P and K treatment combinations produced tillers that were statistically at par with their respective no-fertilizer control. In addition, for the second season, 80:60:00 and 60:00:40 produced number of tillers per hill that were similar to that of the control (00:00:00). For both seasons, N, P and K combination treatment combinations of 60:40:40, 80:60:60 and 100:80:80 out-performed the rest. Variety BW 196 had more tiller numbers per hill than Basmati 370.

Table 4.9*:* Effects of varying fertilizer regimes on the mean of tiller numbers per hill of two rice varieties at 75 days after transplanting in the first and second season at MIAD

Fertilizer regimes	**Variety**					
	First season			**Second season**		
(N: P_2O_5: K_2O)	**Basmati 370**	**BW 196**	**Mean**	**Basmati 370**	**BW 196**	**Mean**
00:00:00	12.07	23.63	17.85	13.90	22.70	18.30
60:40:40	17.19	34.99	26.09	18.66	29.03	23.85
80:60:60	22.34	27.39	24.86	18.22	27.73	22.98
100:80:80	18.01	36.08	27.05	18.81	29.13	23.97
60:40:00	16.40	28.03	22.21	18.79	22.60	20.69
80:60:00	16.73	38.75	27.74	16.73	26.17	21.45
100:80:00	19.63	33.01	26.32	16.94	29.15	23.04
60:00:40	16.70	29.74	23.22	16.28	26.00	21.14
80:00:60	17.11	34.93	26.02	19.82	26.80	23.31
100:00:80	18.30	32.40	25.35	18.66	29.92	24.29
00:40:40	13.84	26.78	20.31	13.28	22.72	18.00
00:60:60	15.12	23.86	19.49	13.99	25.07	19.53
00:80:80	13.17	24.34	18.75	15.69	24.17	19.93
Mean	16.66	30.30	23.48	16.91	26.25	21.58
Fpr V	<.001			<.001		
Fpr F	<.001			0.00		
Fpr F*V	0.10			0.63		
LSD $_{0.05}$ V	1.91*			1.31*		
LSD $_{0.05}$ F	4.87*			3.34*		
LSD $_{0.05}$ F*V	NS			NS		
CV %	17.90			13.40		

Fpr- F probability, LSD- Least significant difference at P $_{0.05,}$ V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at P $_{0.05,}$ * -significant at P $_{0.05,}$, CV-co-efficient of variation Ratio of N: P_2O_5: K_2O refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Days to heading

Variety had a significant effect on number of days to heading in both seasons while fertilizer regime significantly affected the number of days to heading only in the second season. Variety x fertilizer regime interaction had no significant effect on this parameter. Variety BW 196 took a significantly longer time than Basmati 370 to reach 50% heading. The average time taken for 50%

of the plants to head ranged from 85.67 to 89.17 days in the first season and 88.80 and 94.64 days in the second season (Table 4.10). In the second season, 100:80:00, 100:00:80 N, P and K treatments took a longer time to head than the rest of the N, P and K treatments. Variety Basmati 370 plants headed earlier than BW 196.

Table 4.10*: Effect of different fertilizer regimes on days to 50% heading for two rice varieties for the first and the second season at MIAD*

Fertilizer regimes ($N: P_2O_5: K_2O$)	Varieties					
	First season			Second season		
	Basmati 370	BW 196	Mean	Basmati 370	BW 196	Mean
00:00:00	73.33	99.33	86.33	77.30	106.63	91.97
60:40:40	74.33	98.67	86.50	76.97	105.73	91.35
80:60:60	76.00	98.33	87.17	75.97	103.30	89.64
100:80:80	77.33	99.00	88.17	76.30	104.30	90.30
60:40:00	76.33	99.67	88.00	79.97	103.94	91.95
80:60:00	75.67	95.67	85.67	75.63	105.94	90.79
100:80:00	75.67	99.33	87.50	81.30	107.97	94.64
60:00:40	78.00	94.67	86.34	75.30	104.63	89.97
80:00:60	79.67	98.00	88.84	75.30	102.30	88.80
100:00:80	77.00	100.33	88.67	80.30	108.44	94.37
00:40:40	77.33	101.00	89.17	76.30	102.30	89.30
00:60:60	75.67	100.33	88.00	75.63	105.97	90.80
00:80:80	75.33	97.33	86.33	75.30	103.63	89.47
Mean	76.28	98.74	87.51	77.04	105.16	91.10
Fpr V	<.001			<.001		
Fpr F	0.33			0.01		
Fpr F*V	0.15			0.95		
$LSD_{0.05}$ V	1.24*			1.26*		
$LSD_{0.05}$ F	NS			3.22*		
$LSD_{0.05}$ F*V	NS			NS		
CV %	3.10			2.96		

