ECOLOGICAL RISK ASSESSMENT FOR INVASIVENESS, RESPONSE TO WEEDS AND RATOONING ABILITY OF NEW RICE FOR AFRICA (NERICA) AND *Oryza sativa* RICE VARIETIES IN CENTRAL KENYA

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DECLARATION

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DEDICATION

To my husband Humphrey Munene, our children Emmanuel Mutugi and Joy Mwendwa and my beloved parents Mr. M'Ringera M'Twerandu and Mrs. Marion Karegi M'Ringera. Their support, belief, love and encouragement have helped me realise my potential.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
AQIS	Australian Quarantine and Inspection Service
ARC	Africa Rice Centre
AWRAS	Australian Weed Risk Assessment Scheme
CBD	Convention on Biological Diversity
CPWC	Critical period of weed control
DAS	Days after seeding
GMO	Genetically Modified Organisms
IPPC	International Plant Protection Convection
IRRI	International Rice Research Institute
LSD	Least Significant Difference
MIAD	Mwea Irrigation Agricultural Development Center
NERICA	New Rice for Africa
NCST	National Council for Science and Technology
NBA	National Biosafety Authority
NBC	National Biosafety Committee
NIB	National Irrigation Board.
NWRAS	National Weed Risk Assessment System
SSA	Sub-Saharan Africa
WACB	Weeks After Cut-Back
WAP	Weeks After Planting
WARDA	West African Rice Development Association
WF	Weed Free Period
WI	Weed Infested Period
WRA	Weed Risk Assessment
WTO	World Trade Organization

ABSTRACT

Rice belongs to the family Poaceae and genus *Oryza*. Poaceae, on a world scale, is classified among the prominent families that are likely to produce invasive weed species hence a challenge on biosafety. Through modern biotechnology, new rice varieties referred to as the New Rice for Africa (NERICA) have been developed in West Africa. NERICA rice varieties are interspecific hybrids between the two cultivated *Oryza* species i.e. *O. sativa* L and *O. glaberrima* Steud. The varieties are at the verge of deployment in Kenya and other African countries. Being new varieties in the continent, there is limited information about their characteristics they have not been sufficiently investigated. Risk assessment is a requirement of the Cartagena Protocol and the Kenya Biosafety Act of 2009. There is therefore need for risk assessment, as a biosafety measure, particularly on invasiveness, before the NERICA varieties are widely deployed in Kenya. This study attempted to assess the potential ecological risk of selected upland NERICA and *O. sativa* rice varieties in central Kenya for invasiveness, response to weed interference and ratooning ability. Two kinds of study were carried out on; 1) the response to weed interference and the ratooning ability of four upland NERICA [NERICA-1 (WAB 450-1-B-P-38-HB), NERICA-4 (WAB 450-1-B-P-91-HB), NERICA-10 (WAB 450-11-1-1-P41-HB), NERICA-11 (WAB 450-16-2-BL2-DV1)] and one *O. sativa* [Dourado precoce, (WAB 56-104)] rice varieties and 2) the potential risk of invasiveness of the four NERICA rice varieties.

The study was carried out at Mwea Irrigation Agricultural Development (MIAD) Centre in Kirinyaga County, central Kenya. A two-factor split-plot randomized complete block design replicated three times was used. For both the main and the ratoon crop, data were collected on the growth and and yield parameters. The Australia Weed Risk Assessment Scheme was used to assess the potential risk of invasiveness of the rice varieties. Data were collected on traits potentially contributing to invasiveness which included the history, biogeography and biology of each rice variety. These were gathered from study one of the current study, literature and consultation with appropriate experts. Data on response to weed interference and ratooning ability was subjected to Analysis of Variance (ANOVA) at 5% significance level. The Least Significant Difference was used for mean separation at 5% significance level. The weed risk assessment scoring sheet was

used to score the data on invasiveness which were later analysed on Microsoft excel spreadsheet.

The occurrence and composition of weeds at the two study sites was similar and composed of broadleaves, grasses and sedges. The five most dominant weeds out of 44 species at study site one were *Brachiara eruciformis*, *Sida ovata*, *Xanthium pungens*, *Portulaca oleracea* and *Euphorbia geniculata* while site two had *Brachiara eruciformis*, *Cyperus exaltatus*, *Dinebra retroflexa*, *Eclipta prostata* and *Hibiscus trionum* as the five most common out of 48 species. Generally for the main and ratoon crop of NERICA and Duorado precoce, early weeding enhanced plant growth as well as yield and yield components. Leaf area index was however least affected by weeding treatments. From the main crop, the critical period of weed control for NERICA 1 and 4 was established as 3-6 weeks after planting while for NERICAs 10, 11 and Duorado precoce it is between 3-9 weeks after planting. On the ratoon crop, the critical period of weed control for the four NERICAs (NERICA 1, 4, 10 and 11) as well as the standard check Duorado precoce was similar and is between 3-6 weeks after cut back. Weed competition either before or after these critical periods had negligible effects on crop growth and yield.

Total grain yield differed significantly ($p<0.05$) among the rice varieties. NERICA rice varieties attained significantly ($p<0.05$) higher grain yield compared to the traditional upland Duorado precoce in both the main and the ratoon crop. NERICA 4 attained the highest total grain yield (6206 kg ha^{-1}) followed by NERICA 1 (5781kg ha^{-1}) while the Duorado precoce attained the lowest (3376kg ha^{-1}). The yield increase of more than 1500 kg ha-1 (the average yield of upland rice in Sub-sahara Africa) recorded in NERICA 4 and NERICA 10 with no farm additional inputs was very encouraging. This will presumably increase with additional inputs during ratoon. Full season weed infestation resulted in 51 to 67% and 55 to 64% reduction in grain yield of the rice varieties for the main and ratoon crops respectively, confirming the vulnerability of the varieties to weed infestation. Ratooning ability varied significantly ($p<0.05$) among rice varieties with the NERICA varieties showing better ratooning ability than the standard check Duorado precoce. Among the NERICA varieties, NERICA 4 attained the highest ratooning ability (39%) while NERICA 1 attained the least (26%). Duorado precoce attained ratooning ability of 19% which was significantly ($p<0.05$) lower than any of the NERICA rice varieties.

The five upland rice varieties investigated in this study attained overall scores of less than one on invasiveness potential as per the Australian Weed Risk Assessment system varying from -9 to 0 for Duorado precoce and NERICA 10 respectively. These rice varieties are therefore not potentially invasive and do not present any significant ecological risk, hence should be accepted and are recommended for adoption in Central Kenya. The study recommends NERICA-4 and NERICA-1 for Central Kenya as the best yielding, most weed tolerant and least invasive rice varieties. It also recommends NERICA 4 and NERICA 10 as the best ratooning varieties for Central Kenya. Results of this study can serve as a guide on how optimum timing of weed control and ratooning can be used to maximize upland rice yield in Central Kenya.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Rice belongs to the family Poaceae (grasses) (Daehler 1998; Pheloung *et al*., 1999), which on a world scale, is classified among the prominent families that are likely to produce weed species (Daehler and Carino, 2000; Williams *et al*., 2002; Daehler *et al*., 2004). Others include Fabaceae (legumes) and Hydrocharitaceae (water plants) (Daehler, 1998; Pheloung *et al*., 1999; Daehler and Carino, 2000; Williams *et al*., 2002; Daehler *et al*., 2004). Weeds are plants (not necessarily alien) that grow in sites where they are not wanted and which have detectable economic or environmental impact or both (Pysek *et al*., 2004). Rice occupies a central position in the world's agro-based economy, being the most important crop that provides nutrition for more people than any other (Brar and Khush, 2002; Nazeer *et al*., 2012). It is the only cultivated cereal plant adapted to growing in both flooded and non-flooded soils. Grown under a wide range of climatic and geographical conditions on all the five continents, it serves as the staple food throughout much of the world (Clayton and Renvoize, 1986; Brondani *et al*., 2002). In Africa, rice is a staple food for many countries but the production generally does not meet its demand (Malton *et al*., 1998). Low yields constitute one of the main challenges of rice production in sub-Saharan Africa (SSA) (Africa Rice Center, 2008). Scientists within the African continent (WARDA, 1999; Africa Rice Center, 2008) have tried to fill this gap through modern biotechnology or genetic modification techniques by developing high yielding cultivars that are highly resistant to insects and diseases and are adapted to various abiotic stresses in the continent.

According to the Convention on Biological Diversity (CBD), biotechnology is any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific uses (Malton *et al*., 1998). There are two major categories of biotechnology namely traditional and modern biotechnology. Traditional biotechnology refers to early forms of using living organisms to produce new commodities or modify existing ones. The developments and modifications were achieved at the organism, not cellular level. It includes such techniques as selective breeding, fermentation and hybridization. Modern biotechnology such as recombinant DNA techniques (rDNA or genetic engineering) and tissue culture refers to applications that use genes, cells and living tissues in a predictable and controlled manner (Choudhary and Joshi, 2001). The benefits of modern agricultural biotechnology include providing resistance to crop pests, herbicide tolerance and generating products that have enhanced nutritional qualities. The impacts of some of these benefits are increased productivity, reduced chemical use, hence biologically safe for both human health and ecology, and improved profitability in the farming business (WARDA, 1999; Choudhary and Joshi, 2001).

NERICA varieties are interspecific hybrid progenies between the two cultivated *Oryza* species (*O. glaberrima* and *O. sativa*), developed through tissue culture by the West African Rice Development Association (WARDA) (1999), now Africa Rice Centre (ARC) and its National Agricultural Research System (NARS) partners to improve the yield of African rice varieties. *O. sativa* was first domesticated in south-east Asia, India and China between 8000 and 15000 years ago (OECD, 1999: Normile, 2004). Through domestication, *O. sativa* has evolved into many different cultivars e.g. Duorado precoce that are adapted to the wide range of conditions found in rice growing regions such as tropical and temperate climates, a wide range of soils, and greater or lesser dependence on water during their lifecycle (Takahashi, 1984; Oka, 1988; OECD, 1999). *O. glaberrima* has been cultivated since approximately 1000 BC (Ahn *et al*., 1992; Murray, 2005). The domestication of *O. glaberrima* took place at least 3500 years ago (Africa Rice Center, 2008). Its local ancestry and numerous generations of selection *in situ* have made *O. glaberrima* well adapted to the African environment. On the other hand, Asian rice, especially the Green Revolution semidwarf varieties has been bred for intensive production and high yield, but outside of the African continent. The first Asian varieties arrived in Africa about 450 years ago, and they have subsequently replaced the local species over much of the rice-cultivated area (Africa Rice Center, 2008; Ndjiondjop *et al*., 2008). NERICA mixes *O. glaberrima* which is highly resistant to drought and major African insect pests and diseases such as stem borers and rice blast but has very low yields with *O. sativa* which has high yields, but is much more sensitive to environmental conditions leading to increased use of pesticides hence biologically unsafe (Jones *et al*., 1997; Dzomeku *et al*., 2007). *O. glaberrima* is also very competitive with weeds (Audebert *et al*., 1998; Johnson *et al*., 1998), the main constraint to rice production across ecologies in Sub-Saharan Africa (SSA). NERICA varieties have therefore been bred and selected for high yields, short maturation periods, tolerance to abiotic stresses particularly moisture, salinity and high response to mineral fertilization amongst other traits. NERICA is expected to better the health of African citizens, restore agricultural sustainability, and improve the economics of food importation for the continent.

Despite its great benefits, agricultural biotechnology has the potential to be environmentally, scientifically and economically disastrous (Jones *et al*., 1997). A good possibility is the creation of invasive plants particularly from families such as Poaceae, which is classified worldwide among the prominent families that are likely to produce weeds (Daehler, 1998; Pheloung *et al*., 1999; Daehler and Carino, 2000; Williams *et al*., 2002; Daehler *et al*., 2004; Andersen *et al*., 2004). According to the Convention on the Biological Diversity (2000), biosafety refers to the need to protect human health and the environment from possible adverse effects of the products of modern biotechnology. The biosafety aspect is therefore of paramount importance as agricultural biotechnology advances to avoid ecological disasters. The need for risk assessment, particularly on invasiveness of the NERICA varieties, can therefore not be overlooked as these varieties are deployed to different African countries, Kenya inclusive. Kenya is party to the Convention on Biological Diversity (a signatory to the Cartagena Protocol) and currently has a biosafety law that came into operation in the year 2009 (Kenya Biosafety Act, 2009). The fifth schedule of this Act outlines the provisions on risk assessment. To assess invasiveness in the Poaceae family, response to weeds and ratooning ability are two important indicators as invasive species are reported (Parker *et al*., 1999; Andersen *et al*., 2004) as good competitors against weeds and to show good ratooning ability (Chauhan *et al*. 1985; Sanni *et al*., 2009).Vegetative growth is considered as an important attribute of successful invaders (Kolar and Lodge, 2001; Weber and Gut, 2004).

Differences amongst rice varieties in their weed competitiveness have long been established (Fofana and Rauber, 2000). In Asia, Garrity *et al*. (1992) found up to 75% differences in weed suppression among rice varieties. Fischer *et al*. (1997) observed yield losses ranging from 27 to 60% among Latin American irrigated rice varieties growing in competition with Jungle rice. However, such studies are lacking in Kenya and therefore this study investigated the possibility of invasiveness, response to weed interference and ratooning ability of four NERICA rice varieties i.e. [NERICA-1 (WAB 450-1-B-P-38-HB), NERICA-4 (WAB 450-1-B-P-91-HB), NERICA-10 (WAB 450-11-1-1-P41-HB), NERICA-11 and (WAB 450-16-2-BL2-DV1)]. One cultivated upland *Oryza sativa* local landrace [Dourado precoce, (WAB 56-104)] rice variety was used as the standard check.

1.2 Literature review

1.2.1 Taxonomic status of rice

Rice belongs to the family Poaceae, subfamily Bambusoideae, tribe Oryzeae and genus *Oryza* L. (Vaughan, 1994). Genus *Oryza* is classified into four complexes namely *O. sativa, O. officinalis, O. ridleyi and O.granulata* based on their genetic diversity (Vaughan, 1994; Vaughan *et al*., 2003). The genus *Oryza* has 25 species distributed through tropical and subtropical regions of Asia, Africa, Australia, central and South America (Veasey *et al*., 2004), of which 23 are wild species and two, *Oryza sativa* and *O. glaberrima*, are cultivated (Vaughan, 1994; Veasey *et al*., 2004). The *O. sativa* complex to which *O. sativa* and *O. glaberrima* belong are all diploid, have AA-type genomes and are pantropical (Vaughan, 1994; Vaughan *et al*., 2003; Chang, 2003). *O. sativa* is the most widely grown of the two cultivated species. It has a relatively small (430 million base pairs) diploid genome (2n=2x=24). This is the smallest genome of all food crops and approximately 50% of the genome is composed of repetitive sequences (Chang, 2003). Most other *Oryza* species are also diploid though a few are tetraploid (2n=4x=48) (Tateoka, 1964; Chang, 2003; Vaughan *et al*., 2003). *O. sativa* is grown worldwide while *O. glaberrima* is grown solely in West African countries. Hybrids (NERICA) resulting from the two species are replacing *O. glaberrima* due to their high yields (WARDA, 1999).

1.2.2 Rice growing conditions

Rice grows in altitudes ranging from 0-3000m above sea level. It requires an annual precipitation averaging 800-2000mm that is well distributed over the rainy season especially under the rainfed situation. Rice is a semi-aquatic plant and the only major annual food crop (except cocoyam) that thrives on land that is water saturated or even submerged during part or all of its growth (MOA, 2004). A variety of water regimes are used including unsubmerged upland rice, moderately submerged lowland rice (irrigated or rain fed) submerged rice up or floating (Nazeer *et al*., 2012). Optimum temperatures range from 20-38°C. Soils for rice cultivation are varied ranging from poorly drained to well-drained and texture ranging from sand to clay. It can grow in a wide range of soil types including saline, alkaline and acid-sulphur soils (Oka, 1998, Takahashi *et al*., 1991; Vaughan, 1994; Nazeer *et al*., 2012). Frageria *et al*. (1997) observed that upland or rainfed rice could be grown on both flat and sloping fields that are prepared for seeding under dry land conditions and depend on rainfall for moisture. Upland rice culture occupies about 13% of the total rice area of the world and is particularly important in Tropical America and West Africa rice cropping systems. About 60% of the total rice area in West Africa is under upland system (Hanfei, 1992). In Ghana, approximately 5% of land under rice cultivation is rainfed (Dzomeku *et al*., 2007). Concerted efforts are therefore being made within African continent, including Kenya, to increase the contribution of upland rice cultivation to meet the food security needs of the continent.

1.2.3 Varieties of rice cultivated in Kenya

There are four major categories of rice worldwide: Indica, japonica, aromatic and glutinous (Dingkuhn *et al*., 1998). In Kenya rice is popularly known by two trade names; the Pishori and Sindano. The two groups have been grown in Kenya since the 1960's and their selection is based on their yield related traits and resistance to major pests and diseases (Kiambi *et a*l., 2005). Pishori include all aromatic rice varieties such Basmati 217 and Basmati 370 while Sindano varieties are non-aromatic i.e. IR 1561-228-3-3, IR 1529-167-2-2, BR 51-74-6, IR 54, BG -90-2, IR 2035-25-2, IR 2793-80-1 and UP 254 (Table 1.1).

Table 1.1: Characteristics of some of the rice varieties grown in Kenya (MOA, 2011).

Rice variety	Height (cm)	Maturity (days)	Yield (t/ha)	Cooking quality	RYMV	Blast
Basimati (Pishori) 217	118.0	122	4.6	Good	S	S
Basimati 370	118.0	122	5.3	Good	R	S
IR 2035-25-2	86.2	126	5.5	Good	MS	MR
IR 2793-80-1	89.0	142	6.4	Good	S	MR
BW 96	68.0	135	9.0	Fair	S	MS
UP 254	84.2	124	6.4	Good	MS	MR
AD 9246	78.2	128	5.1	Good	MR	MS

KEY

R (resistant), MR (moderately resistant), S (susceptible), MS (moderately susceptible), RYMV (Rice Yellow Mottle Virus)

1.2.4 Rice production in Kenya

About 95% of the rice grown in Kenya is under irrigation managed by National Irrigation Board (NIB). NIB is a government of Kenya statutory board, which manages five rice schemes namely Mwea irrigation scheme (in central Kenya), Ahero irrigation scheme (in western Kenya), West Kano irrigation scheme (in western Kenya), Bunyala irrigation scheme (in western Kenya) and Tana Delta irrigation scheme (in the coastal Region) (Wanjogu and Mugambi, 2001; MOA, 2011). The remaining 5% of the rice (which is rainfed) is cultivated along the Kenyan coast in Kwale, Kilifi, Lamu and Tana River district and also in Busia and Teso districts of western Kenya. The main source of irrigation water is river Tana for Mwea and Tana Delta irrigation schemes and river Nyando for Ahero, Bunyala and west Kano schemes from which water is either pumped or gravitated to the production areas. Although there is great potential for rice cultivation in rainfed ecosystems, only a minimum proportion has been exploited (MOA, 2004). In Kenya rice is increasingly becoming an important foodstuff especially in urban centres. Local rice production only caters for 32% of rice demand (Wanjogu and Mugambi, 2001). The average rice production per hectare under irrigation in Kenya is 5.5 tonnes of aromatic varieties (Pishori) and 7 tonnes for the non-aromatic varieties (Sindano). Rainfed rice yield is about one tonne per hectare (Ministry of Agriculture-Kenya, 2010). The estimated yield of NERICA rice varieties is 4.0-7.0 tonnes per hectare (Africa Rice Center, 2008).

1.2.5 New rice for Africa (NERICA)

New Rice for Africa (NERICA) rice varieties are interspecific hybrids between the two cultivated *Oryza* species i.e. *Oryza sativa* L. as the maternal parent and *Oryza glaberrima* Steud as the paternal parent (Africa Rice Center, 2008). The species do not cross naturally or through traditional hybridization techniques due to their genetic differences hence the application of modern biotechnology in the production of NERICA. During the early decades, attempts to cross *O. sativa* and *O. glaberrima* remained unsuccessful because of hybrid sterility (infertile offspring of the crosses) (Dingkuhn *et al*., 1998; Ndjiondjop *et al*., 2008) in F_1 progenies. The F_1 progenies obtained from the crossing reached almost 100% sterility because of the failure of pollen development (Heuer *et al*., 2003). In the early 1990s, West African Rice Development Association (WARDA) now (Africa Rice Center) breeders turned to modern biotechnology in an attempt to overcome this sterility blockage. The strategy used by WARDA to overcome this sterility issue was to backcross the F_1 lines at least twice with parent *O. sativa*. After cross-fertilization of the two species, embryo-rescue technique was used involving removal of the fertilized embryos and growing them in an artificial media (Heuer *et al*., 2003). The resultant plants were frequently almost sterile, so they were re-crossed (back-crossing) with the *O. sativa* parent wherever possible. Although the progenies from the backcrosses were not fully fertile, hundreds of segregating progenies were developed which gave enough fertile plants to select from. Once the fertility of the progeny was improved (often after 6-8 back-crossings), anther-culture was used to double the gene complement of the male sex cells and thus produce true-breeding plants. Anther culture allowed rapid fixation and helped to retain interspecific lines combining desirable features of the two rice species (Dingkuhn *et al*., 1998; WARDA, 1999; Heuer *et al*., 2003; Ndjiondjop *et al*., 2008) (Figure 1.1).

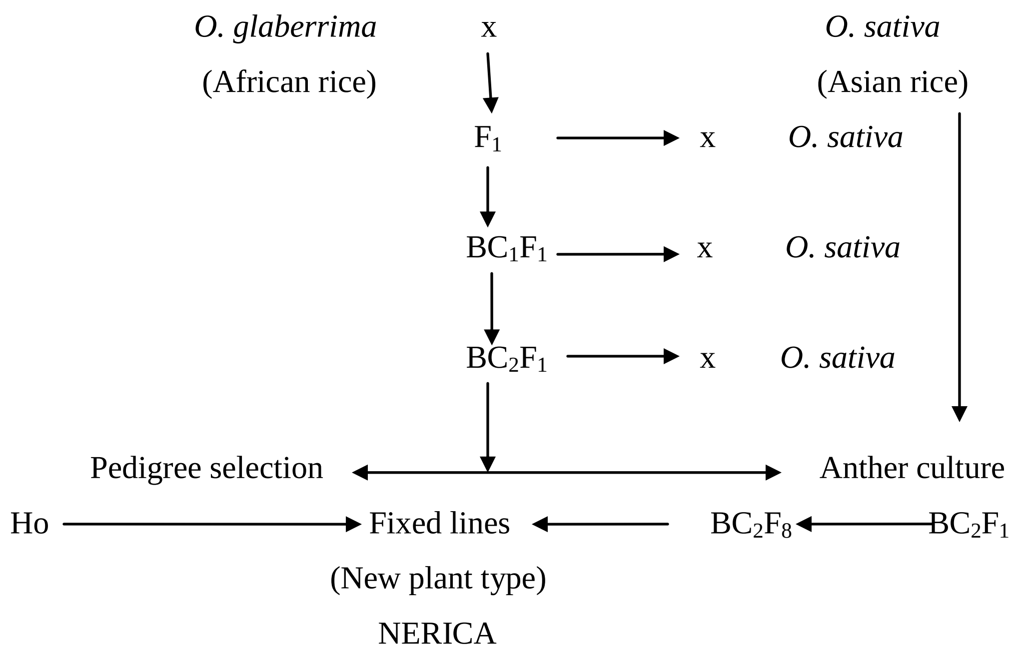

Figure 1.1: Hybridization scheme for the production of NERICA rice varieties (*after* WARDA, 1999)

The first New Rice for Africa variety was developed in 1994 using an *O. sativa japonica* variety (WAB 56-104) and an African *O. glaberrima* Steud variety (CG 14) (Semagn *et al*., 2006). A total of 18 varieties were named with the prefix NERICA, which is an acronym for New Rice for Africa, followed by a number corresponding to their pedigree (Appendix 1.1). The first generation of NERICA varieties 1 to 11, including the WAB 450 progeny, was developed from crosses of the existing released variety CG 14 (*O. glaberrima*) and WAB56-104 which belongs to the subspecies japonica of *O. sativa* L., an upland improved variety. On the other hand, NERICAs 12 to 18 are progeny of two series of crosses, using the same *O. glaberrima* (CG 14) parent but two different *O. sativa* parents (WAB 56-50 and WAB181-18). They include the series of WAB880 and WAB881 progeny (WARDA, 2001, Ndjiondjop *et al*., 2008). Seven NERICA varieties (NERICA 1 to 7) were named in the year 2000, and a further 11 varieties (NERICA 8 to 18) were named in 2005 (Semagn *et al*., 2006; Ndjiondjop *et al*., 2008). All the 18 NERICA varieties have so far been released and adopted in sub-Saharan Africa though the number of varieties released differs from country to country. Four varieties (NERICA-1, NERICA-4, NERICA-10 and NERICA-11) have been adopted in Western Kenya (Bunyatta, 2012). Among them, NERICA-4 and NERICA-10 have been found to be better yielding than NERICA-1 and NERICA-11 (Ndjiondjop *et al*., 2008; Bunyatta, 2012). The potential grain yields of the four rice varieties according to Africa Rice Centre (2008) are 4500, 5000, 6000 and 7000 kg $ha^{-1}$for NERICAs 1, 4, 10 and 11 respectively. Besides the 18 first released upland varieties in West and Central Africa, some 60 lowland NERICA-L varieties directed at lowland-irrigated cropping are being grown in evaluation trials throughout Sub-Saharan Africa (SSA). The main difference between the upland and lowland NERICA varieties is that the japonica *O. sativa* subspecies (traditional rainfed or 'upland' rice) was used in the creation of upland varieties while the indica subspecies was used in developing the lowland varieties (Dingkuhn *et al*., 1998).

NERICA varieties combine the best traits of both parents: high yields from the Asian parent and the ability to thrive in harsh environments from the African parent. *O. glaberrima* is adapted to the African environment, but prone to lodging and grain shattering. *O. sativa* on the other hand is high yielding but susceptible to the stresses of African ecologies. Studies done elsewhere outline the advantages of NERICA compared to their parents; namely, it can grow well in upland, medium and even lowland areas, early maturity, resistance to local stresses such as drought, infertile soils, pests and diseases (especially blast, stem borers and termites), higher yields, higher protein content and good taste (Hanfei, 1992; Frageria *et al*., 1997; Dingkuhn *et al*., 1998: Jones, 1998). The popularity of NERICA has been because of its being rain fed hence a good food security measure within a country. Rain fed rice crop does not require flooding but readily grows by use of rain water or grows in wetlands and in swampy areas or with supplementary irrigation (Pande, 1994). In general, upland NERICA rice can grow in any environment with at least 15-20mm of five-day rainfall during the growing cycle. During germination and early growth stages, 15mm per five-day rainfall is sufficient (Africa Rice Center, 2008).

1.2.6 Agricultural biotechnology and biosafety in Kenya

Invasive species issues have been elevated onto the international agenda via the Convention on Biological Diversity (CBD) to which Kenya is party. The Convention urges countries to prevent the introduction of and to control or eradicate non-native species that threaten ecosystems, habitats or other species. The CBD Biosafety Protocol (Cartagena Protocol) requires decisions regarding the international movement of living modified organisms to be subjected to risk assessment (Andersen *et al*., 2004). In line with the Cartagena Protocol, the Kenya Biosafety Act (2009) schedule 5 outlines the provisions on risk assessment.

Kenya is viewed as a biotechnology role model (Traynor and Macharia, 2003; Thomson, 2004; Harsh, 2005). It is the hub of agricultural biotechnology development in East Africa and all of sub-Saharan Africa (except South Africa). The National Biosafety Authority (NBA) is the government agency responsible for overseeing the implementation of the biosafety regulatory system in Kenya. NBA was established by the Biosafety Act No. 2 of 2009 and came into operation in February 2009 to enhance modern biotechnology and exercise general supervision and control over the transfer, handling and use of genetically modified organisms (GMOs). The authority implements the Cartagena protocol on Biosafety in order to address safety for the environment and human health in relation to modern biotechnology. GMOs are products of modern biotechnology that involve the manipulation of the genetic material of organisms through genetic engineering procedures. It is important to note that NERICA rice varieties are not GMOs as their development did not involve any genetic modification; even though techniques of biotechnology, such as embryo rescue, were used in the process.

1.2.7 Invasive plants

According to Pysek *et al*. (2004) invasive plants are a subset of naturalized (established) plants that reproduce offspring, often in very large numbers, at considerable distances from the parent plants, and have the potential to spread over a large area. Naturalized plants are alien plants that sustain self-replacing populations for at least 10 years without direct intervention by people (or in spite of human intervention) by recruitment from seed or ramets (tillers, tubers, bulbs or fragments) capable of independent growth (Pysek *et al*., 2004). They can be trees, sedges, vines or grasses and have the following characteristics; spread rapidly, reproducing by roots, seeds, shoots or all three, if spread by seed, produce numerous seeds that disperse and sprout easily (Parker *et al*., 1999), mature quickly, good exploiters and colonizers of disturbed ground (Andersen *et al*., 2004), produce large numbers of new plants each season (ratooning), tolerate many soil types and weather conditions (Pheloung, 1995), spread easily and efficiently usually by wind, water or animals (Andersen *et al*., 2004), readily established, self sustaining, grow rapidly allowing them to displace slower growing plants and spread rampantly when they are free of the natural checks and balances found in their native range (Pheloung, 1995; Parker *et al*., 1999; Andersen *et al*., 2004).

Invasive species are implicated in the decline of threatened and endangered species because they alter ecosystem processes, change community structure and displace native species (Daehler, 1998; Gordon, 1998; Sharma and Mahajan, 2009). Over 40% of the species in the list of threatened and endangered species is due to invasive species (Wilcove *et al*., 1998). Prevention and early eradication are considered the most effective means of managing invasive species (Williams, 1997; Lodge *et al*., 2006; Sharma and Mahajan, 2009), figure 1.2.

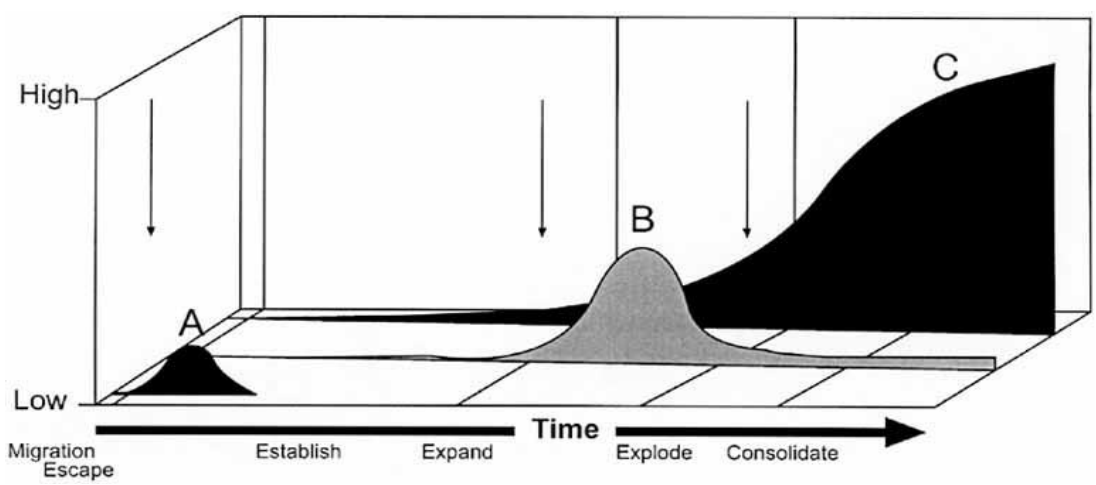

Figure 1.2: Relative combined monetary and environmental costs of undertaking eradication programme (A), together with those of initiating ongoing control programmes at an early (B) and late stage (C) of the invasion. Arrows indicate programme starting points. The differences in area beneath the curves (B-A, C-A, C-B) represent the benefit of control action at the earlier stage (After Williams, 1997).

Failing that, the greatest return for expenditure of money and effort comes from controlling the species before it has spread.The process of biological invasion is broken into four phases i.e.entry, establishment, spread and impact. The entry phase consists of arrival of non-indigenous species at one or more points of entry into a new environment. In the establishment phase, one or more of these arriving populations begins to reproduce *in situ* and escapes immediate danger of local extinction. In the spread phase, the species disperses from its initial site(s) of establishment and occupies available habitat (or infects susceptible hosts) within its new environment. In the impact phase, an established species persists and competes in its new geographical range (Smith *et al*., 1999; Mack *et al*., 2000). Once an invasive species has established and begun to spread, the effort required to eliminate it increases dramatically (Figure 1.2). Species with persistent seed or other regenerative life features that require repeated visits to the site(s) are particularly intransigent. The total accumulative costs over time are the effort required obtaining the funds, the money spent on actual control, plus the impacts on the economy and environment. These accumulated costs become progressively greater with time if control attempts are delayed, as illustrated by the differences in the three shaded curves in Figure 1.2. Available information on invasive species in the eastern African region shows that some 34 different species have invaded Kenya. They include eleven arthropods, ten microorganisms, nine plants and four vertebrates (Farrell, Kibata and Sutherland, 1985; Lyons, 2000). Only few of these species are under control, hence the concern. The South American water hyacinth *Eichhornia crassipes* invaded Africa's Lake Victoria in 1980s and today there is little doubt as to the damages it has caused. Other biological invasions in Kenya that have had significant consequences on the socio-economic status are the larger grain borer *Prostephanus truncatus* (Hodges *et al*., 1983; Muhihu and Kibata, 1985) and the Prosopis species (Keli, 1988; Hill *et al*., 1999).

1.2.7.1 Impacts of invasive exotic plants

Most exotic species in most countries have potential for further spread (FAO, 2001). They also have the potential to cause far reaching ecological and economic impacts;

a) Ecological impacts

Biological species invasions alter ecosystems in a variety of ways (Brooks *et al*., 2004). As highly adaptable and generalized species are introduced to environments already impacted by human activities, some native species survival may be disadvantaged while other species survival is enhanced (Mack *et al*., 2000). Introduced species often prey on many parts of an already established food web or compete with indigenous species for resources such as food or space. In some areas, native species are at the brink of extinction due to the introduction of an exotic species. Exotic species reproduce with natives and produce hybrids (Bhaskar and Pederson, 1998). Hybrids not only change the gene pool of an area (genetic pollution), they also simplify an ecosystem. By simplifying an ecosystem, as well as causing population declines and species extinctions, exotic species can reduce biodiversity. Biodiversity is the variation and variety of genes, organisms and species found in an ecosystem (Sharma and Mahajan, 2009). As biodiversity decreases, the vulnerability of an ecosystem to pests and diseases increases. Hybridization with or without introgression may, nevertheless, threaten a rare species existence (Rhymes, 1996; Potts *et al*., 2001).

b) Economic impacts

Introduced non-native species may cause widespread destruction by rapidly taking over an area and eliminating economically profitable native species. This can result in enormous financial spending in an attempt to eradicate and restore natural species. Numerous other economic sectors may be negatively affected, including agriculture, forestry, fisheries and water use, utilities, and natural areas (Pimentel *et al*., 2001; Thuiller *et al*., 2005; Sharma and Mahajan, 2009). Weeds cause an overall reduction in yield, though they often provide essential nutrients for subsistence farmers. Many introduced weeds in pastures compete with native forage plants and are toxic to young cattle (Rhymes, 1996; Potts *et al*. 2001). The unintentional introduction of forest pest species and plant pathogens can change forest ecology and negatively impact timber industry. These can have impacts on recreational activities such as fishing, hunting, hiking, wildlife viewing and water based recreation. They negatively affect a wide array of environmental attributes that are important to support recreation, including but not limited to water quality and quantity, plant and animal diversity and species abudance

(Eiswerth, 2005). The species may breed with native species, resulting in dangerous or poisonous hybrids, which humans may unknowingly consume (Sharma and Mahajan, 2009). Invasive plant species however have some economic benefits such as biomass production from *Eichhornia crassipes* (Rhymes, 1996; Sharma and Mahajan, 2009).

1.2.8 Risk assessment for invasive species

Risk is an estimate based on probability of an event multiplied by the impact of that event (Orr *et al*., 1993). Risk assessment and risk management are interactive, but functionally separate risk analysis activities. Risk assessment characterizes the likelihood and severity of potential adverse effects of exposure to hazardous agents or activities (i.e. stressors). Risk management is the process of identifying, evaluating, selecting and implementing actions to reduce risk (The Presidential/Congressional Commission on risk assessment and risk management, 1997; Andersen *et al*., 2004). There may be no sharp boundary between risk assessment and risk management in some analytical elements, e.g. the identification and evaluation of risk reduction measures (National Research Council, 1996).

The search for characteristics of invasive species (Crawley *et al*., 1996; Rejmanek, 1996) is a central issue in invasion biology as it determines our ability to predict the invasion success of alien plants in new regions (Kolar and Lodge, 2001; Richardson and Pysek, 2006). This knowledge is translated into Risk Assessment Schemes (RAS) that attempt to predict the behavior of alien species in secondary areas, both as quarantine protocols and as prioritizing tools for existing weeds (Pheloung *et al*., 1999; Daehler and Carino, 2000). Two categories of risk assessment schemes are recognized based on the methods used and the phase of the invasion process they target. The first category consists of the pre-introduction models that predict the potential behavior of a species prior to its introduction (Scott and Panetta, 1993; Pheloung, 1995; Tucker and Richardson, 1995; Rejmanek and Richardson, 1996; Reichard and Hamilton, 1997; Pheloung *et al*., 1999; Daehler and Carino, 2000; Reichard, 2001; Daehler *et al*., 2004; Weber and Gut, 2004). Such approaches often use statistical discrimination analysis and classification and regression trees. These schemes are often based on rating systems (Pheloung, 1995) or on hierarchical decision trees (Reichard and Hamilton, 1997). The second category consists of the post-introduction models that focus on predicting the future behaviour of species that have already become naturalized or invasive in the new area. Such schemes typically rely on geographical information systems (Dark, 2004; Marais *et al*., 2004; Windrlechner *et al*., 2004). Some schemes (e.g. the Australian system) could however be used as pre as well as post-introduction models (Pheloung *et al*., 1999, Daehler and Carino, 2000). All risk assessment schemes require answering a series of questions on attributes such as life history, biogeography, habitat and weed history (Daehler and Carino, 2000; Sharma and Mahajan, 20090), which are important aspects that aid in the recognition of the potential for invasion (Crosti *et al*., 2007; Sharma and Mahajan, 2009). A history of weediness elsewhere has been the most reliable predictor of weediness in several studies (Scott and Panetta, 1993; Reichard and Hamilton, 1997; Williamson, 1998; Daehler and Carino, 2000; Maillet and Lopez, 2000).

1.2.8.1 Australian weed risk assessment system

The Australian Weed Risk Assessment (AWRA) system also known as Pheloung Weed Risk Assessment System, (Pheloung *et al*., 1999) is the most widely known and applied assessment system encompassing all plant groups. It is one of the best systems available in the world for predicting species with the potential to be weeds of agriculture and/or the environment. The system has successfully been applied in New Zealand, Hawaii and other Pacific islands, and may be modified and adopted elsewhere with little development cost (Pheloung *et al*., 1999, Daehler and Carino, 2000; Daehler *et al*., 2004). The system is also recommended as a suitable tool for use as a quarantine tool in developing countries (Williams, 2000) because Australia includes a wide range of climates from desert to tropical rainforest (Daehler and Carino, 2000; Williams, 2000). The central “argument” is that if a species is reported as a weed in another country, then it should be classed as a weed in the country of import, provided that the climate and environment are compatible with the new country (they are assumed to be so if there is no information) (Pheloung *et al*., 1999, Daehler and Carino, 2000; Daehler *et al*., 2004). The AWRA system could also be used as a post-introduction management tool to eradicate and prevent the proliferation of weed species that are already present in farmland and that can harm vegetation remnants in agro-ecosystems (Crosti *et al*., 2007).

The system takes into account both weedy and non-weedy species traits. Weed risk assessments are conducted at species level. However on some occasions (such as when subspecies or varieties have economic benefits or attributes different from parent species, that render them less or more weedy than other members of the species), varieties may be assessed (Pheloung, 1995; NWRAS Review Group, 2006).

The Australia scheme is a question-based assessment which involves answering up to 49 questions (Appendix 6.1) on specific attributes of the weed potential of the plant (Panetta *et al*., 1994; Pheloung *et al*., 1999; NWRAS Review Group, 2006). In addition to being more comprehensive, it is flexible in that there is no need to answer all questions, and positive (non-weedy) traits are taken into account (Pheloung, 1995). Even where information about a species is incomplete, the answered questions lead to a score that allows a recommendation to be made as to the risk of its becoming a weed (IPPC, 2003). This increases the system's predictive power for rare, endangered, recently discovered and little known species (Pheloung, 1995). In addition to an overall score, scores derived from questions of agricultural and environmental relevance are also generated to give an indication of the sectors likely to be affected (Pheloung, 1995). For example, if the agricultural score is negative, but the environmental score is positive and the overall result is *reject*, then the species is probably a potential environmental weed only. A species may however be assessed as likely to become a weed in both categories (Pheloung, 1995; IPPC, 2003; Krivanek and Pysek, 2006). Environmental or natural area invaders are plants that form dense populations in or reported as threatening natural or semi-natural native communities, usually adversely affecting native biodiversity and ecosystem functioning (Humphries *et al*., 1991; Randall, 1997; Daehler, 1998; Space *et al*., 2003) while agricultural weeds are undesirable plants that colonize agricultural lands (Holm *et al*., 1977; Daehler, 1998).

1.2.8.1.1 Rational for answering the questions in the AWRA system

The questions in the scheme are divided into three sections on history, biogeography and biology/ecology of each plant species or variety. The answers are in the form of 'yes', 'no' or 'don't know', and are used to produce a score related to weediness and converts this into an entry recommendation for a specified taxon (Hazard, 1988; Panetta, 1993;

Pheloung *et al*., 1999). A minimum of 10 answers from the three main sections (biogeography, undesirable attributes and biology/ecology) is needed for a species or a variety to be evaluated as follows:

Biogeography: the documented distribution, climate preferences and weediness in other parts of the world. At least two questions should be answered in this section (questions 2-3). The default, if this is not done is to assume the species or variety will readily grow unaided in the region of study.

Undesirable attributes: traits potentially contributing to invasiveness such as toxic fruits and palatability to stock, invasive behaviour such as climbing or smothering growth habit, or the ability to survive in dense shade. At least two questions should be answered in this section (question 4).

Biology/ecology: The attributes that contribute to the capacity of the species or variety to reproduce, spread and persist such as whether the plant is wind or animal dispersed, and whether the seeds would survive passage through an animal's gut (questions 5-8). At least six questions should be answered in this section.

For proper evaluation, it is however recommended that at least one third of the questions be answered (Krivanek and Pysek, 2006). The climate section will result to the worst case if not answered. Among the three sections, biogeography is considered as the best measure of weed potential (Pheloung, 1995; Panetta, 1993; Scott and Panetta, 1993).

1.2.8.1.2 Scoring the questions and converting scores into recommendations

To ensure consistency in scoring the questions and converting scores into recommendations, a standard weed risk assessment question sheet (Appendix 6.1) and a scoring sheet (Appendix 6.3) are used (Pheloung, 1995). Answers to questions in the AWRA system are linked to a score. Most questions result in the addition of a point for weedy attribute or subtraction of a point for a non-weedy attribute depending on the answer (i.e. yes = 1, no = -1 and unknown = 0). Several questions, however, do not fit the typical scoring system and scores are generated using a weighting system where the answer to one question may alter the score for another. Scores are tallied once all the information is entered into the system and the questions are answered. The total score for a species or variety are scored from -3 to +5 (Pheloung *et al*., 1999), and relates to one of the three possible recommendations (*accept*, *evaluate* or *reject*) as follows; score < 1 = accept (non-invasive/non-weedy), score between 1-6 = evaluate (minor weed/average invasiveness or the information obtained was not enough and therefore the final score could have been overestimated), score > 6 = reject (high invasiveness/weedy) (Pheloung, 1995; Daehler and Carino, 2000; NWRAS Review Group, 2006; Crosti *et al*., 2007). Incases where a range of information or opposing but putatively reliable answers are found, the answer that increases the chance of a variety being rejected (potentially high invasiveness) is used. It is reasoned that it is less costly to erroneously reject a non-invasive variety than to admit a future invader (Pheloung *et al*. 1999; Daehler and Carino 2000).

1.2.9 Weed types in rice fields

Weeds in rice fields can be categorised into three main groups: broad leaved, grasses and sedges (Johnson, 1971; Akobundu, 1987; Wanjogu *et al*., 1995; Fischer *et al*., 2001). Broad leaved weeds have leaves that are broad, and are generally produced in pairs or multiples. Leaves are detached from the main stem by a petiole and they may be simple or compound with netted venation in most cases (Akobundu, 1987; Fischer *et al*., 2001). Grass weeds can be annuals or perennials and include crabgrass, goosegrass, dallisgrass, annual bluegrass, crowfootgrass and other undesirable, invasive grasses (Fischer *et al*., 2001). Leaves of grasses are not detached from the main stem, but are narrow with a blade-like appearance. The leaves are produced one at a time in two vertical rows with parallel veins, while the stems are commonly hollow and rounded or flat. Grass weeds are often difficult to control once established and are therefore generally best controlled with preventive or preemergence herbicides (Johnson, 1971). Sedges have two key identifying characteristics: leaves arranged in three vertical rows and solid triangular stems (Johnson, 1971). They are mostly found in moist or irrigated lawns.

1.2.10 Weed control in rice fields

Weed control in rice crop is a required management input for the crop to meet excepted production goals (Fischer *et al*., 2001). Management of weeds in upland rice production is a major constrain and very expensive (Fofana and Rauber, 1999; Fischer *et al*., 2001).

General weed competition in crop plants is severe because of the wide range of adaptability of the weeds which are native to the environment (Remison, 1978), and when early competition is not controlled, the rate of growth of the crop is restricted significantly (Humbert, 1968).

1.2.10.1 Methods of weed control in rice fields

The methods employed to control weeds in rice fields include hand weeding and herbicide application.

a) Hand weeding

This is the most common method of weed control in developing countries such as Kenya, Sierra Leone and Nigeria, often with the aid of hoes or machetes (Akobundu, 1991; Johnson, 1996; Kolo and Umaru, 2012). Several constraints limit the effective use of hand weeding, including household labour constraints, limited cash for hiring labour, and labour not being available for hire during peak periods. It is also complicated by the morphological similarity between rice and grass weed seedlings which leads to uprooting of the rice seedlings alongside the grass seedlings (Kolo and Umaru, 2012). As a result, yields in farmer's fields are as low as 0-0.8t/ha (MAFFS, 2005; Akobundu, 1991). In some areas, adoption of line planting in transplanted rice has allowed the introduction of rotary weeders for cultivation between rice rows, considerably reducing labour requirements for weed control (Johnson, 1996; Parker and Fryer, 1975). Technology including an animal drawn row seeder and hoes, enabling mechanical weed control, may be an appropriate package where animal traction is a possibility, although problems have been encountered with the operation of seeders under farmer conditions (Johnson,1971).

b) Herbicides

Herbicides can be used before planting to remove weeds from a field, they can be applied to the bare soil at planting for residual control of germinating weed seeds, and they can be directly applied to weeds during the growing season. Residual herbicides applied to the soil before the crop and weeds emerge from the ground remain active in controlling germinating weeds until the critical period of weed competition has passed. Herbicides for weed control in upland rice are expensive and often not available to smallholder farmers at the time of need and where available, farmers may lack the requisite knowledge and skill to use the herbicide correctly. Although herbicides use alleviates the problem of labour for weeding, incorrect use of herbicides may bring about other environmental problems (Labrada, 2002) such as the development of herbicide resistance in weeds (Lemerle *et al*., 1996; De Vida *et al*., 2006).

Herbicides are classified as selective or non-selective herbicides (Thompson *et al*., 1987; Ampong-Nyarko and De Datta 1991). Selective herbicides kill weeds with little to no effect on the crop, allowing them to be applied topically. Non-selective herbicides injure or kill both the weed and crop; therefore, they must be directed under the crop canopy rather than topically applied. Glyphosate [N-(phosphonomethyl) glycine] is a non-selective, systemic herbicide that controls a variety of annual and perennial broadleaf, grass, and sedge weeds (Thompson *et al.,* 1987). However, its intensive use can lead to adverse changes in the weed flora towards more aggressive broadleaved weeds and weed resistance to glyphosate. Paraquat (1, 1'-Dimethyl-4, 4'-bipyridinium dichloride) is a broad spectrum, non-selective herbicide whose mode of action is to inhibit photosynthesis (Thompson *et al*., 1987). It is used to prepare the land for cultivating rice and on the bunds (levies) which surround paddy fields to retain the flood water. However, paraquat is immobilised and deactivated on contact with the soil meaning that there are no leaching or root uptake problems to restrict its use (Grist, 1986; Thompson *et al*., 1987). It can be sprayed to burndown weeds before planting a rice crop without risking damage to that crop or subsequent crops in the rotation. Both paraquat and glyphosate have no residual activity in the soil and do not affect the rice crop (Thompson *et al*., 1987).

1.2.10.2 Critical period of weed control in rice fields

Research on the critical period of weed control is usually performed by measuring the effect of early and late season weed competition (Nieto *et al*., 1968; Weaver and Tan, 1983; Tursun *et al*., 2007; Toure *et al*., 2013). Early-season weed competition is the length of time weeds can remain in a crop before inteference begins (Toure *et al*., 2013). It is achieved by allowing weeds to emerge and grow with the crop for certain predetermined times, after which all weeds are removed in a timely manner until harvest (Dzomeku *et al*., 2007; Toure *et al*., 2013). Late-season weed competition is the length of time that weed emergence must be prevented so that subsequent weed growth does not reduce crop yield (Toure *et al*., 2011). This is achieved by keeping the crop free from weeds until certain predetermined times, after which weeds are allowed to emerge and compete with the crop for the remainder of the growing season (Tursun *et al*., 2007; Toure *et al*., 2013). Heemst (1985) has shown that the critical period is related to the competitive ability of the crop. Thus, a crop with a high competitive ability has a critical period that ends early.