Fpr- F probability, LSD- Least significant difference at $P_{0.05}$, V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at $P_{0.05}$, * -significant at $P_{0.05}$, , CV-co-efficient of variation Ratio of $N: P_2O_5: K_2O$ refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Days to 50% maturity

Variety had a significant effect on number of days to maturity, while fertilizer regime significantly influenced it only in the second season. Variety x fertilizer regime interaction had no significant effect on this parameter. Variety Basmati 370 ripened early compared to BW 196. The average time taken for 85% of the plants to mature ranged from 117.50 to 121.5 days in the first season and 117.00 to 125.0 days in the second (Table 4.11). Rice crops supplied with fertilizer regime 100:80:80, 60:40:00, 100:80:00 and 100:00:80 in the second season took a longer time to mature. Fertilizer regime 00:00:00, 80:60:60, 80:60:00, 60:00:40, 00:60:60 and 00:80:80 took significantly shorter days to mature.

Table 4.11: Effect of different fertilizer regimes on days to 50% maturity for two rice varieties for the first and second season at MIAD

Fertilizer regimes	**Varieties**					
	First season			**Second season**		
(N: P_2O_5: K_2O)	**Basmati 370**	**BW 196**	**Means**	**Basmati 370**	**BW 196**	**Means**
00:00:00	108.00	131.67	119.84	104.67	131.67	118.17
60:40:40	108.00	130.67	119.34	107.00	131.52	119.26
80:60:60	109.67	131.00	120.34	104.00	132.67	118.34
100:80:80	110.67	131.67	121.17	106.33	133.33	119.83
60:40:00	110.33	132.67	121.50	110.33	132.00	121.17
80:60:00	107.33	133.00	120.17	101.33	132.67	117.00
100:80:00	108.00	130.67	119.34	111.67	134.00	122.84
60:00:40	108.67	131.00	119.84	104.67	121.00	112.84
80:00:60	110.33	130.00	120.17	106.10	131.63	118.87
100:00:80	110.67	131.67	121.17	114.00	137.00	125.50
00:40:40	107.00	131.33	119.17	105.67	132.00	118.84
00:60:60	107.00	128.00	117.50	103.33	131.33	117.33
00:80:80	106.33	129.00	117.67	103.00	131.33	117.17
Mean	108.62	130.95	119.79	108.62	130.95	119.79
Fpr V	<.001			<.001		
Fpr F	0.10			0.02		
Fpr F*V	0.73			0.56		
LSD $_{0.05}$ V	1.05*			2.30*		
LSD $_{0.05}$ F	NS			5.86*		
LSD $_{0.05}$ F*V	NS			NS		
CV %	1.90			4.20		

Fpr- F probability, LSD- Least significant difference at P $_{0.05,}$ V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at P $_{0.05,}$ * -significant at P $_{0.05,,}$ CV-co-efficient of variation Ratio of N: P_2O_5: K_2O refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Panicle length

Variety and fertilizer regimes had significant ($P \leq 0.05$) effects on the panicle length, but their interaction had no significant influence on this parameter. Variety BW 196 had significantly shorter panicles than Basmati 370. K omission (40:60:00, 80:60:00, 100:80:00) and N omission (00:40:40, 00:60:60, 00:80:80) treatments had panicle lengths that were similar to those of their respective no-fertilizer treatment, in the first and second season, respectively. In addition, 60:40:40 and 60:00:40 were similar to the no-fertilizer control treatment in panicle length in the second season. The longest panicle lengths were registered in 60:40:40, 80:60:60, 100:80:80, 80:00:60, 100:00:80 and 00:40:40 N, P, and K treatments in both seasons (Table 4.12).

Table 4.12: Effect of different fertilizer regimes on panicle length (cm) of two rice varieties planted in first and second season at MIAD

Fertilizer regimes	**Varieties**					
	First season			**Second season**		
(N: P_2O_5: K_2O)	**Basmati 370**	**BW 196**	**Means**	**Basmati 370**	**BW 196**	**Means**
00:00:00	21.70	18.96	20.33	24.16	20.64	22.40
60:40:40	23.30	19.56	21.43	24.44	22.12	23.28
80:60:60	22.43	21.70	22.07	25.36	21.90	23.63
100:80:80	23.50	20.26	21.88	24.68	21.83	23.26
60:40:00	23.04	19.50	21.27	24.32	21.45	22.89
80:60:00	22.53	19.26	20.90	24.25	19.61	21.93
100:80:00	22.93	18.70	20.82	24.63	20.75	22.69
60:00:40	22.96	20.40	21.68	24.64	21.35	22.99
80:00:60	22.63	20.40	21.52	25.56	21.97	23.77
100:00:80	23.43	20.16	21.80	26.16	22.26	24.21
00:40:40	22.10	19.20	20.65	24.33	21.23	22.78
00:60:60	22.39	20.30	21.35	25.11	21.88	23.50
00:80:80	22.26	19.73	21.00	24.41	21.22	22.81
Mean	22.71	19.86	21.28	24.77	21.40	23.09
Fpr V	<.001			<.001		
Fpr F	0.03			0.03		
Fpr F*V	0.16			0.92		
$LSD_{0.05}$ V	0.40*			0.47*		
$LSD_{0.05}$ F	1.03*			1.19*		
$LSD_{0.05}$ F*V	NS			NS		
CV %	4.11			4.40		

Fpr- F probability, LSD- Least significant difference at P $_{0.05}$, V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at P $_{0.05}$, * -significant at P $_{0.05}$, CV-co-efficient of variation Ratio of N: P_2O_5: K_2O refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

1000-Grain weight

Variety had a significant (P ≤0.05) effect on the grain weight, but fertilizer regime and variety × fertilizer regime interactions were not significant in both seasons. Variety BW 196 had higher grain weights than Basmati 370 (Table 4.13).

Table 4.13: Effect of different fertilizer regimes on Grain weight (grams) of two rice varieties planted in the first and second season at MIAD

Fertilizer regimes	Varieties					
	First season			Second season		
(N: P_2O_5: K_2O)	Basmati 370	BW 196	Means	Basmati 370	BW 196	Means
00:00:00	20.65	28.67	24.66	21.23	26.44	23.84
60:40:40	20.37	28.46	24.42	21.59	26.63	24.11
80:60:60	21.27	28.57	24.92	19.81	26.84	23.33
100:80:80	20.45	29.08	24.77	19.28	26.69	22.99
60:40:00	19.54	27.56	23.55	19.49	27.04	23.27
80:60:00	20.96	26.40	23.68	20.05	27.25	23.65
100:80:00	19.29	27.67	23.48	19.86	26.05	22.96
60:00:40	20.86	28.12	24.49	20.70	26.47	23.59
80:00:60	20.54	29.67	25.11	20.23	27.02	23.63
100:00:80	23.23	26.93	25.08	21.61	28.53	25.07
00:40:40	19.80	30.21	25.01	21.61	27.14	24.38
00:60:60	19.65	28.86	24.26	20.82	27.71	24.27
00:80:80	21.00	30.12	25.56	21.73	28.08	24.91
Mean	20.59	28.49	24.54	20.62	27.07	23.84
Fpr V	<.001			<.001		
Fpr F	0.54			0.53		
Fpr F*V	0.11			0.95		
LSD $_{0.05}$ V	0.75*			0.76*		
LSD $_{0.05}$ F	NS			NS		
LSD $_{0.05}$ F*V	NS			NS		
CV %	6.70			5.55		

Fpr- F probability, LSD- Least significant difference at P $_{0.05}$, V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at P $_{0.05}$, * -significant at P $_{0.05}$, CV-co-efficient of variation Ratio of N: P_2O_5: K_2O refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Yield

Variety and fertilizer regimes had significant ($P < 0.05$) effects on the grain yield, but their interaction had no significant effect on this parameter. All fertilizer regimes, except 00:40:40 and 100:80:00, in the first season, and K omission (60:40:00, 80:60:00, 100:80:00) treatment combinations in the second season significantly increased grain yield relative to the control (Table 4.14). In both the first and second season, 80:60:60, 80:00:60, 100:80:80 and 100:00:80 N, P and K fertilizer treatment combinations out-yielded the rest of the treatments. Additionally, in the second season, treatment 60:40:40 performed equally well. Variety BW 196 had a higher crop yield than Basmati 370. The percentage increase of yield, relative to the no fertilizer control ranged from 76.49% in the first season and 33.81% in the second.