1.2.11 Ratooning

Ratoon crop are the new tillers that grow under favorable conditions of moisture and fertility, from stubble of harvested plants (main crop) (De Datta, 1981). The main crop stubble should be left with at least 2-3 nodes for proper ratooning (Chauhan *et al*., 1985). The recommended optimum cutting height for good ratooning is 15-20cm (Chauhan, 1985; Bahar and De Datta, 1977). Reducing the cutting height below 15cm increases the number of missing hills and reduces tillering, thereby reducing grain yield. Low cutting leads to death of the buds in the nodes closer to the ground. Rice ratooning depends on the ability of dormant buds on the stubble of the first crop to remain viable. The buds exist in various stages of development (Nair and Sahadevan, 1961). Auxillary buds that develop at those nodes grow into ratoon tillers. Tillers regenerated from higher nodes form more quickly, grow faster and mature ealier. When the main crop is harvested late, ratoon tillers begin to develop soon after the first crop ripens. In this situation, the culms of the growing ratoon tillers are damaged because they elongate within the old leaf sheaths (Szokolay, 1956).

Ratooning is a characteristic of rice and other members of poaceae family (Sanni *et al*., 2009). This technology is widely used in the production of sugarcane and bananas (Junelyn and de la Rosa, 2004; Sanni *et al*., 2009). The success of a good ratoon crop depends on agronomic practices and growth duration of the main crop (Jones and Snyder, 1987), the care with which the main crop is protected against insect pests and diseases (Rehman *et al*., 2007), inherent ratooning ability of the cultivars (Chauhan *et al*., 1985), light, temperature, soil moisture and fertility (Chauhan *et al*., 1985; Rehman *et al*., 2007). Rice ratooning for large scale commercial farming has not been accepted in many countries probably due to generally low yields, lack of varieties with good ratooning ability, inferior grain quality, uneven matiurity that makes harvesting difficulty, insect and disease problems, lack of assured return from investment and lack of proper ratoon cultural practices (Bahar and De Datta, 1977; Chauhan *et al*., 1985; Oad *et al*., 2002; Tari, 2011).

1.3 Justification

Kenyan farmers need rice varieties, such as the biotechnologically derived NERICA, that can easily grow in their upland farms for food and economic security so as to fulfil Kenya's Vision 2030 that envisages moving the country into a middle-income economy by the year 2030. The use of NERICA has tremendous potential for providing genetic resistance to pests and diseases which are most problematic in the tropics (where most rice is cultivated) because of the climatic conditions that are desirable to their year round growth reproduction (Brondani *et al*., 2002). Small scale farmers representing many diverse systems and growing environments are typically least able to afford the means for combating biotic stresses caused by pests and diseases due to the high cost of pesticides. NERICA varieties which have the ability to withstand these stresses are a possible solution to the small scale farmers. Faced with the prevailing uncertainty of climate change, upland NERICA varieties may be a better option for the Kenyan farmer compared to the traditional rice varieties that require constant flooding. Upland NERICA varieties have carved a special niche as they perfectly adapt to upland conditions where smallholders lack means of irrigation, creating new opportunities of providing farmers with a potential cash crop. However, as biotechnological crops continue to be adopted, the biosafety aspect should not be overlooked hence the need for the assessment of the potential ecological risk of invasiveness of the NERICA rice varieties.

Rice-field soils from the conventional production system i.e. padding and continuous submergence with water affects the environment adversely. The fields are characterized by water logging, oxgen depletion, high moisture and relatively high organic substrate levels, hence an ideal environment for the activity of methanogenic bacteria which generates methane (CH_4) (Matthews *et al*., 2000). Rice flooding cuts off oxygen supply to the soil resulting in anaerobic fermentation of organic matter and hence CH_4 gas production, which has 21 times more global warming potential than carbon dioxide (CO_2) (Verge *et al*., 2007). Some studies report a reduction of CH_4 production arguing that; a) reduction in flooding duration reduces greenhouse gases (GHGs) emissions by about 50% (Cole *et al*., 1997); b) cultivating upland rice cultivars can reduce emissions by up to 20% (Sass *et al*., 1992). Globally, rice production has been estimated to double by the year 2020 in order to meet the demand of an increasing population, which may increase the methane production up to 50%. To curb this, rice cultivation should be looked into not only as an important activity that is related to food security but also as the global climate change agent. In particular, there is need for improved rice production techniques to reduce amount of GHGs released from rice fields. Rice varieties that could be cultivated as upland rain fed could probably meet this demand as they would minimize methane production compared to paddy rice. Paddy rice needs about 3000-5000 litres of water to produce 1kg of grain. There is, therefore, a need to find alternative environmental benign production systems with increasing resource use efficiency (especially water) and at the same time reduce the emission of GHGs from continuously flooded rice field. The mitigation option would involve a change from flooded to upland rice, to which the upland NERICA rice varieties could probably be best suited.

Although the impact of weeds on rice production is well recognized, it has not been addressed by breeders as have diseases and pests (Fischer *et al*., 1997, Kolo and Umaru, 2012). The current study being an upland experiment, response to weeds is an important factor to consider since weed competition is a major yield reducing factor in upland cultivation. The identification of competitive rice varieties may be more effective in weed suppression and provide a tool for integrated weed management (Fischer *et al*., 2001; Caton *et al*., 2003). Evaluation of NERICA rice varieties against weeds could possibly be a better method of weed control compared to herbicides application, and therefore biologically safe. Contrary to other weed control methods, improved varieties have proven better for ease of adoption. In view of this, should upland NERICA rice varieties turn out to be weed-competitive, then this would be a solution for areas such as central Kenya where herbicides such as paraquat and glyphosate are too expensive for small scale farmers and will also minimize pollution of the environment.

Knowledge of critical period of weed control will enable optimum timing of weed control interventions to reduce production costs, minimize pollution of the environment as a biosafety measure and free some labour for other lucrative roles for farmers (Akobundu, 1991; Swanton and Weise, 1991; FAO, 1996; Knezevic *et al*., 2002. By controlling weeds during the critical period, reductions in the yield and quality can be minimized. It allows identification of appropriate timing for weed management and aids in understanding of the effect of weed populations on crop yield (Tursun *et al*., 2007). Many studies have been conducted to determine the critical period of weed control in various crops under various environmental conditions (Dawson 1970; Buchanan *et al*., 1980; Rogers and Buchanan, 1986; Bryson, 1990; Acker *et al*., 1993; Evans *et al*., 2003; Knezevic *et al*., 2003). However, there are limited published studies on the critical period of weed control in rice in general and NERICA in particular. Thus critical period of weed control need to be determined with a view to reducing losses due to weed infestation and maximing upland rice yield.

Ratooning is probably one practical way of increasing rice productivity per unit land with less labour and input than the main crop since neither land preparation nor planting is needed for the ratoon crop (Sanni *et al*., 2009). Ratooning ability is also a good measure of invasiveness as invasive species in general have good ratooning ability (Parker *et al*., 1999; Andersen *et al*., 2004). The current study therefore was to assess the potential ecological risk for invasiveness, response to weed interference and the ratooning ability of NERICA and *O. sativa* rice varieties in central Kenya. This will help decision makers come up with informed decisions on the propagation of new rice varieties. Results of this study can also serve as a guide on how ratooning and optimum timing of weed control can be used to maximize upland rice yield in Central Kenya.

1.4 Objectives of the Study

1.4.1 Overall Objective

The overall objective of this study was to assess the ecological risks of invasiveness, response to weed inteference and ratooning ability of four NERICA and one *Oryza sativa* (Duorado precoce) rice varieties in central Kenya.

1.4.2 Specific Objectives

In order to prove the hypotheses stated below, the following specific objectives were formulated;

(i) To compare the response of four NERICA and one *O. sativa* rice varieties to weed interference.

(ii) To evaluate the ratooning ability of NERICA and *O. sativa* rice varieties,

(iii) To determine the critical period of weed control in fields of NERICA and *O. sativa* rice varieties, and.

(iv) To assess the potential risk of invasiveness of NERICA rice varieties.

1.5 Hypotheses

This study had the following hypotheses:

(i) NERICA and *O. sativa* rice varieties have similar response to weed interference,

(ii) NERICA and *O. sativa* rice varieties have the same ratooning ability,

(iii) NERICA and *O. sativa* rice varieties have the same critical period of weed control, and that

(iv) NERICA rice varieties have the same potential risk of invasiveness.

CHAPTER TWO

STUDY AREA

2.1 Study area location

This study was carried out at Mwea Irrigation Agricultural Development (MIAD) Center in Mwea Tebere Irrigation Scheme also known as Mwea Irrigation Scheme. The scheme is located in the west central region of Mwea Division (Figure 2.1), Kirinyaga county, central province of Kenya, approximately 100 km north east of Nairobi city at the foot hills of Mt Kenya. It lies at latitude 0^o 41'S and longitude 37^o 20'E and an altitude of 1159 m above sea level and covers an area of about 23,640 hactares (NIB, 1996). Mwea Division is the main rice producing area of Kenya.

2.2 Soils

The scheme lies in Agro-Ecological Zone AEZ iii that has high agricultural potential with dark deep vertisols with average pH of 6.8 (Jaetzold and Schimdt, 1982; FAO, 1996). As the soils are low in Nitrogen, Phosphous and Pottasium these minerals are added from inorganic sources such as fertilizers. Carbon is also low and is added from organic manure. More than 75% of the scheme area is used for rice cultivation. The remaining area is used for horticulture and subsistence farming, grazing and community activities. The area is suited for millet, sorghum, green grams, moth beans and cow peas (Pratt *et al*., 1966).

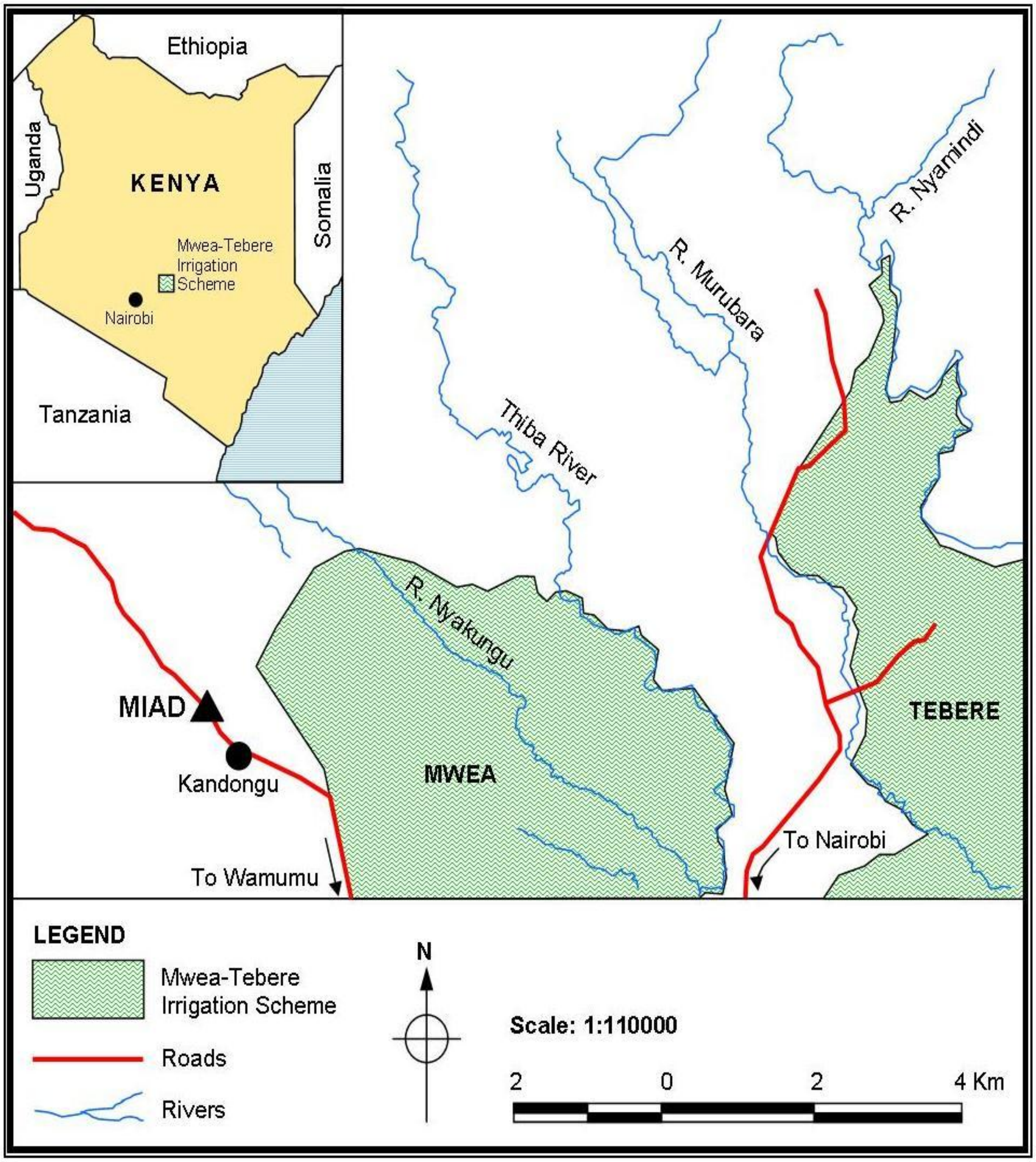

Figure 2.1: Map showing MIAD location in respect to Mwea-Tebere Irrigation Scheme, Kenya

2.3 Meteorological data

Weather data during the growing seasons of the current study was obtained from MIAD weather station. The monthly averages of the daily minimum and maximum temperatures that prevailed during the entire period of the study (January 2010-July 2011) are shown in Figure 2.2. Main crop one was planted on the 9th of April 2010 and harvested on 16th August 2010 with the lowest and the highest average temperatures recorded as 16.7°C in August 2010 and 28.2°C in April 2010 respectively. Ratoon crop one was established on 16th August 2010 and harvested on 17th November 2010 with the lowest and the highest average temperatures recorded as 16.7°C in August and 29.5°C in October 2010 respectively. Main crop two was planted on the 30th of October 2010 and harvested on 18th March 2011 with the lowest and the highest average temperatures recorded as 14.5°C in January 2011 and 28.8°C in December 2010 respectively. Ratoon crop two was established on the 18th of March 2011 and harvested on 22nd June 2011 with the lowest and the highest average temperatures recorded as 14.7°C in June and 35.6°C in May respectively.

The annual rainfall distribution in MIAD is usually bimodal with the long rains starting from March to May with a mid dry season of four months (June to September) while the short rains commence from October to December. However in this study, the long rains started earlier (January) in the year 2010 (Figure 2.3). The highest and the lowest recorded monthly rainfall that prevailed during the study period were 290mm in May 2010 and 0mm in September 2010 for main and ratoon crop one, and 283mm in April 2011 and 6mm in January 2011 for main and ratoon crops two respectively. The annual rainfall for the year 2010 was 976mm while the year 2011 recorded a total of 661mm of rainfall from January to July. The rainfall ranges during the growing period of the current study are within the recommended range for upland rice crop except for ratoon crop one where no rainfall was recorded in September 2010. This month coincided with the early growth stage of the ratoon crop growth where water is very crucial for crop development and therefore supplementary irrigation was applied within this period. According to Africa Rice Center (2008), NERICA rice responds well to low rainfall, a minimum of 20mm per week is required which should be well distributed throughout the growing period.

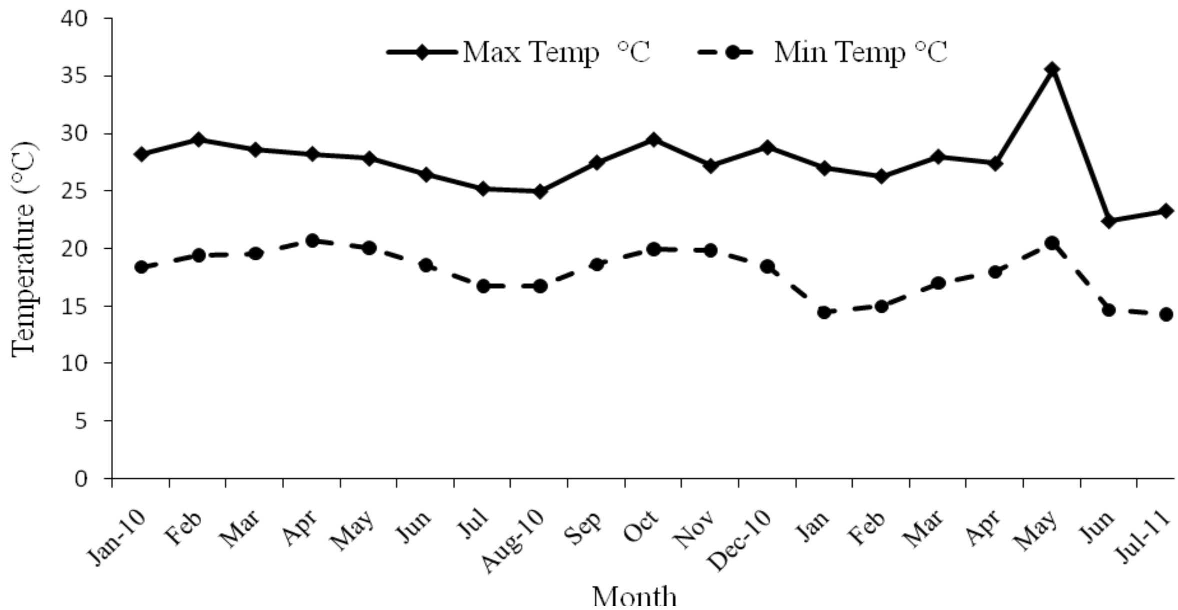

Figure 2.2: Monthly average of the daily minimum and maximum temperature (^{o}C): January 2010-July 2011

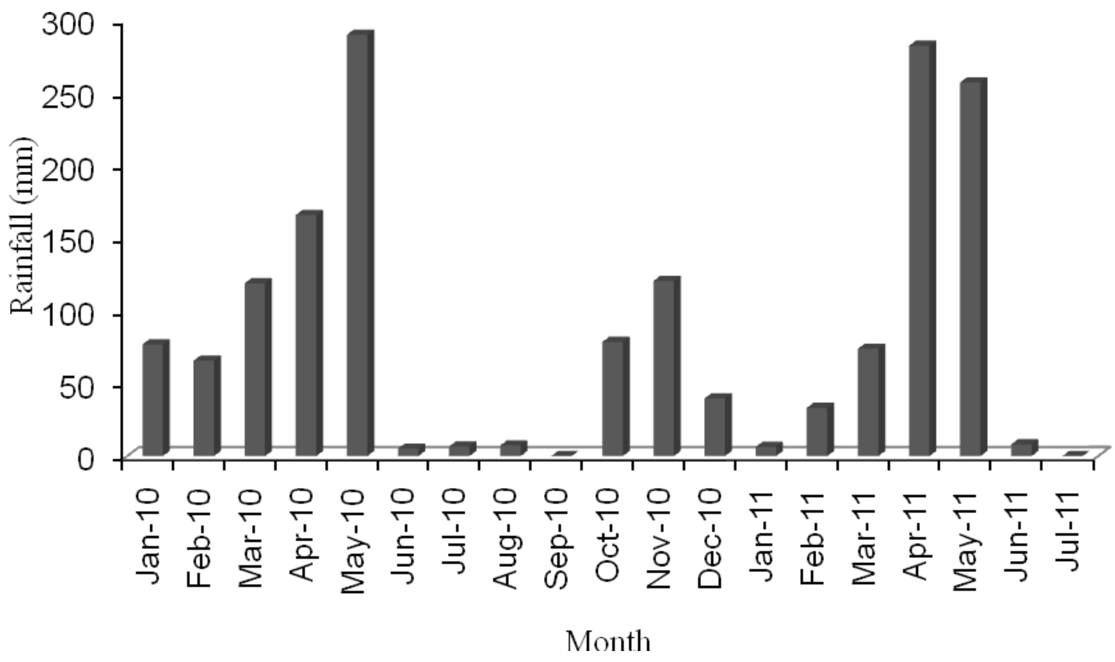

Figure 2.3: Rainfall distribution pattern at MIAD, Central Kenya (2010-2011)

CHAPTER THREE

RESPONSE OF UPLAND NERICA AND ORYZA SATIVA RICE VARIETIES TO WEED INTERFERENCE IN CENTRAL KENYA

3.1 Introduction

Weeds are plants that grow in sites where they are not wanted and which have detectable economic or environmental impact or both (Pysek *et al*., 2004). Weeds are the most universal of all crop pests, proliferating each year on every farm in Africa (Obuo *et al.*, 1997). In Asia, Africa and parts of Latin America, a wide range of weeds infest upland rice, many of which are pan-tropical, including grass weeds: *Digitaria* spp., *Echinochloa colona*, *Eleusine indica*, *Paspalum* spp., *Rottboellia cochinchinensis*, broadleaf weeds: *Commelina* spp., *Ageratum conyzoides*, *Portulaca oleracea*, *Amaranthus* spp. and *Euphorbia* spp. (De Datta, 1991; Chikoye *et al.*, 1997; Obuo *et al.*, 1997). The variability of weed species composition in upland rice tends to be greater than in the other production systems, and is dependent upon ecology, the cropping system and management practice (Ampong-Nyarko and De Datta, 1991). African soils contain 100 to 300 million buried weed seeds per hectare of which a fraction germinate and emerge each year. The soil seed population in a Nigerian experiment was estimated at 20,130 seeds per square meter (200 million per hectare) (Chikoye *et al.*, 1997). A review of crop pests in sub-Saharan Africa indicated that weeds are the most important pest to control in all zones studied (Sibuga, 1997). High humidity and high temperature conditions characteristic of sub-Saharan Africa, favor rapid and excessive weed growth (Akobundu, 1980). Weeds can reduce the yield and quality of rice by competing with the crop for sunlight, water, nutrients, space and their seeds can contaminate the harvested grain (Wanjogu *et al*., 1995; Fischer *et al*., 2001). Some weeds secrete toxic root exudates or leaf leachates, which depress the normal growth of the crop. They also serve as alternate hosts for diseases and pests (Wanjogu *et al*., 1995). In rainfed upland rice, weed competition is the most important yield reducing factor followed by drought, blast, soil acidity, general soil infertility (especially N and P deficiency), stem borers and termites (Akobundu, 1987; Moody, 1994: Johnson *et al*., 1997; Labrada, 2002).

Germination and emergence are the first steps for plant establishment, constituting important traits for competitiveness and colonization capacity (Diarra *et al*., 1985; Gealy *et al.,* 2000; Sanchez-Oliguin *et al.*, 2007). Rice varieties respond differently to competition such that tall, droopy and late maturing varieties are more productive under weed infestations than short stature, semi-dwarf and early maturing ones (Johnson and Jones, 1993; IRRI, 1993). A rice crop is considered mature when about 90% of the panicles are coloured brown and the grains on the lower portion of the panicle are in the hard dough stage at which the crop can be harvested (Yoshida, 1972; Pande, 1994; IRRI, 1992; Baloch *et al*., 2006). Maturity of rice varieties can be classified as very early (less than 105 days), early (105-120), medium (121-135 days), late (136-160 days) and very late (over 160 days) (IRRI, 1992). According to Africa Rice Center (2008), the maturity period of the four NERICAs is 95-100, 90-100 and 75-85 days for NERICA 1 and 4, NERICA 10 and NERICA 11 respectively. They are therefore classified as very early maturing according to classification by IRRI, 1992. Duorado precoce matures within 120-125 days hence classified as medium maturing (IRRI, 1992). Unlike ripening phase, which takes 35 days after 50% heading to reach complete maturity, the vegetative phase, irrespective of the variety is the only growing phase that varies to give differences in maturity periods among rice genotypes. NERICA rice varieties have been reported to mature within 70-120 days and yield from 3500 to 7000kg ha^{-1} under good management and favourable environment (IRRI, 1992; WARDA, 1999; Baloch *et al*., 2006; Nazeer *et al*., 2012).

Tiller numbers and leaf area index (LAI) have been reported (Reissig *et al*., 1986; Fofana and Rauber, 2000; Harding and Jalloh, 2011) as the key growth parameters conferring competitive ability to rice crop. Increasing LAI and tiller number will result in more competitive rice varieties but plant types with excessive mutual shading with vigorous vegetative biomass should be avoided. Tiller density and the ability of the crop to quickly produce an unbroken canopy are highly correlated (Haefele *et al*., 2004). This is especially important in aerobic rice production, where rice is grown as an upland crop and is subject to severe weed infestation (Doust, 2007). Tillering of a plant is advantageous in several ways; It has a decisive influence on grain yield (Li *et al*., 2003; Mitra *et al*., 2005; Baloch *et al*., 2006; Liu *et al*., 2012) since it is closely related to panicle number per unit ground area (Zhong *et al*., 2002), increases flowering points and subsequent seed production, increases canopy cover thereby protecting the ground thus reducing soil moisture loss through evaporation (Hyder, 1972) and suppresses weeds (Haefele *et al*., 2004), especially in aerobic rice production where rice is grown as an upland crop and is subject to severe weed infestation (Doust, 2007), increases the amount of foliage and hence provides more feed to animals, and increases a plant's chances of survival after its apical meristem is 'accidentally' lost through herbivory or fire before maturity hence a good sign of perenniality (Skerman and Riveros, 1990). Flowering is important to provide information on possibility of potential rapid seed and spore dispersal for invasiveness within the rice crop under natural conditions (Langevin *et al*., 1990).

Ferrell *et al*. (2006) observed that crop comptetition is one of the most important, but often overlooked tools in weed control. Cultivar weed competitiveness is a function of weed tolerance, or the ability to maintain high yields despite weed competitiveness, and weed suppression ability is the ability to reduce weed growth through competition (Jannink *et al*., 2000). Haefele *et al*. (2004) observed rice cultivar differences in weed competitiveness and the cultivars that compete well against weeds are often thought to be tall, rapid early growth, droopy leaves and high specific leaf area. Gibson *et al*. (2001) reported that the use of competitive cultivars in an intergrated weed management programme may also be a cost-effective approach for reducing the selective pressure for resistance as competitive cultivars allow lower herbicide rates to be used. They further noted that the use of rice cultivars to suppress weeds is an important tool in weed management in rice; however, research on competitive cultivars of rice is limited. This study therefore attempted to assess *"the response of four NERICA and one Oryza sativa upland rice varieties to weed interference in central Kenya".*

3.2 Materials and Methods

3.2.1. Plant material

The plant materials used were four NERICA; (NERICA-1, NERICA-4, NERICA-10 and NERICA-11) and one locally cultivated *Oryza sativa* (Dourado precoce) upland rice varieties (Appendix 3.1). The four NERICA rice varieties were chosen as they are currently adopted in some parts of the country such as western Kenya and are at the verge of deployement in other parts of the country, while the Dourado precoce is a traditional upland rainfed rice variety within the country (Kouko *et al*., 1992). Dourado precoce therefore compares well with the improved upland NERICA rice varieties. Seeds for the five rice varieties were obtained from the Kenya Agricultural Research Institute (KARI) Mwea located in Central Kenya at latitude 0.7°S and longitude 37°37'E (Kanya *et al*., 2013).

3.2.2 Experimental design

This was a rain fed experiment in a two-factor split-plot randomised complete block design (RCBD) replicated three times. Weeding regimes were the main plots and the five rice varieties the sub-plots. The main plots were 4m x 22m while the sub-plots were 4m x 4m. Ten weeding treatments (3UW-Wfh) (Table 3.1) were devised to examine the effects of differing periods of weed control and interference, and were similar to those of Dzomeku *et al*. (2007). The experimental layout was as shown in Table 3.2.

Table 3.1: Competition types and weeding treatments

Early competition (WI)	**Late competition** (WF)
1. 3UW: Weedy until 3 WAP	6. 3W: Weed-free until 3WAP
2. 6UW: Weedy until 6 WAP	7. 6W: Weed-free until 6WAP
3. 9UW: Weedy until 9 WAP	8. 9W: Weed-free until 9 WAP
4. 12UW: Weedy until 12 WAP	9. 12W: Weed-free until 12 WAP
5. Wih: Weedy from planting to harvesting (control)	10. Wfh: Weed-free from planting to harvesting (control)

Two types of weeding regimes were implemented after planting. The first regime (3UW-12UW) representing early crop-weed competition (WI), rice varieties competed with weeds for 3, 6, 9 and 12 WAP respectively and subsequently weeded until harvesting. In the second regime (3W-12W), representing late crop-weed competition (WF), plots were kept weed-free for 3, 6, 9 and 12 WAP by periodic hand hoeing, after which the crop was allowed to compete with the weeds until harvesting. Two control treatments were included as either full-season weed-infested (Wih) or full-season weed-free (Wfh) treatments. All weeding operations were undertaken at three weeks interval as needed, starting from the third week after planting (Dzomeku *et al*., 2007).

Table 3.2: Experimental layout for one block showing the weeding treatments in weeks

R Weedy until 6WAP	T Weedy until 12WAP	Z Weed-free until harvest (Wfh)	V Weed-free until 6WAP	X Weed-free until 12WAP	W Weed-free until 9WAP	Y Weedy until harvest (Wih)	U Weed-free until 3WAP	S Weedy until 9WAP	Q Weedy Until 3WAP
C_{6uw}	E_{12uw}	D_{Wfh}	C_{6w}	D_{12w}	C_{9w}	B_{Wih}	D_{3w}	E_{9uw}	A_{3uw}
A_{6uw}	D_{12uw}	C_{Wfh}	B_{6w}	A_{12w}	A_{9w}	E_{wih}	E_{3w}	C_{9uw}	D_{3uw}
D_{6uw}	A_{12uw}	E_{Wfh}	A_{6w}	C_{12w}	E_{9w}	C_{Wih}	C_{3w}	B_{9uw}	B_{3uw}
E_{6uw}	C_{12uw}	B_{Wfh}	D_{6w}	E_{12w}	B_{9w}	D_{Wih}	B_{3w}	A_{9uw}	C_{3uw}
B_{6uw}	B_{12uw}	A_{Wfh}	E_{6w}	B_{12w}	D_{9w}	A_{Wih}	A_{3w}	D_{9uw}	E_{3uw}

Main plots Q, R, S and T were unweeded until 3rd, 6th, 9th and 12th week while main plots U, V, W and X were weeded until 3rd, 6th, 9th and 12th week after planting respectively. Main plot Y was left unweeded until rice harvest, while Z was weeded until rice harvest. Sub-plots A-E represents rice varieties (A-NERICA 1, B-NERICA 4, C-NERICA 10, D-NERICA 11 and E-Duorado precoce).

3.2.3 Seed selection and sowing

Seed selection was carried out by water floating method as recommended by the Ministry of Agriculture, (2009). The purpose of selection was to select heavier seeds for planting leading to stronger and healthier seedlings. The process involved having enough water to cover the seeds in wide deep trays (Appendix 3.2) and mixing the seeds with the water till they were well soaked. They were then left to stand for 4 hours after which all the floating seeds were discarded while those that sunk were planted. The land was finely ploughed and harrowed using a tractor while sowing was done by use of man power. Direct seeding was carried out so that the crop and weeds germinate more or less at the same time to ensure that no plant had undue competitive advantage over the others. Seeds of each rice variety were sown at a rate of three seeds per hole and no thinning was carried out. Sowing depth of 3cm and spacing of 20cm between plants inside the row and 40cm between rows was used (Asif *et al*., 2000; Pande, 1994). Di-Ammonium Phosphate (DAP) fertilizer was used as basal application at the rate of 100kg ha-1 during land preparation while Sulphate of Ammonia was applied at the rate of 65kg ha-1 first at tillering and a second time at booting stage of the main crop. These fertilizer rates are recommended by Africa Rice Center (Sahrawat *et al*., 2001; Toure *et al*., 2013). No fertilizer was applied to the ratoon crop. Bird scaring was carried out between 6am and 6pm daily at the reproductive and ripening phase of the rice crop to protect the trial from bird damage. Two seasons of the main crop and two seasons of the ratoon crop were assessed. Main crop one and ratoon crop one were conducted at site one which had been prevously sown to rice (*Oryza sativa* L.) then left fallow for one season in the year 2010 while main crop two and ratoon crop two were conducted in a neighbouring site two in the year 2011 which was previously sown with sorghum (*Sorghum verticilliflorum* (Steud.) Stapf.). The rains started in the year 2011 in October before harvesting of ratoon crop one hence site one could not be used for main crop two. On the other hand, it was not possible to use sites with similar history i.e. planted with rice as these were not available during the period of the study, hence the choice of study site two with a different history.

3.2.4 Data collection

Naturally occurring weed species within the trial were identified and their abundance recorded in each of the four growth seasons. Data were collected on rice plant growth and yield parameters on both the main and the ratoon crop. The growth parameters investigated included plant height, tillering ability, productive tillers and leaf area index while yield parameters included number of panicles per hill, percentage filled spikelets and grain yield.

3.2.4 .1 Weed identification and abundance

Weed identification and abundance was conducted during the first weeding which was at three weeks after planting. Naturally occurring weed populations were assessed in both trials. A $1m^2$ quadrant was randomly located at each sub-plot and the weed species within it identified, counted and recorded (Appendix 3.2). Weed species that were not identified in the field were collected, pressed and taken to the University of Nairobi herbarium for identification. Those identified in the field were also later confirmed in the herbarium. The weeds were classified into different weed types as broadleaves, sedges or grasses (Johnson, 1971; Akobundu, 1987; Fischer *et al*., 2001).

3.2.4.2 Viability test

Viability tests were carried out on the four NERICA and Duorado precoce rice seeds using the tetrazolium test (Chalam *et al*., 1967; Delouche *et al*., 1974; AOSA, 1983). Twenty seeds of each rice variety were softened by soaking in water for 24 hours. They were then split open using a sharp scalpel, soaked in 1% tetrazolium salt solution for 1 hr at 40°C in the dark, after which they were washed several times with distilled water to remove excess solution. Seeds were considered viable when the embryo was completely stained red, orange or pink, or when only the extremities of the scutellum and/or the tip of the radicle remained unstained (Naredo *et al*., 1998). No change in endosperm colour was considered an indication of unviable seeds.

3.2.4.3 Growth parameters

3.2.4.3.1 Plant height

Twenty plants of each rice variety were randomly selected from each sub-plot and tagged for use in all subsequent data scoring in both the main and the ratoon crop. This selection was done at seedling stage of the main crop, two weeks after planting as described by Oosterhuis and Jernstedt, (1999). Plant height was scored every two weeks from the time of radical emergence up to maturity stage. Plant height was scored as the distance from the base of the stem to the tip of the longest leaf using a measuring rule (Yoshida, 1981).

3.2.4.3.2 Tillering ability

Tillering ability was determined by counting the total number of tillers that had emerged from each of the 20-tagged plants (section 3.2.4.3.1). This was done once every week from the time of first tiller emergence to maximum tillering (stage where tillers have increased in number to the point that it is difficult to pick out the main culm).

3.2.4.3.3 Productive tillers

The number of flowering tillers (those that produce panicles at the tip of the stem, thus representing productive tillers) (Atera *et al*., 2011) of the twenty tagged plants were counted and recorded every week starting from the time of first panicle emergence till there was no further emergence.

3.2.4.3.4 Leaf area index

Leaf area index **(**LAI) was obtained to determine the performance of rice plants against the weed-free and weed-infested plots. Sun *et al*. (1999) identified LAI as a major determinant of yield. The length and width of the first, middle and last leaf (flag leaf) from the twenty-tagged plants in each sub-plot were measured (Plate 3.1a and 3.1b) at maturity stage and their averages used to calculate LAI (Dzomeku *et al*., 2007) using equation 3.1 according to Yoshida (1981).

$$LAI = LxWxNx0.72/A \text{---Equation 3.1}$$

Where, L= length of the leaves, W= width of the leaves, N= number of leaves per plant, A= area covered per plant and 0.72 = constant used for determination of LAI of rice.

(a) length (b) width

Plate 3.1 Scoring data on the (a) length and (b) width of NERICA rice flag leaf at maturity stage of rice development.

3.2.4.4 Yield parameters

3.2.4.4.1 Number of panicles per hill

The number of panicles per hill for each of the twenty tagged plants was determined at the maturity stage of the rice crop.

3.2.4.4.2 Percentage filled spikelets

Filled spikelets per panicle were assessed at the seed maturity stage from each of the twenty tagged plants and expressed as a percentage by taking the actual count of filled spikelets to the total number of spikelets in a panicle (equation 3.2).

$$\%FS = \frac{NFSP}{TNSP} * 100 \quad \text{-- Equation 3.2}$$

Where, FS = Filled Spikelets, NFSP = Number of Filled Spikelets per Panicle,
TNSP = Total Number of Spikelets per Panicle (Sum of filled and empty spikelets).

3.2.4.4.3 Grain yield

At maturity, the plants from each sub-plot were harvested using sickle knives to stubble of about 15cm tall from the soil surface (Appendix 3.4) as described by Bahar and De Datta, (1977) and Chauhan, (1985). They were then threshed manually by hand beating the panicles against large stones (Appendix 3.5) then cleaned by hand winnowing (Appendix 3.6) to remove foreign seeds and other impurities and bagged separately on sub-plot basis. Grain weight for each sub-plot was determined after adjusting the yield to moisture content of 14% (Yoshida, 1981; Atera *et al*., 2011).

3.3 Data Analysis

The data was subjected to analysis of variance (ANOVA) procedure using the statistical software GenStat release 12.1 (Anonymous, 2009). The analysis was based on RCBD split-plot design with weeding time as the main plots and rice varieties as the sub-plots. Least significant difference (LSD) was used for mean separation at 5% significance level (Steel and Torrie, 1980; Steel *et al*., 1997; Moore and McCabe, 1999). Simple correlation analysis was used to draw inferences on the relationship between the recorded agronomic traits of rice and rice grain yield.

3.4 Results

3.4.1 Weed identification and abundance

Weed species were found to be diverse and they differed in the two sites of the current study. By grouping weeds according to their methods of reproduction and life cycle, the following groups were distinguished; broadleaves, grasses and sedges, which were annual, perennial or perennial and annual (Appendices 3.7a and 3.7b). The weed flora consisted predominantly of annuals most of which were broadleaves followed by grasses and then sedges irrespective of site of experimentation (Tables 3.3a and 3.3b and Appendices 3.7a and 3.7b).

Table 3.3a: Distribution of weed types (as % of total) at study sites one and two.

Weed type	site one	site two
Broadleaves	86.4	81.3
Grasses	9.1	12.2
Sedges	4.6	6.3

Table 3.3b: Distribution of weeds by life span (as % of total) at study sites one and two.

Life span	site one	site two
Annual	56.8	62.5
Perennial	31.8	22.9
Perennial and annual	11.4	14.6

At study site one, 44 weed species belonging to 19 families were identified (Appendix 3.7a). The family Leguminosae was ranked highest with 18.2% of the species, followed by Euphorbiaceae (11.4%) while Poaceae, Malvaceae and Compositae were ranked third with 9.1% of the species each. The least ranked families were Commelinaceae, Tiliaceae and Cruciferae among others each with 2.3% of the species. In relation to weed type, broadleaved species were the highest (86.4%) while sedges ranked the lowest (4.6%) (Table 3.3a). In terms of life span, annual species were the highest (56.8%) while annual and perennial weed species were the least (11.4%) (Table 3.3b and Appendix 3.7a). The five most dominant and frequent weed species at site one in both the main and ratoon crop were *Brachiara eruciformis*, *Sida ovata*, *Xanthium pungens*, *Euphorbia geniculata*, and *Portulaca oleracea* in order of abundance.

More weed species were found at site two compared to site one with 48 weed species belonging to 15 families (Appendix 3.7b). The difference could probably be due to the edaphic differences between the two experimental sites and management practices in the previous crops. The family Compositae was ranked highest with 16.3% of the species, followed by Poaceae and Euphorbiaceae each with 12.2%. The least ranked families at site two and also least at site one were Commelinaceae, Tiliaceae and Cruciferae each with 2.0% among others. In relation to weed type, broadleaves ranked the highest (81.3%) while sedges were the least (6.3%) (Table 3.3a). In terms of life span, annual species were the majority (62.5%) while annual and perennial were the minority (14.6%) (Table 3.3b). At site two, the five most dominant and frequent weed species were *Cyperus exaltatus*, *Dinebra retroflexa*, *Brachiara eruciformis*, *Eclipta prostata* and *Hibiscus trionum* in order of abundance. The only species found to be common and dominant in the two sites was *B. eruciformis* which was ranked the highest at site one and third highest at site two after *C. exaltatus* and *D. retroflexa.* At both sites, the number of weeds/m^2 for each of the five dominant species was found to be lower in the ratoon crop compared to the main crop.

3.4.2 Viability Test

Results of viability test using tetrazolium salt on the seeds of the four NERICAs (1, 4, 10, 11) and the standard check Duorado precoce showed viability percentages varying from 85% to 95% for NERICA 1 and NERICA 10 respectively (Figure 3.1). The seeds for the five rice varieties were therefore considered viable and used in this study.

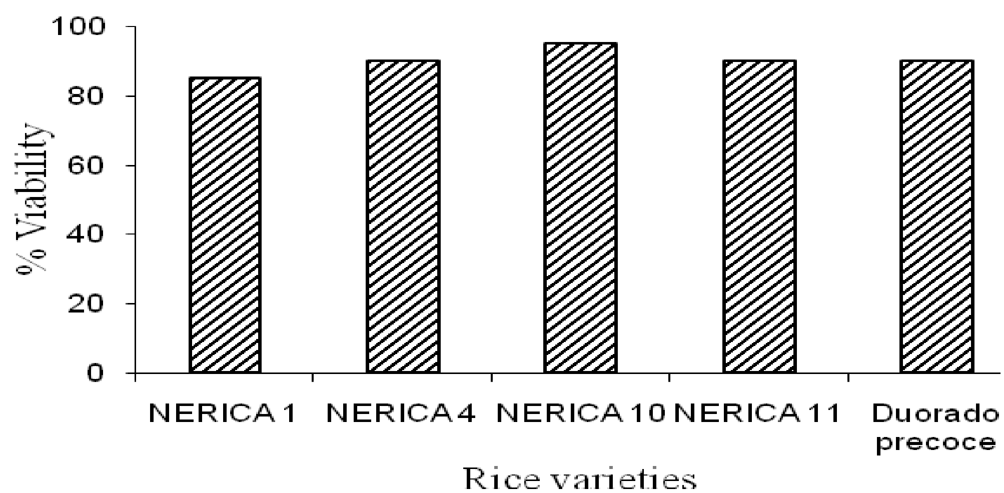

Figure 3.1: Viability of selected upland NERICA and Duorado precoce rice seeds

3.4.3 Crop growth performance

3.4.3.1 Plant height

Results on the mean plant height (cm) from the four seasons are shown in figures 3.2-3.5.

3.4.3.1.1 Mean plant height of rice varieties from main crop one

The mean plant height from main crop one varied significantly ($F_{[4,998]} = 227.47$, $p<0.001$) among the rice varieties. Though the difference in mean plant height was not significant ($p>0.05$) between the competition types, plant height of the five rice varieties increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) (Figures 3.2a-e). Full season weed-free treatment (Wfh) resulted in taller plants for the five rice varieties compared to full season weed-infested treatment (Wih).

Early competition (WI) reduced the mean plant height compared to the late competition (WF) except at 3 WAP for the five rice varieties and at 6WAP for NERICA 11 (Figure 3.2d) and these were comparable to full season weed-free check (Wfh). The rice varieties kept initially weed-free for only 3 WAP and those initially weed-infested for more than 6 WAP produced much shorter plants compared to the weed-free check (Wfh). Additional weed control after 9 WAP did not result in additional gain in plant height of the NERICAs or the Duorado precoce rice varieties relative to full season weed-free check. Keeping the plots unweeded upto 12 weeks (12UW) led to plant heights that were generally comparable to full season weed-infestation treatment (Wih). Duorado precoce attained significantly ($p<0.05$) higher mean plant height (varying from 69.3±3.1cm to 77.6±3.1cm for Wih and Wfh respectively) compared to the four NERICA rice varieties irrespective of the weeding regime. Among the four NERICA varieties, NERICA 11 attained the highest mean plant height in all the treatments varying from 63.4±2.3cm to 71.1± 2.3cm for Wih and Wfh respectively while NERICA 1 attained the shortest height varying from 59.2± 2.0cm to 65.5±2.0cm for Wih and Wfh respectively. The point of interception between the early (WI) and late (WF) competition types indicating the the critical date of weed control in relation to plant height was between 3 and 6 WAP for the five rice varieties.

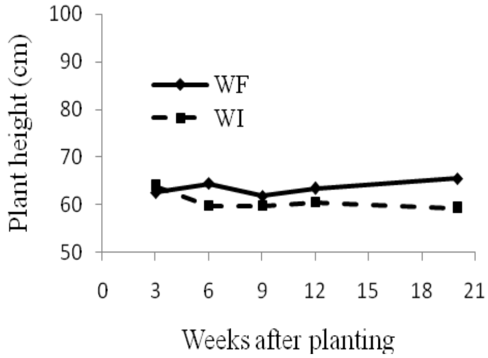

Figure 3.2 (a) NERICA 1

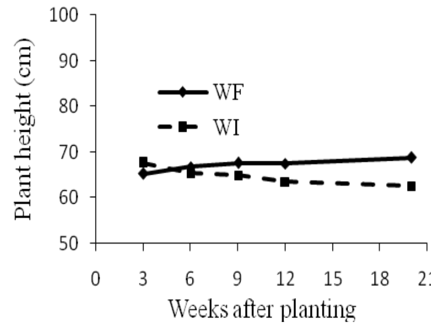

Figure 3.2 (b) NERICA 4

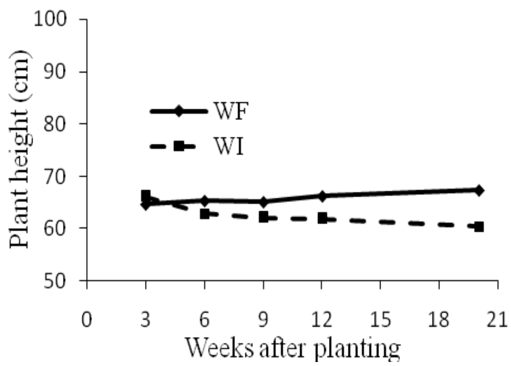

Figure 3.2 (c) NERICA 10

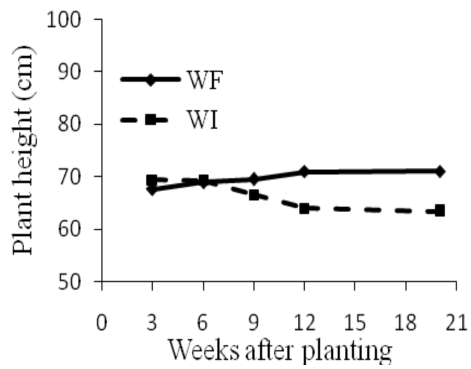

Figure 3.2 (d) NERICA 11

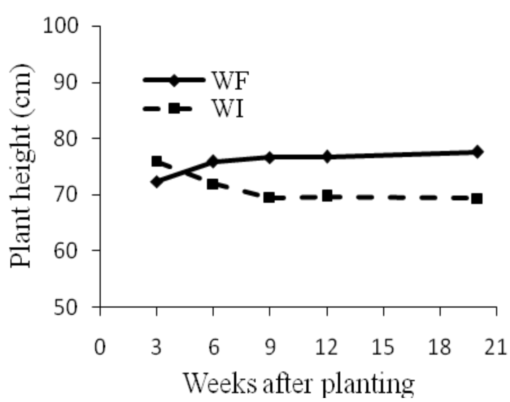

Figure 3.2 (e) Duorado precoce

Figure 3.2a-e: Mean plant height (cm) of NERICA and Duorado precoce rice varieties from main crop one as affected by early (WI) and late (WF) competition

3.4.3.1.2 Mean plant height of rice varieties from ratoon crop one

The mean plant height (cm) from ratoon crop one varied significantly ($F_{[4,898]} = 116.47$, $p<0.001$) among the rice varieties. There was however no significant ($p>0.05$) difference in mean plant height of the five rice varieties between the two competition types. Though the difference was not significant, the mean plant height of the five rice varieties generally increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) (Figures 3.3a-e). Keeping the plots unweeded for only 3 weeks (3UW) resulted in mean plant heights that were comparable to the full season weed-free (Wfh) control treatment for the five rice varieties with the former being taller for NERICA 1, NERICA 11 and Duorado precoce (Figures 3.3a, 3.3d and 3.3e respectively).

The rice varieties kept weed-free for up to 3 WACB only and those weed-infested initially for more than 6 WACB produced much shorter plants compared with the full season weed-free check (Figures 3.3a-e). Weed control after 9 WAP did not result in additional gain in plant height of either the NERICAs or the Duorado precoce rice varieties relative to the full season weed-free check. A third weeding may therefore not be necessary for a ratoon crop to attain the optimum mean plant height. Keeping the plots unweeded upto 12 weeks (12UW) led to plant heights that were generally comparable to full season weed-infestation (Wih). Duorado precoce attained significantly ($p<0.05$) higher mean plant height (varying from 44.4±5.2 cm to 54.9±5.2 cm for Wih and Wfh respectively) compared to the four NERICA rice varieties. Among the four NERICA varieties, NERICA 11 attained the highest mean plant height in all the treatments varying from 37.9±3.1 cm to 48.5±3.1 cm for Wih and Wfh respectively while NERICA 1 attained the shortest mean plant heights of 32.5±4.0 cm to 40.2±4.0 cm for Wih and Wfh respectively. Ratoon crop one had shorter plants compared to main crop one for the five rice varieties irrespective of the treatment. The point of interception between the early and late competition was between 6 and 9 WAP except for NERICA 1 and NERICA 10 where it was between 3 and 6 WAP.

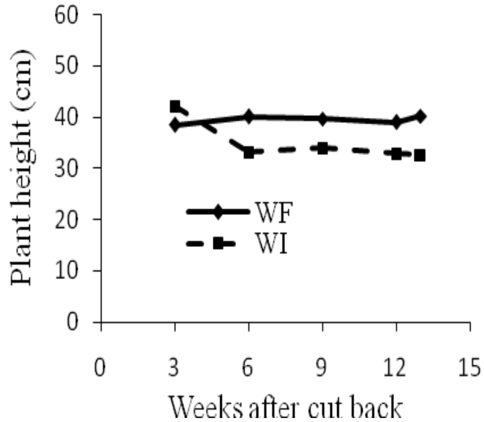

Figure 3.3 (a) NERICA 1

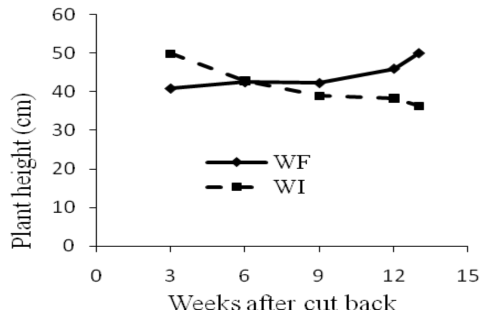

Figure 3.3 (b) NERICA 4

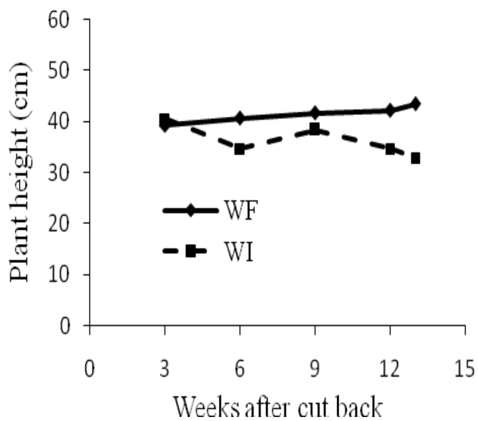

Figure 3.3 (c) NERICA 10

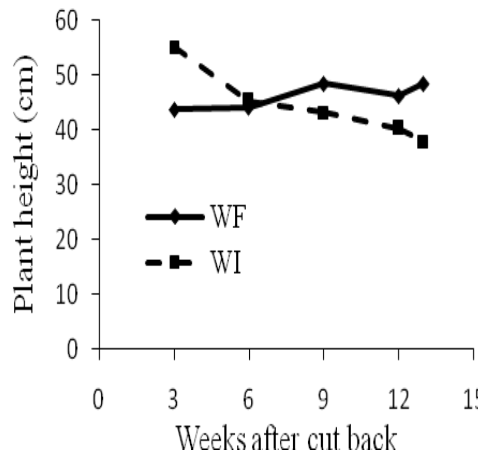

Figure 3.3 (d) NERICA 11

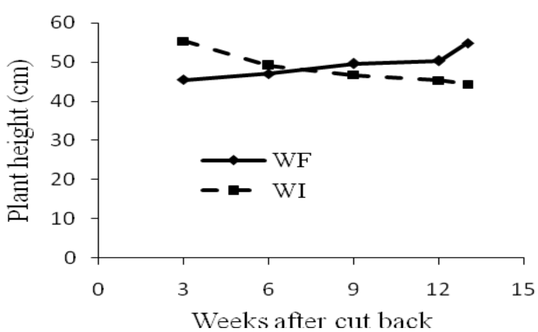

Figure 3.3 (e) Duorado precoce

Figure 3.3a-e: Mean plant height (cm) of NERICA and Duorado precoce rice varieties from ratoon crop one as affected by early (WI) and late (WF) competition

3.4.3.1.3 Mean plant height of rice varieties from main crop two

The mean plant height from main crop two (Figures 3.4a-e) showed significant ($F_{[4, 18]}$ = 3.28, $p<0.05$) variation in NERICA 1 (Figures 3.4a) for the interaction between the competition type (WI and WF) and weeding treatment (WAP). Mean height varied significantly ($F_{[4,898]}$ =137.14, $p<0.001$) among the five rice varieties. Plant height of the five rice varieties increased with increasing weed-free period (WF) and decreased with increasing weed-infestation period (WI). The rice varieties kept weed-free for up to only 3 WAP and those weed-infested initially for more than 6 WAP produced generally much shorter plants compared to the full season weed-free check though the difference was only found to be significant ($p<0.05$) for NERICA 1. Additional weed control after 9 WAP did not result in additional gain in plant height of either NERICA or the Duorado precoce rice varieties relative to full season weed-free check.

Keeping the plots unweeded upto 12 WAP resulted to plant heights that were generally comparable to full season weed-infestation (Wih). Duorado precoce attained significantly ($p<0.05$) higher mean plant height (from 55.5±3.0 cm to 65.4±3.0 cm for Wih and Wfh respectively) compared to the four NERICA rice varieties, which was in line with findings from main one and ratoon one in the current study. Among the four NERICA varieties, NERICA 11 attained the highest mean plant heights in all the treatments varying from 56.1±1.9 cm to 62.6±1.9 cm for Wih and Wfh respectively while NERICA 10 attained the shortest (46.0±1.8 cm to 55.6±1.8 cm for Wih and Wfh respectively). The point of interception between the early (WI) and late (WF) competition types was between 3 and 6 WAP for the five rice varieties.

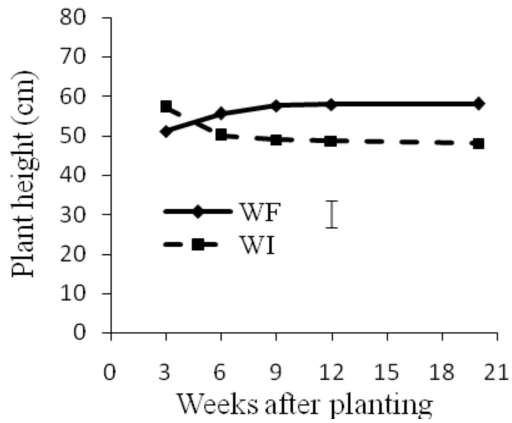

Figure 3.4 (a) NERICA 1 (vertical error bar represents the LSD at p<0.05)

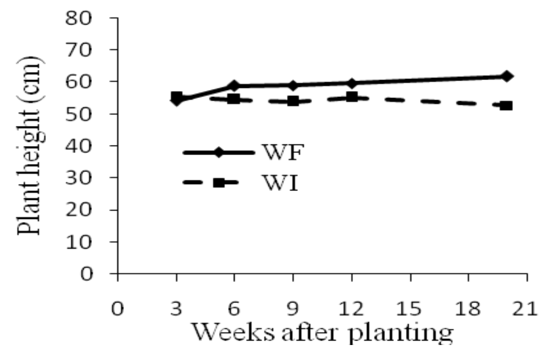

Figure 3.4 (b) NERICA 4

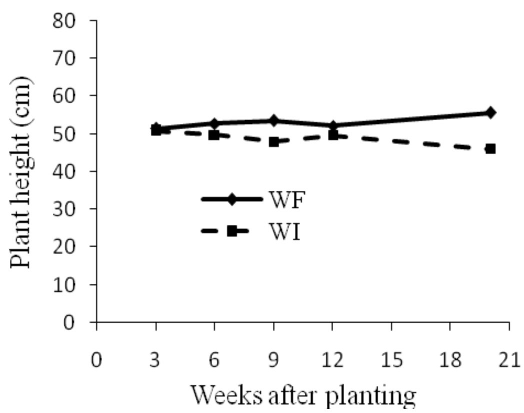

Figure 3.4 (c) NERICA 10

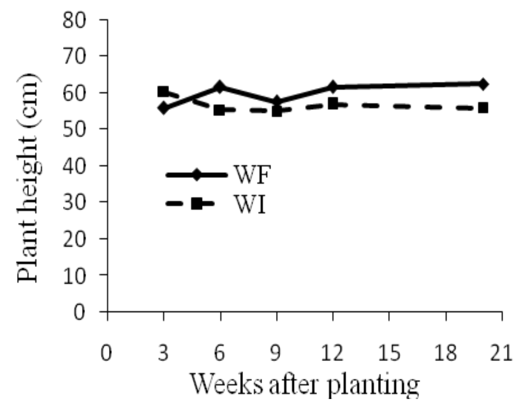

Figure 3.4 (d) NERICA 11

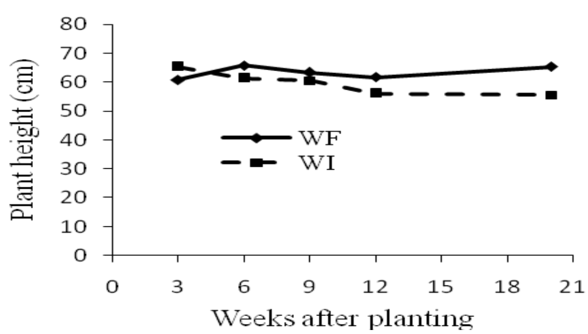

Figure 3.4 (e) Duorado Precoce

Figure 3.3a-e: Mean plant height (cm) of NERICA and Duorado precoce rice varieties from ratoon crop one as affected by early (WI) and late (WF) competition

3.4.3.1.4 Mean plant height of rice varieties from ratoon crop two

The mean plant height from ratoon crop two (Figures 3.5a-e) varied significantly ($F_{[4, 798]} = 227.39$, $p<0.001$) among rice varieties. The plant height of the five rice varieties increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) (Figures 3.5a-e). Early competition (WI) reduced the mean plant height compared to the late competition (WF) except at 3 WAP for all the five rice varieties. The rice varieties kept weed-free for up to 3 WAP only and those weed-infested initially for more than 6 WAP produced generally much shorter plants compared to the full season weed-free check though the difference was only found to be significant ($p<0.05$) for NERICA 1 (Figure 3.5a). Duorado precoce attained significantly ($p<0.05$) higher mean plant heights (ranging from 56.1±3.9 cm to 63.1±3.9 cm from Wih and Wfh respectively) compared to the four NERICA rice varieties irrespective of the weeding treatment. Among the four NERICA varieties, NERICA 11 attained the highest mean plant height in all the treatments ranging from 47.1±4.0 cm to 61.1±4.0 for Wih and Wfh respectively while NERICA 10 attained the shortest heights of 43.4±2.9 to 51.0±2.9 cm for Wih and Wfh respectively. The interception point between the two types of competition (WF and WI) was between 3 and 6 WACB for the five rice varieties.

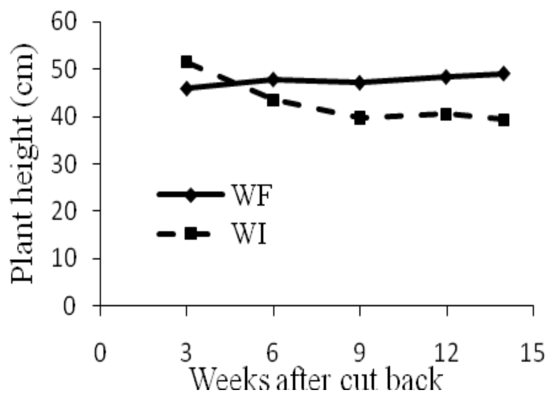

Figure 3.5 (a) NERICA 1

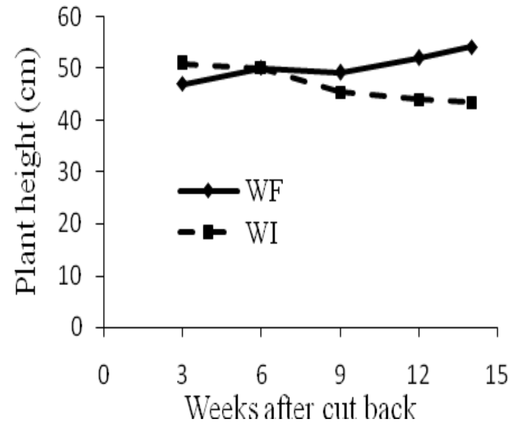

Figure 3.5 (b) NERICA 4

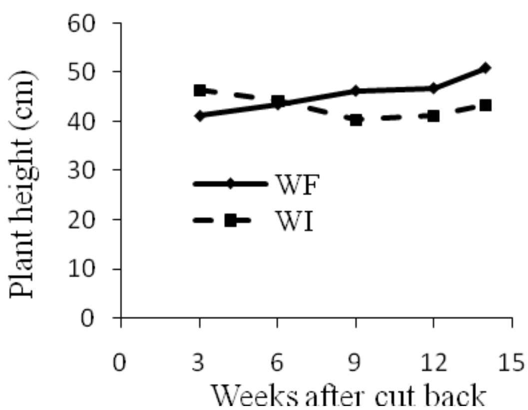

Figure 3.5 (c) NERICA 10

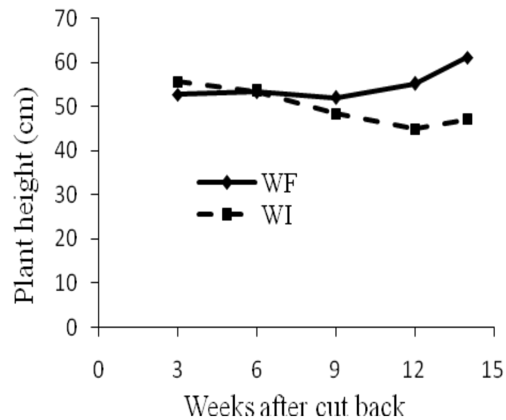

Figure 3.5 (d) NERICA 11

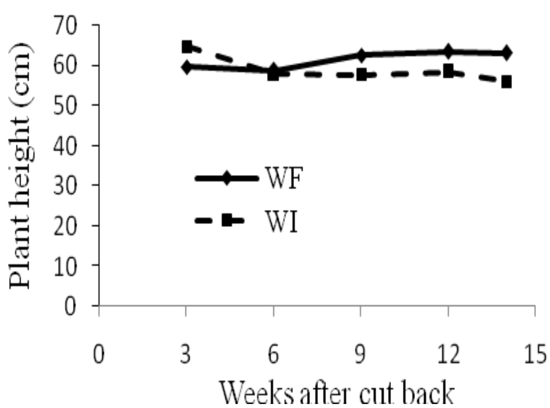

Figure 3.5 (e) Duorado Precoce

Figure 3.5a-e: Mean plant height (cm) of NERICA and Duorado precoce rice varieties from ratoon crop two as affected by early (WI) and late

3.4.3.2 Tillering ability

Results for mean number of tillers per hill for the four seasons are presented in figures 3.6-3.9.

3.4.3.2.1 Tillering ability of rice varieties from main crop one

The mean number of tillers per hill of the rice varieties from main crop one (Figure 3.6a-e) showed significant ($F_{[4, 18]} = 3.51$, $p<0.05$) variation in NERICA 4 for the interaction between the competition type (WF and WI) and the weeding treatment (WAP) (Figure 3.6b). The mean number of tillers of the five rice varieties generally increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI). The crops kept weed infested for only 3WAP attained higher mean number of tillers per hill compared to those kept weed free for the same period and were comparable to full season weed free check (Wfh) for the five rice varieties thus marking the beginning of the CPWC in relation to tiller production. Further weed control after 6 WAP did not result in significant ($p>0.05$) increase in tiller number for NERICA 4 relative to weed-free check.

Remarkably, Duorado precoce (Figure 3.6e) attained higher mean number of tillers when kept weed infested for only 3WAP (16.7±0.8) compared to the weed free check (16.0±0.8). Duorado precoce also demonstrated significantly ($p<0.05$) lower tillering ability with a range of 14.1±0.8 to 3WAP (16.7±0.8) tillers per hill for full season weed-infested and weed infested upto 3WAP (3UW) treatment respectively compared to the four NERICA rice varieties. Among the NERICA varieties, NERICA 1 attained the highest value (22.9±1.2 tillers per hill) from the full season weed-free treatment (Wfh) followed by NERICA 10 (22.0±1.2 tillers per hill) while NERICA 11 attained the least (20.9±1.0 tillers per hill). From the full season weed-infested treatment (Wih), NERICA 10 attained the highest value (17.5±1.2 tillers per hill) while NERICA 4 attained the least (16.1±0.7). Weeding upto 12 weeks led to slight increase in tillering ability for the five rice varieties which was similar to full season weed free treatment (Wfh). The point of interception between the early (WI) and late (WF) competition types signifying the critical date of weed control in relation to tiller production was between 3 and 6 WAP for the five rice varieties.

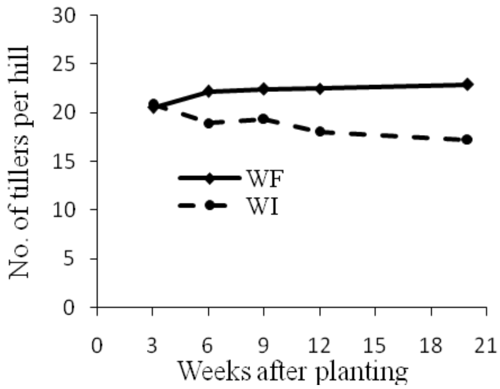

Figure 3.6 (a) NERICA 1

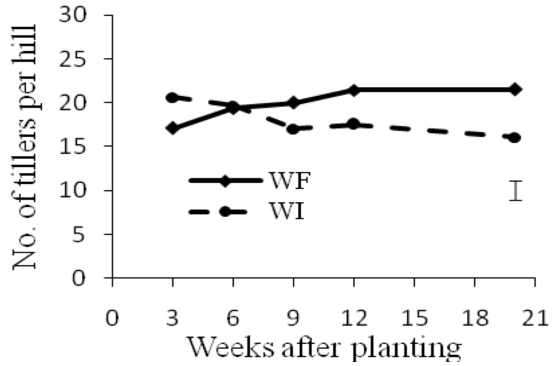

Figure 3.6 (b) NERICA 4 (vertical error bar represents the LSD at p<0.05)

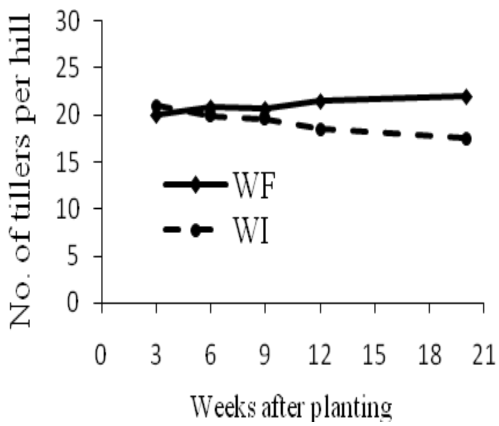

Figure 3.6 (c) NERICA 10

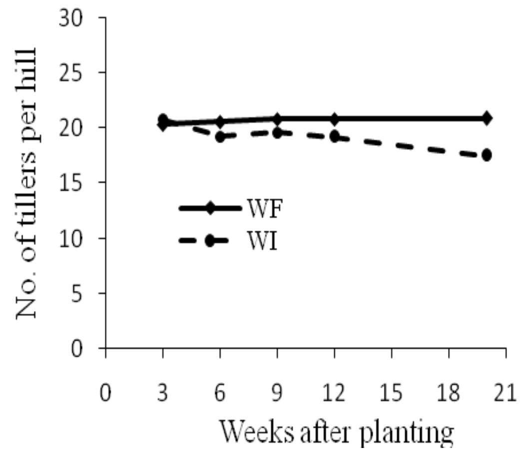

Figure 3.6 (d) NERICA 11

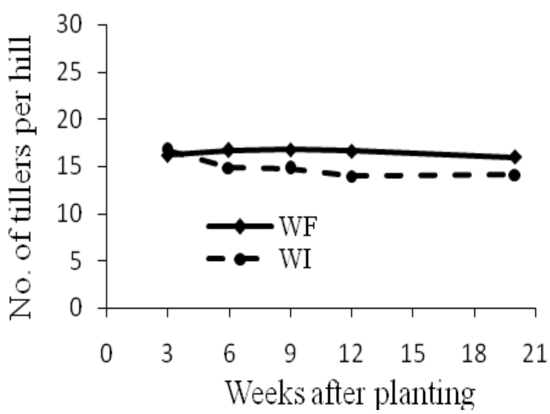

Figure 3.6 (e) Duorado precoce

Figure 3.6a-e: Mean number of tillers of NERICA and Duorado precoce rice varieties from main crop one as affected by early (WI) and late (WF) competition.

3.4.3.2.2 Tillering ability of rice varieties from ratoon crop one

The standard check Duorado precoce as well as the four NERICA rice varieties used in this study produced tillers from stubble of harvested plants from main crop one giving rise to ratoon crop one. Though the difference was not significant ($p>0.05$), the mean number of tillers of the five rice varieties generally increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) (Figure 3.7a-e). This was in line with the findings from main crop one in the current study. The crops kept weed infested for only 3WAP attained higher number of tillers than those kept weed free for the same duration and were comparable to full season weed free (Wfh) check for the five rice varieties. Remarkably, NERICAs 1, 4 and 10 attained higher mean number of tillers (22.8±3.4, 23.4±2.6 and 21.2±2.5) when kept weed infested for only 3WACB compared to their weed free check (20.5±3.4, 16.4±2.6 and 23.3±2.8 respectively).

Duorado precoce demonstrated significantly ($p<0.05$) lower tillering ability with a ranging from 12.5±3.3 to 17.8±3.3 tillers per hill for full season weed-infested and full season weed-free treatments respectively compared to the four NERICA rice varieties. Among NERICA varieties, NERICA 10 attained the highest value (23.3±2.8 tillers per hill) from the full season weed-free treatment (Wfh) followed by NERICA 4 (21.7±2.6 tillers per hill) while NERICA 11 attained the least (18.2±2.5 tillers per hill). Similarly, from the full season weed-infested treatment (Wfi), NERICA 10 attained the highest value (20.4±2.8 tillers per hill) followed by NERICA 4 (14.8±2.6 tillers per hill) while NERICA 11 attained the least (13.4±2.5 tillers per hill). The ratoon crop of NERICA 10 therefore had the best tillering ability among the four NERICAs with or without weeds hence a better competitor while that of NERICA 11 had the least hence a poor competitor against weeds. Though the difference was not significant ($p>0.05$), keeping the ratoon crop of the five rice varieties weed free for 6 WACB or more resulted to tiller count equivalent to the full season weed free check (Figure 3.7a-e). The five rice varieties showed generally lower mean number of tillers from ratoon crop one compared to main crop one (Figures 3.7 and 3.6 respectively). The point of interception between the early (WI) and late (WF) competition types was between 3 and 6 WAP except for NERICA 10 (Figure 3.7c) and Duorado precoce (Figure 3.7e) where it was between 6 and 9 WAP.

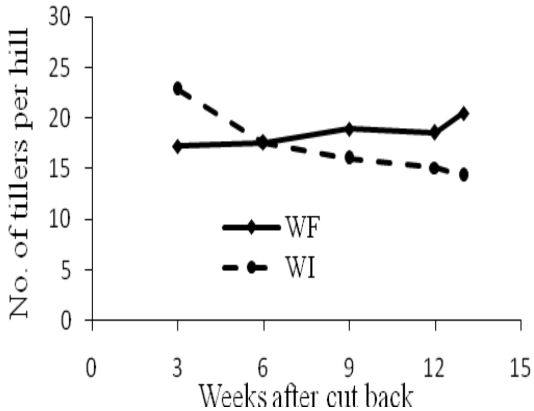

Figure 3.7 (a) NERICA 1

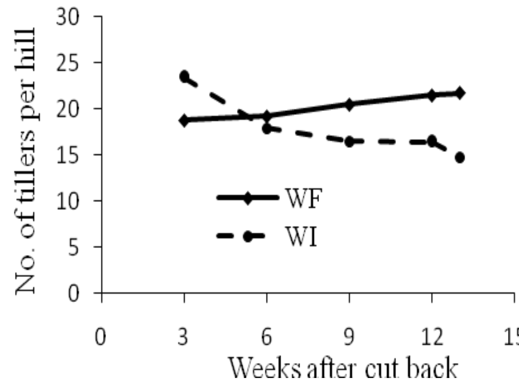

Figure 3.7 (b) NERICA 4

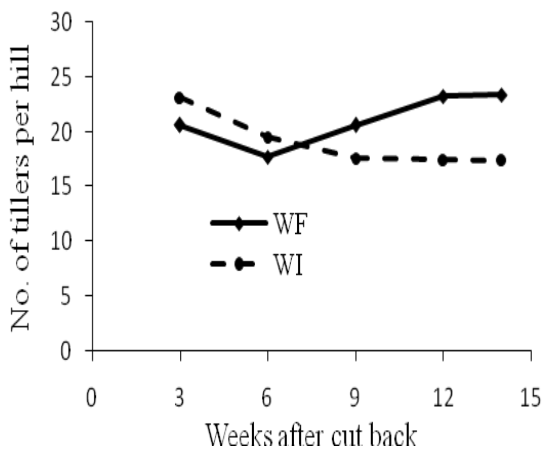

Figure 3.7 (c) NERICA 10

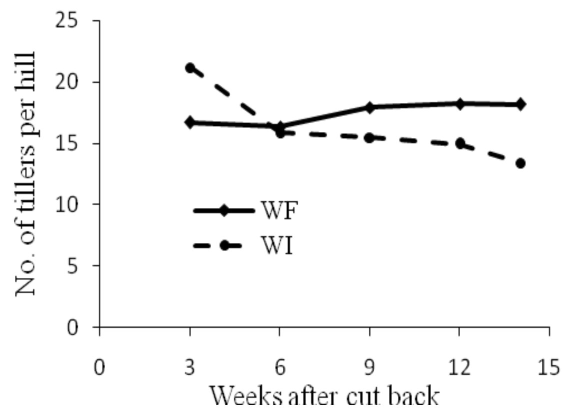

Figure 3.7 (d) NERICA 11

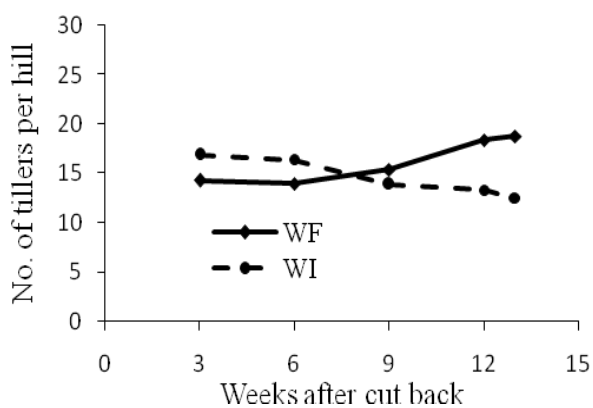

Figure 3.7 (e) Duorado precoce

Figure 3.7a-e: Mean number of tillers of NERICA and Duorado precoce rice varieties from ratoon crop one as affected by early (WI) and late (WF) competition.

3.4.3.2.3 Tillering ability of rice varieties from main crop two

The mean number of tillers per hill of the five rice varieties from main crop two varied significantly ($p<0.05$) among the rice varieties. Though the difference was not significant ($p>0.05$), the mean number of tillers of the five rice varieties generally increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI). This is in line with the findings from main and ratoon crop one in the current study. The crops kept weed infested for only 3 WAP attained higher number of tillers than those kept weed free for the same period. Remarkably, NERICAs 4 and 11 attained higher mean number of tillers (25.1±0.8 and 24.4±1.0) when kept weed infested for only 3WAP compared to their full season weed-free check (24.8±0.8 and 24.3±1.0 respectively).

The standard check Duorado precoce demonstrated lower tillering ability with a range of 17.1±0.1 to 19.0±0.1 tillers per hill from full season weed-infested and full season weed-free treatments respectively compared to the four NERICA rice varieties, which was in agreement with the findings from main and ratoon crop one in the current study. Full season weed-free (Wfh) treatment attained higher mean number of tillers per hill compared to the full season weed-infested (Wih) treatment for the five rice varieties. Among the NERICAs, NERICA 1 and 4 attained the highest values (24.8±0.9 and 24.8±0.8 respectively) from the full season weed-free treatment (Wfh) while NERICA 11 attained the least (24.3±1.0 tillers per hill). From the full season weed-infested treatment (Wih), NERICA 11 attained the highest value (22.8±1.0 tillers per hill) while NERICA 10 attained the least (21.8±0.8tillers per hill). NERICA 11 therefore tillered highly under weed-infested treatment but attained the least number of tillers in the weed-free treatment. Two early weedings at 3 and 6 weeks (6W) led to higher number of tillers per hill compared to a single early weeding at 3 weeks (3W). Weed control from six weeks after planting showed tiller count similar to the full season weed-free treatment. The interception point between the early (WI) and late (WF) competition types was between 3 and 6 WAP for both the NERICAs and the local landrace Duorado precoce which was in conformity with the findings from main crop one.

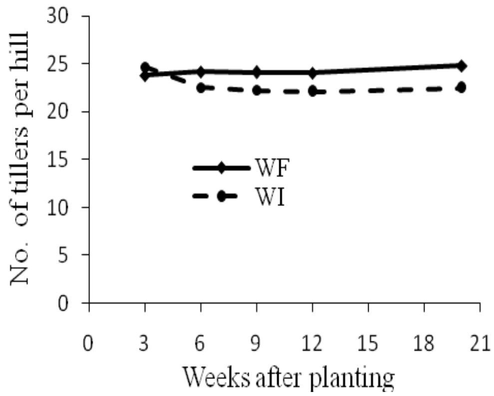

Figure 3.8 (a) NERICA 1

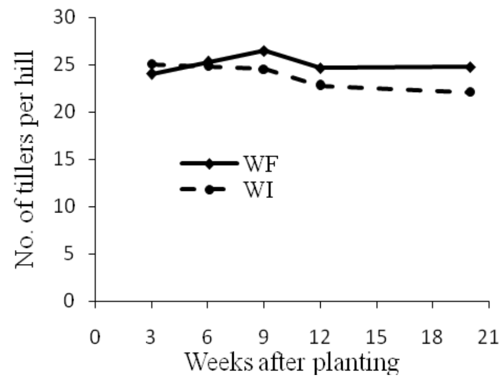

Figure 3.8 (b) NERICA 4

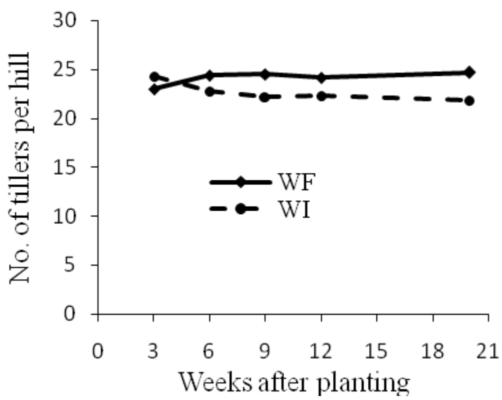

Figure 3.8 (c) NERICA 10

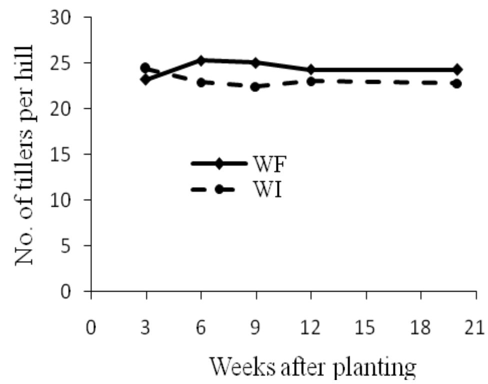

Figure 3.8 (d) NERICA 11

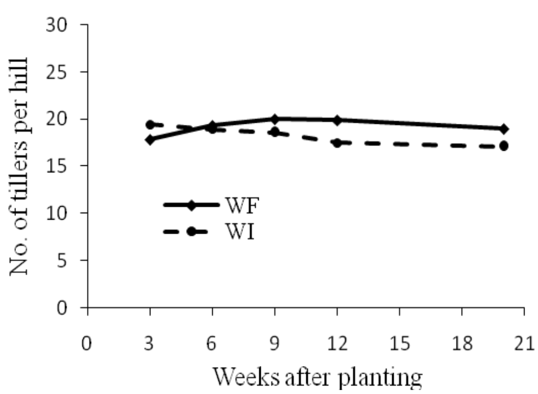

Figure 3.8 (e) Duorado precoce

Figure 3.8a-e: Mean number of tillers of NERICA and Duorado precoce rice varieties from main crop two as affected by early (WI) and late (WF) competition.

3.4.3.2.4 Tillering ability of rice varieties from ratoon crop two

The mean number of tillers from ratoon crop two showed significant ($p<0.05$) differences among the rice varieties. Though the difference was not significant ($p>0.05$), the mean number of tillers of the five rice varieties generally increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) (Figure 3.9a-e), which was in line with the findings from the other three seasons in this study. The crops kept weed infested for only 3 WAP attained higher number of tillers than those kept weed free for the same duration and were comparable to full season weed-free (Wfh) check for the five rice varieties. The full season weed-free check attained the highest mean number of tillers for the five rice varieties which was contrary to the other three seasons in this study where some varieties when kept weed infested for only 3 WACB attained higher tiller count compared to their full season weed-free check. Duorado precoce showed significantly ($p<0.05$) lower tillering ability varying from 11.5±2.3 to 18.3±2.3 tillers per hill for full season weed-infested and full season weed-free treatments respectively compared to the four NERICA rice varieties. Full season weed-free (Wfh) treatment attained higher mean number of tillers per hill compared to the full season weed-infested (Wih) treatment for the five rice varieties. Among the four NERICA varieties, NERICAs 1 and 10 attained the highest values (23.5±2.4 and 23.5±1.8 respectively) from the full season weed-free treatment (Wfh) and also from the the full season weed-infested treatment (Wih) (14.7±2.4 and 14.5±1.8 respectively). This was in line with the findings from ratoon crop one in this study. NERICA 4 attained the least tiller count in both the full season weed-free check (18.8±2.9) and full season weed-infested (13.5±2.9) treatment. Keeping the NERICA rice varieties weed free for 6 WACB or more resulted to tiller count similar to the full season weed-free check (Figure 3.9a-d). The standard check Duorado precoce attained tiller count equivalent to the full season weed-free check from the plots kept weed free upto 9 WACB or more (Figure 3.9e). The five rice varieties showed generally lower mean number of tillers from ratoon crop two compared to main crop two (Figures 3.9 and 3.8 respectively). The point of interception between the early (WI) and late (WF) competition types was between 3 and 6 WAP for both the NERICAs and Duorado precoce.

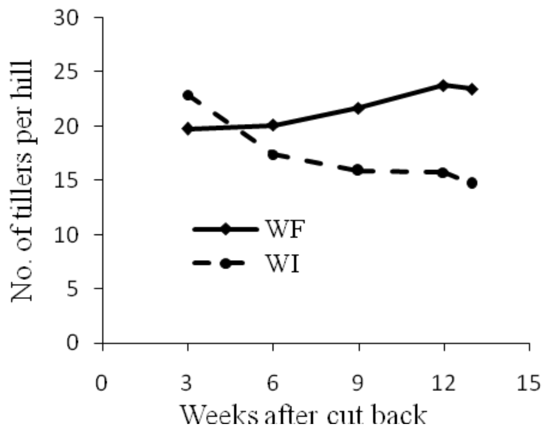

Figure 3.9 (a) NERICA 1

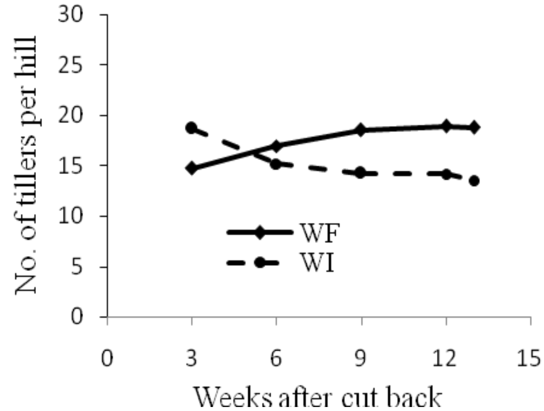

Figure 3.9 (b) NERICA 4

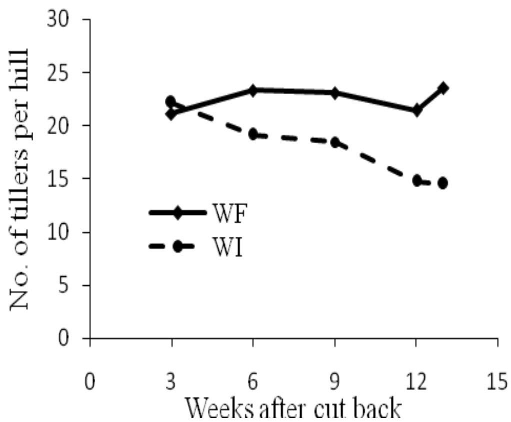

Figure 3.9 (c) NERICA 10

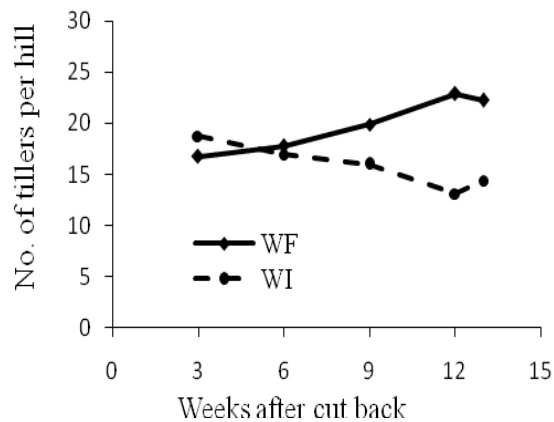

Figure 3.9 (d) NERICA 11

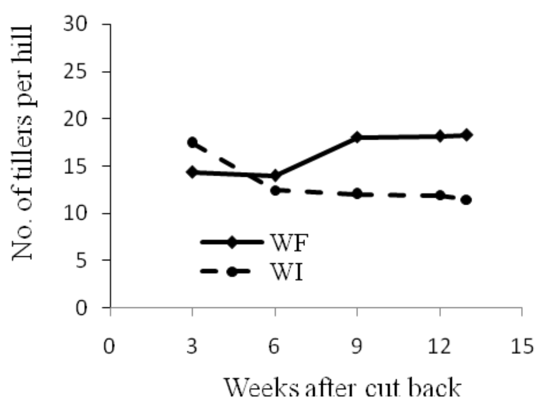

Figure 3.9 (e) Duorado precoce

Figure 3.9a-e: Mean number of tillers of NERICA and Duorado precoce rice varieties from ratoon crop two as affected by early (WI) and late (WF) competition.

3.4.3.3 Productive tillers

Results for mean number of productive (flowering) tillers per hill for the four seasons in this study are as shown in figures 3.10-3.13.

3.4.3.3.1 Productive tillers from main crop one

The mean number of productive tillers from main crop one varied significantly ($p<0.05$) among the rice varieties. Though the difference was not significant ($p>0.05$), the mean number of productive tillers of the five rice varieties increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) (Figure 3.10a-e). The crops kept weed infested for only 3 WAP attained higher number of productive tillers compared to those kept weed free for the same duration and were analogous to full season weed-free (Wfh) check for the five rice varieties. Keeping the five rice varieties weed free for 6 WAP or more resulted in number of productive tillers comparable to full season weed free check. The full season weed free (Wfh) check attained the highest mean number of productive tillers per hill for the five rice varieties while full season weed-infested treatment attained the least. Duorado precoce demonstrated significantly ($p<0.05$) lower number of productive tillers varying from 6.6±0.9 to 9.5±0.9 productive tillers per hill for full season weed-infested and full season weed-free treatments respectively compared to the NERICA rice varieties. Among the four NERICAs, NERICA 4 attained the highest number of productive tillers per hill (13.5±0.9) from the full season weed-free treatment (Wfh) while NERICA 10 attained the highest value (11.0±0.9) from the full season weed-infested treatment. NERICA 1 attained the least values in both the full season weed-free (12.7±1.1) and full season weed-infested (10.0±1.1) treatments. The differences could possibly be due to varietal differences and the effect of duration of interaction with the weeds hence the differences in response to weeds among the varieties. The point of interception of the two types of competition (WF and WI) representing the critical date of weed control in relation to productive tiller production was similar and was found to be between 3 and 6 WAP for the five rice varieties.

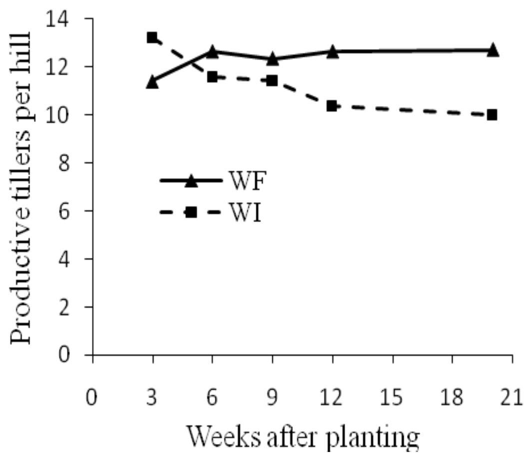

Figure 3.10 (a) NERICA 1

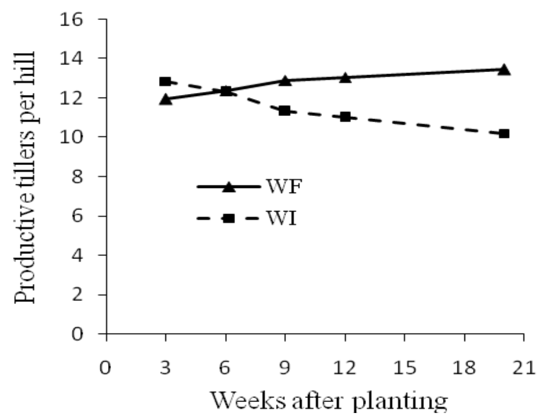

Figure 3.10 (b) NERICA 4

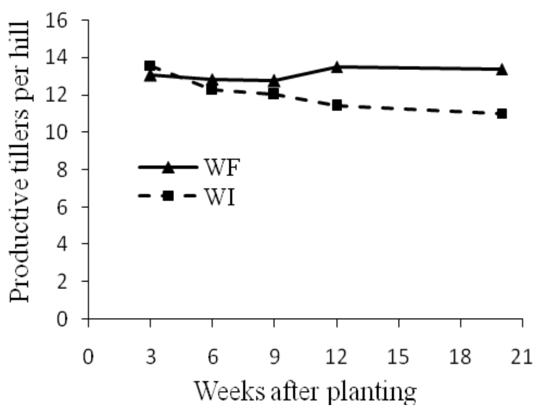

Figure 3.10 (c) NERICA 10

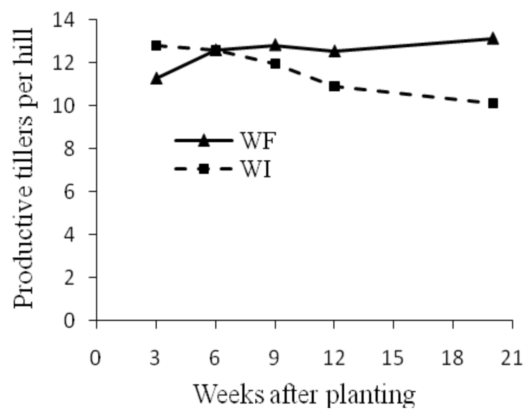

Figure 3.10 (d) NERICA 11

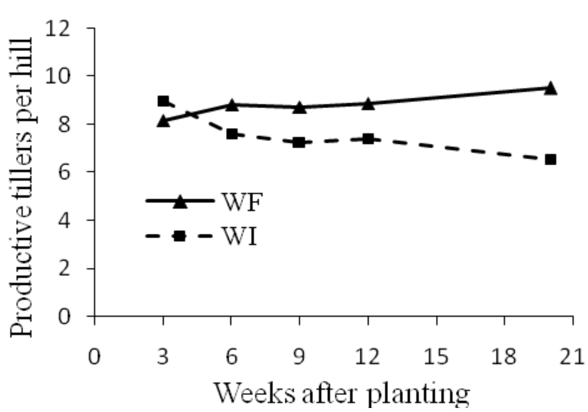

Figure 3.10 (e) Duorado precoce

Figure 3.10a-e: Productive tillers of NERICA and Duorado precoce rice varieties from main crop one as affected by early (WI) and late (WF) competition.

3.4.3.3.2 Productive tillers from ratoon crop one

The mean number of productive tillers of the five rice varieties generally increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) (Figure 3.11a-e), which was in line with the findings from main crop one in the current study. The local variety Duorado precoce showed significantly ($p<0.05$) lower productive tillers with a varying from 4.2±1.3 to 7.1±1.3 productive tillers per hill for full season weed-infested and full season weed-free treatments respectively (Figure 3.11e) compared to the four NERICA rice varieties. Among the NERICA varieties, NERICA 10 attained the highest number of productive tillers per hill (13.6±1.7) from the full season weed-free treatment (Wfh) and also from the full season weed-infested treatment (8.4±1.7) followed closely by NERICA 4. NERICA 11 attained the least values in both the full season weed-free (9.5±1.2) and full season weed-infested (7.1±1.2) treatments. NERICA 10 could therefore be considered a better competitor against weeds as a ratoon crop among the four NERICA varieties. It was also observed that NERICA 10 started flowering earlier than NERICA 4 and NERICA 1 but more or less the same time with NERICA 11. The crops kept weed infested for only 3 WACB or weed free for 6 WACB or more resulted in number of productive tillers as good as to full season weed free check. Keeping the rice varieties weed infested for more than 6 WACB reduced flowering relative to the full season weed free check (Wfh). All the rice varieties from each treatment were found to flower earlier in ratoon crop one compared to the main crop one. The mean number of productive tillers per hill for each variety per treatment was found to be lower in the ratoon than the main crop. The point of interception between the two types of competition was established to be between 3 and 6 WACB for the five upland rice varieties which was in line with the findings from main crop one.

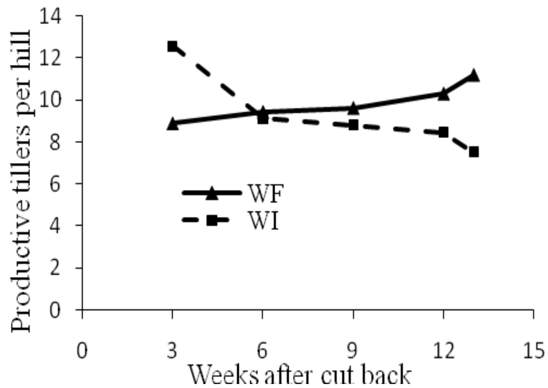

Figure 3.11 (a) NERICA 1

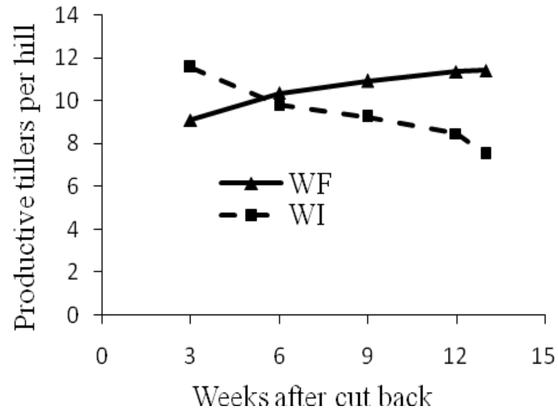

Figure 3.11 (b) NERICA 4

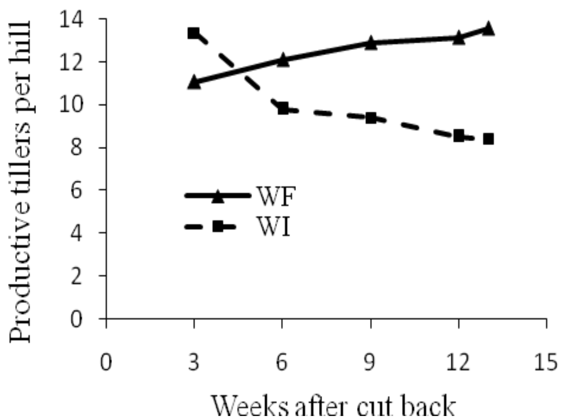

Figure 3.11 (c) NERICA 10

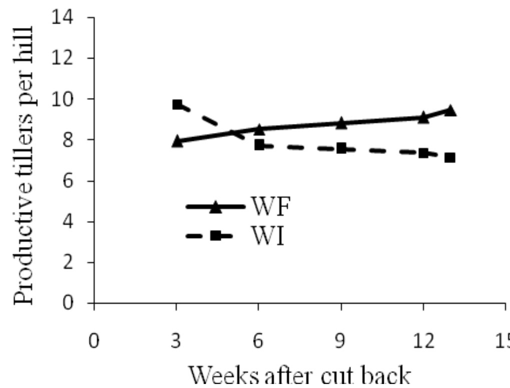

Figure 3.11 (d) NERICA 11

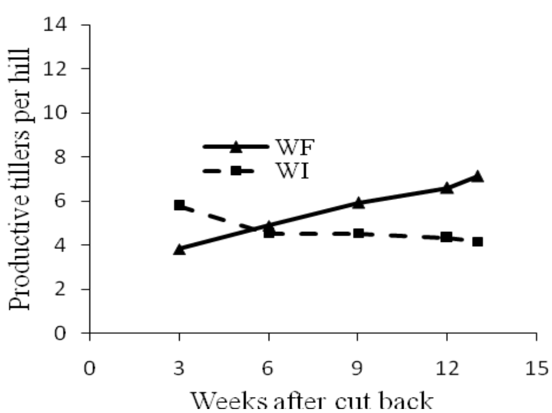

Figure 3.11 (e) Duorado precoce

Figure 3.11a-e: Productive tillers of NERICA and Duorado precoce rice varieties from ratoon crop one as affected by early (WI) and late (WF) competition

3.4.3.3.3 Productive tillers from main crop two

Results on the number of productive tillers from main crop two (Figure 3.12a-e) showed significant differences for the interaction between competition type and weeding treatments for NERICA 10 ($F_{[4, 18]}$ =4.48, p<0.05) Figure 3.12 (c) and NERICA 11 ($F_{[4, 18]}$ =8.67, p<0.001) Figure 3.12 (d), while the other three varieties showed no significant difference (p>0.05) on the same. For the two varieties, (NERICA 10 and 11), the plots initially weed infested for only 3 WAP and those kept weed free for more than 9 WAP exhibited significantly (p<0.05) higher number of productive tillers which were comparable to the full season weed-free treatment (Figures 3.12c and d). It was also observed that NERICA 10 and 11 started flowering earlier than NERICA1 and 4 and the four NERICA rice varieties started flowering earlier than the standard check Duorado precoce.

The crops kept weed infested for only 3 WAP attained higher number of productive tillers than those kept weed free for the same period for the five rice varieties. Keeping the rice varieties weed free for 9 WAP or more resulted in number of productive tillers comparable to full season weed free check except NERICA 1 (Figure 3.12 a) where the same was observed at 6 WAP. Plots subjected to late competition (WF) recorded higher number of productive tillers compared to those subjected to early competition (WI). The local landrace Duorado precoce recorded significantly (p>0.05) lower number of productive tillers varying from 4.2±1.0 to 6.8±1.0 for the full season weed-infested and full season weed-free treatments respectively compared to the four NERICAs. Among the NERICAs, NERICA 11 attained the highest number of productive tillers per hill (13.1±0.9) while NERICA 1 attained the least (11.7±1.2) from the full season weed-free treatment (Wfh). In contrast, NERICA 1 attained the highest value (8.5±1.2) from full season weed-infested treatment while NERICA 11 attained the least value (6.7±1.1). The point of interception of the two types of competition (WF and WI) was found to be between 3 and 6 WAP for the five rice varieties.