Table 4.14: Effect of different fertilizer regimes on yield (t/ha) of two rice varieties planted in the first and the second season, between August 2016 and February 2018 at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Varieties					
	First season			Second season		
	Basmati 370	BW 196	Means	Basmati 370	BW 196	Means
00:00:00	2.42	3.27	2.85	3.96	4.44	4.20
60:40:40	3.95	3.83	3.89	4.74	5.98	5.36
80:60:60	4.36	5.70	5.03	4.71	6.12	5.41
100:80:80	4.19	4.22	4.21	4.82	6.13	5.48
60:40:00	3.72	4.06	3.89	3.54	4.68	4.11
80:60:00	3.60	4.33	3.96	3.93	4.69	4.31
100:80:00	3.70	3.41	3.56	3.63	5.13	4.38
60:00:40	3.71	4.12	3.92	4.70	5.18	4.94
80:00:60	4.16	5.82	4.99	4.97	6.26	5.62
100:00:80	3.67	5.09	4.38	4.57	6.08	5.33
00:40:40	3.10	3.46	3.28	4.10	5.91	5.01
00:60:60	4.27	3.34	3.81	4.30	5.72	5.01
00:80:80	3.79	3.82	3.81	4.40	5.50	4.95
Mean	3.74	4.19	3.97	4.34	5.52	4.93
Fpr V	0.02			<.001		
Fpr F	<.001			<.001		
Fpr F*V	0.17			0.34		
$LSD_{0.05}$ V	0.34*			0.21*		
$LSD_{0.05}$ F	0.85*			0.53*		

Table 4.14: Effect of different fertilizer regimes on yield (t/ha) of two rice varieties planted in the first and the second season, between August 2016 and February 2018 at MIAD

Fertilizer regimes ($N: P_2O_5: K_2O$)	Varieties					
	First season			Second season		
	Basmati 370	BW 196	Means	Basmati 370	BW 196	Means
LSD $_{0.05}$ F*V	NS			NS		
CV %	18.53			9.23		

Fpr- F probability, LSD- Least significant difference at P $_{0.05,}$ V-variety, F-fertilizer regimes, F*V-interaction between Variety and Fertilizer regimes, NS- Not significant at P $_{0.05,}$ * -significant at P $_{0.05,}$, CV-co-efficient of variation Ratio of $N: P_2O_5: K_2O$ refers to N kg/ha:P_2O_5 kg/ha: K_2O kg/ha

Linear regression relationships between growth parameters and yield components

Results of regression analysis showed that there was a positive relationship between yield and tillers at 75-DAT (R^2= 0.3353, 0.2764) and plant height at 75-DAT (R^2= 0.8696, 0.3987) in both the first and second season. Phenological traits expressed a weak negative relationship with yield in the first season, and a weak positive relationship in the second season. Panicle length exhibited a strong positive relationship with yield (R^2= 0.7394, 0.6042), while 1000-grain weight exhibited a very poor positive relationship (R^2= 0.0632, 0.0484) with yield, in both the first and the second season.

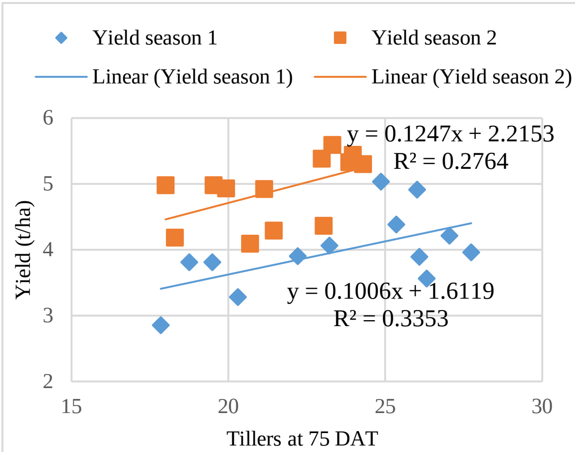

Figure 4.1: Linear regression

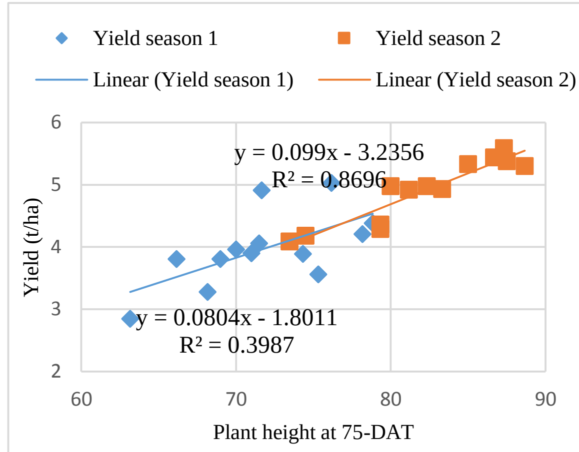

Figure 4.2: Linear regression

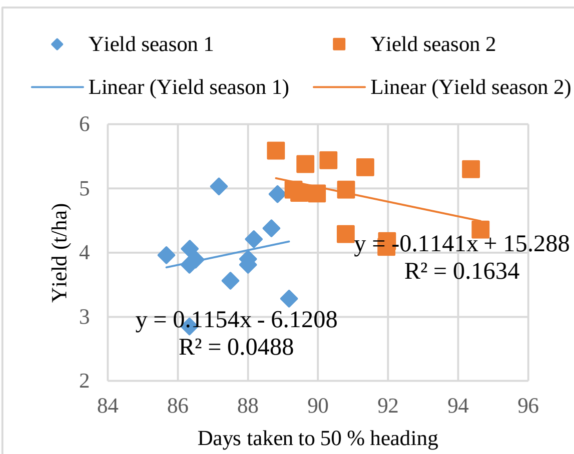

Figure 4.3: Linear regression

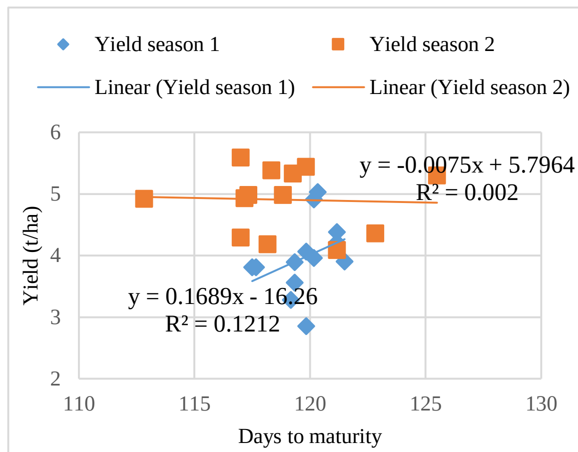

Figure 4.4: Linear regression

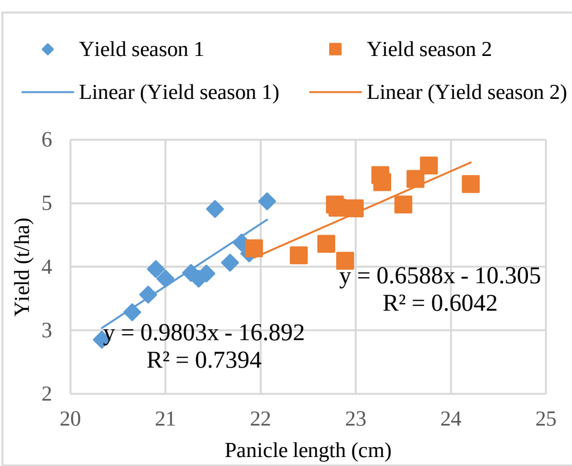

Figure 4.5: Linear regression

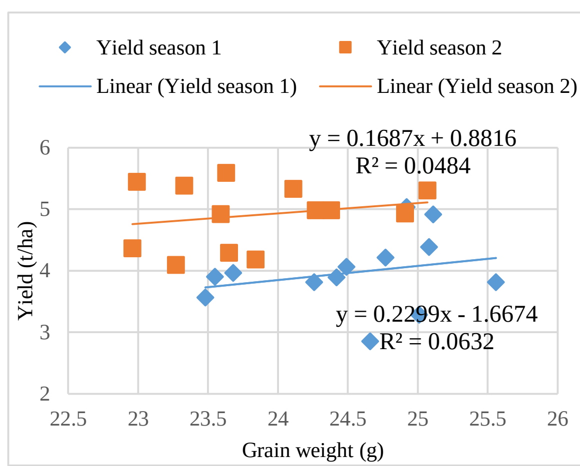

Figure 4.6: Linear regression

4.5: Discussion

The positive response of the selected rice varieties to N, P and K fertilizer, in plant height, tiller count per hill, days taken to heading and maturity, panicle length and grain yield may be explained by the inadequate levels of these plant nutrients in the soils of study (Table 4.1). According to Haefele *et al*., 2014, sixty seven percent of rice soils in East Africa are considered to be problem soils (highly saline) and very poor. Zhang *et al.,* (2004), and Dobermann *et al.,* (2003), recorded decreased soil fertility in rice growing regions in northern China and the southern parts of Asia; respectively. The considerably higher response of rice to K fertilizer in plant height, tiller number, panicle length and grain yield may be explained further, by the fact that rice has higher K requirements than other cereals. For every 4-8 tons of rice harvested, between 56 and 112 kg of K is removed from the soil (Dobermann *et al*., 1998).