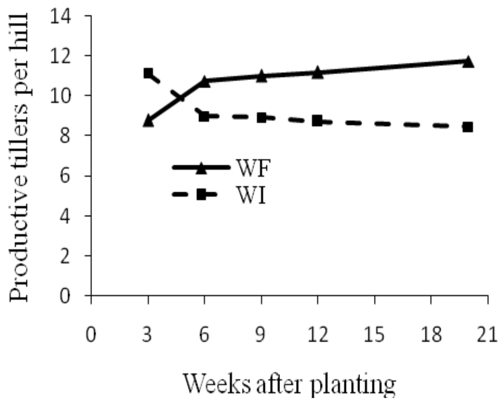

Figure 3.12 (a) NERICA 1

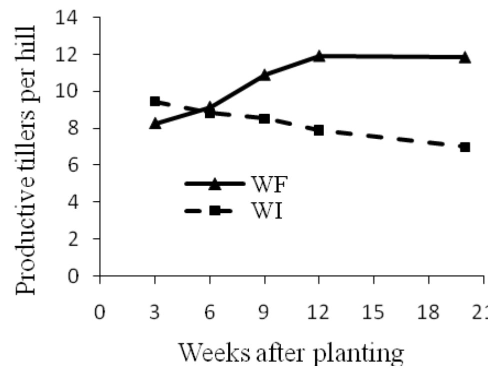

Figure 3.12 (b) NERICA 4

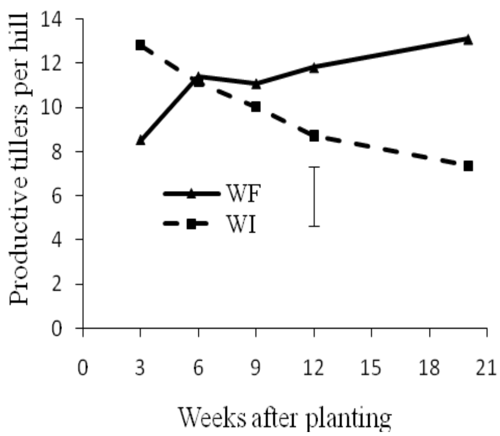

Figure 3.12 (c) NERICA 10. Vertical error bar represents the LSD at $p<0.05$.

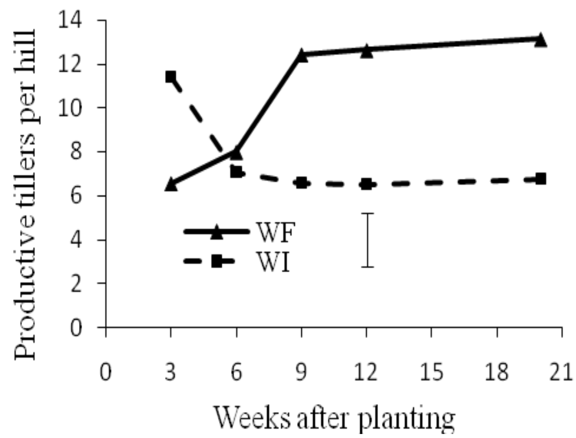

Figure 3.12 (d) NERICA 11.Vertical error bar represents the LSD at $p<0.05$.

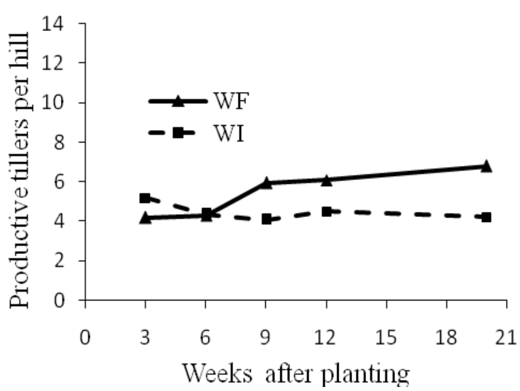

Figure 3.12 (e) Duorado precoce

Figure 3.12a-e: Productive tillers of NERICA and Duorado precoce rice varieties from main crop two as affected by early (WI) and late (WF) competition.

3.4.3.3.4 Productive tillers from ratoon crop two

The mean number of productive tillers from ratoon crop two (Figure 3.13a-d) showed significant ($F_{[4, 18]}$ =22.7, p<0.001) difference for the interaction between the competition type and the weeding treatment for the local variety Duorado precoce (Figure 3.13e). Late competition resulted to higher number of productive tillers than the early competition for the NERICAs as well as Duorado precoce. Duorado precoce produced significantly (p<0.05) lower mean number of productive tillers per hill (Figure 3.13e), with values ranging from 2.4±0.4 to 5.4±0.4 for full season weed-infested and full season weed-free treatments respectively, compared to the NERICA rice varieties. Among the NERICA varieties, NERICA 10 attained the highest values in both the full season weed-infested (7.0±0.8) and full season weed-free treatments (9.7±0.8) well NERICA 11 attained the least values (5.6±0.8 and 8.6±0.8 respectively), which was in line with the findings from ratoon crop one in the current study. The ratoon crop of NERICA 10 could therefore possibly be a better competitor against weeds compared to NERICA 11 and could possibly have translated into the observed higher ratoon grain yield for NERICA 10 compared to NERICA 11 in this study (Table 4.1). All the rice varieties from each treatment were found to flower earlier in ratoon crop two compared to the main crop two. Similarly the mean number of productive tillers per hill for each variety was found to be lower in the ratoon crop two (Figure 3.13) compared to main crop two (Figure 3.12). The point of interception of the two types of competition (WF and WI) was between 3 and 6 WAP for the five rice varieties.

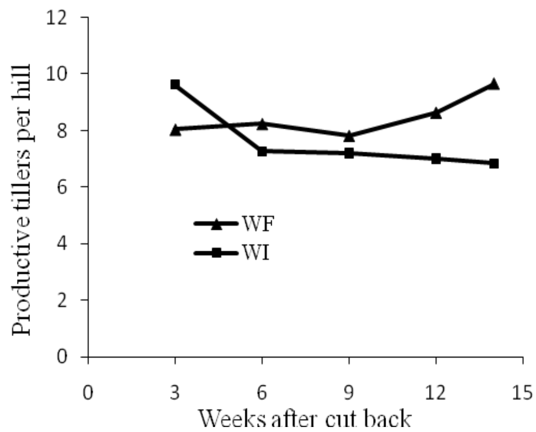

Figure 3.13 (a) NERICA 1

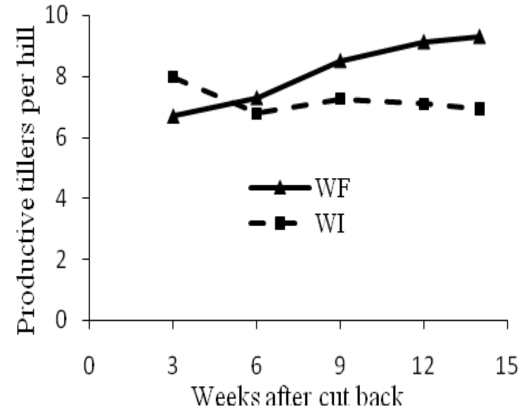

Figure 3.13 (b) NERICA 4

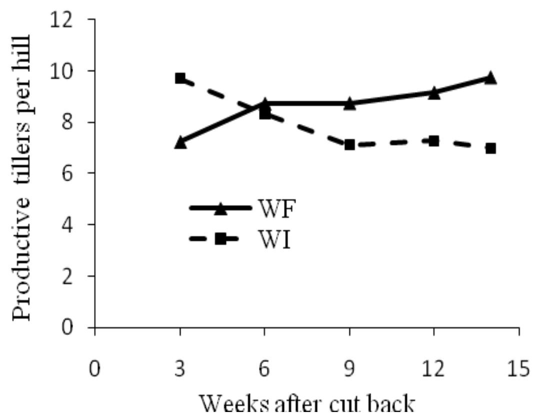

Figure 3.13 (c) NERICA 10

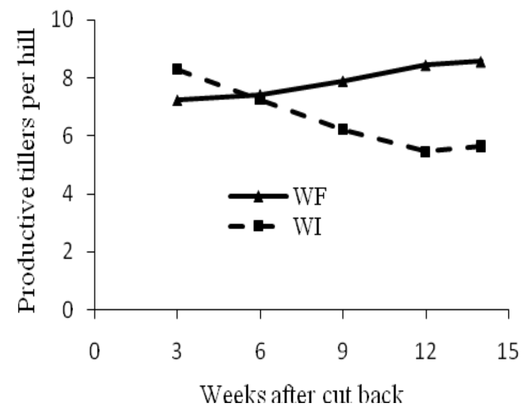

Figure 3.13 (d) NERICA 11

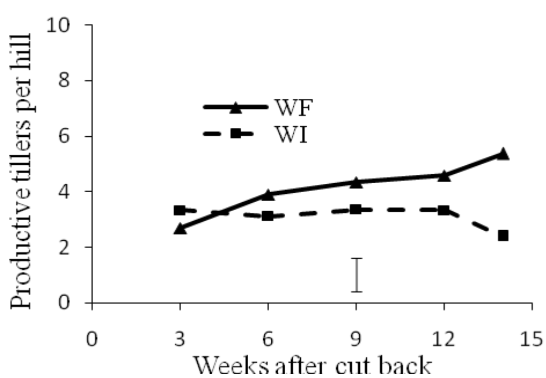

Figure 3.13 (e) Duorado precoce. Vertical error bar represent the LSD at $p<0.05$.

Figure 3.13a-e: Productive tillers of NERICA and Duorado precoce rice varieties from ratoon crop two as affected by early (WI) and late (WF) competition

3.4.3.4 Leaf area index (LAI)

Results on LAI of the five upland rice varieties for the four seasons were as depicted in Tables 3.4a-3.4d.

3.4.3.4.1 Leaf area index from main crop one

Though the difference was not significant ($p>0.05$), plots kept initially weed-free until 3 and 6 WAP gave higher LAI compared to those kept initially weed-infested for the same period for both the NERICA and the standard check Duorado precoce rice varieties (Table 3.4a). Unrestricted weed infestation exceeding 6 WAP appreciably increased LAI while weed restriction exceeding 6 WAP appreciably decreased LAI in the NERICAs as well as Duorado precoce. Prolonged interaction with weeds therefore increased LAI of the rice crop with the full season weed-infested treatment giving higher LAI compared to full season weed-free treatment for the five rice varieties. NERICA 1 attained the highest LAI (10.8±1.5) from the full season weed-infested treatment while NERICA 11 attained the least (7.5±1.6) which was lower than the standard check Duorado precoce (10.5±1.4). From the full season weed-free check, NERICA 10 showed the highest LAI (8.8±1.5) while NERICA 11 gave the least value (5.6±1.6) which was again lower than the standard check Duorado precoce (6.8±1.4) (Table 3.4a).

Table 3.4a: Leaf area index (mean±SE) of NERICA and Duorado precoce rice varieties from main crop one as affected by weed interference period

Variety	Competition type	Weeding treatment (WAP)				
		3	6	9	12	20
NERICA 1	Early (WI)	6.7±1.5	7.7±1.5	7.7±1.5	8.6±1.5	10.8±1.5
	Late (WF)	8.8±1.5	8.2±1.5	6.0±1.5	7.7±1.5	8.3±1.5
NERICA 4	Early (WI)	7.5±1.5	7.9±1.5	7.6±1.5	8.5±1.5	10.1±1.5
	Late (WF)	10.1±1.5	7.5±1.5	6.9±1.5	7.1±1.5	8.1±1.5
NERICA 10	Early (WI)	7.9±1.5	8.1±1.5	8.2±1.5	8.9±1.5	10.5±1.5
	Late (WF)	10.0±1.5	8.8±1.5	6.8±1.5	6.4±1.5	8.8±1.5
NERICA 11	Early (WI)	6.6±1.6	7.3±1.6	7.7±1.6	8.3±1.6	7.5±1.6
	Late (WF)	9.3±1.6	8.1±1.6	7.4±1.6	5.7±1.6	5.6±1.6
Duorado precoce	Early (WI)	7.0±1.4	7.7±1.4	10.0±1.4	9.0±1.4	10.5±1.4
	Late (WF)	10.0±1.4	8.8±1.4	6.2±1.4	6.3±1.4	6.8±1.4

Note: Analysis was done per variety

3.4.3.4.1 Leaf area index from ratoon crop one

The results presented in Table 3.4b show the mean LAI of the five upland rice varieties from ratoon crop one. Keeping the crop initially weed-free or weed-infested until 3 WACB gave similar LAI for NERICA 1 (2.4±0.3) and Duorado precoce (2.5±3.0) after which the plots subjected to early competition (WI) gave higher LAI compared to those subjected to late competition (WF) throughout the growth period for the two varieties. Crops kept initially weed-free until 3 WACB attained higher LAI (3.1±0.5) compared to those kept weed-infested until 3WACB (2.3±0.5) for NERICA 4 after which the plots subjected to early competition (WI) gave higher LAI compared to those subjected to late competition (WF) throughout the growth period. NERICA 10 and 11 showed higher LAI for crops kept initially weed-free until 3 and 6 WACB compared to those kept weed infested for the same period after which the plots subjected to early competition (WI) gave higher LAI compared to those subjected to late competition (WF) throughout the growth period for the two varieties (Table 3.4b). Prolonged interaction with weeds consequently increased LAI of the rice crop with the full season weed-infested treatment giving higher LAI compared to full season weed-free treatment for the five rice varieties. NERICA 10 gave the highest LAI (3.2±0.4) from the full season weed-infested treatment while NERICA 11 gave the least value (2.4±0.5). From the full season weed-free check, Duorado precoce showed the highest LAI (2.2±3.0) followed closely by NERICA 4 (2.1±0.5) while NERICA 1 gave the least value (1.6±0.3). The five rice varieties showed generally lower LAI in ratoon crop one compared to main crop one (Tables 3.4a and 3.4b). The ratoon LAI values varied from 1.6±0.3 for NERICA 1 in the full season weed-free treatment to 3.2±0.4 for NERICA 10 in the full season weed-infested treatment compared to the range of 5.6±1.6 for NERICA 11 in full season weed-free treatment to 10.8±1.5 for NERICA 1 in full season weed-infested treatment for main crop one.

Table 3.4b: Leaf area index (mean±SE) of NERICA and Duorado precoce rice varieties from ratoon crop one as affected by weed interference period

Variety	Competition type	Weeding treatment (WACB) 3	6	9	12	13
NERICA 1	Early (WI)	2.4±0.3	2.0±0.3	2.3±0.3	2.6±0.3	2.5±0.3
	Late (WF)	2.4±0.3	1.8±0.3	1.8±0.3	1.9±0.3	1.6±0.3
NERICA 4	Early (WI)	2.3±0.5	3.2±0.5	2.4±0.5	2.6±0.5	2.8±0.5
	Late (WF)	3.1±0.5	2.0±0.5	2.2±0.5	2.4±0.5	2.1±0.5
NERICA 10	Early (WI)	2.1±0.4	2.4±0.4	2.8±0.4	2.7±0.4	3.2±0.4
	Late (WF)	2.5±0.4	2.6±0.4	1.7±0.4	1.9±0.4	1.8±0.4
NERICA 11	Early (WI)	2.1±0.5	2.1±0.5	2.6±0.5	2.2±0.5	2.4±0.5
	Late (WF)	2.6±0.5	2.2±0.5	2.0±0.5	2.0±0.5	1.7±0.5
Duorado precoce	Early (WI)	2.5±3.0	2.7±3.0	2.6±3.0	2.5±3.0	2.7±3.0
	Late (WF)	2.5±3.0	1.8±3.0	2.1±3.0	2.0±3.0	2.2±3.0

Note: Analysis was done per variety

3.4.3.4.3 Leaf area index from main crop two

Though the difference was not significant (p>0.05), the plots kept initially weed-free until 3 WAP resulted into higher LAI compared to those kept initially weed-infested until 3 WAP and also higher than the full season weed-free check treatment for both the NERICAs and Duorado precoce rice varieties (Table 3.4c). Keeping the plots initially weed-free until 6 WAP resulted into higher LAI values for NERICA 1 (3.3±0.5) and the check Duorado precoce (2.9±0.9) compared to the plots kept initially weed-infested until 6 WAP (2.8±0.5 and 2.7±0.9 respectively). Plots subjected to weed infestation exceeding 6 WAP attained higher LAI values than the plots kept weed free beyond 6 WAP for the four NERICAs and Duorado precoce, with the full season weed-infested treatment giving higher LAI compared to full season weed-free treatment. NERICA 10 gave the highest LAI (4.3±0.8) from the full season weed-infested treatment while NERICA 4 gave the least value (3.1±2.2). From the full season weed-free check, Duorado precoce showed the highest LAI (3.5±0.9) followed closely by NERICA 11 (3.2±0.7) while NERICA 4 gave the least value (2.3±2.2). Main crop two (Table 3.4c) was found to have generally lower mean LAI values compared to main crop one (Table 3.4a) in the current study.

Table 3.4c: Leaf area index (mean±SE) of NERICA and Duorado precoce rice varieties from main crop two as affected by weed interference period

Variety	Competition type	Weeding treatment (WAP)				
		3	6	9	12	20
NERICA 1	Early (WI)	2.5±0.5	2.8±0.5	3.1±0.5	3.3±0.5	3.2±0.5
	Late (WF)	3.7±0.5	3.3±0.5	2.6±0.5	2.5±0.5	2.7±0.5
NERICA 4	Early (WI)	3.0±2.2	3.6±2.2	3.2±2.2	3.3±2.2	3.1±2.2
	Late (WF)	4.1±2.2	3.4±2.2	2.8±2.2	2.3±2.2	2.3±2.2
NERICA 10	Early (WI)	2.5±0.8	2.9±0.8	3.4±0.8	3.3±0.8	4.3±0.8
	Late (WF)	3.7±0.8	2.9±0.8	3.0±0.8	2.7±0.8	2.6±0.8
NERICA 11	Early (WI)	3.1±0.7	2.5±0.7	2.9±0.7	3.9±0.7	4.2±0.7
	Late (WF)	3.6±0.7	2.3±0.7	2.5±0.7	3.2±0.7	3.2±0.7
Duorado precoce	Early (WI)	4.2±0.9	2.7±0.9	3.2±0.9	3.9±0.9	4.0±0.9
	Late (WF)	3.1±0.9	2.9±0.9	2.6±0.9	2.8±0.9	3.5±0.9

Note: Analysis was done per variety

3.4.3.4.4 Leaf area index from ratoon crop two

Results from ratoon crop two (Table 3.4d) showed that though the difference was not significant ($p>0.05$), the plots kept initially weed-free until 3 WACB attained higher LAI compared to those kept initially weed-infested for the same period for NERICAs 1 and 4 and local landrace Duorado precoce. NERICA 10 and 11 showed higher LAI for plots initially kept weed-free until 3 and 6 WAP compared to those initially kept weed-infested for the same duration. Plots subjected to weed infestation exceeding 6 WACB attained higher LAI values than the plots kept weed free beyond 6 WACB for the four NERICAs and Duorado precoce. Though the difference was not significant ($p>0.05$), full season weed-infested treatment scored higher LAI compared to full season weed-free treatment for each rice variety. NERICA 4 attained the highest LAI (1.9±0.5) from the full season weed-infested treatment while NERICA 11 gave the least (1.3±0.4). From the full season weed-free check, NERICA 11 showed the highest LAI (1.9±0.4) while the local land race Duorado precoce gave the least value (1.2±0.3). Ratoon crop two (Table 3.4d) was found to have generally lower mean LAI values compared to main crop two (Table 3.4c).

Table 3.4d: Leaf area index (mean±SE) of NERICA and Duorado precoce rice varieties from ratoon crop two as affected by weed interference period

Variety	Competition type	Weeding treatment (WACB)				
		3	6	9	12	14
NERICA 1	Early (WI)	1.6±0.5	2.0±0.5	1.9±0.5	1.8±0.5	1.8±0.5
	Late (WF)	2.2±0.5	1.3±0.5	1.3±0.5	1.2±0.5	1.4±0.5
NERICA 4	Early (WI)	1.4±0.5	1.7±0.5	2.0±0.5	2.0±0.5	1.9±0.5
	Late (WF)	1.7±0.5	1.2±0.5	1.7±0.5	1.4±0.5	1.7±0.5
NERICA 10	Early (WI)	1.5±0.3	1.7±0.3	1.5±0.3	1.8±0.3	1.8±0.3
	Late (WF)	2.4±0.3	1.9±0.3	1.1±0.3	1.6±0.3	1.5±0.3
NERICA 11	Early (WI)	1.8±0.4	2.0±0.4	1.5±0.4	1.3±0.4	1.3±0.4
	Late (WF)	1.7±0.4	1.7±0.4	2.2±0.4	2.2±0.4	1.9±0.4
Duorado precoce	Early (WI)	1.6±0.3	1.7±0.3	1.6±0.3	1.7±0.3	1.7±0.3
	Late (WF)	2.1±0.3	1.5±0.3	1.4±0.3	1.1±0.3	1.2±0.3

Note: Analysis was done per variety

3.4.4 Yield components

The number of panicles per hill and the percentage filled spikelets were considered in the current study to assess the effect of weed interference on yield components of the five upland rice varieties.

3.4.4.1 Number of panicles per hill

Results on the number of panicles per hill for the four seasons in the current study are presented in figures 3.14-3.17.

3.4.4.1.1 Number of panicles per hill from main crop one

As the results for main crop one show (Figures 3.14a-e), the plots subjected to late competition (WF) recorded higher number of panicles compared to those subjected to early competition (WI) with the full season weed-free treatment attaining the highest number of panicles while the full season weed-infested treatment attained the least for the five rice varieties. From the full season weed-free treatment, Duorado precoce attained higher number of panicles per hill (22.2±1.5) compared to the NERICA varieties. Among the four NERICA rice varieties, NERICA 11 attained the highest number of panicles (19.9±2.4) while NERICA 1 attained the least (19.0±1.8) from the full season weed-free treatment. From the full season weed-infested treatment, NERICA 4 attained the highest value (15.8±1.5) while NERICA 1 attained the least (13.0±1.8) which was lower than the standard check Duorado precoce (13.6±1.5). The crops kept weed-infested for only 3 WAP attained higher number of panicles than those kept weed free for the same duration for the five rice varieties and the values were equivalent to full season weed-free treatment. Keeping the rice varieties weed free for 6 WAP or more resulted in higher number of panicles per hill compared to those kept weed-infested for the same period for the four NERICA rice varieties and the values were comparable to full season weed-free check (Figures 3.14a-d). Keeping Duorado precoce weed free for 9 WAP or more resulted in higher number of panicles per hill compared to those kept weed-infested for the same time and the values were analogous to full season weed-free check (Figure 3.14e). Weeding for the rice crop after 12 weeks did not affect panicle production relative to full season weed infestation. The point of interception between early (WI) and late (WF) competition denoting the critical date of weed control in relation to panicle production was found to be between 3-6 WAP and 6-9 WAP for the NERICAs and local landrace Duorado precoce respectively.

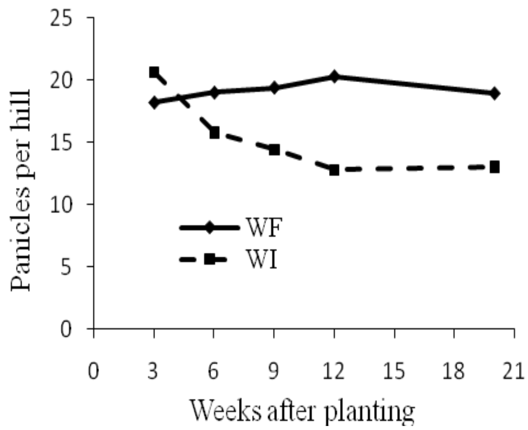

Figure 3.14 (a) NERICA 1

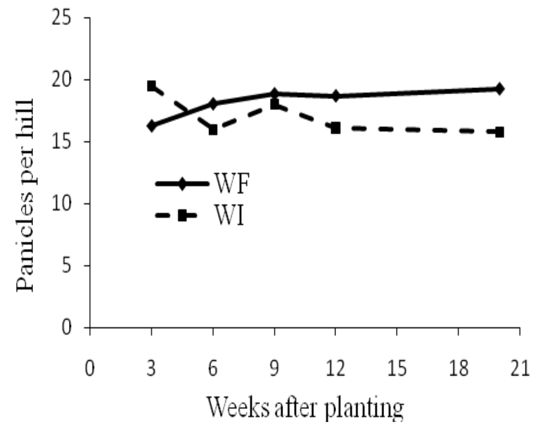

Figure 3.14 (b) NERICA 4

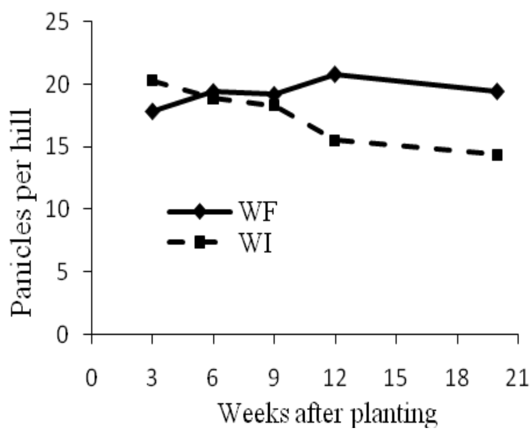

Figure 3.14 (c) NERICA 10

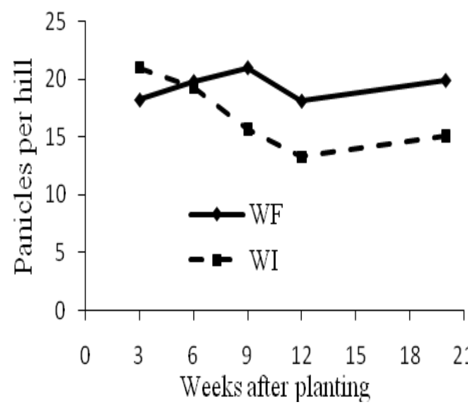

Figure 3.14 (d) NERICA 11

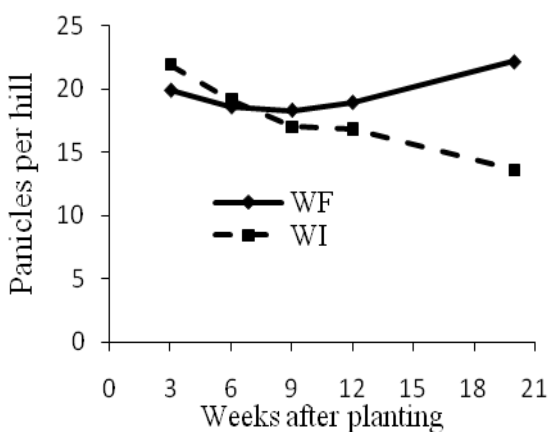

Figure 3.14 (e) Duorado precoce

Figure 3.14a-e: Number of panicles of NERICA and Duorado precoce rice varieties from main crop one as affected by early (WI) and late (WF) competition

3.4.4.1.2 Number of panicles per hill from ratoon crop one

Results from ratoon crop one (Figures 3.15a-e) demonstrated that though the difference was not significant ($p>0.05$), the plots subjected to late competition (WF) recorded higher number of panicles compared to those subjected to early competition (WI) with the full season weed-free treatment attaining the highest number of panicles for the five rice varieties while the full season weed-infested treatment attained the leas. This was in conformity with the findings from main crop one in this study. From the full season weed-free treatment, Duorado precoce attained the highest number of panicles per hill (15.7±2.4) compared to the NERICA varieties, which was in line with the findings from main crop one in this study. Among the four NERICA rice varieties, NERICA 10 attained the highest number of panicles (15.3±2.3) while NERICA 1 attained the least (12.3±2.5) from the full season weed-free treatment which supports the findings from main crop one. From the full season weed-infested treatment, NERICA 11 attained the highest value (9.0±3.4) which was higher than that of Duorado precoce (8.8±2.4) while NERICA 4 attained the least (6.6±1.7).

Keeping Duorado precoce (Figure 3.15e), weed free for 9 WAP or more resulted to higher number of panicles per hill compared to those kept weed-infested for the same period and the values were comparable to full season weed-free check (Figure 3.15e). This is in line with the findings from main crop one in the current study. The CPWC in relation to panicle production could possibly therefore be between 3 and 6 WACB and between 3 and 9 WACB for the NERICAs and Duorado precoce respectively. Duorado precoce attained generally higher number of panicles per hill compared to the NERICAs which was in line with the findings from main crop one. The ratoon crop of the five rice varieties in different weeding treatments produced less panicles compared to the main crop (Figures 3.15 and 3.14 respectively). This could possibly have translated to the observed lower grain yield in the ratoon crop compared to the main crop in the current study (Table 4.1). The point of interception between early (WI) and late (WF) competition denoting the critical date of weed control in relation to panicle production was found to be between 3-6 WACB and 6-9 WACB for the NERICAs and Duorado precoce respectively, which was in conformity to the findings from main crop one in this study.

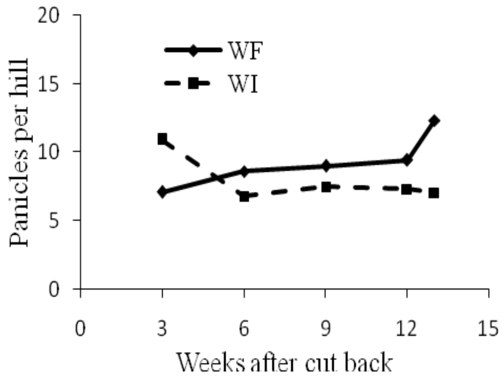

Figure 3.15 (a) NERICA 1

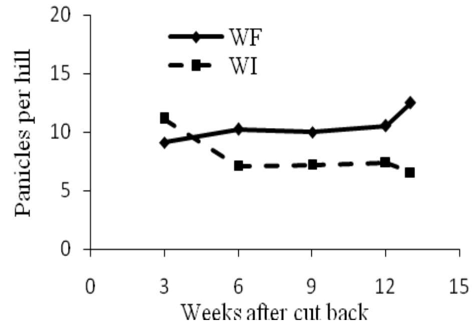

Figure 3.15 (b) NERICA 4

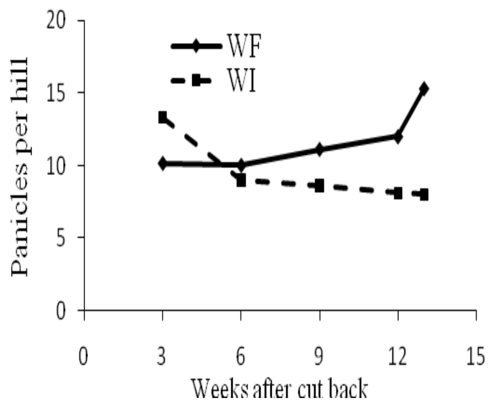

Figure 3.15 (c) NERICA 10

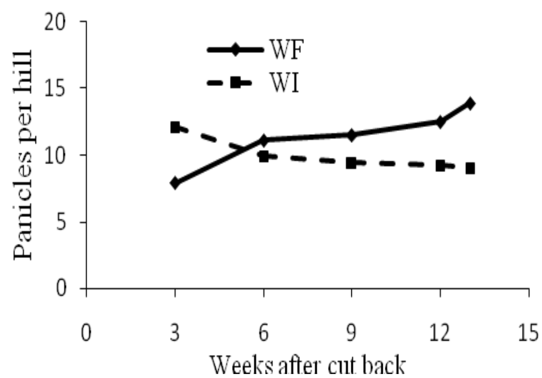

Figure 3.15 (d) NERICA 11

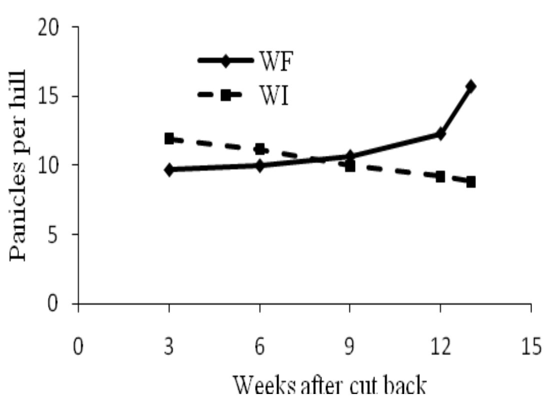

Figure 3.15 (e) Dourado precoce

Figure 3.15a-e: Number of panicles of NERICA and Duorado precoce rice varieties from ratoon crop one as affected by early (WI) and late (WF) competition.

3.4.4.1.3 Number of panicles per hill from main crop two

Results on the number of panicles per hill from main crop two (Figures 3.16a-e) showed significant variation for the interaction between the competition type and the weeding treatments for NERICA 10 ($F_{[4, 18]}$ =10.75, $p<0.001$) (Figure 3.16c) and NERICA 11 ($F_{[4, 18]}$ =4.77, $p<0.05$) (Figure 3.16d), while the other three rice varieties showed no significant variation ($p>0.05$) on the same. For the two varieties (NERICA 10 and 11), the plots initially weed-infested for only 3 WAP and those kept weed free for more than 6 WAP attained significantly ($p<0.05$) high number of panicles than those kept weed infested for the same period. The plots kept initially weed-free for only 3 WAP and those kept weed-infested for more than 6 WAP attained significantly ($p<0.05$) lower number of panicles compared to the full season weed-free treatment (Figure 3.16c and d). For the five rice varieties, plots subjected to late competition (WF) attained higher number of panicles compared to those subjected to early competition (WI). From the full season weed-free treatment (Wfh), NERICA 10 (Figure 3.16 c) gave the highest number of panicles per hill (24.9±1.2) while Duorado precoce (Figure 3.16 e) gave the least (20.8±2.3). From the full season weed-infested treatment, NERICA 4 (Figure 3.16 b) gave the highest value (16.0±1.6) while NERICA 11 (Figure 3.16 d) gave the least (13.0±1.5) which was lower than the standard check Duorado precoce (14.0±2.3) (Figure 3.16 e). The point of interception between early (WI) and late (WF) competition types was determined as 3-6 WAP for the NERICAs and the local landrace Duorado precoce.

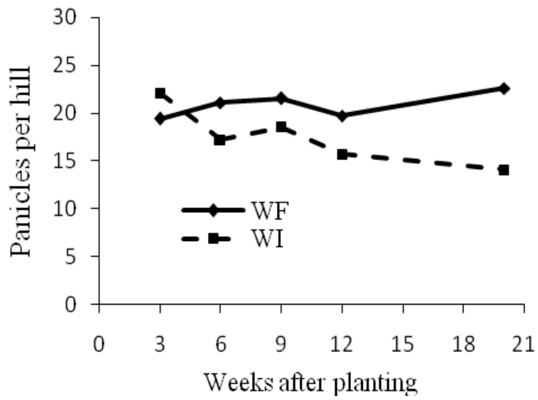

Figure 3.16 (a) NERICA 1

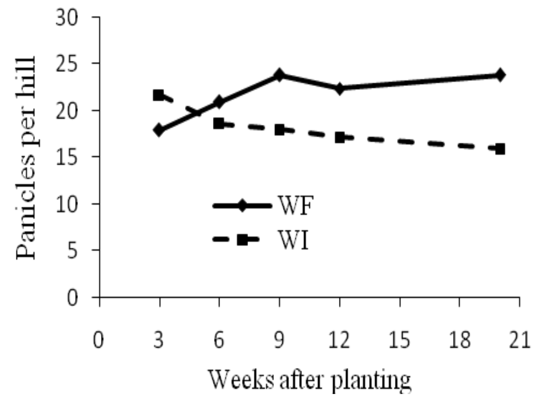

Figure 3.16 (b) NERICA 4

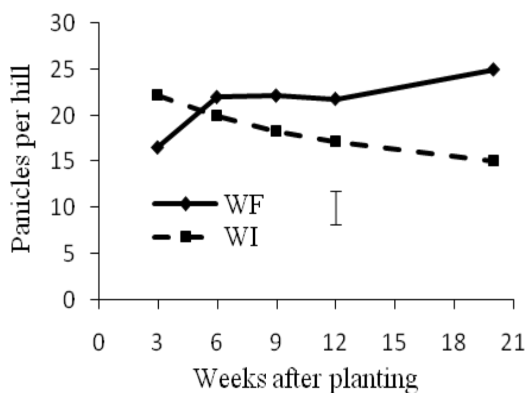

Figure 3.16 (c) NERICA 10. Vertical error bar represent the LSD at p<0.05

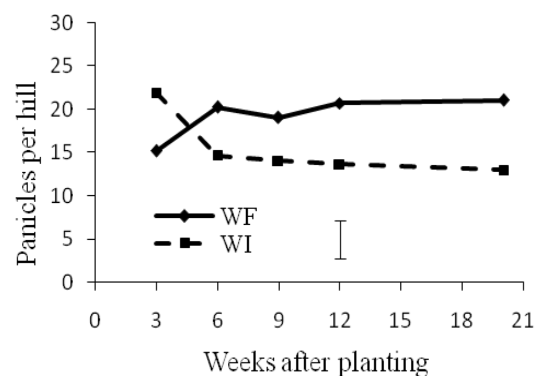

Figure 3.16 (d) NERICA 11. Vertical error bar represent the LSD at p<0.05

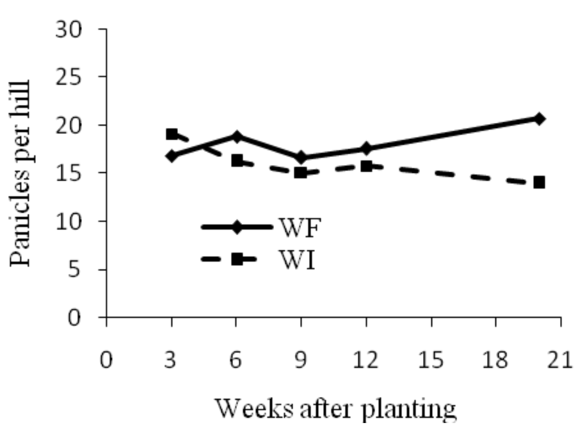

Figure 3.16 (e) Dourado precoce

Figure 3.16a-e: Number of panicles of NERICA and Duorado precoce rice varieties from main crop two as affected by early (WI) and late (WF) competition

3.4.4.1.4 Number of panicles per hill from ratoon crop two

Results for ratoon crop two (Figure 3.17a-e) showed that though the difference was not significant (p>0.05), the plots subjected to late competition (WF) attained higher number of panicles compared to those subjected to early competition (WI) for the five rice varieties, which was in agreement with the other three seasons in the current study. From the full season weed-free treatment, Duorado precoce gave the highest number of panicles per hill (15.7±1.6) among the five rice varieties which was in line with the findings from main crop one and ratoon crop one in this study. Among the four NERICA rice varieties, NERICA 11 gave the highest number of panicles (13.9±2.0) while NERICA 10 gave the least (12.6±1.4) from the full season weed-free treatment. From the full season weed-infested treatment, Duorado precoce again attained the highest value (11.8±1.6) followed by NERICA 1 (9.9±2.1) while NERICA 11 attained the least (8.4±2.0). Though the difference was not significant (p>0.05), keeping the ratoon rice varieties initially weed-infested for only 3 WACB or weed-free for 6 WACB or more resulted in higher number of panicles per hill compared to those kept weed-free or weed-infested for the same period for the four NERICA rice varieties (Figures 3.17a-d). Keeping Duorado precoce weed free for 9 WACB or more resulted in higher number of panicles per hill compared to those kept weed-infested for the same period (Figure 3.17e). The ratoon crop of the five rice varieties in different treatments produced less panicles than the main crop (Figures 3.16 and 3.17). The point of interception between the two types of competition (WF and WI) was found to be 3-6 WACB for the four NERICA rice varieties and 6-9 WACB for Dourado precoce.

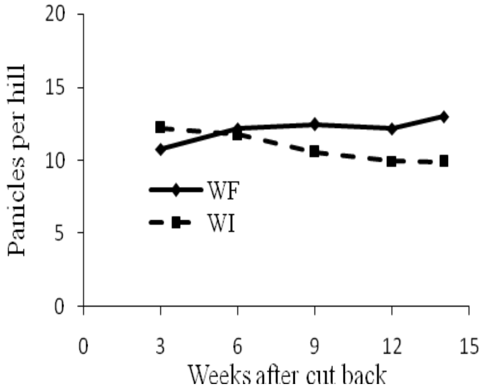

Figure 3.17 (a) NERICA 1

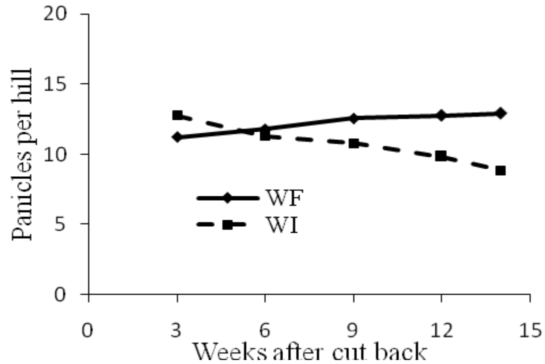

Figure 3.17 (b) NERICA 4

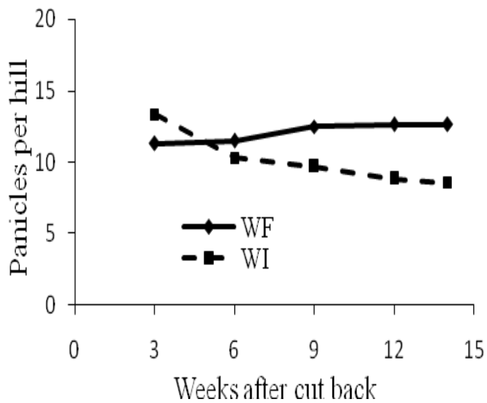

Figure 3.17 (c) NERICA 10

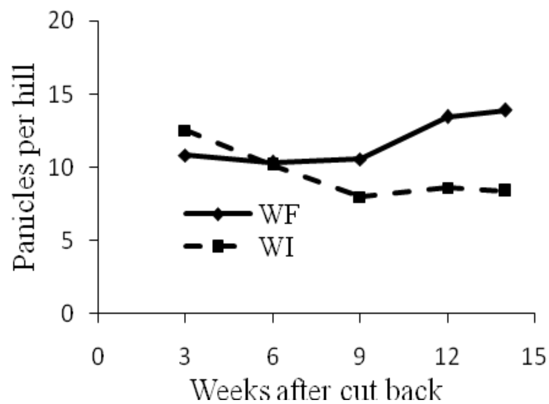

Figure 3.17 (d) NERICA 11

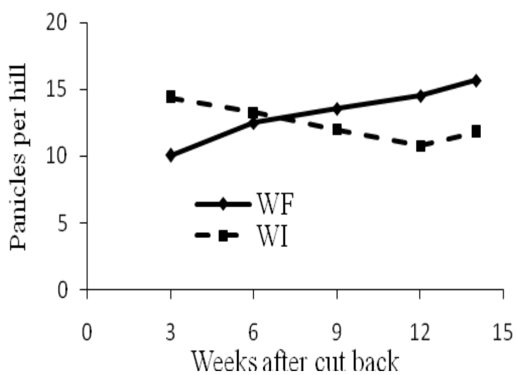

Figure 3.17 (e) Duorado precoce

Figure 3.17a-e: Number of panicles of NERICA and Duorado precoce rice varieties from ratoon crop two as affected by early (WI) and late (WF) competition.

3.4.4.2 Percentage filled spikelets per panicle

The rice varieties used in this study were found to have some empty spikelets (Plate 3.3a-c) which were mainly white in colour contrary to the filled in brown spikelets.

a) NERICA 1

b) NERICA 4

c) Duorado precoce

Plate 3.3a-c: Empty spikelets of a) NERICA 1, b) NERICA 4 and c) Duorado precoce rice varieties.

Results on the percentage filled spikelets per panicle for the four seasons are presented in Figures 3.18-3.21.

3.4.4.2.1 Percentage filled spikelets per panicle from main crop one

Results from main crop one (Figures 3.18a-e) demonstrated that the percentage filled spikelets per panicle increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) for the five rice varieties (Figure 3.18a-e). Though the difference was not significant ($p>0.05$), keeping the five rice varieties initially weed-infested for 3 or 6 WAP resulted in higher percentage filled spikelets per panicle compared to those kept weed-free for the same period (Figures 3.18a-e). NERICA 1 however showed a slight departure from the other varieties in that plots kept weed-free until 6 WAP attained higher percentage filled spikelets than those kept weed-infested for the same period (Figure 3.18a). Keeping the rice varieties weed free for 9 WAP or more resulted in generally higher percentage filled spikelets per panicle compared to those kept weed-infested for the same duration and the values were similar to full season weed-free check (Figure 3.18a-e). Duorado precoce (Figure 3.18 e) showed significantly ($p<0.05$) lower percentage filled spikelets per panicle compared any of the four NERICAs especially from the plots subjected to early competition (WI).

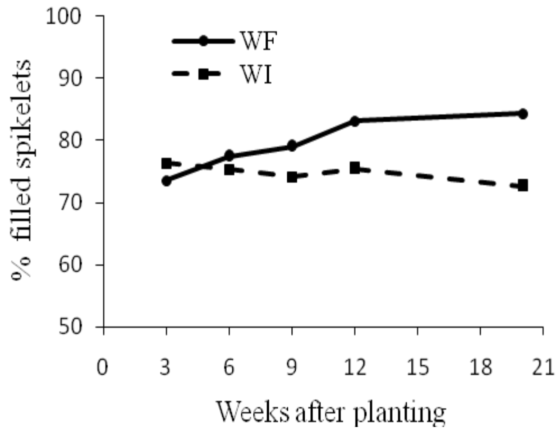

Figure 3.18 (a) NERICA 1

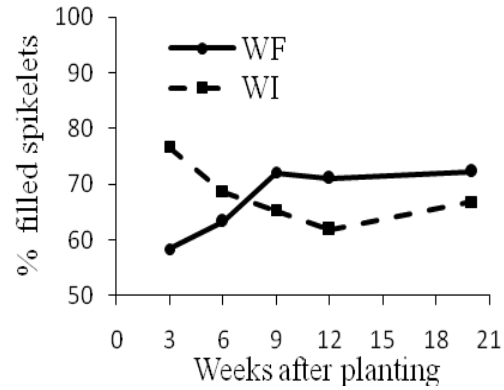

Figure 3.18 (b) NERICA 4

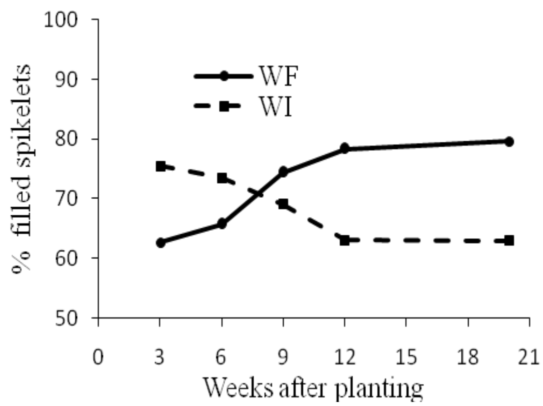

Figure 3.18 (c) NERICA 10

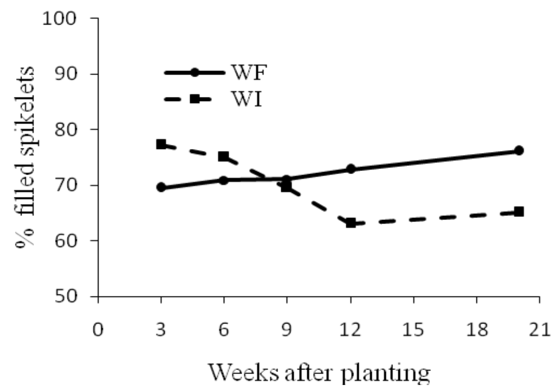

Figure 3.18 (d) NERICA 11

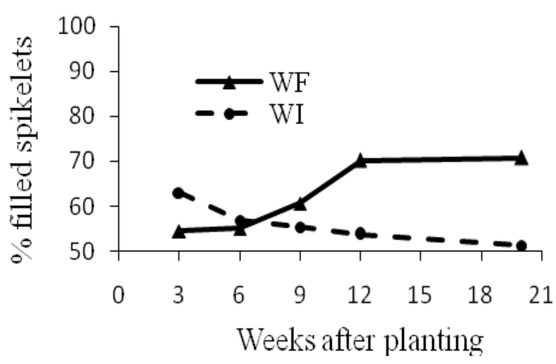

Figure 3.18 (e) Duorado precoce

Figure 3.18a-e: Percentage filled spikelets of NERICA and Duorado precoce rice varieties from main crop one as affected by early (WI) and late (WF) competition.

3.4.4.2.2 Percentage filled spikelets per panicle from ratoon crop one

Ratoon crop one results (Figures 3.19a-e) demonstrated that the percentage filled spikelets per panicle increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) for the five rice varieties, which was in line with the findings from main crop one in the current study. Though the difference was not significant ($p>0.05$), keeping the five rice varieties initially weed-infested for 3 WACB led to higher percentage filled spikelets per panicle compared to those kept weed-free for the same time and the values were analogous to full season weed-free check except for NERICA 10 where the value was much lower (75.8± 3.6) compared to full season weed-free (86.4± 3.6) (Figure 3.19c). Keeping the rice varieties weed free for 6 WACB or more resulted in generally higher percentage filled spikelets compared to those kept weed-infested for the same period (Figure 3.19a-e). This was contrary to the findings from main crop one where the same was observed at 9 WAP or more. Though the difference was not significant ($p>0.05$), full season weed-free treatment attained higher percentage filled spikelets per panicle compared to the full season weed-infested treatment for the five rice varieties. NERICA 10 gave the highest percentage filled spikelets from the full season weed-free (86.4±3.6) while NERICA 1 attained the least value (78.3±7.9) which was lower than the standard check Duorado precoce (83.1±8.0) though the difference was not significant ($p> 0.05$). From the full season weed-infested treatment, NERICA 4 gave the highest percentage filled spikelets per panicle (76.0±4.2) while Duorado precoce gave the least value (68.9±8.0). The point of interception between the two types of competition for the ratoon crop of the five rice varieties was established as 3-6 WAP (Figure 3.19a-e).