In the current study, fertilizer application significantly influenced days to heading and maturity in the second season. When compared to the other fertilizer combinations and the no-fertilizer control, plants supplied with 100:80:00 and 100:00:80 fertilizer combinations took longer days to reach 50% heading and 85% maturity. These results agree with those of Abebe and Abebe, (2016) who reported delayed heading when excess amount of nitrogen was supplied to wheat fields. Application of excess nitrogen boosts vegetative growth resulting in prolonged periods for crops to reach heading (Zayed *et al.,* 2013). Too much nitrogen causes increased demand for P and K P deficiencies cause slow growth and development of crops, resulting in delayed crop maturity (Fairhurst *et al.,* 2007). In the current study, Variety Basmati 370 matured approximately three weeks earlier than BW 196. This finding is in agreement with that of Vergara *et al.,* (1966), who reported that different rice varieties take different days to reach maturity. According to Ntanos and

Koutroubas, (2002), short and late maturing rice varieties tend to have a higher dry matter and nitrogen translocation than their long and early maturing counterparts. Dry matter and N translocation is directly related with rice grain yield.

The present study showed that application of 80:60:60, 100:80:80 and 100:00:80 fertilizer combination increased plant height relative to the no-fertilizer control. Fertilizer treatment combinations without N (00:40:40, 00:60:60, 00:80:80) did not increase rice plant height relative to the no-fertilizer control. The significant increase in plant height in 80:60:60 and 100:80:80 fertilizer combination, could be due to sufficient supply of essential nutrition to the rice crop. The results in this study corroborates those of Umar *et al.*, (2015) who registered increased plant height with increased rates of fertilizer. The inadequate supply of N in the N-omission plots (00:40:40, 00:60:60, 00:80:80) resulted in plants that were as short as the no-fertilizer control, because nitrogen deficiency is known to disrupt the metabolic processes of plants (Reddy and Dakota, 2007).

The least number of tillers per hill was recorded in 00:40:40, 00:60:60, 00:80:80, 60:40:00 and the no-fertilizer control plots. This poor performance of the tillers could be explained by inadequate N and K fertilizer in the soils of study. The good performance in N, P, K (60:40:40, 80:60:60, 100:80:80), N, P (60:40:00, 80:60:00, 100:80:00) and N, K (100:00:80 and 80:00:60) treatments could be due to increased uptake of N, P and K from the soils of study. Nitrogen stimulates plant growth by increasing cell division and elongation (Drew and Morgan, 2000). Potassium could have improved the crop's metabolic processes, hence the increased tiller number per hill. Phosphorus stimulated good development of roots and production of large leaves (Plenet *et al*., 2000). Bekele and Getahun (2016), also reported varying tiller numbers under varying fertilizer treatments.

In both seasons, 60:40:40, 80:60:60, 100:80:80, N, P and K treatment combinations had significantly higher rice panicle lengths than the control and 00:40:40. Applying this fertilizer combination may have ensured improved nutrient use efficiency by the rice crop, hence increasing the chlorophyll content and proper translocation of assimilates to reproductive parts, and increased crop yield (Sarkar and Malik, 2001). Poor development of panicles in plots in which K was omitted (80:60:00, 100:80:00) could be due to the low level of K in the soils of study (68 ppm against critical ranges of between 131 and 175 ppm). Crops become highly susceptible to both biotic and abiotic pressures under low K levels (Johnston *et al*., 2001). The poor development in 00:00:00 and 00:40:40 treatments could be due to nutrient deficiency which resulted in poor development of panicles, in the rice crops. N deficiency and excess P and K fertilizer (00:80:80) could have inhibited the development of the panicles.

The results of this study have revealed that fertilizer application did not increase 1000-grain weight of rice. One thousand grain weight is a stable plant characteristic which is controlled genetically and is less prone to effects of external conditions (Yoshida, 1981). This explains why BW 196 had higher 1000-grain weight than Basmati 370. Awan *et al.,* (1984) found similar results in his study. In the current study, BW 196 registered higher mean grain yield (4.86 t/ha) than Basmati 370 (4.04 t/ha). The grain yields recorded in this study are lower than the potential yields (5.54 and 7.91 t/ha for Basmati 370 and BW 196, respectively) that were reported by Vincent, 2016, although Basmati 370 yield in the current study falls within the range (4.1 to 6 t/ha) that was reported from farmers' fields within Mwea (Ndiiri *et al.,* 2013). Except for 100:80:00 and 00:40:40, in the first season and

K omission treatments in the second season, all the fertilizer regimes increased grain yield relative to the control. In both seasons, maximum grain yield was realized in fertilizer regime: 80:60:60, 80:00:60, 100:80:80 and 100:00:80. Additionally, in the second season, fertilizer regime 60:40:40 performed equally well. For the purpose of sustainable land use, 80:60:60 and 100:80:80 fertilizer regime would be the recommended. Balanced nutrition entails the application of fertilizer in their appropriate quantities and appropriate proportion using the right methods. It results in sustained soil fertility, sustainable land use and crop production. Unbalanced nutrition results in nutrient mining which produces soils short of nutrients (Gupta and Mahajan, 2009). The better performance of 60:40:40 in the second season than in the first could be explained by the fact that the land was left fallow between February and August 2017. Research shows that withholding irrigation water between planting reduces the buildup of viruses and disease vectors (Thresh, 1991). Continuous cropping of rice results in: decreased supply of indigenous nitrogen, because of declined supply of organic matter, long term changes in the soil chemistry and microbiology due to continuous submergence of the soil, increased deficiency of both macro and micro nutrients, reduced soil rooting volume and bulk density (Dawe *et al.,* 2000; Cassman *et al.*, 1997). Despite the low levels of phosphorus in the soil (average of 2.00 ppm against critical ranges of between 22 and 34 ppm), 80:0:60 and 100:0:80 N, P and K fertilizer regimes expressed high grain yield. Phosphorus is essential in grain development. It is a key element, essential in the stimulation of root development, tiller production and protein synthesis (Panhawar and Othman, 2011). Future research should seek to explain how long fertilizers 80:00:60 and 100:00:80 can consistently produce high rice yields to ensure maximal use of the available P in the soil. Research should also check the feasibility of alternating fertilizer regimes 80:00:60 and 80:60:60 to ensure that P is not depleted fully in rice production soils in Mwea. All the fertilizer combinations that exhibited better performance had potassium (Table 4.14). This could be an indication that K is one of the most limiting soil nutrients in Mwea. Potassium is responsible for the production of high amounts of starch, owed to the potassium-moderated carbohydrate metabolism. It is also important in the translocation of sugars to the sinks/grains (Beringer, 1978), and it ensures full utilization of N and P from the soil. Application of nitrogen fertilizer increases the concentration and uptake of nutrients such as K, P, Zn, Fe, Cu, and Mn in rice (Romeo *et al.,* 2004 and Lakshmanan *et al.*, 2005), which are essential in grain formation.

Application of 80:60:60 and 100:80:80 N, P and K fertilizer regimes could be appropriate only for varieties BW 196 and Basmati 370 grown in the fields adjacent to MIAD station. To avoid using blanket fertilizer rates for rice production in Kenya, it is important to refocus research to aid in outlining geo-referenced soil maps to ensure that soil recommendations site specific, guided by fertilizer prescriptions that are soil-test based.

In the current study, the interaction effect between variety and fertilizer regime was not significant, in all the studied parameters. This could be attributed to the narrow range of cultivars tested (only two varieties) because several studies have demonstrated significant variety x fertilizer treatment interactions in rice plant attributes (Kamrun *et al.*, 2017; Jahan *et al.*, 2014; Sarkar et *al.,* 2014), However, Strong, (1986) and Buri *et al.,* (2015), reported a lack of interaction between variety and fertilization as observed in the current study. To validate this information, experiments similar to this could be set up in more locations within Mwea and involving many more varieties.

4.6: Conclusion

Plant height, number of tillers, panicle length and yield of rice increased with increased fertilizer application. The highest grain yield was realized in fertilizer regimes: 80:60:60, 80:00:60, 100:00:80 and 100:80:80. 80:00:60 is the recommended fertilizer regime for rice production in Mwea, because it is the most cost effective when compared to the rest.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

In the present study, seed source did not have a significant effect on phenological characteristics of rice. Phenological characteristics are important crop parameters that affect grain yield (Ntanos and Koutroubas, 2002). The panicle exsertion varied from well-exserted to partly-exseterd and moderately well-exserted. Panicle exsertion determines the chances of occurrence of outcrossing (Sidharthan *et al.,* 2007). Leaf blade color variations were influenced by seed sources. Intensity of green color ranged from dark to medium green color. Using the intensity of green color to classify plants is not a reliable plant trait, in characterization of crops (Ashwani *et al.,* 2013). In Basmati 370 seeds from NIB, 3% of the sampled plants did not have awns. All the other plots had awns at the tips only, whose color at ripening stage ranged from light gold to reddish brown. Awns play a crucial role in protecting the crop against predation (Takahashi *et al.,* 1986). Both varieties, irrespective of seed source had white colored stigmas. Panicle length, grain weight, panicle length of the main axis, presence of secondary branching, grain width, and decorticated grain length were not affected by the seed sources under study. Grains that are long and slender tend to have lower grain weights than broader and shorter grains (Zafar *et al*., 2004). Apart from a significantly narrower leaf blade in Basmati 370 plants generated from MRGM, all the other studied quantitative characteristics didn't exhibit any significant differences within variety, from varying seed sources.