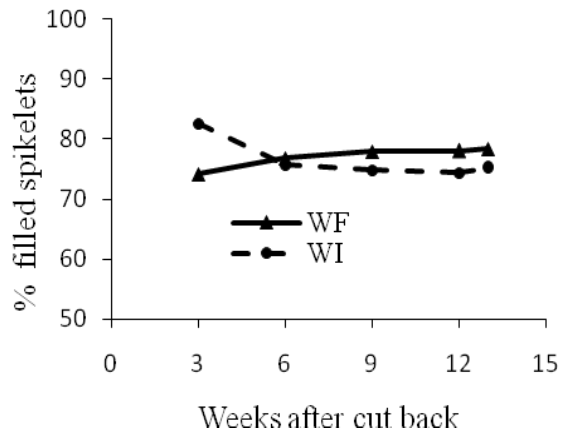

Figure 3.19 (a) NERICA 1

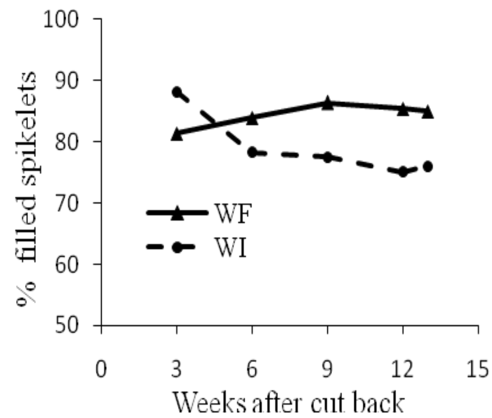

Figure 3.19 (b) NERICA 4

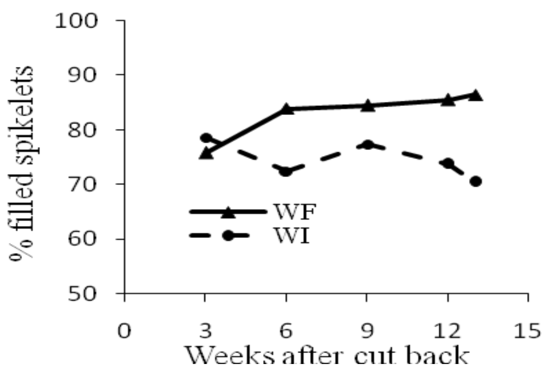

Figure 3.19 (c) NERICA 10

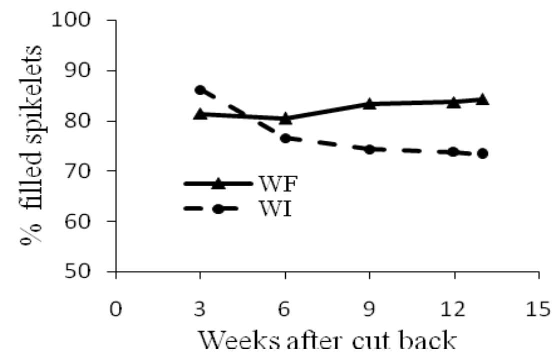

Figure 3.19 (d) NERICA 11

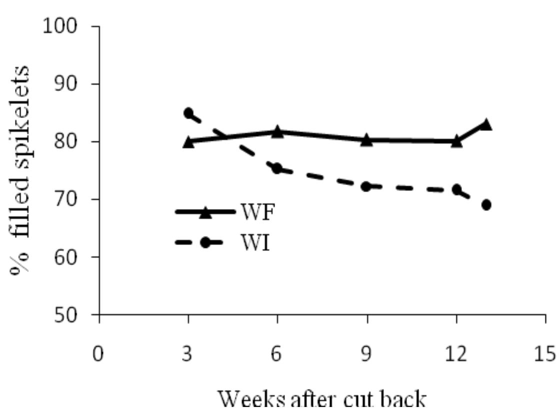

Figure 3.19 (e) Duorado precoce

Figure 3.19a-e: Percentage filled spikelets of NERICA and Duorado precoce rice varieties from ratoon crop one as affected by early (WI) and late (WF) competition.

3.4.4.2.3 Percentage filled spikelets per panicle from main crop two

Main crop two results (Figures 3.20a-e) showed that the percentage filled spikelets per panicle increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) for the five rice varieties (Figure 3.20a-e), which was in line with the findings from main and ratoon crop one in the current study. Though the difference was not significant ($p>0.05$), keeping the five rice varieties initially weed-infested for 3 or 6 WAP resulted into higher percentage filled spikelets per panicle compared to those kept weed-free for the same period, which was in agreement with the findings from main crop one. Keeping the five rice varieties weed free for 9 WAP or more resulted in generally higher percentage filled spikelets compared to those kept weed-infested for the same time and the values were comparable to full season weed-free check (Figure 3.20a-e). NERICA 1 scored the highest percentage filled spikelets per panicle (90.7±3.7) from the full season weed-free treatment while Duorado precoce gave the least value (79.4±6.2). From the full season weed-infested treatment, NERICA 11 gave the highest percentage filled spikelets per panicle (84.4±1.1) while Duorado precoce gave the least (73.6±6.2). Duorado precoce registered generally lower percentage filled spikelets per panicle (Figure 3.20e) compared any of the four NERICAs (Figure 3.20a-d), which was in line with the findings from main and ratoon crop one. The point of interception was established as 6-9 WAP for the five rice varieties (Figure 3.20a-e).

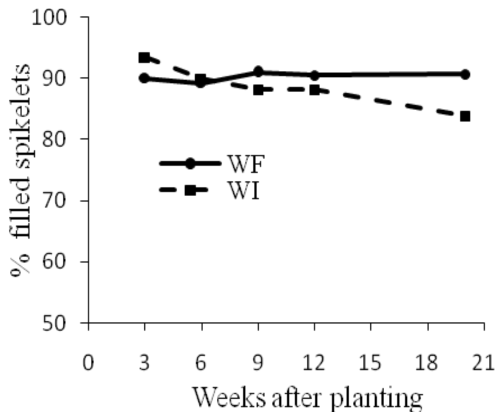

Figure 3.20 (a) NERICA 1

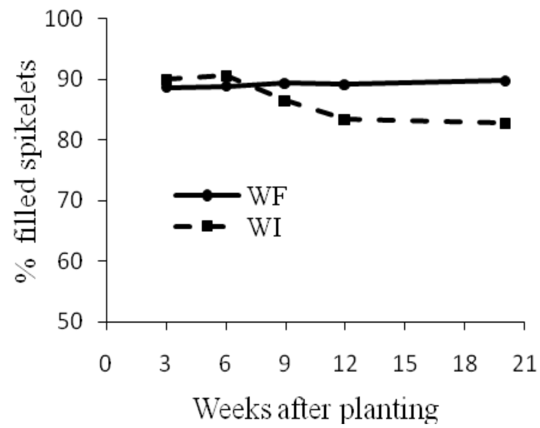

Figure 3.20 (b) NERICA 4

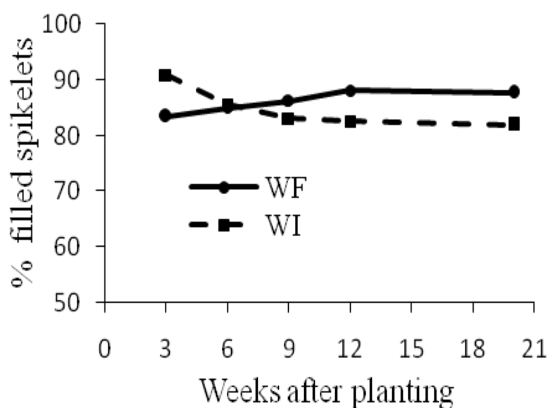

Figure 3.20 (c) NERICA 10

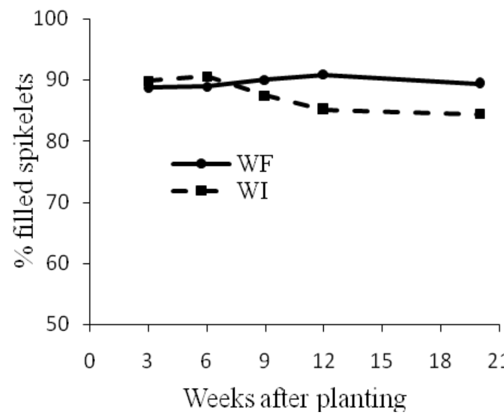

Figure 3.20 (d) NERICA 11

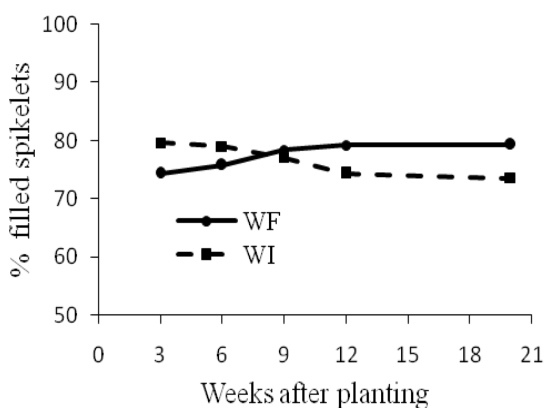

Figure 3.20 (e) Duorado precoce

Figure 3.20a-e: Percentage filled spikelets of NERICA and Duorado precoce rice varieties from main crop two as affected by early (WI) and late (WF) competition.

3.4.4.2.4 Percentage filled spikelets per panicle from ratoon crop two

Ratoon crop two results (Figures 3.21a-e) showed that the percentage filled spikelets per panicle increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) for the five rice varieties. This is in conformity with the findings from the other three seasons in the current study. Though the difference was not significant ($p>0.05$), keeping the five rice varieties initially weed-infested for 3 WACB led to higher percentage filled spikelets per panicle compared to those kept weed-free for the same period and the values were comparable to full season weed-free check (Figures 3.21a-e). Keeping the rice varieties weed free for 6 WACB or more resulted in generally higher percentage filled spikelets compared to those kept weed-infested for the same duration, which is in conformity with the findings from ratoon crop one (Figure 3.19a-e). Though the difference was not significant ($p>0.05$), full season weed-free treatment registered higher percentage filled spikelets per panicle compared to the full season weed-infested treatment for the five rice varieties. NERICA 11 recorded the highest percentage filled spikelets from the full season weed-free treatment (89.7±2.6) while Duorado precoce recorded the least (76.9±2.3). From the full season weed-infested treatment, NERICA 1 recorded the highest percentage filled spikelets per panicle (82.4±3.3) while Duorado precoce gave the least (68.0±2.3). The standard check Duorado precoce recorded generally lower percentage filled spikelets per panicle (Figure 3.21e) compared any of the four NERICAs (Figure 3.20a-d). The point of interception between the two types of competition for the five rice varieties was established as 3-6 WACB (Figure 3.21a-e).

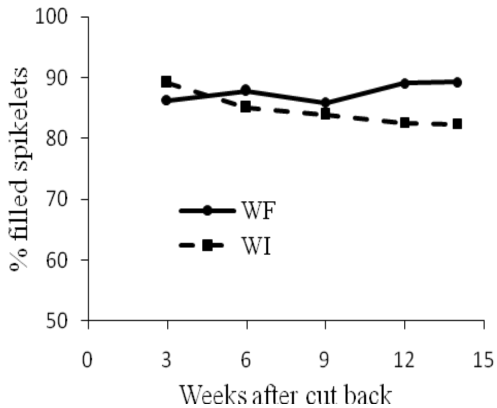

Figure 3.21 (a) NERICA 1

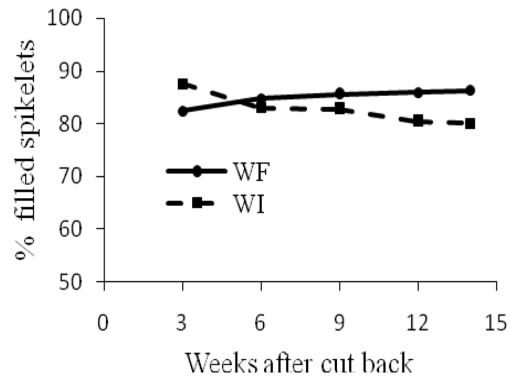

Figure 3.21 (b) NERICA 4

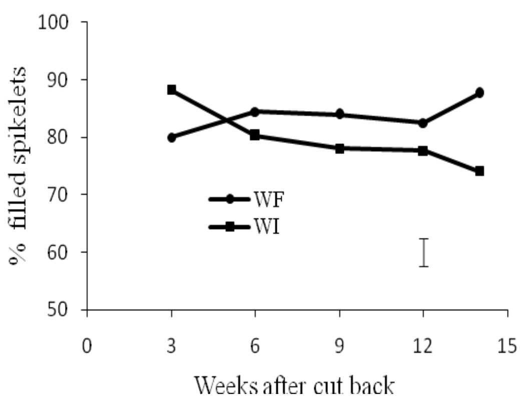

Figure 3.21 (c) NERICA 10. Vertical error bar represents the LSD at $p<0.05$

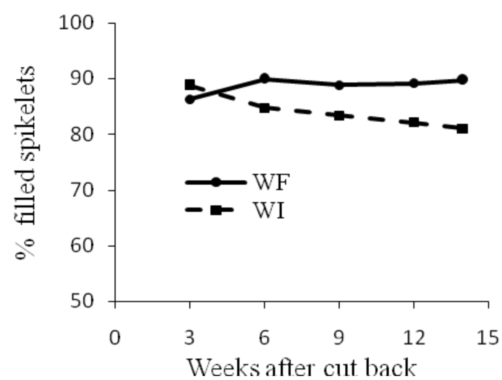

Figure 3.21 (d) NERICA 11

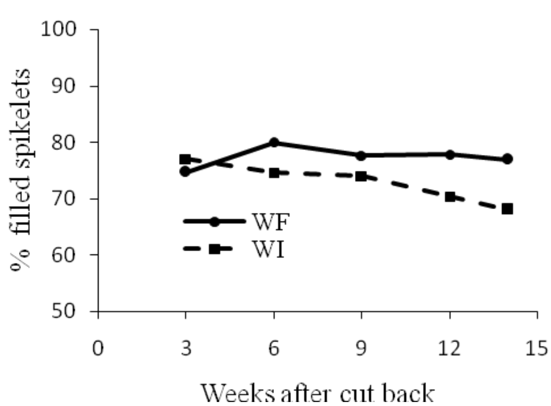

Figure 3.21 (e) Duorado precoce

Figure 3.21a-e: Percentage filled spikelets of NERICA and Duorado precoce rice varieties from ratoon crop two as affected by early (WI) and late (WF) competition.

3.4.5 Maturity period (days) and maturity classification of the upland rice varieties.

Results on the maturity period (days) of four upland NERICA and Duorado precoce from both the main and ratoon crop are as depicted in table 3.5.

Table 3.5: Maturity period (days) and maturity classification of the upland NERICA and Duorado precoce rice varieties from main and ratoon crops (IRRI, 1992).

	Main crop		**Ratoon crop**	
Rice variety	Maturity period (Days)	Maturity classification	Maturity period (Days)	Maturity classification
NERICA 1	124-127	medium	86-89	very early
NERICA 4	122-125	medium	85-87	very early
NERICA 10	110-116	early	79-82	very early
NERICA 11	106-110	early	75-77	very early
Duorado precoce	122-137	Medium/late	88-92	very early

The main crop of NERICA 1 and NERICA 4 matured between 121-135 days and were therefore classified as medium maturing, while NERICA 10 and NERICA 11 matured between 105-120 days and were classified as early maturing according to classification by IRRI, (1992). The standard check Duorado precoce matured between 122-137 days hence classified as medium/late maturing. The ratoon crop of the NERICAs and Duorado precoce rice varieties matured in less than 105 days and were therefore classified as very early maturing.

3.4.6 Correlation between grain yield and the agronomic traits of the five upland rice varieties.

Results on the correlation between the various growth and yield parameters investigated in the current study are depicted in appendices 3.8 and 3.9. These are the average of main crops one and two and ratoon crops one and two respectively. Results on the correlation between grain yield and the agronomic traits of the rice varieties are depicted in table 3.6.

Table 3.6: Correlation coefficients (r) between grain yield (kg ha^{-1}) and agronomic traits from the main and ratoon crops of the five upland rice varieties

	Harvest type					
Agronomic traits	Main one	Ratoon one	Main two	Ratoon two	Main one + main two	Ratoon one + ratoon two
Plant height	-0.055ns	0.438***	0.137ns	-0.123ns	-0.053ns	0.172**
Tiller number	0.510***	0.462***	0.353***	0.307***	0.601***	0.487***
Flowering tillers	0.601***	0.417***	0.378***	0.454***	0.586***	0.528***
LAI	-0.171**	-0.036ns	-0.149ns	-0.054ns	-0.238**	-0.091ns
Panicles per hill	0.250**	0.291***	0.522***	0.029ns	0.521***	0.133ns
% filled spikelets	0.441***	0.324***	0.215***	-0.072ns	0.350***	0.274***

, *, ns: Significant at $p<0.05$, $p<0.001$ and non-significant respectively.

The correlation coefficients between agronomic traits and grain yield revealed varied results depending on the harvest type (Table 3.6). Grain yield was poorly correlated to plant height in all the harvest types except in ratoon one where it was significantly positively correlated ($r = 0.438$, $p<0.001$). Some traits (tiller number, number of flowering tillers, number of panicles per hill and percentage filled spikelets) from all the harvest types correlated significantly positively with grain yield except in ratoon crop two where the number of panicles per hill was non-significant ($r = 0.029$, $p>0.05$) while the percentage filled spikelets was poorly negatively correlated ($r = -0.072$, $p>0.05$) to grain yield. LAI showed non-significant negative correlation with grain yield in all harvest types except in main crop one and combination of the two main crops where the correlation was significant ($r = -0.171$, $p<0.05$ and $r = -0.238$, $p<0.001$ respectively).

Averaged over the main crops, some traits (tiller number, number of flowering tillers, number of panicles per hill and percentage filled spikelets) were significantly positively correlated with grain yield with the strongest correlation ($r = 0.601$, $p<0.001$)

displayed by tiller number and the weakest by percentage filled spikelets (r = 0.350, $p<0.001$) (Table 3.6). Plant height and LAI correlated negatively with grain yield with the weakest non-significant correlation (r = -0.053, $p>0.05$) displayed by plant height. Averaged over the ratoon crops, the same traits as in the main crops (tiller number, number of flowering tillers, number of panicles per hill and percentage filled spikelets) were significantly positively correlated with grain yield except for number of panicles per hill where the correlation was not significant (r = 0.133, $p>0.05$) (Table 3.6). Similarly, LAI showed weak negative correlation with grain yield while plant height gave a significantly positive weak correlation (r = 0.172, $p<0.05$) which was contrary to results of the main crops from the current study.

3.5 Discussion

The weed flora at the experimental sites was variable in composition but showed broadleaves as the most dominant flora, followed by grasses and sedges. The results were in conformity with earlier reports (Akobundu, 1987; Dzomeku, 2007) where broadleaves were found to be the most and sedges the least dominant species in upland environment. The high broadleaves composition of the weed flora was possibly due to favourable abiotic factors of temperature, rainfall, light, nutrient as well as cultivation practices, which provides ideal environmental conditions for weed growth. Despite the fewer number of grasses observed, they create serious physiological threats to upland rice and farm management practices. Grasses are very difficulty to control in upland crop production systems, due to similarity of seedlings of the weed and rice and their highly efficient mode of carbon fixation (Akobundu, 1987). Since grass weeds are often difficult to control once established in cultivated fields, they are generally best controlled with preventive or pre-emergence herbicides which are applied prior to germination and act by preventing establishment. Season long weed infestation resulted in reduction in grain yield in all the rice varieties in both the main and the ratoon crop, suggesting the vulnerability of the crop to weed infestation. At both sites, the number of weeds/m^2 for each of the five dominant species was found to be lower in the ratoon crop compared to the main crop. Similar results were reported in earlier studies (Mitra *et al*., 2005; Kolo and Umaru, 2012).

Results further showed that the mean plant height of the four NERICA and Duorado precoce rice varieties increased with increasing weed-free period (WF) but decreased with increasing weed infestation period (WI) from both the main and ratoon crops. This was possibly due to severe competition for nutrients and sunlight between the crop and weeds in the weed-infested plots. This confirms earlier findings (Buchanan *et al*., 1971; Kasasian, 1971) where it was cited that weeds suppress plant height of crops. Weeds prevent crops from growing upright thus causing crop stalks to grow shorter than the actual height. It also supports findings by Cao *et al*. (2007) where weed-crop competition was reported as one of the major causes of low growth rate hence shorter plants and grain yield loss in rice crop. However, it was contrary to the findings of Auma (1971) who reported that unweeded crop was significantly taller than those subjected to different methods of weed control. There is therefore need for early weed control in the rice fields of both NERICA and Duorado precoce for enhanced plant growth. This coincides with the research results obtained by WARDA (1999) citing the need for early weed control in rice fields. Two early weedings at 3 and 6 WAP resulted in taller plants than a single weeding at 3 WAP for the five rice varieties and the former would therefore be recommended for optimum plant height as additional weeding after 6 WAP did not contribute to increased plant height relative to the full season weed-free check. This is in conformity with the report of Dzomeku (2007) who observed the optimum plant height with plots kept weed-free up to six or more weeks after planting due probably to attainment of the maximum period of weed control required to produce the optimum plant height. The main crops attained taller mean plant height than the ratoon crops irrespective of the weeding treatments for the five rice varieties and this was in agreement with earlier findings (Balasubramanian *et al*., 1970; Oad *et al*., 2002; Mahadevappa, 1988; Dzomeku, 2007; Sanni *et al*., 2009; Tari, 2011) who cited taller plants in the main crop compared to the ratoon crop. The observed mean plant heights in both the main and ratoon crop (Figures 3.2-3.5) for the four NERICA rice varieties were lower than the documented WARDA (1999) heights of 100cm, 120cm, 110cm and 105cm for NERICAs 1, 4, 10 and 11 respectively. This could probably be due to differences in the environmental conditions between the two areas of study.

Variations in plant height indicated that the local rice variety (Duorado precoce) was morphologically taller than the four NERICA rice varieties in the main and the ratoon rice crop irrespective of the weeding treatment but this did not translate to grain yield as it attained the least grain yield in both the main and ratoon crop (2837 and 539 kg ha^{-1} respectively) (Table 4.1). Among the NERICAs, NERICA 1 was the shortest (65.5±2.0cm) but produced the highest grain yield (4588 kg ha^{-1}) from the main crops (Table 4.1). Higher plant height possibly gave Duorado precoce advantage over the NERICA varieties mainly in competition for light as it has been reported that tall stature is more advantageous than short stature for light penetration (Yoshida, 1972). It has also been reported (McGregor *et al.,* 1988; Kwon *et al*., 1991; Johnson and Jones, 1993; IRRI, 1993; Fischer *et al*., 1995; Oad *et al*., 2002) that tall rice cultivars are more competitive than those with short stature.

The five rice varieties under this study were classified as semi-dwarf based on the classification of IRRI, (1992) as their plant heights were less than 90cm. Salisbury and Ross (1985) noted that increased grain yields are obtained with dwarf or semid-warf varieties that allocate relatively more photosynthates to grain than to stems. Short plants as demonstrated by the NERICA varieties could probably be an adaptation to increase grain yield. The short and stiff culms of the NERICA varieties that were observed in this study also prevent lodging which decreases the rice grain yield (Yoshida, 1972). Among the plant characters associated with lodging, plant height is the predominant factor affecting lodging resistance (Chang, 1967; Yoshida, 1972). Lodging reduces the cross-sectional area of vascular bundles which in turn disturbs the movement of photosynthetic assimilates and absorbed nutrients through roots. In addition, lodging disturbs leaf display which results in increased shading, and eventually increases the number of unfilled grains (Yoshida, 1972; Hatika, 1968). In relation to photosynthesis-respiration balance, shorter culm may minimize respiration loss by the culm thereby improving net gains (Yoshida, 1972; Hatika, 1968). However, extremely short culm would be disadvantageous because leaves are vey closely spaced on a short culm, resulting in serious shading within the plant.

There was observed non-uniformity in plant height among NERICA varieties from one season to another (Figures 3.2-3.5). This could possibly be due to genetic make up of the varieties, their behaviour and interaction with the environment. This was in line with the findings of Atera *et al*. (2011) who noted non uniformity in plant height among NERICA cultivars from different seasons. Some authors (Fischer *et al*., 1997; Harding and Jalloh, 2011) reported that competition affected rice plant heights only at late growth stages. This was attributed to modern rice plant types which have erect leaves that allow good light penetration deep into the canopy. They also found that plants in competition were elongated and their heights similar to those in weed-free plots. They therefore argued that plant height would not be a parameter for enhancing competitiveness. In other studies involving different plant types, it was concluded that tall, vigorous and leafy varieties were more competitive than short plant types with erect leaves (Jennings and Herrera, 1968; Atera *et al*., 2011). Plant height in the current study was found to be non-significantly ($p>0.05$) correlated to grain yield in four out of the six harvest types with the weakest non-significant ($r= -0.053$, $p>0.05$) correlation displayed by the total harvest of the main crops (Table 3.6). Plant height as a trait can therefore not be used on its own to determine the critical period of weed control of the rice varieties investigated in the current study. Contrasting reports exist on whether plant height contributes to weed suppression in weed-rice competition which affects grain yield. Haefele *et al*. (2004) observed rice cultivar differences in weed competitiveness and the cultivars that compete well against weeds are often thought to be tall, rapid early growth, droopy leaves and high specific leaf area. Rice varieties respond differently to competition such that tall droopy varieties are more productive under weed infestations than short stature ones (Johnson and Jones, 1993; IRRI, 1993).

Results from the current study further indicated tiller count per hill differed significantly ($p<0.05$) among the rice varieties in the four seasons with the NERICA rice varieties showing higher tillering ability than the standard check Duorado precoce. This could probably be due to differences in the genetic and morphological characteristics of the rice varieties and the effect of weeds. The findings support earlier results (Atera *et al*., 2011; Tari, 2011) where the total number of tillers was found to be influenced by variety and attributed the same to genetic differences among the varieties. Other factors reported to affect the number of tillers produced by the rice varieties include availability of nutrients (water and sunlight) (Reissig *et al*., 1986), crop management such as weed control (Lafarge, 2000), radiation, temperature, soil water status and the general health of the plant (Moynul *et al*., 2003; Zhong *et al*., 2003). High tillering ability could possibly be an adaptive mechanism developed by the NERICA rice varieties for competition against weeds.

Competition with weeds reduced the tillering ability of rice varieties in both the main and ratoon crop as demonstrated by the significantly ($p<0.05$) higher number of tillers from the full season weed-free treatment compared to full season weed-infested treatment hence the need for weeding. This is in line with the work of Mitra *et al*. (2005) who observed higher number of rice tillers in weed-free compared to weed infested treatment. This also supports findings by other authors (Humbert, 1968; Auma, 1971; Feakin, 1971 and Atera *et al*. 2011) who reported that weeds reduce the tillering of crop plants especially where competition is severe. Crops that were subjected to late competition (WF) resulted into higher mean number of tillers per hill compared to those subjected to early competition (WI) for both the main and ratoon crops (Figures 3.6-3.9). Prolonged interaction with weeds therefore lowered the tillering ability of the rice crop which may have contributed to the observed reduced grain yield with increased weed interference period from the current study (Sections 5.4.1 and 5.4.2). The increase in tiller number with early weeding was possibly due to less competition for nutrients compared to late weeding, which gives the tillers the advantage of early establishment thereby utilizing the nutrients and moisture quite adequately. These findings were in line with those of Dzomeku *et al*. (2007) who reported that plots kept weed-infested for more than nine weeks after planting exhibited less tillering ability compared to full season weed-free. Atera *et al*. (2011) observed that tillers that developed in the early weeded crop grew profusely producing panicles at the tips of the stem and contributed to grain yield as productive tillers. Nuruzzaman *et al*. (1997) reported that the number of panicles in a yield component largely depend on the number of productive tillers. This was supported by the findings in the current study where positive correlation ($r=0.524$; $p<0.001$ and $r=0.182$; $p<0.05$) between the number of panicles and the flowering (productive) tillers was observed for both the main and the ratoon crops respectively (Appendices 3.7 and 3.8).

From the main crop, plots kept weed free for 9 WAP or more led to higher number of tillers compared to those kept weed infested for the same period and the values were comparable to full season weed-free check (Figures 3.6 and 3.8). Rice main crop should therefore be kept weed-free for at least 9 WAP for optimum tillering. This is in conformity with IRRI, (1978) where it was reported that the critical period of weed control for rice crop is 4-9 weeks after transplanting. From the ratoon crop, keeping the crop weed free for 6 or more WACB resulted to tiller count comparable to full season weed free check for the NERICA rice varieties. This supports Dzomeku *et al*. (2007) who observed that NERICA rice varieties required at least 6 weed-free weeks for the formation of cover that can suppress weeds. This period is shorter than that of the main crop possibly because the ratoon crop takes a shorter time to mature compared to the main crop hence a shorter time of interaction with weeds during the growth period. The period between three to nine weeks and three to six weeks is perhaps the maximum tillering stage for the main and ratoon crops respectively and if kept weed-free, more tillers are likely to be formed. Duorado precoce ratoon recorded tiller count similar to full season weed-free check when kept weed free for 9 WACB or more. The ratoon crop of this variety may therefore need to be kept weed free up to 9 WACB for maximum tillering. This could possibly be due to the fact that the NERICA varieties profusely produced tillers early in the growth period which competed successfully with weeds late in the growth period hence are better competitors than the standard check Duorado precoce. Weeding upto 12 WAP led to slight increase in tillering ability for the five rice varieties which was similar to full season weed free treatment. NERICA 11 from main crop two tillered highly under weed-infested treatment but attained the least number of tillers in the weed-free treatment. This could possibly be an adaptive mechanism by NERICA 11 to tiller highly under weed competition so as to produce a cover and out compete the weeds hence a good competitor against weeds. These findings support those of Atera *et al*. (2011) where it was reported that NERICA 11 produced the highest number of tillers among the four NERICA varieties.

The mean number of tillers per variety varied significantly ($p<0.05$) among the four seasons possibly due to differences in environmental and edaphic factors from one season to another. This supports Atera *et al*. (2011) who reported that tiller number differed over years, and attributed the differences to environmental factors. Ntanos and Koutroubas (2002) reported that in addition to the environmental factors, nutrients absorbed and carbohydrates metabolized play a role in tiller development. The five rice varieties showed generally lower mean number of tillers per hill in each weeding treatment for ratoon crop compared to the main crop. This supports earlier findings by Sanni *et al*. (2009) where it was reported that the ratoon crop produced lower number of tillers than the main crop. This possibly contributed to the observed lower grain yield in the rice ratoon crop compared to the main crop in the current study (Table 4.1). The four NERICA varieties in this study scored more than 16 tillers per hill and were therefore rated as high tillering while the Duorado precoce scored less than 16 tillers per hill hence rated as low tillering (Chauhan *et al*., 1985; Africa Rice Center, 2008). The four NERICA rice varieties were classified as good tillering according to Africa Rice Center, (2008) with scores of at least 20 tillers per hill and 16 tillers per hill for main and ratoon crops respectively. This supports other findings by McGregor *et al*. (1988); Fischer *et al*. (1995); Estorninos *et al*. (2002); Haefele *et al*. (2004); Doust, (2007); Nazeer *et al*. (2012) who reported that rice cultivars with higher tillering ability are better competitors than those with low tillering ability. The four NERICA rice varieties investigated in this study that tillered more than the local landrace Duorado precoce could perhaps be better competitors against weeds. They could also be capable of compensating for missing hills in direct seeded rice and faster leaf area development for transplanted rice hence higher yields than the local landraces (Haefele *et al*., 2004; Doust, 2007). Higher tiller production increases the ability of a rice plant to expand rapidly into an available space (Johnson *et al*., 1998), in addition to its ability to produce more panicles. All the rice varieties used in this study were found to have upright (compact) tillers which is a characteristic associated with high yielding potential as it permits greater penetration of incident light into canopy (Yoshida, 1972).

The mean number of productive tillers per hill was significantly ($p<0.05$) affected by the variety in both the main and the ratoon crops. The observed lower mean number of productive tillers for Duorado precoce compared to the NERICA rice varieties in both the main and ratoon crop may have contributed to the observed lower grain yield for the former (Table 4.1). The four NERICA rice varieties displayed an impressive early flowering compared to the standard check Duorado precoce an indication of a strong potential for yield improvement. Timely flowering has been cited (Gott *et al*., 1955;

Kanya *et al*., 2013) as an important factor in determining grain yield, as early flowering gives the spikelets sufficient time to be filled with assimilates (Yoshida, 1972). The NERICA rice varieties which flowered earlier in this study may have filled the grains earlier and possibly this translated into the observed higher yields compared to the standard check Duorado precoce (Table 4.1). Full season weed-free (Wfh) treatment attained higher mean number of flowering tillers per hill compared to the full season weed-infested (Wih) treatment for both the main and ratoon crop. Uncontrolled weed growth therefore reduced the flowering rate of the rice crop possibly due to reduced growth rate irrespective of the variety hence the need for weeding. This is in agreement with Ekeleme *et al*. (2007) who reported reduced flowering rate of the rice crop due to uncontrolled weed growth. Prolonged interaction with weeds lowered the flowering of the rice crop in all the seasons which may have contributed to the reduced grain yield observed from the plots subjected to early competiton compared to those subjected to late competition (Figures 5.1 and 5.2) since the number of flowering tillers per crop are reported to affect grain yield (Yoshida, 1972; Dzomeku *et al*., 2007).Weeding the main crop upto 9 or 12 WAP generally resulted in higher flowering comparable to full season weed-free check. This is best demonstrated by NERICA 10 from main crop two where the plots kept weed free for only 3 WAP and those kept weed infested for more than 9 WAP exhibited significantly ($p<0.05$) less productive tillers compared to full season weed free control (Figure 3.12c). Three to nine weeks after planting could therefore be considered as the CPWC for NERICA 10 in relation to productive tiller production. This is in support of IRRI, (1978) where it was reported that the CPWC l is 4-9 WAP, a period that generally coincides with the time of maximum flowering. It was observed that the plots subjected to early competition (WI) flowered earlier than those subjected to late competition (WF). This supports earlier findings where weed competition has been reported to shorten the time to flowering and panicle emergence of the crop (Donald, 1951; Stern, 1955; Auma, 1971; Kasasian, 1971). The authors argued that with higher competition for nutrients, early flowering is enhanced. All the rice varieties from each treatment were found to flower earlier in ratoon crop compared to main crop which could possibly be due to faster growth rate for the former compared to the latter since the ratoons are already established by having previously developed rooting systems than new plants from seeds.

Though the difference was not significant ($p>0.05$), keeping the ratoon crop of the five rice varieties weed infested for more than 6 WACB appreciably reduced the number of flowering tillers relative to the full season weed-free check. Among the NERICA varieties, NERICA 10 attained the highest values in both the full season weed-infested and full season weed-free treatments while NERICA 11 attained the least values from the ratoon crops (Figures 3.11 and 3.13). The ratoon crop of NERICA 10 could therefore possibly be a better competitor against weeds compared to NERICA 11 and may have translated to the observed higher ratoon grain yield for NERICA 10 compared to NERICA 11 in this study (Table 4.1). The mean number of productive tillers was found to be lower in the ratoon crop than the main crop hence likely to have contributed to the observed lower grain yield in the formery (Table 4.1). The point of interception between the early (WI) and late (WF) competition types denoting the the critical date of weed control in relation to productive tillers production was estsblished as 3-6 WAP for the five upland rice varieties in both the main and the ratoon crop.

Results from the current study further showed that LAI of the five rice varieties was not significantly ($p>0.05$) affected by weed interference period. These findings contrast earlier studies (Ochieng, 1982; Remison, 1978) where LAI was significantly reduced by competition. Remison (1978) attributed low LAI in his investigation to tremendous competition for light with shading of lower leaves. Amazingly, prolonged interaction with weeds from the start of the rice growth period increased LAI of the rice crop in both the main and ratoon crops from the current study. Full season weed-infested (Wih) treatment attained higher LAI compared to full season weed-free (Wfh) treatment for the five rice varieties in both the main and ratoon crop. The findings contrast Mitra *et al*. (2005) who reported that weed-free treatment maintained the highest LAI throughout the growth period. They also contrast studies by Remison (1978) where LAI was reported to be significantly reduced by competition for light that resulted from shading of lower leaves. Main crop one was found to have generally higher mean LAI values (ranging from 5.6±1.6 to 10.8±1.5 for NERICA 11 and NERICA 1 respectively from the full season weed-infested treatments) compared the the other three seasons in this study. The values were however within the documented (Dingkuhn *et al*., 1999; Harding and Jalloh, 2011; Kiniry et al., 2001) range of 5 to 13 for rice crop. The difference could possibly be due to differences in the edaphic and environmental differences in the two growing seasons as main one growth period recorded higher rainfall than main two (Figure 2.3).

The ratoon crop registered lower LAI than the main crop hence the former may not compete well against weeds as low LAI in rice plants has been associated with inability to compete with weeds (IRRI, 1976). This may possibly have resulted to the observed lower grain yield in the ratoon crop compared to the main crop (Table 4.1). However, LAI of the rice plant has been reported (Yoshida, 1972; Remison, 1978) not to be directly related to yields. Yoshida (1972) reported that LAI as large as 12 is not detrimental to grain yield unless the crop lodges. Hence, the LAI values obtained from this study which ranged from 1.09 for ratoon to 10.9 for the main crop were within the documented values (Yoshida, 1972) for rice and are not detrimental to grain yield. It was observed that all the rice varieties used in this study displayed erect leaf habit which increases sunlight leaf surface area, thereby permitting more even distribution of incident light hence higher yielding potential. Direct evidence of the effect of erect leaves in increasing photosynthesis and hence yields have been reported for rice (Yoshida, 1972). Among the three leaves used in the determination of the LAI in this study (the first, middle and flag leaf), the flag leaf was found to be the smallest in size. This may have contributed to larger panicles as more assimilates were transported to the panicles than to the flag leaf. In grain crops, panicles and leaves grow at the same time. Therefore the distribution of assimilates between panicles and leaves also determine the size of the panicle. Consequently, most high yielding rice varieties have a small flag leaf. This is probably because the flag leaf competes with the developing panicle for assimilates (Yoshida, 1972). Among the growth parameters considered in this study, LAI was found to be the most variable and one least affected by the weeding regimes. Based on the findings from this study, the parameter could therefore not be used to determine the critical period of weed control of the rice varieties. Earlier studies (Yoshida, 1972; Remison, 1978) reported LAI as a parameter that is very variable and one that can be widely changed by manipulating plant density and application of fertilizers.

Unlike the other parameters used in this study, LAI showed non-significant negative correlation with grain yield in the four seasons except in main crop one where the correlation was significant ($r = -0.171$, $p<0.05$) (Table 3.6). This was in conformity with earlier studies (Lei and Wang, 1961; Tanaka *et al*., 1966; Yoshida and Hayakawa, 1970; Graf *et al*., 1990; Zhong *et al*., 2002; Liu *et al*., 2012) where increasing LAI has been associated with lower yields. Fageria *et al*. (1997) also showed that high LAI does not necessarily translate into higher grain yield. Increased LAI has been reported to cause increased shading, tiller mortality and is associated with reduced tillering rate in rice crops hence lower yields. Nevertheless, the findings from the current study were contrary to the findings by Ghosh and Singh (1998) who observed a strong and positive correlation between LAI and grain yield. Balouch *et al*. (2006) reported that increased LAI contributed towards higher paddy yield. Yoshida and Parao, (1976) also noted that the total LAI of rice is closely related to grain yield because at flowering, the parameter was reported to greatly affect the amount of photosynthates available to the panicle.

Results of the current experiment also demonstrated that plots subjected to late competition (WF) attained higher number of panicles per hill compared to those subjected to early competition (W1) for both the main and the ratoon crop. Panicle production also declined with increasing duration of weed presence and this reponse was in agreement with previous findings reported on rice (Tursun *et al*., 2007; Ekeleme *et al*., 2008; Toure *et al*., 2013). Early weeding is therefore recommended for better panicle production hence possibly better grain yield as the number of panicles was found to be positively correlated to grain yield (Table 3.6). Conversely, early interaction of the rice crop with weeds upto 3 WAP during the growth period of the crop did not show significant reduction on the number of panicles per hill relative to the full season weed-free treatment for any of the five rice varieties possibly because competition is not severe due to availability of sufficient nutrients. Weeds may therefore remain in the rice crop for 3 WAP before competition begins which would perhaps not amount to reduced panicle production. This is consistent with findings from Eleftherohorines *et al.* (2002) who pointed out that competition between rice crop and weeds begins three weeks after rice emergence.

The observed higher mean number of panicles from weed-free treatment compared to the full season weed-infested treatment in both the main and ratoon crop for the five rice varieties was in support of earlier findings (Moynul *et al*., 2003; Mitra *et al*., 2005; Kega and Maingu, 2006; Ekeleme *et al*., 2008; Kolo and Umaru, 2012) where higher rice panicle production was observed in weed-free condition compared to weed-infested. This could perhaps be due to less crop-weed competition from the weed-free treatment that ensured sufficient nutrients and other growth resources, thereby enhancing higher panicle production (Kolo and Umaru, 2012). The ratoon crop gave less number of panicles per hill compared to main crop. This may have led to the observed lower grain yield in the ratoon crop compared to the main crop (Table 4.1). Duorado precoce attained generally higher number of panicles per hill compared to the NERICAs in both the main and ratoon crop. This however did not translate to higher grain yield for Duorado precoce compared to the NERICAs as observed from this study (Table 4.1). This was perhaps due to the observed lower percentage filled spikelets from the Duorado precoce compared to the NERICA rice varieties. The NERICA varieties also differed in panicle production depending on the treatments and seasons. The findings support earlier studies (Kega and Maingu, 2006; Kouko *et al*., 2006; Kolo and Umaru, 2012) where NERICAs were reported to differ in panicle production, with NERICAs 10 and 11 attaining higher values compared to NERICAs 1 and 4. Weeding after 12 weeks did not affect rice panicle production for either the main or ratoon crop of the five upland rice varieties relative to full season weed infestation. The point of interception between the early (WI) and late (WF) competition was established as 3-6 WAP for the four NERICA rice varieties and 6-9 WAP for Dourado precoce except for main crop two where Dourado precoce had interception point between 3 and 6 WAP. These findings support those of IRRI, (1978) where it was reported that the CPWC in rice crop is 4-9 WAP. The CPWC for rice therefore coincides with the optimum time for panicle production.

The observed empty spikelets from the five upland rice varieties could have been due to the cold weather that prevailed during the period of the study particularly during the ripening and maturity stage of the rice varieties, with minimum temperatures being as low as 14.7°C in June 2011 (Figure 2.2). This was the ripening stage of ratoon crop two. Low temperature has been cited as one of the main limitations on rice crop yield

(McDonald, 1979; McDonald, 1994). Japonica cultivars that are predominately grown in temperate regions can germinate and grow under lower temperatures (15 to 20°C) than the tropical and sub tropical Indica cultivars such as *O. sativa*. Temperatures below 18°C at night during pollen formation results in sterile pollen in rice cultivars (McDonald, 1994). The lowest temperature (14.7°C) experienced in the current study was lower than the minimum required for the Japonica cultivars (18°C), the parent to the NERICA varieties consequently likely to have contributed to the empty spikelets.

The percentage filled spikelets per panicle increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) for the five rice varieties. Early crop-weed competition therefore lowered the filling of the rice spikelets perhaps due to fewer nutrients hence less assimilates translocated to grains under early competition. In both the main and the ratoon crop, full season weed-free treatment obtained higher percentage filled spikelets per panicle compared to the other treatments while the full season weed-infested treatment recorded the lowest percentage. This could possibly be associated with less crop-weed competition in weed-free treatment thus sufficient translocation of assimilates to the crop grains. This is in agreement with earlier findings by Mitra *et al*. (2005) who obtained the highest percentage filled spikelets per panicle in weed-free treatment, which was attributed to less crop-weed competition. Ekeleme *et al*. (2007) also observed that uncontrolled weed growth reduced filled spikelets of rice cultivars. He noted more than 30% reduction in filled spikelets in NERICA varieties in weedy plots compared to weed-free plots. Prolonged interaction with weeds from the start of rice growth cycle to rice maturity generally lowered the percentage filled spikelets per panicle in both the main and the ratoon rice crop which may have led to the observed reduced grain yield from the early competition plots in this study (Figures 5.1 and 5.2). Keeping the main crop of the five rice varieties weed free for 9 WAP or more resulted in generally higher percentage filled spikelets compared to those kept weed-infested for the same period and the values were comparable to full season weed-free check. For best grain filling therefore, the main crop should be kept weed-free for at least 9 weeks from the start of the season. These findings support those of IRRI, 1978 where the critical period of weed control was reported as 4-9 weeks after seeding. Keeping the ratoon crop of the five rice varieties weed free for 6 WACB or more resulted in generally higher percentage filled spikelets compared to those kept weed-infested for the same period and the values were comparable to full season weed-free check. The critical period of weed control for the ratoon crop in relation to spikelet filling could therefore be considered as 3-6 WAP.

The percentage filled spikelets in this study possibly affected grain yield since filled spikelets per panicle have been cited as one of the principal traits that determine grain yield (Hsieh *et al*., 1964; Yoshida, 1972; Palchamy and Kolandaswamy, 1982; Chauhan *et al*., 1985). A significantly positive correlation ($r = 0.350$; $p<0.001$ and $r = 0.274$; $p<0.001$) was observed (Appendix 3.8 and 3.9) between grain yield and the percentage filled spikelets for the main and ratoon crops respectively. This is in compliance with earlier findings (Kato *et al*., 2008; Atera *et al*., 2011) where grain yield was reported to increase with increased number of filled spikelets per panicle and vice versa. The standard check Duorado precoce registered generally lower percentage filled spikelets per panicle compared to the NERICAs in both the main and ratoon crop. This could probably have contributed to the observed lower grain yield from Duorado precoce compared to the NERICAs (Table 4.1). The point of interception between the two types of competition (WF and WI) denoting the critical date of weed control in relation to percentage filled spikelets was between 3 and 6 WACB for the five rice varieties from the ratoon crop and between 6 and 9 WAP from the main crop. Many factors such as genotype, cultural practices used (planting date, weeding, seeding rate and soil fertility (Baloch *et al*., 2006) and growing conditions (air and soil temperature, relative humidity and rainfall) (Singh, 1994) affect the number of spikelets per panicle as well as the filling of the spikelets. From the results of the current study therefore, though percentage filled spikelets may have been influenced by weeding treatments, the variation was not significant. It might be due to the fact that percentage filled spikelets is a genetically controlled character and also influenced by environmental factors such as low temperatures and influenced little by management practices such as weeding.

Early maturity as demonstrated by NERICAs 10 and 11 in the current study (Table 3.5) was in line with earlier studies (Hanfei, 1992; Frageria *et al*., 1997; Dingkuhn *et al*., 1998) where all NERICAs were classified as early maturing, but differed from the same for NERICAs 1 and 4 which in this study were classified as medium maturing. This could possibly be due to differences in the environmental conditions especially temperature and rainfall among the areas of study. Early maturity has been reported as a defence mechanism against weeds (Andersen *et al*., 2004). Rapid growth allows a plant to displace slower growing plants and spread rampantly within the growth area, which is a characteristic of invasive plants (Pheloung, 1995; Parker *et al*., 1999; Andersen *et al*., 2004). Atera *et al*. (2011) classified NERICA 10 and NERICA 1 as early maturing (97 and 102 maturity days respectively) while Duorado precoce and NERICA 11 were classified as late maturing (116 and 109 maturity days respectively). They also observed that varieties affected by moisture stress during grain filling stage such as NERICA 4 delayed physiological maturity period as compared to WARDA (1999) passport data. When plants are exposed to drought their carbohydrates metabolism is affected. In turn the disorder slows down growth rate and delays development stages in stressed plants thus affecting maturity period. In the current study, the maturity period of the four NERICA rice varieties was found to be longer than the Africa Rice Center (2008) report where all the four varieties were reported to be early maturing. This could possibly be due to differences in the environmental conditions especially temperature and rainfall between the areas of study. It has also been reported (Johnson and Jones, 1993; IRRI, 1993) that rice varieties respond differently to competition where late maturing varieties are more productive under weed infestations than early maturing ones. Main crop one from this study matured earlier and yielded higher grains compared to main crop two. Likewise, ratoon crop one matured earlier and yielded higher grains than ratoon crop two. This could possibly be due to lower temperatures and rainfall in main crop two and ratoon crop two compared to main crop one and ratoon crop one respectively.

While it is documented (Kende *et al*., 1998; Zafar *et al*., 2004) that plant height characters are important in improving rice grain yield, in this study plant height correlated poorly to grain yield which is in agreement with earlier studies by Fofana and Rauber (1999). Also, according to Evans (1998), dwarf plants have a superior advantage over tall plants in that they have increased grain yield through an improved ‘harvest index’ (the proportion of plant weight in the grain). This means that a greater proportion of the products of photosynthesis accumulate in the grains rather than in the leaves. Short stems also reduce high investment costs incurred in construction and maintenance of the stem and improve translocation of resources from stems and leaves to seeds (WARDA, 1999; Falster *et al*. 2011). This is however contrary to Oad *et al*. (2002) who reported that per unit area, taller plants intercept higher amounts of light and traps more CO_2, hence increases grain yield due to improved photosynthesis. It also contradicts other authors (Kende *et al*., 1998; Zafar *et al*., 2004) where it was reported that longer culms can accumilate more assimilates, which can be translocated to grain thus increasing grain yield. However, taller plants indicate a higher proportion of non-photosynthetic plant parts and greater possibility of lodging. Thus deployement of NERICA varieties with intermediate heights in the current study is significant in that it can be utilized to achieve balanced advantages of height.

Generally, tiller number, number of productive tillers, number of panicles per hill and percentage filled spikelets correlated significantly positively with grain yield, which is in agreement with earlier studies (Gott *et al*., 1955; Johnson *et al*., 1998; WARDA, 1999; Kato *et al*., 2008; Atera *et al*., 2011; Kanya *et al*., 2013). Higher tiller production increases the ability of a rice plant to produce more panicles hence higher grain yield (Johnson *et al*., 1998). High flowering is an important factor in determining grain yield as it ensures sufficient filling of the spikelets with assimilates that translates into grain yield (Yoshida, 1972; Johnson *et al*., 1998). Filled spikelets per panicle have been cited as the principal trait that determines grain yield (Hsieh *et al*., 1964; Yoshida, 1972; Palchamy and Kolandaswamy, 1982; Chauhan *et al*., 1985). Grain yield increases with increased number of filled spikelets per panicle (Kato *et al*., 2008; Atera *et al*., 2011). LAI showed negative correlation with grain yield which is in line with earlier studies (Yoshida, 1972; Remison, 1978) who opinioned that LAI of the rice plant is not directly related to yields. Liu *et al*. (2012) attributed lower grain yield to higher LAI. LAI has been reported to cause increased shading, tiller mortality and is associated with reduced tillering rate in rice crops hence lower yields (Lei and Wang, 1961; Tanaka *et al*., 1966; Yoshida and Hayakawa, 1970; Graf *et al*., 1990; Zhong *et al*., 2002). The results from this study were however contrary to some authors (Ghosh and Singh, 1998; Balouch *et al*., 2006) who observed a strong and positive correlation between LAI and grain yield. The four NERICA and the local landrace Duorado precoce rice varieties investigated in this study differed in their response to weeds in support of earlier studies (Tanaka *et al*., 1968; Haefele *et al*., 2004). Tanaka *et al*. (1968) reported that varieties with morphological characters contributing to high yields include shorter plant height, higher tillering capacity and more erect leaves.

3.6 Conclusion

This study showed that the four upland NERICAs (NERICA 1, 4, 10 and 11) and the local landrace *O. sativa* (Duorado precoce) rice varieties differed in their response to weed interference, therefore rejecting hypothesis number one in this study that NERICA and *O. sativa* rice varieties have the similar response to weeds. The agronomic traits investigated i.e. plant height, tiller number, number of flowering tillers, number of panicles per hill and the percentage filled spikelets declined with increasing duration of weed interference and increased with decreasing duration of weed interference. On the contrary, LAI increased with increasing duration of weed interference and declined with decreasing duration of weed interference for the five rice varieties. Among the growth parameters considered in this study, LAI was found to be the most variable and the one least affected by competition and weeding regime treatments. The parameter could therefore not be used on its own to determine the critical period of weed control of the rice varieties. Early weed control until 3 and 6 WAP generally increased LAI above the full season weed-free season and similarly so plots subjected to weed infestation exceeding 6 WAP. Early crop-weed competition reduces the growth and production of both the NERICA and the standard check Duorado precoce hence the need for early weed control. From the correlation results of this study, it was demonstrated that tiller number, number of productive tillers, number of panicles per hill and percentage filled spikelets are good agronomic traits for determining grain yield while plant height and LAI are poor measures for grain yield for both the main and the ratoon crops. It is also concluded that no single agronomic trait can be used alone as a measure for grain yield but rather a combination of more traits and exogenous factors.

CHAPTER FOUR

RATOONING ABILITY OF UPLAND NERICA RICE VARIETIES

4.1 Introduction

Ratooning (from Spanish *retoño*, "sprout") is the practice of obtaining a second harvest from tillers originating from the stubble of the previously harvested (main) crop (Jones and Snyder, 1987). Rice ratooning has been used in several countries including India, Thailand, Taiwan, Swaziland, China, the United States and Philippines (Liu, 2012; Nakano and Morita, 2007). Several studies have reported a high grain yield in ratoon crop in the tropics (Chauhan *et al*., 1985), in India (Reddy *et al*., 1979), in Ethiopia (Prashar, 1970) and in China (Liu, 2012). The main benefits of rice ratooning are that the crop matures earlier and increases production without expanding land area and hence increases farmers' income, lower production costs because of savings in land preparation and plant care during early growth, lower water requirements than the main crop, possible maintenance of genetic purity of a variety or hybrid rice through several seasons and good cooking quality (Chauhan *et al*., 1985; Oad *et al*., 2002; Tari, 2011, Liu, 2012).

Tillering ability has been cited as one of the most important genetic factors affecting ratoon performance of grasses (Chauhan *et al*., 1985; Oad *et al*., 2002). Oad *et al*. (2002) reported that ratoon crop should have sufficient tillers in the early stage of the main crop harvest to achieve high yields. Too few tillers result in too few panicles; but excess tillers cause high tiller abortion, small panicles, poor grain filling and a consequent reduction in grain yield (Peng *et al*., 1994). Optimization of tiller production by regulating tillering through in-season crop management is essential for achieving high rice yield (Jiang, 1994; Su *et al*., 1996). Ratooning is known to give a steady yield for three years under moist conditions, for the crops for which it is most often used (Jones and Snyder, 1987). Ratooning ability is therefore a good measure of invasiveness as invasive species reproduce consistently and sustain populations over many life cycles without direct intervention by humans (Krivanek and Pysek, 2006). Ratooning of rice should therefore be evaluated not only as a means of making the land productive but also as a measure of invasiveness (Bahar and De Datta, 1977; Williams *et al*., 2002). Studies on rice ratooning are lacking in Kenya. The present study therefore investigated *"the* *ratooning ability of four upland NERICA rice varieties and one local landrace Duorado precoce as a means of assessing invasiveness and increasing rice grain yield in central Kenya".*

4.2 Materials and methods

4.2.1 Experimental design

After harvesting the main crop of the four upland NERICA (NERICAs 1, 4, 10 and 11) and Duorado precoce rice varieties as in section 3.2.4.4.3, the entire set up was dug to remove the weeds and establish the ratoon crop from the stubble of the main crop (Appendix 4.1) using the same experimental design as for the main crop (Table 3.1). The stubble from each sub-plot were then subjected to the same weeding treatments as the main crop (Section 3.2.2) but without any further input until the ratooned plants were ready for harvest.

4.2.2 Data collection

Data on the main and ratoon crop grain yield for the four NERICA rice varieties and the standard check Duorado precoce were collected for the four seasons as described in section 3.2.4.4.3. These were then used to calculate the ratooning ability of the five rice varieties.

4.3 Data Analysis

Data were statistically analyzed with the General Linear Model (GLM) of the Genstat program. Fischer's protected LSD was used for mean separation at 5% probability level. Ratooning ability of the rice varieties was calculated as a percentage of the main crop grain yield using equation 4.1 (Sanni *et al*., 2009).

$$RA = \frac{RCGY}{MCGY} * 100 \quad \text{-- Equation 4.1}$$

Where, RA = Ratooning Ability, RCGY = Ratoon Crop Grain Yield, MCGY = Main Crop Grain Yield.

4.4 Results

The results presented in Table 4.1 show the main, ratoon and total grain yields of the five upland rice varieties.

Table 4.1: The main, ratoon and total grain yields of five upland rice varieties

	Yield (kg ha^{-1})		
Variety	Main crop	Ratoon crop	Total
NERICA 1	4588^{a}	1193^{b}	5781^{ab}
NERICA 4	4465^{a}	1741^{a}	6206^{a}
NERICA 10	4099^{b}	1517^{ab}	5616^{b}
NERICA 11	4436^{ab}	1242^{b}	5678^{b}
Duorado precoce	2837^{c}	539^{c}	3376^{c}

Means in the same column followed by the same letter(s) are not significantly ($p>0.05$) different according to Fischer's protected LSD.

4.4.1 Grain yield in the main crop

Significant differences ($F_{(4, 80)} = 33.08$, $p<0.001$) in grain yield were found among the five upland rice varieties in the main crop (Table 4.1, Appendix 4.1). Among the four NERICA rice varieties, NERICA 1 had the highest grain yield (4588 kg ha^{-1}) followed by NERICA 4 (4465 kg ha^{-1}) while NERICA 10 had the lowest (4099 kg ha^{-1}). The standard check Duorado precoce attained grain yield of 2837 kg ha^{-1} which was significantly ($p<0.05$) lower than that of the four NERICA rice varieties.

4.4.2 Grain yield in the ratoon crop

There was significant difference ($F_{(4, 80)} = 15.48$, $p<0.001$) in the ratoon crop grain yield among the five upland rice varieties (Table 4.1, Appendix 4.2). Among the four NERICA rice varieties, NERICA 4 achieved the highest ratoon grain yield (1741 kg ha^{-1}) followed by NERICA 10 (1517 kg ha^{-1}) while NERICA 1 had the lowest (1193 kg ha^{-1}). The standard check Duorado precoce attained grain yield of 539 kg ha^{-1} which was significantly ($p<0.05$) lower than that of the four NERICA rice varieties.

4.4.3 Total grain yield in double harvest

The total grain yield which equals the sum of the main and ratoon grain yield differed significantly ($F_{(4, 98)} = 11.41$, $p<0.001$) among the five rice varieties (Table 4.1, Appendix 4.3). NERICA 4 had the highest total grain yield (6206 kg ha^{-1}) followed by NERICA 1 (5781 kg ha^{-1}) while NERICA 10 had the lowest (5616 kg ha^{-1}) among the four NERICA rice varieties. Duorado precoce recorded a total grain yield of 3376 kg ha^{-1} which was significantly ($p<0.05$) lower than any of the four NERICA rice varieties.

4.4.4 Comparative ratooning ability as a percentage of the main grain yield

The results on the comparative ratooning ability of the five upland rice varieties are depicted in figure 4.1. The ratooning ability varied significantly ($F_{(4, 98)} = 6.89$, $p<0.001$) among rice varieties (Appendix 4.4). The lowest ratooning ability (19%) was observed in the standard check Duorado precoce which was significantly ($p<0.05$) lower compared to the four NERICA rice varieties. Among the four NERICA varieties, NERICA 4 had superior ratooning ability of 39% followed by NERICA 10 with 37%, while NERICA 1 recorded the lowest (26%).

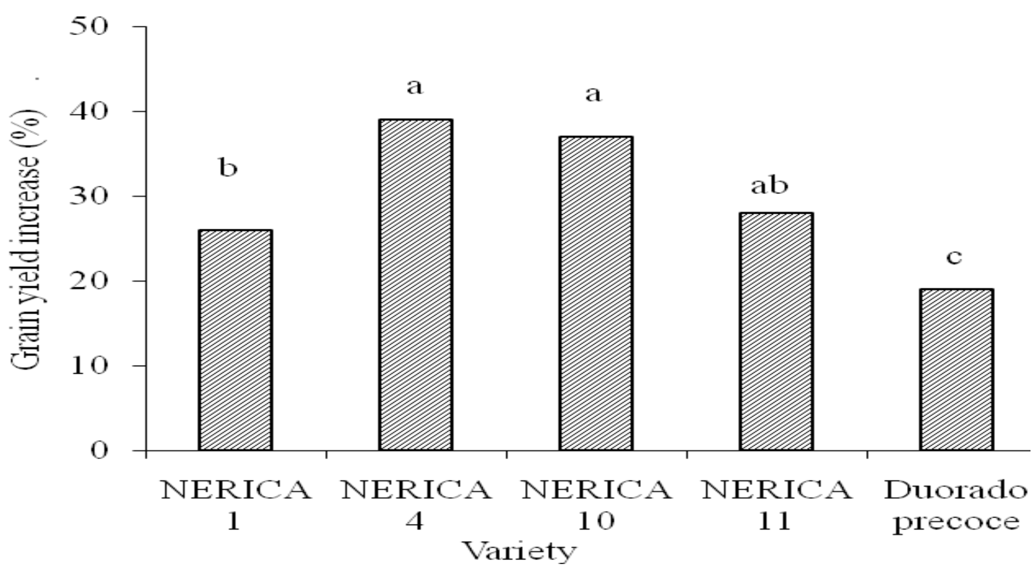

Figure 4.1: Percentage increase in grain yield of five upland rice varieties due to ratooning. The values are the average of main crops 1 & 2 and ratoon crops 1 & 2. Bars with the same letter(s) are not significantly different at the 5% level.

4.5 Discussion

Grain yields from this study differed among the five upland rice varieties in the main as well as the ratoon crop with the NERICA rice varieties attaining significantly ($p<0.001$) higher yields (kg ha^{-1}) compared to the standard check Duorado precoce. This is in consonance with earlier studies (Singh, 1994; WARDA, 1999; Mitra *et al*., 2005; Baloch *et al*., 2006; Ekeleme *et al*., 2007; Sanni *et al*., 2009; Liu *et al*., 2012) where differences in grain yield were reported among rice varieties. Among them, Ekeleme *et al*. (2007) and Sanni *et al*. (2009) reported higher yields from NERICA rice varieties compared to local landrace CG 14 with NERICAs 1 and 4 attaining the highest yield. The results were however contrary to Atera *et al*. (2012) who noted no significant difference in grain yield among rice varieties. From the main crop, the NERICA grain yields which varied from 4099 kg ha^{-1} to 4588 kg ha^{-1} for NERICA 10 and NERICA 1 respectively were within the estimated yield of NERICA rice varieties of 4000-7000 kg ha^{-1} (Africa Rice Center, 2008). This is however lower compared to Liu *et al*. (2012) who reported main crop grain yields varying between 6000-7000kg ha^{-1}. This could possibly be due to use of different rice varieties and also differences in climatic and edaphic factors between the two areas of study. NERICA rice varieties therefore have higher potential for increasing rice production compared to the traditional rice varieties hence food sufficiency for the achievement of Kenya's vision 2030. Some studies reported that rice yield in upland systems of Africa is about 1000 kg ha^{-1}(Kijima *et al*., 2006; Africa Rice Center, 2008; Atera *et al*., 2011). Inclusion of upland NERICA cultivars in the cropping system has been found to bring significant increase in the potential yield of rice. Kijima *et al*. (2006) stated that upland NERICA varieties yield in Uganda was twice as much compared to traditional upland rice varieties. Results in West Africa showed that NERICA yields about 2500 kg ha^{-1} with low use of inputs and under prudent fertilizer use yield of 5000 kg ha^{-1} or more is achievable (WARDA, 1999; Kijima *et al*., 2006). Preliminary evaluations from WARDA showed that NERICA has surpassed the local landraces in yield with a potential to revolutionize the rice industry (Atera *et al*., 2011). This is supported by the findings from this study where the NERICA rice varieties attained significantly higher grain yields than the local upland variety Duorado precoce in both the main and the ratoon crop (Table 4.1).

Ratooning in rice has been reported in earlier studies (Chauhan *et al*., 1985: Nakano and Morita, 2007) and also the prospects of increasing rice production in the tropics through ratooning (Bahar and De Datta, 1977). NERICA rice ratoon grain yields from current study varying from 1193 kg ha^{-1} to 1741 kg ha^{-}1 were in agreement with the results gotten by Bahar and Datta (1977) when they evaluated six rice cultivars in Philippines. The observed values from the current study were however lower compared to Liu *et al*. (2012) who reported ratoon crop grain yields between 4000-4500 kg ha^{-1}. This could possibly be due to differences in climatic and edaphic factors in the areas of study. Chauhan *et al*. (1985) also reported a wide variation in ratoon yield ranging from 100-8700 kg ha^{-1} which they suggested was an encouraging potential for ratoon cropping.

The ratoon grain yield from this study was found to be lower than the main crop yield for the five upland rice varieties (Table 4.1). This was in agreement with earlier findings (Bahar and De Datta, 1977; Bardhan *et al*., 1982; Bollich *et al*., 1988; Web *et al*., 2002; Tari, 2011; Liu *et al*., 2012) that reported lower grain yield from the ratoon crop compared to the main crop.The findings were however contrary to some studies (Parago, 1963; Prashar, 1970; Reddy *et al*., 1979) where ratoon yields surpassed main-crop yields. The lower ratoon crop yield in the current study was perhaps due to lower number of tillers and productive tillers, fewer panicles per hill and lower percentage filled spikelets from the ratoon crop compared to the main crop, which were found to be significantly positively correlated to grain yield (Table 3.6). Ratoon grain yield is reported (Tari, 2011; Bollich *et al*., 1988) to be affected by main crop harvesting time, climate condition, water and fertilizer management in the ratoon, temperature at the ratoon reproductive stage, main crop cutting height and growth regulators. It has been opinioned that main crop should be harvested immediately when mature grains are at maximum and their stems are physiologically alive (Bahar and De Datta, 1977). Delay in harvesting time causes low ratoon grain yield. If ratoon growth encounters low temperatures, growth duration is increased. In this case the flowering stage may encounter low temperatures thereby leading to increased number of sterile spikelets per panicle hence lower grain yield (Web *et al*., 2002; Bahar and De Datta, 1977). Oad *et al*. (2002) reported that the general low yield obtained from the ratoon crop is mainly due to the reduction in the number of productive tillers and short growth duration. The variation in growth duration in rice is largely due to differences in vegetative growth period (Yoshida, 1972). There is a positive correlation between growth duration and the length of period from panicle intiation to heading. An early maturing rice crop has a relatively short period for panicle growth that is accompanied by decreased grain yield (Akimoto and Togari, 1939; Owen, 1969). The early maturity of the ratoon crop compared to the main crop may therefore have contributed to lower yield in the former compared to the latter.

Ratooning ability varied significantly ($p<0.001$) among the five upland rice varieties investigated in this study with the NERICA rice varieties recording higher ratooning ability than Duorado precoce. The results support earlier studies (WARDA, 1999; Kouko *et al*., 2006; Sanni *et al*., 2009) where the NERICA varieties were reported to show great variation in their ratooning ability. Among them Kouko *et al*. (2006) reported ratooning ability ranging from 13 to 39% with no additional fertilizer applied to the ratoon crop. The same authors also reported NERICA rice varieties as having better ratooning ability compared to their parents, *O. sativa* and *O. glaberrima*. Tillering ability is reported as a good indicator of ratooning ability of the rice crop (Chauhan *et al*., 1985; Sanni *et al*., 2009). The four NERICA varieties used in this study showed superior tillering ability than the standard check Duorado precoce (Figures 3.6-3.9) which translated to better ratooning ability for the four NERICAs compared to Duorado precoce. Results from the current study showed significantly positive correlation between tillering ability and grain yield from both the main ($r = 0.601$, $p<0.001$) and ratoon crop ($r = 0.487$, $p<0.001$) (Appendix 3.8 and 3.9 respectively). Tillering ability differed among the NERICA rice varieties which perhaps contributed to the observed differences in their ratooning ability in the current study (Figure 4.1) possibly due to genetical differences among the varieties. Chauhan *et al*. (1985) outlined the major factors affecting the ratooning ability of rice crop as the inherent ratooning ability of the cultivars, genetical differences, light, temperature, soil moisture, fertility and management such as weeding. Tari, (2011) reported that ratooning ability is a result of interaction between the genetical, climate and management variables. Root vigor and distribution also affect ratooning (Chauhan *et al*., 1985). Ratoon tillers for rice varieties such as IR44 were found to depend on main crop root system for nutrients until at least

21 days after harvest. A vigorous main-crop root system may therefore be a prerequisite for a successful ratoon crop (Chauhan *et al*., 1985).

Main crop growth duration has also been reported to influence ratooning ability (Chauhan *et al*., 1985; Chaetterjee *et al*., 1982). Very early and early maturing cultivars usually produce a successful ratoon, medium-maturing cultivars produce satisfactory ratoon grain yield while late maturing do not produce a consistent ratoon crop (Chauhan *et al*., 1985; Chaetterjee *et al*., 1982). Duorado precoce was classified as medium/late maturing (Table 3.5) and attained the lowest ratoon yield (Table 4.1) and ratooning ability (Figure 4.1) hence supporting earlier findings (Chauhan *et al*., 1985; Chaetterjee *et al*., 1982) that the main crop growth duration influence ratooning ability of the rice crop. In contrast, Hsieh *et al*. (1964) reported that some cultivars with longer growth duration have better ratooning ability. A ratoon crop of late-maturing IR42 yielded significantly more than early-maturing IR36 and medium-maturing IR38. In IR42, increased ratoon grain yield was due to higher panicle densities and filled spikelets per panicle. However, longer main-crop growth duration increases the possibility of virus disease in the ratoon crop which is a major constraint in the tropics. In support of Hsieh *et al*. (1964), NERICA 4 which was classified as medium maturing showed better ratooning ability than NERICAs 10 and 11 that were classified as early maturing. Zandstra and Samson (1979) recommended that breeding for ratooning ability should emphasize medium duration cultivars that produce large panicles and grain because early-maturing varieties may not have the yield potential of longer duration cultivars. As such, a combination of these growth and yield variables explains variations in ratooning ability of rice better than any individual growth or yield variable (Ghosh and Singh, 1998).

Total grain yield which equals the sum of the main and the ratoon crop yield differed significantly ($p<0.05$) among the varieties. NERICA 4 had the highest yield of (6206kg ha^{1}) followed by NERICA 1 (5781 kg ha^{-1}). The lowest yields (3376 and 5616 kg ha^{-1}) were recorded for Duorado precoce and NERICA 10 respectively. The yield increase of more than 1500 kg ha-1 (the average yield of upland rice in Sub-sahara Africa) recorded in NERICAs 4 and 10 (Table 4.1) with no additional input were very encouraging. This will presumably increase with additional input during ratoon. Chauhan *et al*. (1985) reported that nitrogen and phosphorus affect ratoon growth, and especially phosphorus is important because it promotes good root development. Applying nitrogen increases ratoon grain yield. Liu *et al*. (2012) reported that better yield of ratoon crop is possible by adopting appropriate management practices for the main crop as well as the ratoon crop. Values as high as 12633kg ha^{-1} and 7115kg ha^{-1} for main and ratoon crops respectively have been reported in China (Li *et al*., 2003; Liu *et al*., 2012). The ratooning ability varying from 26% to 39% that was observed in this study (Figure 4.1) was also encouraging. Although the grain yield from the ratoon crop was relatively lower than the main crop, it however increased the total grain yield with no extra cost, which implies more earning if applied by the resource poor farmers. These results indicate that NERICA has a high potential grain yield in double harvest. Ratooning should therefore be incorporated into the cropping systems so as to increase grain yield hence more profit for farmers.

Among the four NERICA rice varieties evaluated in the current study, NERICA-4 and NERICA-1 were found to be better yielding than NERICA-10 and NERICA-11. Similar studies carried out in Western Kenya with the same varieties found NERICA-4 and NERICA-10 to be better yielding than NERICA-1 and NERICA-11 (Ndjiondjop *et al*., 2008). This could possibly be due to differences in climatic and edaphic factors between the two regions of study. Ekeleme *et al*. (2007) also showed that NERICA 4 was more tolerant to weed pressure than the other NERICA varieties. NERICA-4 and NERICA-1 rice varieties are therefore recommended for Central Kenya as the best yielding varieties though the yield of the other two NERICAs was also very encouraging compared to the local landrace Duorado precoce.

4.6 Conclusion

Ratooning ability varied significantly ($p<0.05$) among the upland rice varieties hence nullifying the third hypothesis in the current study that NERICA and *O. sativa* rice varieties have the same ratooning ability. The NERICA varieties demonstrated higher ratooning ability than the *O. sativa* rice variety (Duorado precoce). Ratooning increased the total grain yield of the five upland rice varieties. The results of this study provide an initial basis for the potentiality of using ratoon cropping in NERICA as a means of increasing rice yield in Central Kenya.

CHAPTER FIVE

CRITICAL PERIOD OF WEED CONTROL IN UPLAND NERICA AND *ORYZA SATIVA* RICE CROP

5.1 Introduction

An improved weed management system is necessary to reduce labour inputs through the use of integrated weed management approach for enhanced crop production (Akobundu, 1991). For the implementation of a sound integrated weed management, knowledge of the critical period of weed control (CPWC) is one of the basic requirements, which Knezevic *et al*. (2002) defined as the period in the crop growth cycle during which weeds must be controlled to avoid yield losses. Yield reduction depends on multiple factors, including weed species, weed density, time of weed emergence relative to crop emergence, weed distribution, soil type, soil moisture, pH and soil fertility level (Tursun *et al*., 2007). By controlling weeds during the critical period, reductions in grain quality can also be minimized (Tursun *et al*., 2007). When weed control is neglected, there is a decrease in yield; even if other means of increasing production, including application of fertilizers, are practiced because weeds compete with crop plants for light, nutrients, water and space (Mitra *et al*., 2005). Numerous studies have documented the negative effects on yield of season-long weed competition in Africa. Under unweeded conditions, crop losses have been realised for: rice (50-100%), maize (55-90%), common bean (50%), sorghum (40-80%), cowpea (40-60%), cotton (80%), wheat (50-80%), groundnut (80%), and cassava (90%) (Olowe *et al.*,1987; Akobundu, 1991; Ambe *et al.*, 1992; Johnson, 1996; Ngouajio *et al.*, 1997; Chikoye *et al.*, 2004; Dadari and Mani, 2005; Ishaya *et al.*, 2007). Ekeleme *et al*. (2007) noted that uncontrolled weed growth depressed grain yield of rice varieties by over 86% compared to one or two weedings. Harding and Jalloh (2011) reported a positive relationship between competition (calculated as yield in competition/yield in weed-free plots) and yield potential.

NERICA rice varieties have desirable agronomic traits that are potentially useful for weed competitiveness including good vigor at seedling and vegetative stages for weed suppression, intermediate to tall stature and moderate tillering ability making them more superior to local land races (Johnson *et al*., 1998; Kaneda, 2007). In addition, they have characteristic wide, droopy leaves that could suppress weeds (Kaneda, 2007). Dzomeku *et al*. (2007) observed that NERICA rice varieties require at least 6 weeks of weed-free for the formation of cover that can suppress weeds. In upland rice farming, the CPWC is approximately 15-40 days after seeding, while in transplanted rice, the crop can form a canopy more rapidly (Akobundu, 1991; Knezevic *et al*., 2002). Where a crop is exposed to prolonged weed competition during this period it is not usually able to recover sufficiently to give a good yield (Langevin *et al*., 1990; Haefele *et al*., 2004). According to Toure *et al*. (2011), the CPWC is generally located between 15 and 60 days after seeding (DAS) for short-cyle annual crops (rice, cotton, corn, sorghum) and between 30 and 90 DAS for long-cyle annual crops (yams, cassava, sugarcane). There are only limited published studies on the CPWC in the newly developed NERICA rice varieties in general (Dzomeku *et al*., 2007). These studies are lacking in Kenya in particular. The objective of this study was therefore to determine the *"critical period of weed control in four upland NERICA (NERICA 1, 4, 10 and 11) and one O. sativa (Duorado precoce) rice varieties for upland rice production to enable development of more precise weed management recommendations and support their dissemination to farmers in Central Kenya".*

5.2 Materials and Methods

5.2.1. Experimental design

The critical period of weed control for the four upland NERICA rice varieties (NERICA 1,4,10, 11) and Duorado precoce was determined for both the main and ratoon crop using the design as in section 3.2.2. After harvesting the main crop, the stubble from each sub-plot was then subjected to the same treatment as the main crop in the two sets of treatment inorder to determine the critical period of weed control of the ratoon crop.

5.2.2. Data collection

Data on the grain yield were separately collected from each weeding treatment for the main and ratoon crop of the five rice varieties.

5.2.3 Data analysis

Rice relative grain yield of each weeding treatment was calculated in relation to the full season weed-free (Wfh) control treatment by dividing the yield of the treatment by the control yield and expressing the result as a percentage using equation 5.1 (Dzomeku *et al*., 2007; Toure *et al*., 2013).

$$RY = \frac{TY}{FSWFY} * 100 \quad \text{--- Equation 5.1}$$

Where; RY = Relative Yield, TY = Treatment Yield, FSWFY = Full Season Weed Free Yield.

The relative yield data were subjected to ANOVA procedure and treatment means were compared using LSD where F-values were significant ($p<0.05$) (Moore and McCabe, 1999).

5.3 Results

5.3.1 Relative grain yield response from the main crop

Results on the relative grain yield (percentage of full season weed-free treatment) responses of upland NERICA and local landrace Duorado precoce rice varieties from the main crop are shown in Figures 5.1a-5.1e.

The relative grain yield responses of the four NERICA (NERICAs 1, 4, 10 and 11) rice varieties as well as the standard check Duorado precoce exhibited significant ($p<0.05$) changes to periods of weed infestation. For the five rice varieties, early competition (WI) reduced grain yield compared to late competition (WF) except at 3 WAP. There is therefore need for early weed control in the rice fields of both NERICA and Duorado precoce. Full season weed-free treatment attained significantly ($p<0.05$) higher grain yield (kg ha^{-1}) compared to full season weed-infested treatment for the five rice varieties (Figures 5.1a-e). Keeping the rice varieties weed infested for only upto 3 WAP did not reduce grain yields significantly ($p>0.05$) relative to full season weed-free treatment for both the standard check Duorado precoce and the four NERICA rice varieties. On the other hand, keeping the rice varieties weed free for upto 3 WAP only significantly

($p<0.05$) reduced grain yields relative to full season weed-free treatment for the five rice varieties.

Keeping the rice varieties weed infested for upto 6 WAP significantly ($p<0.05$) reduced grain yields relative to full season weed-free for the NERICAs and Duorado precoce. Grain yield decreased tremendously when plots were weed infested for more than 9 WAP for the five rice varieties and were comparable ($p>0.05$) to full season weed-infested treatment. The average relative yields of the full season weed-infested treatment compared to full season weed-free treatment (reflecting the highest relative yield losses) for the five upland rice varieties were 54.3, 50.9, 55.4, 53.4 and 67.2% respectively for NERICA 1, NERICA 4, NERICA 10, NERICA 11 and Duorado precoce, with an average of 56.2%. Keeping the rice varieties weed free for upto 6 WAP produced grain yields comparable ($p>0.05$) to full season weed-free for NERICA 1 and 4. NERICAs 10, 11 and Duorado precoce produced grain yields comparable ($p>0.05$) to full season weed-free when kept weed free for upto 9 WAP. Notably, additional weed control after 9 WAP did not result in additional gain in grain yield of either NERICA or the Duorado precoce rice varieties relative to weed-free check.

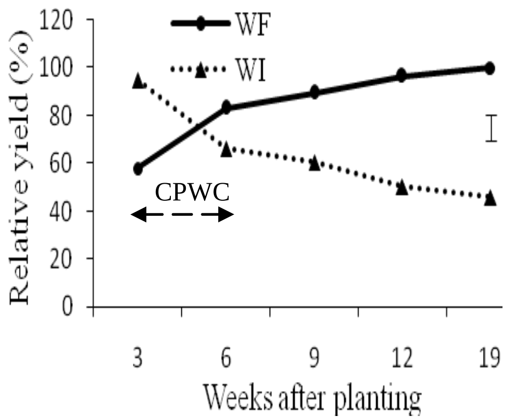

Figure 5.1 (a) NERICA 1

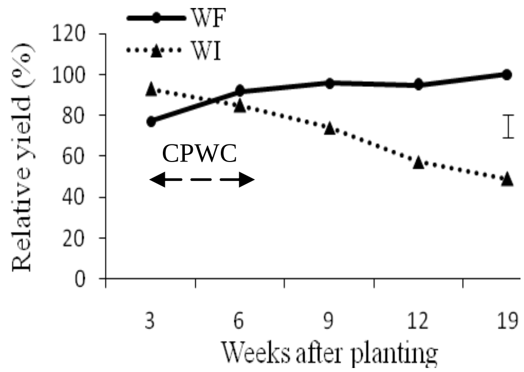

Figure 5.1 (b) NERICA 4

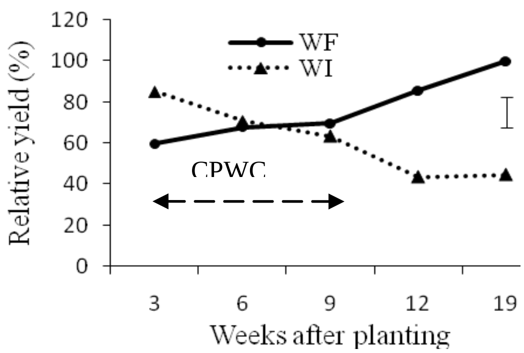

Figure 5.1 (c) NERICA 10

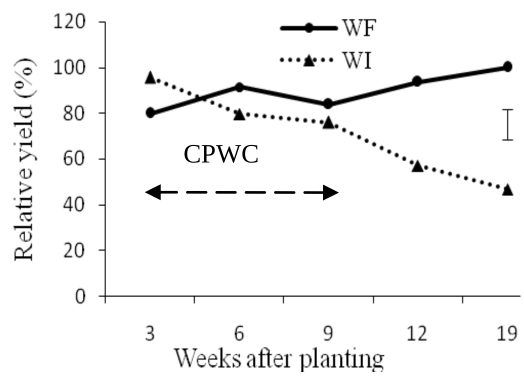

Figure 5.1 (d) NERICA 11

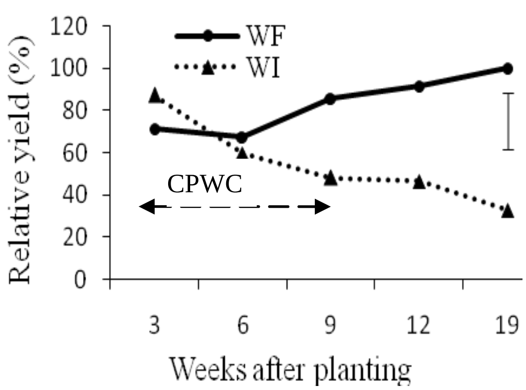

Figure 5.1 (e) Duorado precoce

Figure 5.1a-e: Effect of period of weed interference on relative grain yields of four NERICAs and Duorado precoce from the main crop. WF=Weed Free period; WI=Weed Infested period. Horizontal dashed line represents the CPWC in WAP. Vertical error bar represents the LSD at $p<0.05$

5.3.2 Relative grain yield response from the ratoon crop

Results on the relative grain yield (percentage of full season weed-free treatment) responses of the four NERICAs and Duorado precoce rice varieties from the ratoon crop are shown in Figures 5.2a-5.2e. The ratoon crop relative grain yield responses of the four NERICAs and Duorado precoce rice varieties to periods of weed infestation exhibited highly significant ($p<0.001$) changes. The full season weed-free treatment achieved significantly ($p<0.05$) higher grain yield (kg ha^{-1}) compared to full season weed-infested treatment for the five rice varieties from the ratoon crop (Figure 5.2a-e). Keeping the rice varieties weed infested for only upto 3 WACB did not reduce grain yields significantly ($p>0.05$) relative to full season weed-free treatment for either the NERICAs or Duorado precoce (Figures 5.2a-5.2e). On the other hand, keeping the rice varieties weed free for only upto 3 WACB significantly ($p<0.05$) reduced grain yields relative to full season weed-free treatment for the five rice varieties.

Keeping the ratoon crop weed infested for upto or more than 6 WACB significantly ($p<0.05$) reduced grain yields relative to full season weed-free for both the NERICAs as well as Duorado precoce. Grain yield decreased tremendously when plots were weed infested for more than 9 WACB for the five rice varieties and were analogous ($p>0.05$) to full season weed infestation. The average relative yields of the full season weed-infested treatment compared to full season weed-free (reflecting the highest relative yield losses) for the ratoon crop of the five upland rice varieties were 56.0, 57.4, 56.3, 55.1 and 63.0% respectively for NERICA 1, NERICA 4, NERICA 10, NERICA 11 and Duorado precoce, with an average of 57.6%. Keeping the rice varieties weed free for upto 6 WACB showed grain yields equivalent ($p>0.05$) to full season weed-free for the five rice varieties (Figures 5.2a-e). Markedly, additional weed control after 6 WACB did not result in additional gain in the ratoon grain yield of either NERICA or the Duorado precoce rice varieties relative to full season weed-free check.

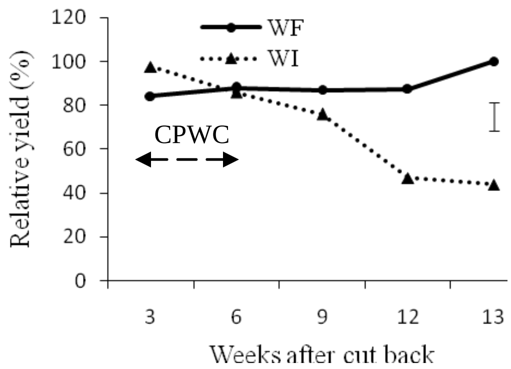

Figure 5.2 (a) NERICA 1

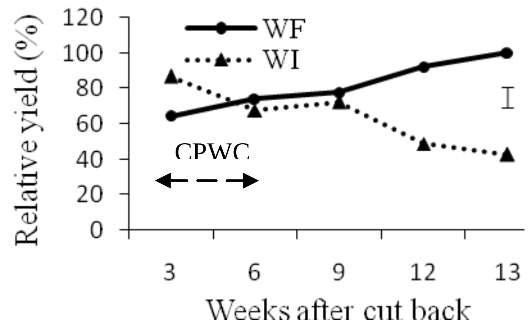

Figure 5.2 (b) NERICA 4

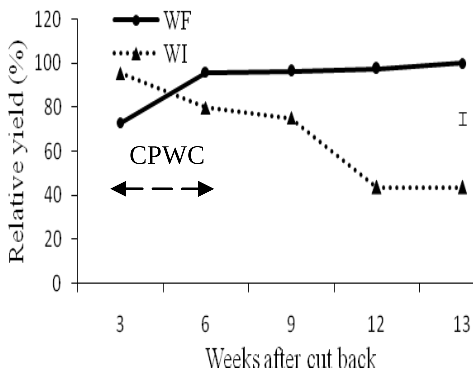

Figure 5.2 (c) NERICA10

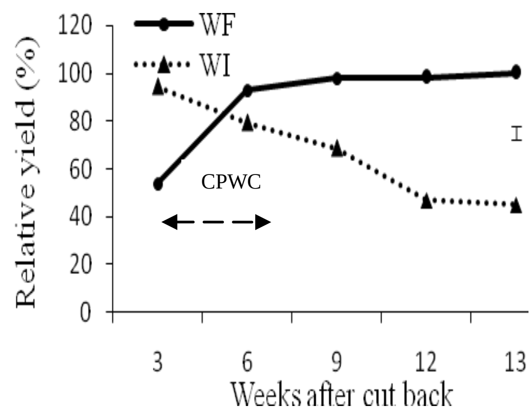

Figure 5.2 (d) NERICA 11

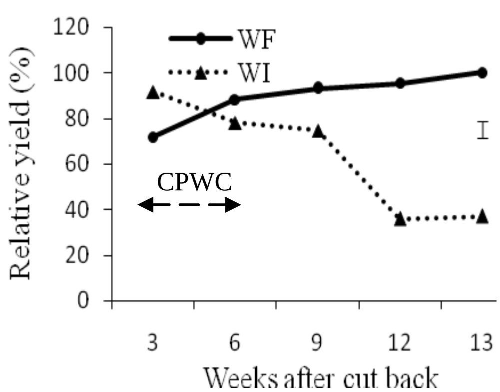

Figure 5.2 (e) Duorado precoce

Figure 5.2a-e: Effect of period of weed interference on relative grain yields of four upland NERICAs and Duorado precoce from the ratoon crop. WF=Weed Free period; WI=Weed Infested period. Horizontal dashed line represents the CPWC in WACB. Vertical error bar represents the LSD at $p<0.05$.

5.4 Discussion

Results from this study showed that grain yield of the five upland rice varieties increased with increasing weed-free period (WF) and decreased with increasing weed infestation period (WI) from the main and ratoon crops. This could possibly be due to severe crop-weed competition for nutrients hence fewer assimilates translocated to the grains. This response is in agreement with previous findings reported on other crops (Hall *et al*., 1992; Van Acker *et al*., 1993; Ngouajio *et al*., 1997; Amador–Ramirez, 2002; Bukun, 2004; Tursun *et al*., 2007). The findings are also in support of Dzomeku *et al*. (2007) who pointed out that grain yield responses of NERICA 1 and 2 to periods of weed infestation were similar and exhibited significant changes. This is also in consonance with earlier studies (Singh, 1994; Mitra *et al*., 2005; Baloch *et al*., 2006; Atera *et al*., 2011) who reported differences in rice grain yield among the weeding times.

Higher grain yields (kg ha^{-1}) from the full season weed-free treatment compared to full season weed-infested treatment for the five upland rice varieties from both the main and ratoon crop was in support of earlier studies (Bari *et al*., 1993; Singh, 1994; Moynul *et al*., 2003; Baloch *et al*., 2006; Atera *et al*., 2011) where the highest grain yields were obtained from the full season weed-free treatment. This was attributed to less crop-weed competition that ensured sufficient nutrients and other growth resources for the rice crop in addition to higher number of tillers and panicles which are attributes of yield, thus enhancing higher grain production from the full season weed-free treatment. Similarly, Mitra *et al*. (2005) obtained the highest grain yield for transplanted aman rice from weed-free treatment. Tursun *et al*. (2007) also found that growth and yield of leek (*Allium porrum* L.) were substantially reduced by weed competition for nutrients, water and light. The results were however contrary to Ekeleme *et al*. (2007) who noted no significant difference in grain yield between varieties in weedy plots.

The observed non-significant reduction in relative grain yields of the rice varieties weed infested for only upto 3 WAP in both the main and ratoon crops (Figures 5.1and 5.2 respectively) could perhaps be attributed to presences of sufficient nutrients at the early growth stage of the crop hence no severe competition between the crop and the weeds. Weeds within the first three weeks of the crop growth therefore did not significantly affect crop yield of the rice varieties. This was in line with earlier report by Dzomeku *et al*.

(2007) on NERICA rice varieties and also supports Eleftherohorines *et al.* (2002) who pointed out that competition between rice crop and weeds began three weeks after rice emergence. In this case weeds germinating very early in the crop cycle did not significantly affect yields. In addition, during the early stage of crop cycle the weed flora is less developed; making weed controls easier with greater efficiency.

Rice varieties kept weed free for only upto 3 WAP significantly ($p<0.05$) reduced grain yields relative to full season weed-free treatment in both the main and ratoon crops (Figures 5.1-5.2) of the five rice varieties. The results were contrary to previous findings by Dzomeku *et al*. (2007) who reported no reduction in grain yield of NERICA rice varieties when kept weed-free for only upto 3 WAP. On the main crop, the comparable relative grain yields from the plots kept weed-free up to 6 WAP for NERICAs 1 and 4 (Figures 5.1a and 5.1b respectively) marks the end of their CPWC while the same is true upto 9 WAP for NERICAs 10, 11 and the check Duorado precoce (Figures 5.1c, 5.1d and 5.1e respectively). These findings are in agreement with earlier findings (Labrada, 2002; Dzomeku *et al*., 2007; Toure *et al*., 2013) where the CPWC for rice varieties was reported as 3-9 WAP. From the ratoon crop, comparable grain yields produced by crops kept weed-free up to 6 WAP with weed-free check for the five rice varieties marks the end of their CPWC. The comparable grain yields at these periods could be attributed to adequate elimination of weeds during this period which enhances the rice varieties abilty to tiller and close out with sufficient canopy to prevent further growth of weeds (Akobudu, 1987). The CPWC for the NERICA ratoon crop was found to be generally shorter than for the main crop possibly due to the shorter growth period of the former. Additional weed control after 6 WACB and 9 WAP did not result in additional gain in grain yield for the ratoon and the main crop respectively of the four upland NERICA or Duorado precoce rice varieties relative to weed-free check. In effect, earlier weed removal especially between 3 and 9 WAP may obviate yield reduction for the upland rice main and ratoon crops.

The average relative yields of the full season weed-infested treatment compared to full season weed-free (reflecting the highest relative yield losses) for the NERICA main crop varied from 51 to 57% for NERICA 4 and NERICA 10 respectively while Duorado precoce recorded 67% loss. The loss for the NERICA ratoon crop varied from 55 to 57.4% for NERICA 11 and NERICA 4 respectively while Duorado precoce recorded 63%

loss. Based on these findings, the four NERICA rice varieties are therefore better competitors against weeds than the local landrace Duorado precoce both in the main and the ratoon crop. The average loss of 56.2% and 57.6% for main and ratoon crops respectively of the five rice varieties investigated in this study lie in the range (50-100%) of rice yield loss due to uncontrolled weed growth in upland rice ecosystems in Africa (Akobundu, 1991; Dzomeku *et al*., 2007; Toure *et al*., 2013).

For the five rice varieties, early competition (WI) reduced grain yield compared to late competition (WF) for both the main and the ratoon crop. This highlights the negative effect of the early compared to late competition in relation to rice yield loss. There is therefore need for early weed control in the main as well as the ratoon crop of both NERICA and Duorado precoce rice varieties. This is in support of Humbert, (1968) who reported that when early crop-weed competition is not controlled; the rate of growth of the crop is restricted significantly leading to decrease in grain yield. Weeding time has also been reported as positively collated to yield with the early weeded crop producing higher yield (Garrity *et al*., 1992; Haefele *et al*., 2004). This also concurs with the research result obtained by WARDA (1999) citing the need for early weed control in rice fields. These early weeding controls avoid rhizomes of some perennial weeds such as Cyperus spp., annual grasses such as *Brachiara eruciformis*, *Brachiara leucacrantha* and *Branchiara serrata* that were common in the study sites. For these annual species with short life cycle, the early weedings prevent development, flowering, fruiting and seed production which would increase the seed stock in the soil (Akobundu, 1987). The drawback in the early weeding resides in the close resemblance of those grass weeds with the rice plants at seedling and vegetative stage, and those weeds can be mistaken for rice plant and therefore evade eradication during the hand weeding (Akobundu, 1987). For both the main and the ratoon crops, the highest grain yields were obtained from the weed-free condition. From these findings, keeping rice fields weed-free throughout the season ensures higher grain yield, which concurs with earlier studies (De Datta, 1980; Alam *et al*., 1995). Nevertheless, from practical point of view it may not be feasible since it involves labour, time and money.

Results from the current study further showed a point of intersection between the early (WI) and late (WF) competition types (Figures 5.1 and 5.2) indicating the time during which weeds may remain in the plots and the period of time during which the plots should be weeded, suggesting that a single weeding at this time can prevent significant yield loss. This time was between 3 and 6 WAP for all the five rice varieties in both main and ratoon crops except the main crop of NERICA 10 (Figure 5.1c) where it was between 6 and 9 WAP. However, the present study did not include the effect of weeding on this specific date. Nevertheless, a previous study (Toure *et al*., 2011) was able to establish that a single weeding done on 31 DAS (close to 5 WAP) had a yield comparable to the double weeding done at 3 and 6 WAP. If a single weeding done on a specific date between 3 and 6 WAP did not have a significantly lower yield than the weed-free control, then it would not be a critical period but a critical date for weeding (Toure *et al*., 2011; Toure *et al*., 2013). From the investigations in this study, the CPWC for the five rice varieties is 3-6 WAP for NERICAs 1 and 4 and 3-9 WAP for NERICAs 10, 11 and Duorado precoce from the main crop. This CPWC is in compliance with previous studies. In Ghana, Dzomeku *et al*. (2007) determined in rainfed condition that the CPWC of two varieties to NERICA rice (NERICA 1 and NERICA 2) was between 3 and 6 WAP. For irrigated rice in the Sahel, this period was between 4 and 5 WAP during the rainy season and between 1 and 12 WAP during the dry season (Johnson *et al*., 2004). In rainfed rice in southern Togo, weed competition is more harmful between 3 and 4 WAP (Toure *et al*., 2013). On the ratoon crop, the CPWC for the four NERICAs plus the standard check Duorado precoce was established as 3-6 WACB. During this period, weeds should be theoretically removed for best rice grain yield.

5.5 Conclusion

Based on the results of this study, it is concluded that NERICA and *O. sativa* rice varieties have different critical periods of weed control. The CPWC also differs among the four NERICA rice varieties. From the main crop, the CPWC for NERICA 1 and 4 was established as 3-6 WAP while for NERICAs 10, 11 and Duorado precoce it is 3-9 WAP. On the ratoon crop, the CPWC for the four NERICAs as well as Duorado precoce was established as 3-6 weeks after cut back. The hypothesis in this study that NERICA *and O. sativa* rice varieties have similar critical period of weed control was therefore rejected for the main crop and accepted for the ratoon crop.

CHAPTER SIX

INVASIVENESS OF UPLAND NERICA RICE VARIETIES

6.1 Introduction

There is increasing concern from environmentalists on the threats posed to biodiversity by potentially invasive weeds (Pheloung, 1995; Parker *et al*., 1999; Andersen *et al*., 2004). Prevention of import at the borders, along with early control of those weeds already present in a country is considered the most effective form of management (Williams, 1997). According to the Convention on Biological Diversity (2000), to which Kenya is party, biosafety refers to the need to protect human health and the environment from possible adverse effects of the products of modern biotechnology such as the NERICA rice varieties. NERICA rice being a member of the poaceae family which on a world scale, is classified among the prominent families that are likely to produce weed species (Daehler and Carino, 2000; Williams *et al*., 2002; Daehler *et al*., 2004), and with the best traits from the cultivated *O. sativa* and *O. glaberrima* rice species, could probably turn out be invasive hence the need for risk assessment. Being new varieties in the continent, there is only limited information about NERICAs and the characteristics of each NERICA variety have not been sufficiently investigated. In Kenya, only a few studies have been conducted in western Kenya (Kouko *et al*., 2006) that have focused on response to drought, pests and diseases, yield and maturity rate of NERICA. In these studies, the biosafety aspect was not addressed and hence the need for this study. No studies have been carried out in central Kenya province, which is a great producer of rice particularly from Mwea Tebere Iirrigation Scheme. It is therefore necessary to evaluate the potential of NERICA varieties for invasiveness in central Kenya.

Both the Cartagena Protocol (2000) and the Kenya Biosafety Act (2009) have the objective to facilitate responsible research into, and minimize the risks that may be posed by biotechnologically developed or genetically modified organisms. In order to meet this objective, there is need to assess the potential risks that may be posed by the introduction of NERICA rice in Kenya before the varieties are widely deployed in the country. This study therefore attempted to assess *“the potential ecological risk for invasiveness of NERICA rice varieties in central Kenya”.*

6.2 Materials and Methods

6.2.1 Plant material

Four NERICA rice varieties; (NERICAs 1, 4, 10 and 11) and one standard check cultivated *Oryza sativa* (Dourado precoce) rice variety were evaluated.

6.2.2 Data collection

The Australia Weed Risk Assessment Scheme (AWRA) (Appendix 6.1) was used in this study to investigate the invasive potential of the NERICA rice varieties. This scheme was used in this study since it is recommended as a suitable tool for use as a quarantine tool in developing countries such as Kenya (Williams, 2000) because Australia includes a wide range of climates from desert to tropical rainforest (Daehler and Carino, 2000; Williams, 2000). It was modified where necessary, to fit the Kenyan situation. The modifications were particularly on the climate parameters since the scheme originates from temperate regions and it was tried out in the tropics. The modifications included; question 2.04 'native or naturalized in regions with extended dry seasons?' changed to 'native or naturalized in regions with tropical or sub-tropical climates?' a question that reflects the environment of Kenya, questions referring specifically to Australia (questions 2.01, 4.03 and 8.05) were substituted with "Kenya". Question 4.10 relating to soil conditions, a modification made for New Zealand was followed, changing 'grows on infertile soils?' to 'grows on a wide range of soil conditions?' a question that reflects the soils in Kenya (Pheloung *et al*., 1999). A questionnaire tool (Appendix 6.2) was formulated from the standard weed risk assessment scheme and used in the current study. Information on the rice varieties were gathered from different sources which included; observations especially on growth and reproductive biology of the rice varieties from investigations on the response to weed interference and ratooning ability of the rice varieties in the current study (Chapters three and four), primary literature, floras, initial variety descriptions particularly the Africa rice center, (2008) passport data and consultation with appropriate experts using the developed questionnaire tool (Appendix 6.2). The information was recorded in the standard weed risk assessment question sheet (Appendix 6.1) and scored using the standard weed risk scoring sheet (Appendix 6.3).

6.3 Data analysis

The data were ran on Microsoft excel version 7.0 xls on a windows computer on which the electronic version of the WRAdemo system is designed to run. The overall score for a variety related to one of the three possible recommendations (*accept*, *evaluate* or *reject*) as follows; score < 1 = accept, score between 1- 6 = evaluate, score > 6 = reject (Pheloung, 1995). A satistical summary on score partitioning was calculated to determine the contribution of each of three main sectors (biogeography, undesirable attributes, and biology/ecology) to the overall score. Besides the overall score, scores from questions of agricultural and environmental relevance were generated to give an indication of the sectors likely to be affected (Pheloung, 1995).