According to field observation results, variety BW 196 plots had more than two off-types per plot, totaling to a minimum of 6 off-types in 1500 plants. Based on the UPOV standards of seed certification, BW 196 seed would be considered genetically impure. Basmati 370 plots had between 0 and 1 off-types, hence in 1500 plants the number of off-types was below the minimum threshold (4). Basmati 370 seed will therefore be considered pure, genetically. Farmers who obtain their seed from either NIB or MRGM risk harvesting reduced yields, because of planting impure seed of variety BW 196. There is need to identify gaps that result in impure rice seed production in Mwea and develop strategies to avert the problem.

In the present study, applying fertilizer treatment 100:80:00 and 100:00:80 significantly prolonged the number of days taken by rice crop to head and to mature. Surplus application of nitrogen in combination with inadequate supply of P or K fertilizer results in delayed growth and maturity of crops. Plots supplied with fertilizer regime 80:60:60, 100:80:80 and 100:00:80 had significantly longer plants compared to the no fertilizer control. With regard to the tiller number hill^{-1}, fertilizer regime 60:40:40, 80:60:60, 100:80:80, 60:40:00, 80:60:00, 100:80:00, 100:00:80 and 80:00:60 out-performed the rest of the treatments. Fertilizer treatment 60:40:40, 80:60:60 and 100:80:80 had panicles that were significantly longer than those of the no fertilizer control (00:00:00). Balanced plant nutrition increases a crop's nutrient use efficiency (Sarkar and Malik, 2001). The 1000-grain weight of rice in the current study was not influenced by fertilizer. 1000-grain weight is known to be a constant genetic factor that is not influenced by environmental conditions (Yoshida, 1981).

In this study, variety Basmati 370 recorded lower yields (4.04 t/ha) than BW 196 (4.86 t/ha). In both the first and the second season, fertilizer regime: 80:60:60, 80:00:60,100:80:80 and 100:00:80 recorded the highest yield. All the fertilizer regimes that performed better had potassium. This could be a clear highlight that potassium is one of the most limiting nutrients in Mwea. Potassium is important in the efficient utilization of P and N in the soil and in the translocation of sugars to sinks hence critical in grain development (Beringer, 1978). The recommended fertilizer for rice production in Mwea is 80:00:60, but for sustained soil health and crop production 80:60:60 and 100:80:80 would be the appropriate fertilizer for rice production in Mwea.

5.2 Conclusion

Seed of Variety Basmati 370 from the NIB and MRGM, together with their respective nuclear seed exhibited minimal phenotypic diversity. Together with their respective nuclear seed, NIB and MRGM seeds of variety BW 196 produced seed that is genetically impure.

Plant height, number of tillers, panicle length and grain yield increased with increasing fertilizer application. The highest rice grain yield was realized in fertilizer regimes: 80:60:60, 80:00:60, 100:80:80 and 100:00:80. The recommended fertilizer for rice production would be 80:00:60, because it's the most cost effective when compared with the rest.

5.3 Recommendations

1. The present study revealed high genetic diversity within variety BW 196 and low diversity within variety Basmati 370. Future research should focus on investigating the factors that contribute to production of impure seed of Variety BW 196 and provide workable solutions that ensure that genetic purity of BW 196 rice seed is maintained.
2. In the current study, agro-morphological characterization was used to determine the genetic diversity of rice seed from various sources in Mwea. Despite the efficiency of this test, it is usually prone to effects of climate and management. To better explore the diversities that have been noted, molecular techniques could be used to give a better understanding of these results.

3. In the present study, the recommended fertilizer regime for BW 196 and Basmati 370 was 80:00:60. Since this study was carried out in fields adjacent to MIAD center, it's possible that these recommendations are ideal only for these sites. To avoid the use of blanket fertilizer application, research should be refocused to develop soil-test based, geo-referenced soil maps to ensure that soil recommendations are site specific.
4. Despite the low phosphorus levels in the soil (2 ppm against critical ranges of 22-34 ppm), 80:00:60 and 100:00:80 fertilizer treatments performed as well as 80:60:60 and 100:80:80 fertilizer regimes. Future research in rice should seek to explain how long fertilizer regime 80:00:60 can consistently produce high yields. The possibility of alternating the use of 80:00:60 and 80:60:60 in rice production should be checked to ensure that the inherent capacities of the soils to supply P fertilizer is not inhibited.
5. In the current study, there was no Variety × Fertilizer interaction. To affirm this finding, experiments similar to those of this study should be established in more locations within Mwea and more varieties should be incorporated.

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