6.4 Results

Results on risk assessment for invasiveness of the four upland NERICA rice varieties (NERICAs 1,4,10 and 11) and the standard check Duorado precoce used in the current study are presented in tables 6.1a–e.

Table 6.1 a: Risk assessment for invasiveness of upland NERICA 1 rice variety

	Botanical name: *Oryza sativa***Oryza glaberrima* (WAB 450-I-B-P38-HB) Common name: NERICA 1		**Outcome**: 0(Accept)
	Family: Poaceae		**Score**: -6
	Area/Attribute	**HISTORY (SECTION A)**	**Response**
A	1.0 Domestication/ cultivation	1.01 Is the variety highly domesticated	Y
C		1.02 Is the variety naturalised where grown?	N
C		1.03 Does the variety have weedy races?	Y
	BIOGEOGRAPHY (SECTION B)		
	2.0 Climate and distribution	2.01 Variety suited to Kenyan climates (0-low; 1-intermediate; 2-high)	2
		2.02 Quality of climate match data (0-low; 1-intermediate; 2-high)	2
C		2.03 Broad climate suitability (environmental versatility)	Y
C		2.04 Native or naturalized in regions with tropical or sub-tropical climates?	Y
		2.05 Does the variety have a history of repeated introductions outside its natural range?	-
C	3.0 Weed elsewhere	3.01 Naturalised beyond native range	N
E		3.02 Garden and amenity disturbance weed	N
A		3.03 Weed of agriculture, horticulture and forestry	N
E		3.04 Environmental weed	N
		3.05 Congeneric weed	Y
	BIOLOGY/ECOLOGY (SECTION C)		

A	4.0 Undesirable traits	4.01 Produces spines, thorns or burrs	N
C		4.02 Allelopathic	N
C		4.03 Parasitic	N
A		4.04 Unpalatable to grazing animals	N
C		4.05 Toxic to animals	N
C		4.06 Host for recognised pests and pathogens	N
C		4.07 Causes allergies or is otherwise toxic to humans	N
E		4.08 Creates a fire hazard in natural ecosystems	N
E		4.09 Is a shade tolerant plant at some stage of its life cycle	N
E		4.10 Grows on a wide range of soil types?’	Y
E		4.11 Climbing or smothering growth habit	N
E		4.12 Forms dense thickets	N
	5.0 Plant type	5.01 Aquatic	N
		5.02 Grass	Y
		5.03 Nitrogen fixing woody plant	N
		5.04 Geophytes	N
C	6.0 Reproduction	6.01 Evidence of substantial reproductive failure in native habitat	-
C		6.02 Produces viable seed	Y
C		6.03 Hybridises naturally	N
C		6.04 Self-fertilisation	Y
C		6.05 Requires specialist pollinators	N
C		6.06 Reproduction by vegetative propagation	N
C		6.07 Minimum generative time (years)	1
A	7.0 Dispersal mechanisms	7.01 Propagules likely to be dispersed unintentionally	N
C		7.02 Propagules dispersed intentionally by people	Y
A		7.03 Propagules likely to disperse as contaminants of produce	N
C		7.04 Propagules adapted to wind dispersal	N
E		7.05 Propagules buoyant	N
E		7.06 Propagules bird dispersed	N
C		7.07 Propagules dispersed by other animals (externally)	N
C		7.08 Propagules dispersed by other animals (internally)	N
C	8.0 Persistence attributes	8.01 Prolific seed production	-
A		8.02 Evidence that a persistent propagule bank is formed (>1yr)	N
A		8.03 Well controlled by herbicides	Y
A		8.04 Tolerates or benefits from mutilation, cultivation or fire	N
E		8.05 Effective natural enemies present in Kenya	N
	Statistical summary of scoring	Score partition: Biogeography	0
		Undesirable attributes	0
		Biology/Ecology	-6
		Questions answered: Biogeography	10
		Undesirable attributes	12
		Biology/Ecology	22
		Total	44
		Sector affected: Agricultural	-5
		Environmental	1

A = Agricultural E = Environmental C = Combined Y = Yes N =No

Table 6.1 b: Risk assessment for invasiveness of upland NERICA 4 rice variety

	Botanical name: *Oryza sativa*Oryza glaberrima* (WAB 450-I-B-P91-HB) Common name: NERICA 4 Family: Poaceae		Outcome: 0 (Accept) Score: -5
	Area/Attribute	**HISTORY (SECTION A)**	**Response**
A	1.0Domestication/ cultivation	1.01 Is the variety highly domesticated?	Y
C		1.02 Is the variety naturalised where grown?	N
C		1.03 Does the variety have weedy races?	Y
	BIOGEOGRAPHY (SECTION B)		
	2.0 Climate and distribution	2.01 Variety suited to Kenyan climates (0-low; 1-intermediate; 2-high)	2
		2.02 Quality of climate match data (0-low; 1-intermediate; 2-high)	2
C		2.03 Broad climate suitability (environmental versatility)	Y
C		2.04 Native or naturalized in regions with tropical or sub-tropical climates?	Y
		2.05 Does the variety have a history of repeated introductions outside its natural range?	-
C	3.0 Weed elsewhere	3.01 Naturalised beyond native range	-
E		3.02 Garden and amenitydisturbance weed	N
A		3.03 Weed of agriculture, horticulture and forestry	N
E		3.04 Environmental weed	N
		3.05 Congeneric weed	Y
	BIOLOGY/ECOLOGY (SECTION C)		
A	4.0 Undesirable traits	4.01 Produces spines, thorns or burrs	N
C		4.02 Allelopathic	N
C		4.03 Parasitic	N
A		4.04 Unpalatable to grazing animals	N
C		4.05 Toxic to animals	N
C		4.06 Host for recognised pests and pathogens	N
C		4.07 Causes allergies or is otherwise toxic to humans	N
E		4.08 Creates a fire hazard in natural ecosystems	N
E		4.09 Is a shade tolerant plant at some stage of its life cycle	N
E		4.10 Grows on a wide range of soil types?'	Y
E		4.11 Climbing or smothering growth habit	N
E		4.12 Forms dense thickets	N
	5.0 Plant type	5.01 Aquatic	N
		5.02 Grass	Y
		5.03 Nitrogen fixing woody plant	N
		5.04 Geophytes	N
C	6.0 Reproduction	6.01 Evidence of substantial reproductive failure in native habitat	-
C		6.02 Produces viable seed	Y
C		6.03 Hybridises naturally	N

C		6.04 Self-fertilisation	Y
C		6.05 Requires specialist pollinators	N
C		6.06 Reproduction by vegetative propagation	N
C		6.07 Minimum generative time (years)	1
A	7.0 Dispersal mechanisms	7.01 Propagules likely to be dispersed unintentionally	N
C		7.02 Propagules dispersed intentionally by people	Y
A		7.03 Propagules likely to disperse as contaminants of produce	N
C		7.04 Propagules adapted to wind dispersal	N
E		7.05 Propagules buoyant	N
E		7.06 Propagules bird dispersed	N
C		7.07 Propagules dispersed by other animals (externally)	N
C		7.08 Propagules dispersed by other animals (internally)	N
C	8.0 Persistence attributes	8.01 Prolific seed production	-
A		8.02 Evidence that a persistent propagule bank is formed (>1yr)	N
A		8.03 Well controlled by herbicides	Y
A		8.04 Tolerates or benefits from mutilation, cultivation or fire	N
E		8.05 Effective natural enemies present in Kenya.	N
	Statistical summary of scoring	Score partition : Biogeography	1
		Undesirable attributes	0
		Biology/Ecology	-6
	Questions answered:	Biogeography	9
		Undesirable attributes	12
		Biology/Ecology	22
		Total	43
	Sector affected	Agricultural	-4
		Environmental	2

A = Agricultural E = Environmental C = Combined Y = Yes N =No

Table 6.1c: Risk assessment for invasiveness of upland NERICA 10 rice variety

	Botanical name: *Oryza sativa*Oryza glaberrima* (WAB 450-11-1-1-P41-HB) Common name: NERICA 10		Outcome: 0 (Accept)
	Family: Poaceae		Score: 0
	Area/Attribute	**HISTORY (SECTION A)**	**Response**
A	1.0Domestication /cultivation	1.01 Is the variety highly domesticated?	Y
C		1.02 Is the variety naturalised where grown?	N
C		1.03 Does the variety have weedy races?	Y
		BIOGEOGRAPHY (SECTION B)	
	2.0 Climate and distribution	2.01 Variety suited to Kenyan climates (0-low; 1-intermediate; 2-high)	2
		2.02 Quality of climate match data (0-low; 1-intermediate; 2-high)	2
C		2.03 Broad climate suitability (environmental versatility)	Y
C		2.04 Native or naturalized in regions with tropical or sub-tropical climates?	Y
		2.05 Does the variety have a history of repeated introductions outside its natural range?	-
C	3.0 Weed elsewhere	3.01 Naturalised beyond native range	-
E		3.02 Garden and amenity disturbance weed	N
A		3.03 Weed of agriculture, horticulture and forestry	N
E		3.04 Environmental weed	N
		3.05 Congeneric weed	Y
		BIOLOGY/ECOLOGY (SECTION C)	
A	4.0 Undesirable traits	4.01 Produces spines, thorns or burrs	Y
C		4.02 Allelopathic	N
C		4.03 Parasitic	N
A		4.04 Unpalatable to grazing animals	N
C		4.05 Toxic to animals	N
C		4.06 Host for recognised pests and pathogens	N
C		4.07 Causes allergies or is otherwise toxic to humans	N
E		4.08 Creates a fire hazard in natural ecosystems	N
E		4.09 Is a shade tolerant plant at some stage of its life cycle	N
E		4.10 Grows on a wide range of soil types?’	Y
E		4.11 Climbing or smothering growth habit	N
E		4.12 Forms dense thickets	N
	5.0 Plant type	5.01 Aquatic	N
		5.02 Grass	Y
		5.03 Nitrogen fixing woody plant	N
		5.04 Geophytes	N
C	6.0Reproduction	6.01 Evidence of substantial reproductive failure in native habitat	-
C		6.02 Produces viable seed	Y
C		6.03 Hybridises naturally	N
C		6.04 Self-fertilisation	Y

C		6.05 Requires specialist pollinators	N
C		6.06 Reproduction by vegetative propagation	N
C		6.07 Minimum generative time (years)	1
A	7.0 Dispersal mechanisms	7.01 Propagules likely to be dispersed unintentionally	Y
C		7.02 Propagules dispersed intentionally by people	Y
A		7.03 Propagules likely to disperse as contaminants of produce	N
C		7.04 Propagules adapted to wind dispersal	N
E		7.05 Propagules buoyant	N
E		7.06 Propagules bird dispersed	N
C		7.07 Propagules dispersed by other animals (externally)	Y
C		7.08 Propagules dispersed by other animals (internally)	N
C	8.0 Persistence attributes	8.01 Prolific seed production	-
A		8.02 Evidence that a persistent propagule bank is formed (>1yr)	N
A		8.03 Well controlled by herbicides	Y
A		8.04 Tolerates or benefits from mutilation, cultivation or fire	N
E		8.05 Effective natural enemies present in Kenya.	N
	Statistical summary of scoring	Score partition : Biogeography	1
		Undesirable attributes	1
		Biology/Ecology	-2
		Questions answered: Biogeography	9
		Undesirable attributes	12
		Biology/Ecology	22
		Total	43
	Sector affected:	Agricultural	1
		Environmental	5

A = Agricultural E = Environmental C = Combined Y = Yes N =No

Table 6.1d: Risk assessment for invasiveness of upland NERICA 11 rice variety

	Botanical name: *Oryza sativa*Oryza glaberrima* (WAB 450-16-2-BL2-DV1) Common name: NERICA 11		Outcome: 0 (Accept)
	Family: Poaceae		Score: -3
	Area/Attribute	**HISTORY (SECTION A)**	**Response**
A	1.0Domestication /cultivation	1.01 Is the variety highly domesticated?	Y
C		1.02 Is the variety naturalised where grown?	N
C		1.03 Does the variety have weedy races?	Y
	BIOGEOGRAPHY (SECTION B)		
	2.0 Climate and distribution	2.01 Variety suited to Kenyan climates (0-low; 1-intermediate; 2-high)	2
		2.02 Quality of climate match data (0-low; 1-intermediate; 2-high)	2
C		2.03 Broad climate suitability (environmental versatility)	Y
C		2.04 Native or naturalized in regions with tropical or sub-tropical climates?	Y
		2.05 Does the variety have a history of repeated introductions outside its natural range?	-
C	3.0 Weed elsewhere	3.01 Naturalised beyond native range	N
E		3.02 Garden and amenity disturbance weed	N
A		3.03 Weed of agriculture, horticulture and forestry	N
E		3.04 Environmental weed	N
		3.05 Congeneric weed	Y
		BIOLOGY/ECOLOGY (SECTION C)	
A	4.0 Undesirable traits	4.01 Produces spines, thorns or burrs	N
C		4.02 Allelopathic	N
C		4.03 Parasitic	N
A		4.04 Unpalatable to grazing animals	N
C		4.05 Toxic to animals	N
C		4.06 Host for recognised pests and pathogens	N
C		4.07 Causes allergies or is otherwise toxic to humans	N
E		4.08 Creates a fire hazard in natural ecosystems	N
E		4.09 Is a shade tolerant plant at some stage of its life cycle	N
E		4.10 Grows on a wide range of soil types?'	Y
E		4.11 Climbing or smothering growth habit	N
E		4.12 Forms dense thickets	N
	5.0 Plant type	5.01 Aquatic	N
		5.02 Grass	Y
		5.03 Nitrogen fixing woody plant	N
		5.04 Geophytes	N
C	6.0 Reproduction	6.01 Evidence of substantial reproductive failure in native habitat	-
C		6.02 Produces viable seed	Y

C		6.03 Hybridises naturally	N
C		6.04 Self-fertilisation	Y
C		6.05 Requires specialist pollinators	N
C		6.06 Reproduction by vegetative propagation	N
C		6.07 Minimum generative time (years)	1
A	7.0 Dispersal mechanisms	7.01 Propagules likely to be dispersed unintentionally	N
C		7.02 Propagules dispersed intentionally by people	Y
A		7.03 Propagules likely to disperse as contaminants of produce	N
C		7.04 Propagules adapted to wind dispersal	N
E		7.05 Propagules buoyant	N
E		7.06 Propagules bird dispersed	N
C		7.07 Propagules dispersed by other animals (externally)	N
C		7.08 Propagules dispersed by other animals (internally)	N
C	8.0 Persistence attributes	8.01 Prolific seed production	-
A		8.02 Evidence that a persistent propagule bank is formed (>1yr)	N
A		8.03 Well controlled by herbicides	Y
A		8.04 Tolerates or benefits from mutilation, cultivation or fire	N
E		8.05 Effective natural enemies present in Kenya.	N
	Statistical summary of scoring	Score partition : Biogeography	1
		Undesirable attributes	0
		Biology/Ecology	-4
	Questions answered:	Biogeography	9
		Undesirable attributes	12
		Biology/Ecology	22
		Total	43
	Sector affected:	Agricultural	-2
		Environmental	2

A = Agricultural E = Environmental C = Combined Y = Yes N =No

Table 6.1e: Risk assessment for invasiveness of upland Duorado precoce rice variety

	Botanical name: *Oryza sativa* Common name: Duorado precoce		Outcome: 0(Accept)
	Family: Poaceae		Score: -9
	Area/Attribute	**HISTORY (SECTION A)**	**Response**
A	1.0 Domestication /cultivation	1.01 Is the variety highly domesticated?	Y
C		1.02 Is the variety naturalised where grown?	N
C		1.03 Does the variety have weedy races?	Y
		BIOGEOGRAPHY (SECTION B)	
	2.0 Climate and distribution	2.01 Variety suited to Kenyan climates (0-low; 1-intermediate; 2-high)	2
		2.02 Quality of climate match data (0-low; 1-intermediate; 2-high)	2
C		2.03 Broad climate suitability (environmental versatility)	N
C		2.04 Native or naturalized in regions with tropical or sub-tropical climates?	N
		2.05 Does the variety have a history of repeated introductions outside its natural range?	-
C	3.0 Weed elsewhere	3.01 Naturalised beyond native range	N
E		3.02 Garden and amenity disturbance weed	N
A		3.03 Weed of agriculture, horticulture and forestry	N
E		3.04 Environmental weed	N
		3.05 Congeneric weed	Y
		BIOLOGY/ECOLOGY (SECTION C)	
A	4.0 Undesirable traits	4.01 Produces spines, thorns or burrs	N
C		4.02 Allelopathic	N
C		4.03 Parasitic	N
A		4.04 Unpalatable to grazing animals	N
C		4.05 Toxic to animals	N
C		4.06 Host for recognised pests and pathogens	N
C		4.07 Causes allergies or is otherwise toxic to humans	N
E		4.08 Creates a fire hazard in natural ecosystems	N
E		4.09 Is a shade tolerant plant at some stage of its life cycle	N
E		4.10 Grows on a wide range of soil types?'	N
E		4.11 Climbing or smothering growth habit	N
E		4.12 Forms dense thickets	N
	5.0 Plant type	5.01 Aquatic	N
		5.02 Grass	Y
		5.03 Nitrogen fixing woody plant	N
		5.04 Geophytes	N
C	6.0 Reproduction	6.01 Evidence of substantial reproductive failure in native habitat	-
C		6.02 Produces viable seed	Y
C		6.03 Hybridises naturally	N
C		6.04 Self-fertilisation	Y
C		6.05 Requires specialist pollinators	N
C		6.06 Reproduction by vegetative propagation	N
C		6.07 Minimum generative time (years)	1

A	7.0 Dispersal mechanisms	7.01 Propagules likely to be dispersed unintentionally	N
C		7.02 Propagules dispersed intentionally by people	Y
A		7.03 Propagules likely to disperse as contaminants of produce	N
C		7.04 Propagules adapted to wind dispersal	N
E		7.05 Propagules buoyant	N
E		7.06 Propagules bird dispersed	N
C		7.07 Propagules dispersed by other animals (externally)	N
C		7.08 Propagules dispersed by other animals (internally)	N
C	8.0 Persistence attributes	8.01 Prolific seed production	-
A		8.02 Evidence that a persistent propagule bank is formed (>1yr)	N
A		8.03 Well controlled by herbicides	Y
A		8.04 Tolerates or benefits from mutilation, cultivation or fire	N
E		8.05 Effective natural enemies present in Kenya.	Y
	Statistical summary of scoring	Score partition : Biogeography	0
		Undesirable attributes	-1
		Biology/Ecology	-8
		Questions answered: Biogeography	9
		Undesirable attributes	12
		Biology/Ecology	22
		Total	43
		Sector affected: Agricultural	-7
		Environmental	-2

A = Agricultural E = Environmental C = Combined Y = Yes N =No

6.4.1 Statistical summary on invasiveness potential of NERICA and Duorado precoce rice varieties

The statistical summary on invasiveness potential of the five upland rice varieties is as tabulated in table 6.2.

Table 6.2: Statistical summary on the invasiveness potential of four NERICAs and Duorado precoce upland rice varieties

Rice variety	Score partition			Questions answered				Sector affected		Overall Score	Outcome
	Biogeo	UT	Bio/ Eco	Biogeo	UT	Bio/ Eco	Total	Agric	Env		
NERICA 1	0	0	-6	10	12	22	44	-5	1	-6	0 (Accept)
NERICA 4	1	0	-6	9	12	22	43	-4	2	-5	0 (Accept)
NERICA 10	1	1	-2	9	12	22	43	1	5	0	0 (Accept)
NERICA 11	1	0	-4	9	12	22	43	-2	2	-3	0 (Accept)
Duorado precoce	0	-1	-8	9	12	22	43	-7	-2	-9	0 (Accept)

Where; Biogeo = Biogeography, UT= Undesirable attributes,

Bio/ Eco = Biology/Ecology, Agric = Agricultural, Env = Environmental,

6.5 Discussion

1.0 Domestication/cultivation

1.01 Is the variety highly domesticated?

As the results show (Tables 6.1a-6.1e), both the standard check Duorado precoce and NERICAs 1,4,10 and 11 rice varieties used in this study have been cultivated and subjected to substantial human selection for at least 20 generations (Pheloung, 1995). Domestication generally reduces the weediness of a species by breeding out noxious characteristics. NERICA 1 and NERICA 4 were among the first seven NERICAs (NERICAs 1 to 7) that were named and released by Africa Rice Center in 2000 (Semagn *et al*., 2006; Kaneda, 2007; Africa Rice Center, 2008) while NERICAs 10 and 11 were among a further 11 varieties (NERICAs 8 to 18) that were released in 2005 (Semagn *et al*., 2006; Ndjiondjop *et al*., 2008; Africa Rice Center, 2008). With average maturity period of four months (Africa Rice Center, 2008) NERICAs 1 and 4 have therefore been cultivated for 42 generations while NERICAs 10 and 11 have been cultivated for 27 generations. The four NERICA rice varieties (NERICAs 1, 4, 10, and 11) were released in Kenya in April 2009.

1.02 Has the variety become naturalised where grown? i.e. growing without human input.

Results on naturalisation of the rice varieties used in this study (Tables 6.1a-6.1e), showed that none of the varieties has become naturalised where grown. These are all cultivated varieties whose growth is largely dependent on human intervention unlike their wild relatives. This is in support of Oka, (1998) who reported that the effects of domestication are apparent when cultivars are compared to their wild relatives. Wild relatives propagate independently of humans while cultivated rice is much more dependent on human interventions (Oka, 1998). This dependence has possibly come about through selection against survival traits such as seed shatter, dormancy and ratooning. Out-crossing has also diminished through changes in the morphology of the rice flowers. Wild rice varieties have longer, exserted (protruding) stigmas that are more exposed to pollen from the nearby plants than those of the cultivars, which tend to remain at least partially within the hull and are more protected from non-self pollen. In cultivars, the anthers are also shorter and overhang the stigma, and pollen is released shortly after the florets open. Wild pollen is released later, from longer anthers (Oka, 1998).

1.03 Does the variety have weedy races?

Results from the current study (Tables 6.1a-6.1e), showed that rice varieties have weedy races, which was in agreement with reports by earlier authors (Vaughan, 1994; Vaughan and Morishima, 2003). Rice plants (*O. sativa* or other species) that are grown unintentionally in and around rice growing areas are regarded as weeds (Vaughan and Morishima, 2003). Rice has a tendency to become weedy in areas where wild and cultivated rice plants grow sympatrically. In these areas, wild and cultivated rice plants can hybridise, producing plants that compete with cultivars and produce inferior seed, thus decreasing the yield from the rice crop (Oka, 1998). However weedy rice can also develop in areas without native wild rice populations (Bres-Patry *et al*., 2001; Vaughan and Morishima, 2003). This could possibly be derived from hybridisation between different cultivars, selection of weedy traits present in cultivars, relics of abandoned cultivars or brought into the growing region through contaminated seed stocks (Vaughan and Morishima, 2003). Literature describing weedy rice identifies both *O. sativa* and other *Oryza* species as weeds. In the case of *O. sativa*, the weeds are known as red rice due to the coloured pericarp associated with these plants. Red rice is viewed as a major economic problem when it occurs in rice fields as it causes losses in yield through competition with the cultivars as well as decreasing the value of the harvested grain through its colour. Other *Oryza* species growing in and around rice fields are known as weedy rice and can produce red seeds. NERICAs are registered varieties of domesticated species i.e. *O. sativa* and *O. glaberrimma*. Weedy races of NERICA include the wild species in the genus *Oryza* namely *O. punctata, O. longistaminata, O. barthii and O. rufipogon*, as well as red rice (*O. sativa f. spontanea*) (Holm *et al*., 1997; Vaughan *et al*., 2003). There is however no documented evidence on NERICAs capacity to revert to weedy forms hence reduced risk of invasion from these varieties.

2.0 Climate and distribution

2.01 Variety suited to Kenyan climate (0-low; 1-intermediate; 2-high)

As the results show (Tables 6.1a-6.1e), the maximum score of 2 was assigned to all the rice varieties as they were found to be highly suited to Kenyan climates. More than 75% of the respondents from the current study rated the suitability of the five rice varieties to Kenyan climate as high while none of the varieties was rated as low suitability hence the score of 2 from WRAdemo system.

2.02 Quality of climate match data (0-low; 1-intermediate; 2-high)

According to WRAdemo system requirement, the maximum score of 2 (Tables 6.1a-6.1e) was also assigned to this question for the five upland rice varieties investigated in this study since it was not possible to obtain climate match data.

2.03 Broad climate suitability (environmental versatility)

Results of the current study (Tables 6.1a-6.1e) further showed that the standard check Duorado precoce did not demonstrate broad climate suitability unlike the four NERICA rice varieties. NERICA varieties are found to grow in a broad range of climate types including tropical, subtropical, equatorial and semi arid regions unlike the local landrace Duorado precoce which is only suited to tropical or sub-tropical climate. The results are in consonance with those of Vaughan (1994) where it was reported that *O. sativa* cultivars exist that are adapted to a wide range of habitats. Different cultivars are grown widely throughout the world, from latitude 50°N in China to 35°S in New South Wales and Argentina, tropical, temperate, lowland and highland regions and on a wide range of soil types. This is a demonstration of the high level of adaptability within this species that may enable it to colonise new areas quickly. However, individual cultivars may not span this entire geographical and environmental range, being limited to specific ecological niches. With broader climate suitability, the NERICA varieties would perhaps demonstrate higher invasive potential than the local landrace Duorado precoce.

2.04 Native or naturalized in regions with tropical or sub-tropical climates?

Results from the current study (Tables 6.1a-6.1e) showed that the standard check Duorado precoce as well as the four NERICA rice varieties are native in regions with tropical or sub-tropical climates. They may therefore grow and survive in Kenyan conditions which fall under the tropical climate.

2.05 Does the variety have a history of repeated introductions outside its natural range?

No documented evidence was obtained on history of repeated introductions outside their natural range for either the standard check Duorado precoce or the four NERICAs hence the ‘uncertain’ response for the five rice varieties.

3.0 Weed elsewhere

3.01 Naturalised beyond native range

NERICA rice varieties have been reported (Semagn *et al*., 2006; Ndjiondjop *et al*., 2008; Africa Rice Center, 2008) to grow in agricultural environment and similarly the environment into which they are introduced in Kenya is a typical agricultural environment. Rice is planted and harvested as an annual crop and so are the NERICA rice cultivars. Wild populations such as *O. punctata and O. longistaminata* with which it could cross-pollinate and which could establish themselves outside agricultural habitats are minimised by agricultural practices. The main form of dispersal is the seed, which may give rise to volunteer plants when there are favourable water and temperature conditions that allow germination. Vaughan *et al*. (2003) however reported that rice can establish itself outside the agricultural environment, which is illustrated by the establishment of weedy rice or red rice (*O. sativa* f. *spontanea*). Nevertheless, cultivated rice crop is prevented from weed infestation by the weedy rice by planting seed that is free of red rice and cultural methods are used to control its incidence. The common wild rice species present in Kenya include *O. punctata* and *O. longistaminata* that are distributed in the coastal region of Kenya and are not prevalent in Central Kenya where the current research was conducted. There is no documented evidence of rice varieties cited in floras of localities which are clearly outside of their native range and hence the “no” response (Tables 6.1a-6.1e) for the five rice varieties used in this study.

3.02 Garden/amenity/disturbance weed

For both the NERICAs and the Duorado precoce rice varieties used in this study, the option that attained the highest scores from the questionnaire was “others” specifically in farm fields where the rice crop was previously grown hence germinating from the seed bank or reproducing as ratoon crop. The percentage scores varied from 76% to 87% for NERICA 4 and Duorado precoce respectively. The option of the plant being generally an intrusive weed of gardens, parklands, roadsides and quarries scored very low percentage for the five varieties with scores ranging from 0% for parklands, roadsides and quarries to 12% for weed of gardens for Duorado precoce. The varieties are possibily therefore not garden, amenity or disturbance weeds (Tables 6.1a-6.1e).

3.03 Weed of agriculture/horticulture/forestry

The four NERICA varieties as well as Duorado precoce were found not to be weeds of agriculture, horticulture or forestry and not to cause productivity losses and/or costs due to control (Tables 6.1a-6.1e). The occurrence of the NERICA varieties as well as the standard check Duorado precoce is largely limited to agricultural fields where they were previously grown and not in horticulture or forest environments (Oka, 1998; Ndjiondjop *et al*., 2008). Rice seed could shatter before or during harvest and be moved off site by birds and rodents. However, the five rice varieties used in this study exhibited little or no dormancy and as such are likely to germinate quickly if the water and temperature regime are favourable, hence the seed is unlikely to survive outside agricultural sites. Agronomic practices such as weeding and crop rotations easily control the varieties from agricultural fields and contain the spread of volunteer seed and plants hence unlikely to cause productivity losses in agriculture, horticulture or forestry. The five rice varieties also do not easily shatter before or during harvest and therefore unlikely to be moved off site by birds and rodents. This was in conformity with earlier findings (Messeguer *et al*., 2001) who reported that cultivated rice does not shatter or disperse its seed, and it has not acquired extended dormancy.

3.04 Environmental weed

Interactions of the NERICA varieties as well as the standard check Duorado precoce with other organisms are largely limited to the agricultural environment (See 3.03 above), and are not recorded as weeds or as altering the structure or normal activity of a natural ecosystem. The varieties are therefore unlikely to be environmental weeds (Tables 6.1a-6.1e).

3.05 *Congeneric weed*

There was documented evidence (Pheloung *et al*., 1999) of some species with similar biology, within the genus *Oryza* being evaluated as weeds. These include *O. punctata, O.longistaminata, O.barthii, O.rufipogo* and *red rice* (*O. sativa f. spontanea*) (Vaughan, 1994; Holm *et al*., 1977; Pheloung *et al*., 1999; Vaughan *et al*., 2003).

4.0 Undesirable traits

4.01 Produces spines, thorns or burrs

The plants that produce structures such as spines, thorns or burrs are known to cause fouling (interfering with product processing or quality), discomfort or pain to animals or people. If the taxon is a thornless subspecies, variety or cultivar, then there must be good evidence that it does not retain the capacity to revert to a thorny form (Pheloung *et al*., 1999). The four NERICAs (1, 4, 10 and 11) and Duorado precoce rice varieties assessed in this study were found to be thornless cultivars and there was no documented evidence of their capacity to revert to thorny forms. NERICA 10 (Table 6.1C) however possesses awns which may cause discomfort or pain to grazing animals and to people particularly at maturity stage during the harvesting. This increases the invasive potential of NERICA 10 compared to the other varieties as it cannot be easily kept under check by grazing animals.

4.02 Allelopathic

As the results show (Tables 6.1a-6.1e) the four NERICA varieties and Duorado precoce were not found to be allelopathic. No documented evidence was obtained on these rice varieties as being allelopathic. All the varieties were accorded 0% by the respondents on their potential to suppress the growth of other species by chemical (eg. hormonal) means. The only noted mode of weed suppression from these rice varieties was excessive tillering particularly from the NERICA varieties that were classified as high tillering as opposed to the local land race Duorado precoce that was classified as low tillering (Chauhan *et al*., 1985; Africa Rice Center, 2008).

4.03 Parasitic

Results on the parasitic nature of NERICAs 1, 4, 10 and 11 as well as Duorado precoce (Tables 6.1a-6.1e) showed that none of these rice varieties is parasitic. The “no” reponse received the highest percentage for all the varieties with values varying from 92-100% for NERICA 1 and Duorado precoce respectively. There was no documented evidence of rice generally being either wholly and semi-parasitic plants. This perhaps contributed to the observed low invasive potential of the five rice varieties from this study.

4.04 Unpalatable to grazing animals

Results on palatability of the rice varieties (Tables 6.1a-6.1e) showed that none of the varieties is unpalatable to grazing animals. The five varieties are fed on by grazing animals and used as fodder hence palatable. This is in line with earlier authors (Jackson, 1978; Drake *et al*., 2002; FAO 2004) who reported that the rice plants are readily eaten by grazing animals and also used as fodder.

4.05 *Toxic to animals*

There is no evidence of any toxicity associated with the use of rice grains as a food crop for humans (Jackson, 1978). However, rice straw, which is used as stock feed in many parts of the world (Jackson, 1978; Drake *et al*. 2002; FAO, 2004), has the potential to cause toxicity if fed in large quantities. This occurs through the high levels of oxalates present in the straw (Jackson, 1978) that can result in calcium deficiencies if supplements are not provided (FAO, 2004). Rice straw is neither particularly attractive to stock, nor highly nutritive and is mostly fed in combination with other feed as a way of decreasing feed costs (Drake *et al*., 2002). Since rice straw is not attractive to stock, it is unlikely that it would be heavily grazed or fed on in large quantities that would cause toxicity to animals.

4.06 Host for recognised pests and pathogens

The main concerns here are plants that are hosts of toxic pathogens and alternate or alternative hosts of crop pests and diseases. Where suitable alternative or alternate hosts are already widespread in cropping or natural systems the answer should be `no' unless the species will affect the current control strategies for the pathogen or pest. A reasonable level of specificity is usually applied such that a pathogen of an entire family should not be the basis for answering `yes' for an individual species or variety (Pheloung *et al*., 1999). A large range of pests e.g. termites, bugs, rats, birds and diseases attack rice, with weed infestation being one of the most important sources of economic crop losses (Wanjogu *et al*., 1995). In a rice field there are also beneficial predators and parasitoid species such as spiders, grasshoppers, ants, wasps and beetles that seek out eggs and larvae of pests (Wanjogu and Mugambi, 2001; Kouko *et al*., 2006). However, since there are suitable alternative and alternate hosts such as sorghum, beans and cow pea already widespread in cropping and natural systems, the NERICA rice varieties will not affect the current control strategies for the pests or pathogens. The pests and pathogens are for the entire Poaceae family and not for an individual species hence the “no” response to all the five rice varieties evaluated in this study.

4.07 Causes allergies or is otherwise toxic to humans

In the general population, rice is considered to be of low allegenicity (Hill *et al*., 1997; Besler, 1999). There is no evidence of any toxicity associated with the use of rice grains as a food crop for humans (Jackson 1978; Drake *et al*. 2002; FAO 2004). While rice is not considered to be a common cause of allergic reactions to food, allergic reactions have been documented, and certain proteins in rice have been identified as allergens. The first reported allergens in rice were 14-16 kDa proteins which were detected using sera from patients allergic to rice (Matsuda *et al*., 1991). With regard to human health, rice contains endogenous allergenic proteins. They are present in the albumin and globulin fractions of rice endosperm proteins and have significant homology with the alphaamylase/trypsin inhibitor family from wheat and barley. Rice pollen, like pollen from all other plants can cause allergic reactions in susceptible individuals, when inhaled. However, such allergies have not been reported for NERICAs 1,4,10 and 11 or the local landrace Duorado precoce. This decreases their invasive potential as they can be kept under control by humans without posing allergic problems to man.

4.08 Creates a fire hazard in natural ecosystems

There is no documented growth habit on the five rice varieties investigated in this study that leads to the rapid accumulation of fuel for fires when growing in natural or unmanaged ecosystems. The varieties are therefore unlikely to create fire hazard in natural ecosystems, which perhaps decreases their invasive potential.

4.09 *Is a shade tolerant plant at some stage of its life cycle?*

The results (Tables 6.1a-6.1e) further showed that none of the evaluated rice varieties is a shade tolerant plant at any stage of its life cycle. Shade tolerance can enhance the invasive potential of a plant (Pheloung, 1995; Pheloung *et al*., 1999). The invasive potential of the NERICA rice varieties as well as the Duorado precoce is therefore not enhanced in relation to shade tolerance.

4.10 Grows on a wide range of soil conditions.

NERICA rice varieties grow well in a wide range of soil conditions including different soil types (clay, loam, black cotton) except sandy soil and neutral to slightly acid soil with a PH range of 4.5-7.0 (Africa Rice Center, 2008) hence the “yes” reponse for NERICAs 1, 4, 10 and 11 (Tables 6.1a-6.1d). This increases the invasive potential of these varieties. The standard check Duorado precoce is however reported (Wanjogu and Mugambi, 2001; Kouko *et al*., 2006) to thrive best in clay or black cotton soil only hence the “no” reponse to this question for this variety (Table 6.1e), which possibly decreased its invasive potential relative to the NERICA varieties.

4.11 Climbing or smothering growth habit

The results from this study (Tables 6.1a-6.1e) also showed no climbing or smothering growth habit for both the NERICAs and Duorado precoce. This trait makes plants grow quickly and they cover and kill or suppress the growth of the supporting vegetation (Pheloung *et al*., 1999) which increases their invasive potential. The invasive potential of the five rice varieties investigated in this study is therefore reduced in this respect.

4.12 Forms dense thickets

Though rice is a Poaceae, the crop does not grow densely so as to obstruct passage or access, or exclude other species (Pheloung, 1995; Pheloung *et al*., 1999). Similarly, no dense thickets were observed for either the NERICA rice varieties or the standard check Duorado precoce from this study.

5.0 Plant type

5.01 Aquatic

This question includes any plants normally found growing on rivers, lakes and ponds. These species have the potential to choke waterways and starve the system of light, oxygen and nutrients. It applies to obligate aquatic taxa. Wetland taxa and those that grow on stream banks do not qualify (Pheloung *et al*., 1999). Rice is a semi-aquatic plant that thrives on land that is water saturated or even submerged during part or all of its growth (MOA, 2011). A variety of water regimes are used including unsubmerged upland rice, moderately submerged lowland rice (irrigated or rain fed) and submerged rice up to 6m of water or floating. The four NERICA rice varieties (NERICAs 1,4,10 and 11) and the local Duorado precoce used in this study are upland rainfed varieties and do not belong to obligate aquatic taxa hence the “no” response for the five rice varieties (Tables 6.1a-6.1e). This possibly contributed to the observed low invasive potential of the five rice varieties.

5.02 Grass

Rice belongs to the grass family (Poaceae) which on a world scale is classified among the prominent families that are likely to produce natural weed invaders (Cronk and

Fuller, 1995) as well as agricultural weeds (Heywood, 1993; Daehler and Carino, 2000; Williams *et al*., 2002; Daehler *et al*., 2004). The five rice varieties used in this study therefore have the possibility of being weeds thus increasing their invasive potential.

5.03 Nitrogen fixing woody plant

A large proportion of woody legumes (Family Leguminosae/Fabaceae) are weeds, particularly of conservation areas (Pheloung *et al*., 1999). As with congeneric weed species, there is a high probability that a variety from this family will be a weed. Rice belongs to family Poaceae which is composed of grasses that are neither nitrogen fixing nor woody hence the "no" response for the five rice varieties on this question (Tables 6.1a-6.1e). This decreases the possibility of the varieties being weeds hence decreased invasiveness potential.

5.04 Geophytes

Geophytes are perennial plants that propagate by underground structures such as bulbs, tubers or corms (Pheloung *et al*., 1999). These structures enable them to survive for many years hence the possibility of being invasive. This question specifically deals with plants that have specialised organs and does not include plants merely with rhizomes or stolons (see 6.06). Cultivated rice is an annual crop and propagates through seeds (Grist, 1986; Wanjogu *et al*., 1995) and not by underground bulbs, tubers or corms hence not geophytes (Tables 6.1a-6.1e). This lowers the invasive potential of the five rice varieties used in this study.

6.0 Reproduction

6.01 Evidence of substantial reproductive failure in native habitat

Predators and other factors present (e.g. disease) in the native habitat can cause substantial reductions in reproductive capacity. The reproductive output of a species or variety may greatly increase when the plant grows in areas without these factors. NERICA rice varieties are resistant to pests and diseases (Africa Rice Center, 2008; Ndjiondjop *et al*., 2008), and tolerate drought and infertile soils better than Asian varieties (Dingkuhn *et al*., 1998; Africa Rice Center, 2008) both within and beyond their native habitat. Their reproductive capacity is therefore unlikely to be substantially reduced both within and beyond their native habitat. On the other hand, Duorado precoce is not resistant to pests and diseases (Dingkuhn *et al.*, 1998) hence the possibility of reproductive failure. However, no documented evidence of substantial reproductive failure in its native habitat was obtained hence the “uncertain” response.

6.02 Produces viable seed

Cultivated rice is an annual crop that propagates through seeds (Grist, 1986; Wanjogu *et al.*, 1995). Both the standard check Duorado precoce and NERICAs 1,4,10 and 11 were found to produce viable seeds.

6.03 Hybridises naturally

Oryza species with different genome types have significant reproductive isolation (Gealy *et al.*, 2003) making them unlikely to hybridise with each other naturally. Hybridisation between species in different genera within the tribe Oryzeae is extremely difficult, even using artificial conditions, such as embryo rescue. It has been reported (Dingkuhn *et al.*, 1998; Heuer *et al.*, 2003; Ndjiondjop *et al.*, 2008) that rice species do not cross naturally or through traditional hybridization techniques due to their genetic differences hence the application of modern biotechnology in the production of NERICA rice varieties. During the early decades, attempts to cross *O. sativa* and *O. glaberrima* remained unsuccessful because of hybrid sterility (infertile offspring of the crosses) (Dingkuhn *et al.*, 1998; Ndjiondjop *et al.*, 2008) in F_1 progenies. Indeed the F_1 progenies obtained from the crossing reached almost 100% sterility because of the failure of pollen development (Heuer *et al.*, 2003). There was no documented evidence of interspecific hybrids occurring, without assistance, under natural conditions among the *Oryza* species which lowers the invasive potential of the rice varieties used in this study.

6.04 Self-fertilisation

As the results show (Tables 6.1a-6.1e) the rice varieties used in this study are capable of self-fertilisation. Rice is primarily an autogamous, self-pollinating plant, which means that rice plants usually fertilise themselves with their own pollen (Grist, 1986;

Messeguer *et al*., 2001; Vaughan *et al*., 2003). Reported out crossing rates are less than one percent and are limited by climate and the biological characteristics of rice (Messeguer *et al*., 2001; Vaughan *et al*., 2003). Factors including flower morphology e.g. short style and stigma (1.5-4mm in combined length) (majority of cultivated rice does not have stigmas that exert beyond the glumes), the short life (viability) span of the pollen (3-5 minutes) (Koga *et al*., 1969), brief period between opening of florets and release of pollen (between 30 seconds and nine minutes) (Morishima, 1984; Oka 1988) and a lack of insect vectors for pollen spread contribute to the low propensity of rice to cross-pollinate (Messeguer *et al*., 2001). Pollen grain morphology changes dramatically after shedding from the anther. Initially the grains are spherical but within minutes they begin to collapse. The collapse of the pollen grains coincides with a measured loss of viability. In one study, 90% of pollen grains were found to be viable up to four minutes, while between 5-8 minutes after shedding, viability decreased to approximately 33% (Koga *et al*., 1969). Cross-pollination however occurs at a rate of approximately one to four percent depending on climate and varietal differences (Grist, 1986; Vaughan *et al*., 2003). Wild rices differ from cultivars in all these characteristics, tending to encourage outcrossing with longer styles, stigmas and anthers, and pollen that remains viable for up to twice as long as in the cultivated rice (Oka, 1998). Species such as *Oryza* species that are capable of self seeding can spread from seed produced by an isolated plant hence increased invasive potential.

6.05 *Requires specialist pollinators*

All wild and cultivated rice varieties are wind-pollinated, with a few varieties having scented flowers that attract bees (Oka, 1998), therefore no need for specialist pollinators. This could possibly increase the invasive potential of the rice varieties since the invasive potential of a plant is reduced if the species requires specialist pollinating agents that are not present or rare in the area of assessment (Pheloung, 1995; Pheloung *et al*., 1999).

6.06 *Reproduction by vegetative propagation*

Cultivated rice replicates sexually through seeds and vegetatively through tillers in favourable temperature and water conditions. It does not reproduce by rhizomes, stolons, root fragments, suckers or division except some wild rice species such as *O. longistaminata* that are rhizomatous. The five rice varieties used in this study were found to replicate sexually through seeds and vegetatively through tillers and not by rhizomes, stolons or root fragments, suckers or division. This perhaps contributed to the observed low invasive potential from the current study.

6.07 *Minimum generative time (years)*

This is the time from germination to production of viable seed, or the time taken for a vegetatively reproduced plant to duplicate itself. The shorter the life span, the weedier a plant is likely to be. Rice is grown as an annual crop with a generative time of 4-6 months. A second crop can sometimes be obtained from the tillers or ratoon, under favourable water and temperature conditions which matures within 3-4 months. The four NERICAs used in the current study matured within 4 months while the ratoon crop matured in 3 months hence both crops generative time is less than one year. The short life span could possibly make the varieties more weedy hence higher invasive potential compared to the local landraces that mature in 5-6 months though the difference is minimal as both have generative time less than one year. The score for this question from AWRAS for values on generative time less than one year is one therefore all the five rice varieties from this study had a score of one. This could possibly lead to the varieties being more weedy hence higher invasive potential.

7.0 Dispersal mechanisms

7.01 Propagules likely to be dispersed unintentionally

The NERICA and Duorado precoce rice cultivars that were used in this study do not grow in heavily trafficked areas such as farm paddocks or roadsides and therefore the propagules are unlikely to be dispersed unintentionally from human activity. Most rice cultivars have limited seed dispersal ability, being bred to allow maximal harvest by farmers. In wild rices and some cultivars, mature rice seeds can be shed from the plant through seed shatter. Shattered seed can be buried in the soil for subsequent germination, eaten or dispersed by animals. The presence or absence of awns at the tip of the lemma which is cultivar specific influences the potential for seed dispersal through attachment to passing animals (Oka. 1988). Among the rice varieties used in the current study, only NERICA 10 is awned hence the possibility of unintentional dispersal of its seeds through attachment to clothings of passing human beings.

7.02 Propagules dispersed intentionally by people

Plant propagules are dispersed intentionally by people when the plant has properties that make it attractive or desirable, such as an edible fruit, an ornamental or curiosity or if a species is readily collected as a cutting or seed (Pheloung *et al*., 1999). The grains of the five rice varieties evaluated in this study are useful as food for human beings. The seeds are therefore likely to be dispersed intentionally by people, thus increasing their invasive potential.

7.03 Propagules likely to disperse as contaminants of produce

Produce in this concept is the economic output from any agricultural, forestry or horticultural activity (Pheloung *et al*., 1999), e.g. grain shipments that contain seeds of weed species. No documented evidence was found on the likelihood of the rice varieties used in this study being dispersed as contaminants of produce. For all the five varieties, the “no” reponse attained the highest percentage from the respondents with percentages ranging from 86% for NERICA 1 to 96% for NERICA 11. The propagules are therefore unlikely to disperse as contaminants of produce which further reduces their invasive potential.

7.04 Propagules adapted to wind dispersal

There is no documented evidence that wind significantly increases the dispersal range of the propagules of the four NERICA rice varieties or the standard check Duorado precoce. Plants using wind to disperse their seeds exhibit the following characteristics; very light seeds, as in many grasses like "Fowl foot" grass (*Eleusine indica*), seeds covered in feathery materials that act like parachutes when caught in the wind, as in the Oleander (*Nerium oleander*), seeds that look and act like helicopter rotors, which may spin and fly in the wind such as the mahogany (*Swietenia mahagoni*), seeds that flutter or spin in the wind such as the Jacaranda. Propagues from the four NERICA rice varieties and the standard check Duorado precoce used in the current study do not show any of the above characteristics hence not adapted to wind dispersal. This may have contributed to the observed low invasive potential of the five rice varieties from the current study (Table 6.2).

7.05 Propagules buoyant

This question includes any structure containing the propagule that typically becomes detached from the plant and is buoyant, e.g. a pod of a legume. This is a limited method of distribution of land plants (Pheloung *et al*., 1999). Plants using water to disperse their seeds may have a tendency to grow near the sea or rivers e.g. coconut trees (*Cocos nucifera*) and manchineel tree (*Hippomane mancinella*) which grows on the beach, or seeds or fruit that can float (buoyant), allowing them to be carried away from the mother plant by water (Pheloung *et al*., 1999). The four NERICA rice varieties as well as the standard check Duorado precoce do not possess buoyant propagules hence cannot be dispersed by water. This further reduces their invasive potential.

7.06 Propagules bird dispersed

This question refers to any propagule that may be transported and/or consumed by birds, and will grow after defecation, e.g. the small red berries with indigestible seeds. The four NERICAs and the local landrace Duorado precoce seeds are consumed by birds but they are digestible hence do not grow after defecation.

7.07 Propagules dispersed by other animals (externally)

The plant has adaptations, such as burrs, awns and/or grows in situations that make it likely that propagules become temporarily attached to the animal. This can include the spread of plant parts on clothing. This dispersal group includes seeds with an oily or fat-rich outgrowth that aids in ant seed dispersal. Among the rice varieties used in this study only NERICA 10 (Tables 6.1c) was found to have awns and can therefore be dispersed externally through attachment to passing animals. This increases the invasive potential of NERICA 10 compared to NERICAs 1, 4, 11 and also Duorado precoce, as shown by the highest overall score of zero for NERICA 10 from the weed risk assessment system among the five varieties (Table 6.2).

7.08 *Propagules dispersed by other animals (internally)*

This refers to propagules that are eaten by other animals apart from birds, dispersed and will grow after defecation (Pheloung *et al*., 1999). The standard check Duorado precoce and NERICAs 1,4,10 and 11 seeds are eaten by both wild and domestic animals but are digestible hence do not grow after defecation, and hence the “no” response for the five rice varieties (Tables 6.1a-6.1e). This further amounts to reduced invasive potential of these rice varieties.

8.0 Persistence attributes

8.01 Prolific seed production

The general response on prolific seed production (Tables 6.1a-6.1e) for both the standard check Duorado precoce and the four NERICA rice varieties (NERICA 1, 4, 10 and 11) was “uncertain”. The level of seed production must be met under natural conditions and applies only to viable seed. For grasses such as rice and annual species this rate should be (>5000-10000/m^2/yr). Both the standard check and the NERICA varieties are cultivated rice varieties and information on their prolific seed production under natural conditions was lacking. From experiment one on response to weed interference in this study (chapter three), a great percentage of the spikelets were found to be empty with higher percentages observed in the ratoon crop compared to the main crop. The full season weed-infested treatment which could possibly represent natural conditions recorded the highest percentage of empty spikelets for the five rice varieties hence higher nonviable seed production under natural conditions.

8.02 Evidence that a persistent propagule bank is formed (>1 yr)

There was no evidence that a persistent propagule bank is formed more than one year for any of the four NERICAs or the standard check Duorado precoce (Tables 6.1a-6.1e). Cultivated rice is an annual crop which does not shatter or disperse its seed, and it has not acquired extended dormancy (Messeguer *et al*., 2001). This ensures no persistent propagule bank is formed in the field for more than one year. Cultivated rice seed viability in the soil is also less than one year (Messeguer *et al*., 2001; Vaughan *et al*., 2003), which further reduces their invasive potential.

8.03 Well controlled by herbicides

The four NERICAs as well as the standard check Duorado precoce used in this study were found to be well controlled by herbicides (Tables 6.1a-6.1e). The "yes" reponse from the questionnaire scored over 80% with values varying from 84.3 to 98.2% for NERICA 10 and NERICA 4 respectively. The non-selective systematic glyphosate [N-(phosphonomethyl) glycine] and the broad spectrum paraquat (1, 1'-Dimethyl-4, 4'-bipyridinium dichloride) herbicides are reported to easily control cultivated rice varieties (Grist, 1986; Thompson *et al*., 1987). This control is acceptable in Kenya and it is safe for other desirable plants that are likely to be present. Both glyphosate and paraquat have no residual activity in the soil and do not affect the unintended plants (Thompson *et al*., 1987).

8.04 Tolerates or benefits from mutilation, cultivation or fire

Documented evidence on the tolerance or benefits of the five rice varieties from disturbance such as mutilation, cultivation or fire was lacking. However, responses from the questionnaire showed that none of the varieties benefits from these disturbances (Tables 6.1a-6.1e). Plants that tolerate or benefit from such disturbance may out-compete other species. The five rice varieties are therefore unlikely to out-compete other species thus decreasing their invasive potential.

8.05 Effective natural enemies present in Kenya.

A number of natural enemies for upland rice are reported in Kenya which include rice whorl maggot (*Hydrellia prosternalis*), rice leafminers, rice stem borer, rice leaf hoppers, stalk eyed fly and termites (Wanjogu *et al*., 1995) which affect the traditional upland varieties such as Duorado precoce therefore decreasing their invasive potential. The four upland NERICA rice varieties (NERICAs 1, 4, 10 and 11) are however reported

(Dingkuhn *et al*., 1998; Kuoko *et al*., 2006; Africa Rice Center, 2008) as being resistant to the above natural enemies hence increasing their invasive potential.

The four upland NERICA and Duorado precoce rice varieties investigated in this study attained overall scores less than one on invasiveness potential as per the Australian Weed Risk Assessment system with values varying from -9 to 0 for Duorado precoce and NERICA 10 respectively which relates to the accept recommendation (Table 6.2). The biogeography sector contributed the highest score to the total score followed by the undesirable traits while biology and ecology contributed the least. The environmental sector attained higher values than the agricultural sector (Table 6.2) hence the former is more likely to be affected by these rice varieties. However, this may not occur as the outcome for the five varieties is “accept” implying non-invasive or non-weedy. The four NERICA rice varieties scored higher values than the local landrace Duorado precoce possibly due to hybrid vigour of the former.

6.6 Conclusion

From the current study, the standard check Duorado precoce and the four NERICA rice varieties (NERICA 1, NERICA 4, NERICA 10, and NERICA 11) attained overall scores of less than one as per the Australian Weed Risk Assessment System thus not potentially invasive. NERICA rice has no potential invasive characteristics that would make it a weedy problem outside cultivation it therefore would not affect the bioderversity of wild relatives. The NERICA rice varieties will have the same interactions in the environment as the local landrace rice such as Duorado precoce hence not potentially invasive and do not present any significant ecological risk. Hypothesis number four in this study stating that NERICA rice varieties have the same potential of invasiveness was therefore rejected. The varieties were also determined not to present any significant environmental or agricultural risk. They should therefore be accepted and deployed in Central Kenya and minimal measures are required to avoid their spread.

CHAPTER SEVEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

From the results of this study it can be concluded that the four upland NERICAs (NERICA 1, 4, 10 and 11) and *O. sativa* (Duorado precoce) rice varieties differ in their response to weed interference. The agronomic traits investigated i.e. plant height, tiller number, number of productive tillers, number of panicles per hill, percentage filled spikelets and grain yield increased with decreasing duration of weed interference and decreased with increasing duration of weed interference. LAI however increased with increasing duration of weed interference and declined with decreasing duration of weed interference for the five upland rice varieties. Among the growth parameters considered in this study, LAI was found to be the most variable and the one least affected by competition and weeding treatments. Early crop-weed competition reduced the growth and production of both the NERICA and the standard check Duorado precoce hence the need for early weed control. From the correlation results of this study, it was demonstrated that tiller number, number of productive tillers, number of panicles per hill and percentage filled spikelets are good agronomic traits for determining grain yield while plant height and LAI are poor measures for grain yield for both the main and the ratoon rice crop. This study has also demonstrated that no single agronomic trait can be used alone as a measure for grain yield but rather a combination of more traits and exogenous factors. A combination of growth and yield parameters should also be used to determine and explain the response of the rice varieties to weed interference as well as the critical period of weed control and not a single parameter such as LAI which generally showed no significant difference among the treatments and a negative correlation with grain yield. A combination of these growth variables explains variations in upland rice yield better than any individual growth variable.

The study further showed that ratooning ability varied significantly ($p<0.05$) among the five rice varieties hence nullifying the third hypothesis in the current study that NERICA and *O. sativa* rice varieties have the same ratooning ability. The NERICA rice varieties exhibited higher ratooning ability compared to the *O. sativa* rice variety (Duorado precoce). The results provide a preliminary basis for the potentiality of using ratoon cropping in NERICA as a means of increasing rice yield in Central Kenya. The study also demonstrated that NERICA and *O.sativa* rice varieties have different critical periods of weed control. The CPWC also differs among the NERICA rice varieties. From both the main and the ratoon rice crop, the highest grain yields were obtained from the full season weed-free condition which was significantly higher than the other treatments. For best practice for farmer's condition, two weedings between 3 and 6 WACB for ratoon crop and three weedings between 3 and 9 WAP for main crop are recommended as the time between which weeds should be controlled in the fields of NERICA and *O.sativa* rice varieties to avoid yield losses. This is an important guide for the NERICA rice dissemination programme in Kenya for optimum timing of weed control to maximize the rice yield. The harmful effects of early crop-weed competition were also demonstrated.

The study also showed that NERICA rice varieties matured earlier than the local landrace Duorado precoce. With early maturity, NERICA varieties would possibly be preferred to *O. sativa* by farmers hence recommended as a supplement to the local landraces such as Duorado precoce. The NERICAs demonstrated higher potential for increasing rice production compared to the traditional variety Duorado precoce hence food sufficiency for the achievement of vision 2030 in Kenya. Inclusion of NERICA cultivars in the cropping system would therefore bring significant increase in the potential yield of rice in Kenya and revolutionize the rice industry in general. Among the four NERICA rice varieties evaluated in the current study, NERICA-4 and NERICA-1 were found to be more tolerant to weed pressure and better yielding than NERICA-10 and NERICA-11.

The study further demonstrated that the four NERICA rice varieties (NERICA 1, NERICA 4, NERICA 10, and NERICA 11) plus the standard check Duorado precoce are not potentially invasive and do not present any significant environmental or agricultural risk. They should therefore be accepted and deployed in Central Kenya and minimal measures are required to avoid their spread. The NERICA varieties were found to be better competitors against weeds than the standard check Duorado precoce as evidenced by higher yields from the weed infested plots for the former. Modern biotechnology as employed in the development of the NERICA rice varieties consequently has positive ecological impact in that it can be used for weed control instead of the large dependence on herbicides.

7.2 Recommendations

Based on the results of this study, the following are recommended for future action;

i. For optimum growth and best grain yield, upland rice crop should be weeded early between 3-9 weeks in the growth cycle before competition between the crop and weeds become severe. Further work should include whether full season weed-free plots are cost effective.

ii. NERICA rice varieties should be included in cropping systems in Central Kenya in particular and other rice growing regions in the country so as to increase the potential yield of rice and ultimately help in poverty alleviation through increased income and food security.

iii. NERICA-4 and NERICA-1 rice varieties are recommended for Central Kenya as the best yielding, most weed tolerant and least invasive varieties among the studied rice varieties.

iv. High tillering capacity, as demonstrated by NERICA rice varieties should be considered when breeding for rice cultivars that are competitive against weeds and also as forage.

v. Ratoon cropping in NERICA should be incorporated in the cropping systems as a means of increasing rice yield hence achievement of Kenya’s vision 2030 on food security. NERICA-4 and NERICA-10 are recommended for Central Kenya as the best ratooning among the studied rice varieties.

vi. Policy-makers need to urge farmers to pay more attention to the problems posed by weeds in upland NERICA rice farming as an important issue affecting upland rice productivity. Support to weed research programmes and farmers’ training in improved weed management in upland rice is required for further improvement of rice production.

7.3 Suggested further research

Future experiments should be designed with more seasons and regions in Kenya for comparison purposes on performance of the growth and yield parameters of upland NERICA rice varieties and their effect on grain yield. Further research should be carried out to establish the mechanisms contributing to the ratooning ability of the NERICA rice varieties, which was not investigated in this study. A cost-benefit analysis on ratoon production should be carried out to ascertain the overall income in terms of yield for the rice farmer per annum. Further research should be carried out to establish the critical date of weeding for the upland NERICA rice varieties which was not investigated in this study.

REFERENCES

Adeosun, J.O. (2008) *Predicting Yield of Upland Rice (Oryza sativa L) Under Weed Infestation*. Journal of Weed Science Society of Nigeria, 21(6): 321-326.

Africa Rice Center (WARDA)/FAO/SAA (2008). *NERICA®: The New Rice for Africa-a Compendium*. EA Somado, RG Guei and SO Keya (eds). Cotonou, Benin: Africa Rice Center (WARDA); Rome, Italy: FAO; Tokyo, Japan: Sasakawa Africa Association. 210 pp.

Ahmed, G.J.U., Mamun, A.A., Hossain, S.M.A., Siddique, S.B. and Mridha, A.J. (1997) *Effect of Bosagran and raking combined with hand-weeding to control weeds in aus rice*. Bangladesh Agronomy Journal, 7: 31-32.

Ahn, S. W., Bonman, J.M., Brandon, D.M., Groth, D.E., Gunnell, P.S., Hibino, H., Hollier, C.A., Lee, F.N., Mew, T.W., Prot, J.C., Rush, M.C., Schneider, R.W., Webster, R.K. and Whitney, G. (1992) *Compendium of rice diseases*. Webster, R.K., Gunnell, P.S. (eds). APS Press.

Akimoto, S and Togari, Y. (1939) *Varietal difference in panicle development of rice with reference to early or late transplanting*. Proceedings of the Crop Science Society of Japan 11: 168-184.

Akinbile, C.O. (2010) *Behavioural pattern of upland rice agronomic parameters to variable water supply in Nigeria*. Journal of Plant Breeding and Crop Science, 2 (4): 073-080.

Akobundu, I. O. (1980). *Weed science research at the International Institute of Tropical agriculture and research needs in Africa*. Weed Science, 28 (4): 439-445.

Akobundu, I.O. (1987) *Weed science in the tropics and practices*. John Wiley and Sons. New York, USA, PP: 522.

Akobundu, I.O. (1991) *Weed in human affairs in Sub-Saharan Africa: implications for sustainable food production*. Weed Technology, 5: 680-690.

Alam, M.S., Biswas, B.K., Gaffer, M.A. and Hossain, M.K. (1995) *Weed control in upland rice. Efficiency of weeding at different stages of seedling emergence in direct seeded aus rice*. Bangladesh Journal of Science India Research, 30: 155-167.

Amador–Ramirez, M.D. (2002). *Critical period of weed control in transplanted chili pepper*. Weed Research, 42:203–209.

Ambe, J. T., A. A. Agboola, and S. K. Hahn. (1992) *Studies of Weeding Frequency in Cassava in Cameroon*. Tropical Pest Management, 38 (3): 302-304.

Ampong-Nyarko, K. & De Datta, S. K. (1991) *A Handbook for Weed Control in Rice*. International Rice Research Institute, Manila, Phillipines.

Andersen,M.C., Adams, W., Hope, B., and Powell, M. (2004) *Risk assessment for invasive species*. Risk Analysis, 24 (4): 787-793.

Anonymous, (2009) *GenStat release 12.1*. VSN International Ltd.

Ashraf, A., Khalid, A. and Ali, K. (1999) *Effect of seedling age and density on growth and yield of rice in saline soil*. Parkistan Journal of Biological Sciences, 2 (30): 860-862.

Asif, M. Aslam, M. Jabbar, A. Rafique, K. Babar, M. and Ehsanullah, R. (2000) *Panicle Structure, Kernel Quality and Yield of Fine Rice as Influenced by NPK Rates and Split Nitrogen application*. International Journal of Agriculture and Biology, 4: 306-308.

Atera, E.A. Onyango, J.C. Azuma, T. Asanuma, S. and Itoh, K. (2011) *Field evaluation of selected NERICA rice cultivars in Western Kenya*. Africa Journal of Agricultural Research, 6 (1): 60-66.

Attia, T., Busso, C. and Robbelen, G. (1987) *Digenomic triploids for an assessment of chromosome relationships in the cultivated diploid Brassica species*. Genome, 29: 326-330.

Bahar, F.A. and De Datta, S.K. (1977) *Prospects of increasing tropical rice production through ratooning*. Agronomy Journal, 69 (4): 536-540.

Baloch M.S., Awan I.U. and Hassan, G. (2006) *Growth and yield of rice as affected by transplanting dates and seedlings per hill under high temperature of Dera Ismail Khan, Parkistan.*Journal of Zhejang University Science B, **7** (7): 572-579.

Bajpai, R.P. and Singh, V.K. (1992) *Effect of butachlor application of sprouted direct seeded rice (Oryza sativa) in puddle field.* Indian Journal of Agronomy, 37: 171-173.

Bardhan Roy, S.K., Ghosh, R. and Mondal, J. (1982) *Yield and yield contributing characters of photoperiod sensitive rice varieties and their ratoons*. International Rice Research Newsletter, 7 (3): 19.

Bari, M.N., Mamun, A.A., Kamal, A.M.A. and Sarkar, M.A.R. (1993) *Performance of transplant aman rice as affected by cultivar and weeding regime*. Bangladesh Journal of Crop Science, 4: 23-31.

Becker, M. and Johnson, D.E. (2001) *Cropping intensify effects on upland rice yield and sustainability in West Africa Nutrient Cycling in Agroecosystems*. Kluwer Academic Publishers, the Netherlands, 59: 107-117.

Berhanu, S. (1985). *Weed Control System Adopted in the MSFD Wheat Growing Regions*. Proceedings of the Tenth East African Weed Science Society Conference. Nairobi, Kenya. Pp 27-31.

Besler, M. (1999) *Allergen data collection: Rice (Oryza sativa)*. Internet Symposium on Food Allergens, 1: 147-160.

Bhaskar, R. and Pederson, J. (1998) *Exotic species an ecological roulette with nature*: Coastal resources fact sheet.

Bolfrey-Arku, G., Owusu-Akyaw, M., Afun, J.V.K., Adu-Mensah, J., Anno-Nyako, F.O., Moses, E., Osei, K., Osei-Yeboah, S., Mochiah, M.B., Adama, I., Dankyi, A.A., Brandenburg, R.L., Bailey, J.E., and Jordan, D.L. (2006). *Survey of weed management in Peanut Fields in Southern Ghana, West Africa.* Peanut Science, 33 (2):90-96.

Bollich, C.N. Web, B.D. and Scott, J.E. (1988) *Breeding and testing for superior ratooning ability of rice in Texas*. In: *Rice ratooning*. International Rice Research Institute. Manila, Philippines, pp 47-54.

Brar, D.S. and Khush, G.S. (2002) *Transfering genes from wild species into rice*. In Quantitative Genetics, Genenomics and Plant Breeding, Kang, M.S. (Ed.). CAB International, Wallingford, UK. ISBN: 978-0851996011, pp:197-217.

Briske, D.D. (1986) *Plant response to defoliation: morphological considerations and allocation priotities*. *In*: Joss, P.J., Lynch, P.W. and Williams, O.B. (eds.) Rangelands: a resource under siege. Australian Academic Science Canberra, Australia, pp 425-427.

Bres-Patry, C. Lorieux, M. Clement, G., Bangratz, M. and Ghesquiere, A. (2001). *Heredity and genetic mapping of domestication-related traits in a temperate japonica weedy rice*. Theoretical and Applied Genetics, 102: 118-126.

Briske, D.D. and Heitschmidt, R.K. (1991) *An ecological perspective*. P 11-26. *In*; Heitschmidt, R.K. and Stuth, J.W. (eds). Grazing management-an ecological perspective. Timber Press. Inc., Portland, or USA.

Brondani, C., Rangel N., Brondani, V. and Ferreria, E. (2002) *QTL mapping and introgression of yield related traits from Oryza glumaepatula to cultivated rice (Oryza sativa) using microsatellite markers*. Theoretical and Applied Genetics, 104:1192- 1203.

Brooks, M.L., D'Antonio, C.M., and Richardson, D.M., (2004) *Effects of invasive alien plants on fire regimes*. Bioscience, 54:677-688.

Bryson, C.T. (1990) *Interference and critical time of removal of hemp Sesbania (Sesbania exeltata) in cotton (Gospium hirsutum)*. Weed Technology, 4: 833-837.

Buchanan, G. A. and Burns, E. R. (1971). *Influence of weed competition on cotton, sicklepod and tall morning glory*. Weed Science, 19: 576 – 579.

Buchanan, G.A. Crowley, J.E., Street, J.E.and McGuire, J.A. (1980) *Competition of sicklepod (Cassia obtusiflexus) and redroot pigweed (Amaranthus retroflexus) cotton (Gospium hirsutum)*. Weed Science, 28: 258-262.

Bukun, B. (2004). *Critical periods for weed control in cotton in Turkey*. Weed Research, 44:404–412.

Bunyatta, D.K (2012) *Guideline for growing New Rice for Africa (NERICA): an Upland Rice Variety as an alternative food Security crop in Semi Arid lands of Kenya*. Ministry of Agriculture, Nairobi, Kenya.

Cao, Q.J., Li. B., Song, Z.P., Cai, X.X., and Lu, B. (2007) *Impact of weedy rice populations on the growth and yield of direct-seeded and transplanted rice*. Weed Biology and Management, **7**: 97 - 104.

Caton, B.P., Cope, E.A. and Mortimer, M. (2003) *Growth traits of diverse rice cultivars under severe competition: Implication for screening for competitiveness.* Field Crops Research, 83: 157-172.

Chaetterjee, B.N., Bhattacharya, S. and Debnath, P. (1982) *Ratooning of rice*. Oryza, 19 (3/4):226-227.

Chang, T.T. (2003). Origin, domestication and Diversification. Chapter 1.1. In Smith, W.C. and Dilday, R.H., eds. *Rice. Origin, History, Technology and Production*. John Wiley and Sons, Inc. Hoboken, New Jersey. pp 3-25

Chauhan, J.S., Vergara, B.S. and Lopez, S.S.F. (1985) *Rice ratooning*. IRRI Research Paper Series Number 102, Manila, Philippines.

Chikoye, D., J. Ellis-Jones, C. Riches, and L. Kanyomeka (2007) *Weed management in Africa: experiences, challenges and opportunities*. XVI International Plant Protection Congress, pp 652-653.

Chikoye, D., S. Schultz, and F. Ekeleme (2004) *Evaluation of integrated weed management practices for maize in the northern Guinea savanna of Nigeria*. Crop Protection, 23: 895-900.

Chivinge, O.A. (1990) *Weed Science Technological Needs for the Communal Areas of Zimbabwe*. Zambezia, 17 (2): 133-143**.**

Choudhary, B.R. Joshi, P. and Ramarao, S. (2000) *Interspecific hybridization between Brassica carinata and B. rapa*. Plant Breeding, 119: 417-420.

Choudhary, B.R. and Joshi, P. (2001) *Genetic diversity in advanced derivatives of Brassica interspecific hybrids*. Euphytica, 121:1-7.

Clayton, W.D. and Renvoize, S.A. (1986) *Genera graminum*. London, HMSO.

Convention on the Biological Diversity (2000) *Cartagena Protocol on Biosafety to the convention on Biological Diversity: text and annexes.* Montreal: Convention on the Biological Diversity.

Crawley, M.J., Harvey, P.H. and Purvis, A. (1996) *Comparative ecology of the native and alien floras of the British Isles*. Philosophical translations of the loyal society of London series B, Biological Sciences, 351: 1251-1259.

Cronk, Q.C.B. and Fuller, J.L., (1995) *Plant invaders.* Chapman and Hall, New York.

Crosti, R. Cascone, C. and Testa, W. (2007) *Towards a weed risk assessment for the Italian peninsula: preliminary validation of a scheme for the Central Mediterranean region in Italy*. Proceedings of the MEDICOS XI Conference, Perth, Western Australia.

Dadari, S.A. and Hamza M. (2005) *The effect of post-emergence weed control on irrigated wheat in the Sudan savannah of Nigeria*. Crop Protection, 24: 842-847.

Daehler, C.C. (1998) *The taxonomic distribution of invasive angiosperm plants: ecological insights and comparision to agriculture weeds*. Biological Conservation, 84: 167-180.

Daehler, C.C. and Carino, D.A. (2000) *Predicting invasive plants: Prospects for general screening system based on current regional models*. Biological Invasions, 2: 93-102.

Daehler, C.C., Denslow, J.S., Ansari, S and Kuo, H.C. (2004) *A risk assessment system for screening out invasive pest plants from Hawaii and other Pacific Islands*. Conservation Biology, 18: 360-368.

Dahama, A.K., Bhagal, K.L. and Singh, H. (1992) *Weed management in direct seeded upland rice (Oryza sativa)*. Indian Journal of Agronomy, 37: 705-709.

Dark, S.J. (2004) *The biogeography of invasive alien plants in California: an application of GIS and spatial regression analysis*. Diversity and Distributions 10: 1-9.

Dawson, J.W. (1970) *Time and duration of weed infestations in relation to crop-weed competition*. Proc. South Weed Science Society, 23: 13-15.

De Datta, S.K. (1980) *Weed control in rice in South and Southeast Asia*. Food and Fert Technology Center Ext. Bull. Taipei, Taiwan, 156: 24.

De Datta, S.K. (1981a) *Principles and practices of rice production.* John Willy and Sons, Inc. New York, pp 45-86.

De Datta, S.K. (1981b) *Weed control in rice in South and Southeast Asia*. In: Weed and weed control in Asia. FETC Book Series No. 20 ASPEC, Taipei, Taiwan, pp: 101.

De Vida, F.B.P., Laca, E.A., Mackill, D.J., Grisel, M. and Fischer, A.J. (2006) *Relating rice traits to weed competitiveness and yield: a path analysis.* Weed Science, 54: 1122-1131.

Diarra, A.R.J., Smith, R. J. and Talbert, R. E. (1985) *Growth and morphological characteristics of red rice (Oryza sativa) biotypes.* Weed Science, 33: 310 -314.

Diaz, S., Carbido, M., Casanoves, F. (1998) *Plant functional traits and environmental filters at a regional scale.* Journal of Vegetation Science, 9: 113-122.

Dingkuhn, M., Johnson, D.E., Sow, A. and A udebert, A.Y. (1999) *Relatiponships between upland rice canopy characteristics and weed competitiveness*. Field Crops Research, 61: 79-95.

Dingkuhn, M., Jones, M.P., Johnson, D.E. and Sow, A. (1998) *Growth and yield potential of O. sativa and O. glaberrima upland rice cultivars and their interspecific progenies*. Field Crops Research, 57: 57-69.

Drake, D.J., Nader, G. and Forero, L. (2002) *Feeding rice straw to cattle*. University of California, Division of Agriculture and Natural Resources, pp 13-21.

Goodwin, B.F., McAllister, A.J., and Fahrig, L. (1999) *Predicting invasiveness of plant species based on biological information*. Conservation Biology 13 (2): 422-426.

Doust, A. (2007) *Architectural evolution and its implications for domestication in grasses*. Annals of Botany 100: 941-950.

Dzomeku, I.K., Dogbe,W. and Agawu,E.T. (2007) *Responses of NERICA rice varieties to weed interference in the Guinea Savannah Uplands*. Journal of Agronomy, 6 (2): 262-269.

Eiswerth, M.E. (2005) *Input Output modelling, outdoor recreation and the economic impacts of weeds*. Weed Science, 53:130-137.

Ekeleme, F., Kamara, A.Y., Oikeh, S.O., Chikoye, D and Omoigui, K.O. (2007) *Effect of weed competition on upland rice production in north-eastern Nigeria*. African Crop Science Conference Proceedings, 8: 61-65.

Ekeleme, F., Kamara, A.Y., Oikeh, S.O., Omoigui, K.O., Amaza, P., Abdoulaye, T. and Chikoye, D. (2008) *Response of upland rice cultivars to weed competition in the savannas of West Africa.* Crop Protection, 28: 90-96.

Elefhterohorinos, I. G., Dhima, K. V. and Vasilakoglou, I. B. (2002) *Interference of red rice in rice grown in Greece.* Weed Science, 50:167–172

Estorninos, L.E. Jr., Gealy, D. R. and Talbert, R.E. (2002) *Growth response of rice (Oryza sativa) and red rice (O. sativa) in a replacement series study*. Weed Technology, 16: 401-406.

Evans, S.P. Knezevic, S.Z., Lindquist, J.L. Shapiro, C.A. and Blankenship, E.E. (2003) *Nitrogen application influences the critical period of weed control in corn*. Weed Science, 51: 408-417.

Fageria, N.K., Baliger, V.C. and Jones, C.A. (1997) *Growth and mineral nutrition of field crops*. Marcel Dekker Inc. New York, Basel, Hong Kong, pp 283-289.

Falster, D.S., Reich, P.B., Ellsworth, D.S., Wright, I.J., Westoby, M., Oleksyn, J. and Lee,T.D. (2011) *Lifetime return on investment increases with leaf lifespan among 10 Australian woodland species*. New Phytology, 10: 1469-1489.

FAO (1996) *Weed management in rice*. In: Weed management in developing countries. Food and Agriculture Organization Paper No. 120, pp: 29-30.

FAO (2001) *International Standards for Phytosanitory Measures, Glossary of phytosanitary terms.* Publication No. 5. Rome, Secretariat of the Int. Plant Convention of the Food and Agriculture Organization (FAO) of the United Nations.

FAO (2004) *Species description Oryza sativa L.* http://www.fao.org/ag/AGP/AGPC/doc/GBASE/data/pf000274.htm, (Accessed 12/03/2012).

FAO (2005) *Procedures for Weed Risk Assessment*. Plant Production and Protection Division, FAO Rome.

Farrell, G., Kibata, G.N. and Sutherland, J. A. eds. (1995) *A review of crop protection research in Kenya.* KARI/ODA Crop Protection Project. Nairobi, Kenya, Kenya Agricultural Research Institute, pp 165.

Feakin, S.D. (1971) *Pest control in rice*. Pans manual no 3. Tropical pesticides research headquarters and information unit. London, England, p 270.

Ferrell, J.A. MacDonald, G.E. and Brecke, B.J. (2006) *Weed management in soyabean*. FAS Exte. University of Florida, http//edisi.iFasUFhedv/bodywgolo pp 1-14 (Accessed 25/ 04/ 2011).

Fischer, A.J., Ramizer, H.V. Gibson, D.K. and Da Silveira, P.B (2001) *Competitiveness of semi dwarf Upland Rice cultivars against Palisadegrass (Brachiaria brizantha) and Signalgrass (Brachiaria decumbens)*. Agronomy Journal, 93: 967-973.

Fischer, A.J., Ramizer, H.V. and Lozano, J. (1997) *Suppression of junglerice [Echinochloa colona (L) Link] by irrigated rice cultivars in Latin America.* Agronomy Journal, 89: 516-521.

Fischer, A., Chatel, M., Ramirez, H., Lozana, J. and Guimarase, E. (1995) *Components of early competition between upland rice (O. sativa) and Brachiaria brizantha*. Intergrated Journal of Pest Management, 41: 100-103.

Fofana, B and Rauber, R (1999) *Weed suppression ability of upland rice under low-input conditions in West Africa*. Weed Research, 40: 271- 280.

Frageria, N.K., Baliger, V.C. and Jones. C.A. (1997) *Growth and mineral nutrition of field crops*. Marcel Dekker Inc. New York, Basel, Hong Kong, pp 283-289.

Fujii, M. Andoh, C. and Ishihara S. (2005) *Drought resistance of NERICA (New Rice for Africa) compared with Oryza sativa L. and millet evaluated by stomata conductance and soil water content*. Proceedings of the 4th International Crop Science Congress, New Delhi, India, pp 331-338.

Fukai, S. and Lilley, J.M. (1994) *Effects of timing and severity of water deficit on four diverse rice cultivars. Phenological development, Crop growth and grain yield*. Field Crop Research, 37: 225-234.

Garrity, D.P., Movillon, M. and Moody, K. (1992) *Differential weed suppression ability in the upland rice cultivars*. Agronomy Journal, 84: 586-591.

Gealy, D.R., Saldain, N.E. and Talbert, R.E. (2000) *Emergence of red rice (Oryza sativa) ecotypes under dry seeded rice (Oryza sativa) culture.* Weed Technology, 14: 406-412.

Ghosh, D.C. and Singh, B.P. (1998) Crop growth modelling for wetland rice managament. Environment and Ecology, 16 (2): 446-449.

Gibson, K.D., Hill, J.E., Foin, T.C., Caton B.P. and Fischer A.J. (2001) *Water seeded rice cultivars differ in ability to interfere with watergrass*. Agronomy Journal, 93: 326-332.

Gordon, D.R. (1998) *Effects of invasive, non-indigenous plant species on ecosystem processes: lessons from Florida*. Ecological Application, 975-989.

Gott, M.B., Gregory F.G. and Purvis, O.N. (1955) *Studies on vernalisation of cereals*. Annals of Botany, 19: 87-126.

Graf, B., Rakotobe, O., Zahner, P., Delucchi, V. and Gutierrez, A.P. (1990) *A simulation model for the dynamics of rice growth and development. 1. The carbon balance*. Agricultural Systems, 32: 341-365.

Grist, D. H. (1986) *Rice*. 6th ed. Longman, London, pp 134-156.

Haefele, S.M., Johnson, D.E., M'Bodj, D., Wopereis M.C.S. and Miezan, K.M. (2004) *Field screening for diverse rice genotypes for weed competitiveness in irrigated lowland ecosystems*. Field Crops Research, 88: 39-56.

Hall, M.R., Swanton, C.J. and Anderson, G.W. (1992). *The critical period of weed control in grain corn (Zea mays)*. Weed Science, 40: 441–447.

Harlan, J.R. (1973) *Comparative evolution of cereals*. Evolution, 27: 311-325.

Hanfei, D. (1992) *Upland Rice System*. In: Field crop Ecosystem. Person, C.J. (Ed.), Elsevier Publications, Amsterdam, pp: 183-204.

Harding, S.S. and Jalloh, A.B. (2011) *Evaluation of the relative weed competitiveness of upland rice varieties in Sierra Leone.* African Journal of Plant Science, 5 (7) 396-400.

Harsh, M. (2005) *Formal and in formal governance of agricultural biotechnology in K enya: Participation and accountability in controversy surrounding the draft biosafety bill*. Journal of International Development, 17: 661-677.

Hazard, W.H.L. **(**1988) *Introducing crop, pasture and ornamental species into Australia-the risk of introducing new weeds*. Australian Plant Introduction Review, 19:19-36.

Heemst, H.D.J. van (1985) *The influence of weed competition on crop yield*. Agricultural Systems, 18: 81-93.

Heuer, S., Miezan, K., Sie, M. and Gaye, S. (2003) *Increasing Biodivesity of irrigated rice in Africa by interspecific crossing of O. glaberrima (Steud) x O. sativa indica (L.)*. Euphytica, 132: 31-40.

Heywood, V.H. (1993) *Flowering plants of of the world*. Oxford University Press, New York, pp 134-141.

Higgins, S. and Richardson, D.M. (1998) *Pine invasions in southern hemisphere: modeling interactions between organisms, environment and disturbance*. Plant Ecology, 135: 79-93.

Hill, D.J. Hosking, C.S., Zhie, C.Y., Leung, R., Baratwidjaja, K., Iikura, y., Iyngkaran, N., Gonzalez, A.A., Wah, L.B. and Hsieh, K.H. (1997) *The frequency of food allergy in Australia and Asia*. Environmental Toxicology and Pharmacology, 4: 101-110.

Hill, G., Cock, M., and Howard, G. (1999) *Water hyacinth, its control and utilisation: a global review*. CABI Bioscience and IUCN. Publications on water resources: No.15. Stockholm, Swenden, Swedish International Development Cooperation Agency (SIDA), pp 54.

Hodges, R.J., Dunstan, W.R., Magazini, I.A. and Golob, (1983) *An outbreak of Prostephanus tracatus (Horn) (Coleoptera: Bostrichidae) in East Africa*. Protection Ecology, 5: 183-194.

Holm, L.G., Plucknett, D.L., Pancho, J.V. and Herberger, J.P. (1977) *The World's Worst Weeds*. University Press of Hawaii, Honolulu, pp 5-7.

Holm, L.G., Pancho, J.V., Herberger, J.P. and Plucknett, D.L. (1979) *A Geographical Atlas of World Weeds*. New York, John Wiley and Sons, pp 10.

Hsieh, C.F., Kao, S., and Chiang, C. (1964) *Studies on the cultivation of ratooned rice. Varietal variation on ratooning ability and yield*. Journal of Taiwan Agricultural Research, 13 (3):14-21.

Humphries, S. E., Groves, R. H. and Mitchell, D. S. (1991) *Plant invasions of Australian ecosystems*. Kowari, 2: 1-134.

Hyder, D.N. (1972) *A general hypothesis of species diversity*. American Naturalist, 113:81-101.

Idris, H. (1970) *Chemical Control of Weeds in Cotton in the Sudan Gezira*. PANS 16 (1): 96-105.

IPPC, (2003) *Identification of risks and management of invasive alien species using IPPC framework*. Proceedings of a workshop in Braunschweig, Germany, pp 22-26.

IRRI (1992) A *farmer's primer on growing rice* (Editor by Veragara B.S), pp 219.

IRRI, (1993) International Rice Research Institute. *Program report for (1992)*. Los Banos and Philippines, pp 22.

Ishaya, D.B., Dadari, S.A. and Shebayan, J.A.Y (2007) *Evaluation of herbicides for weed control in sorghum (Sorghum bicolour) in Nigeria*. Crop Protection, 26:1697-1701.

Jackson, M.G. (1978) *Rice straw as livestock feed*. In FAO, ed. Ruminant nutrition: selected articles from the World Animal Review *http://www.fao.org/DOCREP/004/X6512E/X6512EOO.htm#TOC*, (Accessed 14/11/2011).

Jaetzold, R. and Schimdt, H. (1982). *Farm management hand book: Natural condition and farm management information, Vol. II/A: East and West Kenya*. Ministry of agriculture (MOA).

Jannink, J.L., Orf, J.H., Jordan N.R. and Shaw, R.G. (2000) *Index selection for weed suppressive ability in soyabean*. Crop Science, 40: 1087-1094.

Jennings, P.R. and Herrera, R.M. (1968) *Studies on competition in rice. Competition in segregating population*. Evolution, 2: 332-336.

Jiang, P.Y., (1994) *Several biological principles for high yielding rice*. China Rice Bulletin, 2: 43-45.

Johnson, D.E., Wopereis, M.C.S., Mbodj, D., Diallo, S., Powers, S.,Haefele, S.M.,(2004) *Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel*. Field Crops Research, 85:31-42.

Johnson, P., Dingkuhn, M., Jones, K., and Mahamane, L. (1998) *The influence of rice plant type on the effect of weed competition on Oryza sativa and Oryza glaberrima*. Weed Research, 38 (3): 207-216.

Johnson, D.E., Riches C.R, Diallo and Jones M.J. (1997) *Striga on rice in West Africa; crop host range and the potential of crop resistance*. Crop Protection 16: 153-157.

Johnson, D. and Jones, M. (1993) *Competitiveness of rice with weeds*. In WARDA Annual Report 1992. West Africa Rice Development Association (WARDA). Cote d' Ivory, pp: 14-15.

Johnson, D.E. (1971) *Weed Management in Small Holder Rice Production in the Tropics*. Natural Resources Institute, University of Greenwich Chatham, Kent, UK.

Jones, M.P. (1998) *Basic breeding strategies for high yielding rice varieties at WARDA*. Japanese Journal of Crop Science, 67: extra issue 2. Pp 14.

Jones, M.P., Dingkuhn, M., Aluko, G.K. and Semon, M. (1997) *Interspecific Oryza sativa L. and O. glaberrima Steud. Progenies in upland rice improvement*. Euphytica, 92: 237-246.

Jones, D.B. and Snyder, G.H. (1987) *Seeding rate and row spacing effects on yield and yield components of ratoon rice*. Agronomy Journal, 79: 627-629.

Junelyn, S. and de la Rosa (2004) *Harvest more rice with ratooning*. BAR Today.

Kaneda, C. (2007) *Breeding and dissemination efforts of "NERICA" (2) evaluation of important characreistics*. Japanese Journal of Tropical Agriculture, 51**:**41-45.

Kanya, J.I., Njiruh, P.N., Kimani, J.M., Wanjogu, R.K. and Kariuki, S.N. (2013) *Evaluation of photoperiod and thermosensitive genic male sterile lines for hybrid rice seeds production in Kenya.*International Journal of Agronomy and Agricultural Research (IJAAR), 3 (2): 21-39.

Kato, Y., Kamoshita, A. and Yamagishi, J. (2008) *Preflowering abortion reduces spikelets number in upland rice (Oryza sativa L.) under water stress*. Crop Science, 48: 2389-2395.

Katiyar, R.K. Chamola, R. and Chopra, V.L. (1998*) Tetracular mustard, Brassica juncea: New promising variability though interspecific hybridization*. Plant Breed 117: 398-399.

Keddy, P.A. (1992) *Assembly and response rules: two goals for predictive community ecology*. Journal of Vegetation Science, 3: 157-164.

Kega, V.M. and Maingu A.R. (2006) *Evaluation of new rice for Africa (NERICA) cultivars in coastal lowlands of Kenya*. Kenya Agriculture Research Institute, Matuga, Kenya.

Keli, H. (1988) *Losses caused by the larger grain borer in farm stored maize*. In G.G.M. Schulten and A.J. Toet, eds. Workshop on the containment and control of the larger grain borere, Arusha, Tanzania, 16-21 May 1988, pp 28- 52. Rome, Italy, FAO.

Kende, H., van der Knaap, E. and Cho H.T. (1998). *Deep water rice: a model plant to study stem elongation.* Plant Physiology, 118: 1105–1110.

Kenya Biosafety Act, (2009). Government Printer. Nairobi, Kenya.

Knezevic, S.Z., Evans, S.P., Blankenship E.E., Van Acker and Lindquist, J.L. (2002) *Critical period for weed control: The concept and data analysis*. Weed Science, 50: 773-786.

Kijima, Y, Sserunkuuma, D, and Otsuka, K. (2006). *How revolutionary is the "NERICA revolution*"? *Evidence from Uganda*. Developing Economies, 44:252-267.

Kiniry, J.R., McCauley, G., Xie, Y. and Arnold J.G. (2001) *Rice parameters describing crop performance of four U.S. cultivars*. Agronomy Journal, 93: 1354-1361.

Koga, Y., Akihama, T., Fujimaki, H. and Yokoo, M. (1969) *Studies on the longevity of pollen grains of rice, Oryza sativa* L.I. Morphological change of pollen grains after shedding. Cytologia, 36: 104-110.

Kolar, C.S. and Lodge, D.M. (2001) *Progress in invasion biology: predicting invaders*. Trends in Ecology and Evolution, 16: 199-204.

Kolo, M.G.M. and Umaru, I. (2012) *Weed competitiveness and yield of inter-and-intraspecific upland rice (Oryza sativa L.) under different weed control practices at Badeggi, Niger State, Nigeria.* African Journal of Agricultural Research, 7 (1): 1687-1693.

Krivanek, M. and Pysek, P. (2006) *Predicting invasions by woody species in temperate zone: a test of three risk assessment schemes in the Czech Republic* (*Central Europe*). Diversity and Distributions, 12: 319-327.

Kouko, W.O., Okech, J.N. and Odhiambo, G.D. (1992). *Rice varietal tolerance/ resistance to Striga hermothica screening*. KARI- Kibos, Annual report, pp 2-3.

Kouko, W.O., Makihara, D., Choke, J and Wakhu, P. (2006) *NERICA research and promotion in Kenya*. JICA seminar on sustainable rice farming in Africa. Dec.6-8, Accra, Ghana.

Labrada, R. (2002) *The need for improved weed management in rice*. In: Sustainable rice production for food security. Proceedings of the 20th session of the international rice commission (Bangkok, Thailand, 23-26 July 2002), pp 306.

Lafarge, M. (2000) *Phenotypes and the onset of competition in spring barley stands of one genotype: Daylength and density effects on tillering*. European Journal of Agronomy, 12:211-223.

Langevin, S.A., Clay, K. and Grace, J.B. (1990) *The incidence and effects of hybridization between cultivated rice and its related weed red rice (Oryza sativa L.)*. Evolution, 44: 1000-1008.

Lei, H.S. and Wang, T.D. (1961) *Effects of planting density on nitrogen fertilizer on the total shoot number of rice communities*. Acta Biologiae Experimentalis Sinica, **7**: 227-239.

Lemerle, D., Verbeck, B., Cousens, R.D. and Coombes, N.E. (1996) *The poential for selecting wheat varieties strongly competitive against weeds*. Weed Research, 36: 505-513.

Li, X., Qian, Q., Fu, Z., Wang, Y., Xiang, G., Zeng, D., Liu. X., Teng. S., Hiroshi, F., Yuan, M., Luo, D., Han, B. and Li, J. (2003) *Control of tillering in rice*. Nature, 422: 618-621.

Liu, K., Qin, J., Zhang, B. and Zhao, Y. (2012) *Physiological traits, yields and nitrogen translocation of ratoon rice in response to dufferent cultivations and planting periods*. African Journal of Agricultural Research, 7 (16): 2539-2545.

Lockhart, J.A.R. and Wiseman, A.J.L. (1988) *Introduction to crop husbandry*. Wheaton & Co. Ltd., Pergamon Press. Oxford, UK, pp 70-180.

Lodge, D.M. Williams S., MacIsaac, H.J., Hayes, K.R., Leung, B., Reichard, s., Mack, R.N., Moyle, P.B., Smith, M., Andow, D.A., Carlton, J.T.and McMichael, A. (2006) *Biological innovations: recommendations for US policy and management*. Ecological Applications, 16:2035-2054.

Lu, B.R. (1999) *Taxonomy of genus Oryza (Poaceae): a historical perspective and current status*. International Rice Research Notes, 24:4-8.

Lu, Q., Jiang, d., Weng, X.Y., Xi, H.F., (1999) *The effect of potassium nutrition on dry matter production and photosynthesis of different genotypes of rice*. Journal of Zhejiang Agricultural University 25 (3): 267-270.

Lyons, E.E. (2000) *Preliminary survey of invasive species in Eastern Africa*. In Lyons, E.E. and Miller, S.E., EDS. Invasive species in Eastern A frica: Proceedings of a workshop held at ICIPE, July 5-6, 1999. Pp 65-70. Nairobi, Kenya, International Centre of Insect Physiology and Ecology (ICIPE) Science press, pp 108.

Mack, R.N., Simberloff, D. and Lonsdale, W.M., Evans, H., Clout, M., and Bazzaz, F. (2000) *Biotic invasions: causes, epidemiology, global consequences and control*. Ecological applications, 10:689-710.

MAFFS, (2005) Ministry of Agriculture, Forestry and Food Security. Rice Research Station: Crop Productions Guidelines for Sierra Leone, pp.3-8.

Mahadevappa, H. (1988) *Rice ratooning practices in India*. In: *Rice ratooning* pp 69-78. International Rice Research Institute. Los Banos, Philippines.

Maillet, J., Lopez-Gacia, C. (2000) *What criteria are relevant for predicting the invasive capacity of new agricultural weeds? The case of invasive American species in France*. Weed Research, 40: 11-26.

Malton, P., Randolph, T. and Guei, R. (1998) *Impact of rice research in West Africa*. In: Impact of rice research, Pingali, P.L. and M. Hossain, Eds.). Thailand Development (IRRI), ISBN: 971-22-0106-6, Manila Philippines, pp:383-404.

Marais, C., van Wilgen, B.W. and Stevens, D. (2004) *The clearing of invasive alien plants in South Africa: a preliminary assessment of cost and progress*. South African Journal of Science, 100: 97- 103.

Mathew, T. (2001) *Survey of Kenya and National Irrigation Board*. Mwea IDRC Project and Partners.

Matsuda, T., Nomura, R., Sugiyama, M. and Nakamura, R. (1991) *Immunochemical studies on rice allergenic proteins.* Agricultural and Biological Chemistry, 55: 509-513.

Mavudzi, Z., Mashingaidze, A.B. Chivinge, O.A., Ellis-Jones, J. and Riches, C. (2001) *Improving weed management in a cotton-maize system in the Zambezi valley Zimbabwe*. Brighton Crop Protection Conference, Weeds, 169-174.

Messeguer, J., Fogher, C., Guiderdoni, E., Marfa, V. Catala, M.M., Baldi, G. and Mele, E. (2001) *Field assessment of gene flow from transgenic to cultivated rices (Oryza sativa L.) using a herbicide resistance genes as tracer markers*. Theoretical and Applied Genetics, 103:1151-1159.

McDonald, D.J. (1979) Rice. Chapter 3. In: *Australian field crops vol. 2: Tropical cereals, oilseeds, grain legumes and other crops.* Augus and Robertson, London. pp 70-94.

McDonald, D.J. (1994) *Temperate rice technology for the 21st century: an Australian example.* Australian Journal of Experimental Agriculture, 34: 877-888.

McGregor, J.T., Roy, J.R., Smith, J.R. and Talbert, R.E. (1988). *Broadleaf signal grass (Brachiaria platyphylla) duration of interference in rice (Oryza sativa).* Weed Science 36: 747-750.

Ministry of Agriculture (2010). *The ministry of Agriculture at a Glance*. Office of the Permanent Secretary, Kenya.

Mitra, B.K., Karim, A.J.M.S., Haque, M.M., Ahmed, G.J.U. and Bari, M.N. (2005) *Effect of weed management practice on transplanted aman rice.* Journal of Agronomy, 4 (3): 238-241.

Mizushima, U. (1980) *Genome analysis in Brassica and allied genera*. In: Tsunoda, S. Hinata, K. and Gomez-Campo C (eds) Brassica crops and wild allies, Japan Science Society Press, Tokyo, pp 89-106.

MOA, (2004) Ministry of Agriculture Kenya; Crop Development Division, Annual Report.

MOA, (2011) Ministry of Agriculture Kenya; Crop Development Division, Annual Report.

Islam, M.D., Hasanuzzaman, M. and Rokonuzzaman, M. (2009) *Effect of split application of nitrogen fertilizer on morphophysiological parameters of rice genotypes*. International Journal of Plant Production, 3 (1): 1735-1756.

Muhammad, A., Khan, A.S., Khan, S.H.U, and Ahmad, R. (2012). *Association of various morphological traits with yield and genetic divergence in rice (Oryza sativa)*. International Journal of Agriculture and Biology, 1814–1839.

Moody, K. and Mian, A.L. (1979) In*: Rain fed rice selected papers for IRRI conference 17-21 April 1978*. IRRI, Los Banos, Philippines, pp: 235-245.

Moody, K. (1994) *Weed management in rice*. In: Weed management for developing countries. FAO Plant production and protection paper, 120: 249-259.

Moore, D.S. and McCabe, G.P. (1999) *Introduction to the practice of statistics*. W.H. Freeman and Company, New York.

Morishima, H. (1984) Wild plants and domestication. Chapter 1, In: Tsunoda, S. and Takahashi, N. (eds.) *Biology of rice*, volume 7. Elsevier, Amsterdam. Pp 3-30.

Moynul, M.D.H., Hossain, M.D.M., Rezaul, M.D. Halequzzaman, H.R. and Karim, S.M.R. (2003) *Effects of varieties of rice and weeding on weed growth and yield of transplant among rice.* Asian Journal of Plant Sciences 2:993-998.

Muhihu, S.K. and Kibata, G.N. (1985) *Developing a control programme to combat an outbreak of Prostephanus trunctus Horn (coleopteran: Bostrichidae) in Kenya.* Tropical Science, 25: 239-248.

Murray, S.S. (2005) *Searching for the origins of African rice domestication*. http://antiquity.ac.uk/ProjGall/murray. (Accessed 12/02/2012).

Nakano, H. and Morita, S. (2007) *Effects of twice harvesting on total dry matter yield of rice*. Field Crops Research, 101:269-275.

Nair, A.S. and Rosamma, C.A. (2002) *Character association in ratoon crop of rice (Oryza sativa L.)*. Journal of Tropical Agriculture, 40: 1-3.

Nair, N.R. and Sahadevan, P.C. (1961) *A note on vegetative propagation of cultivated rice*. Current Science, 30:474-476.

Naredo, M.E.B., Juliano, A.B., Lu, B.R., Guzman, F.de and Jackson, M.T. (1998) *Response to seed dormancy-breaking treatments in rice species* (*Oryza* L.). Seed Science and Technology, 26: 675-689.

National Research Council (1996) *Understanding risk: Informing decisions in a democratic society*. Washington, DC: National Academy Press.

Nazeer, A., Malik, A.U., Nazir, G.and Ahmad, J. (2012) *Effectiveness of tillage systems and farm manure levels on rice productivity*. Journal of Animal and Plant Sciences, 22 (2): 334-338.

Ndjiondjop, M.N., Semagn, K., Sie, M., Cissoko, M., Fatondji, B. and Jones, M. (2008) *Molecular profiling of interspecific lowland rice populations derived from IR64 (Oryza sativa) and Tog5681 (Oryza glaberrima)*. African Journal of Biotechnology, 7 (23): 4219-4229.

Ngouajio, M., Foko, J. and Fouejio, D. (1997) *The Critical Period of Weed Control in Common bean (Phaseolus vulgaris L.) in Cameroon*. Crop Protection, 16 (2)**:**127-133**.**

NIB (1996) *Progress report*. Mwea Irrigation Agricultural Development Project.

Nieto, H.J., Brondo, M.A., Gonzales, J.T. (1968) *Critical period of crop growth periods for competition from weeds.* Pest Artic. News Summ. (C) 14:159-166.

NWRAS review group (2006) *Review of the National Weed Rsk Assessment System*. NRMSC 12 Canberra.

Obuo, J. E., Adipala, E. and Osiru. D. S. O. (1997). *Weed Suppression in a Cowpea/Sorghum Intercrop*. 16th East African Biennial Weed Science Conference Proceedings, 113-118.

Obuo, J. E., Okurut-Akol, H. and Adipala, E. (1999) *Effect of weeding regimes on grain yield of an Improved cowpea variety in northeastern Uganda*. 17th East African Biennial Weed Science Conference Proceedings, 79-83.

Oad F.C., Pompe S.C., Memon, N., Oad, N.L. and Zia-Ul-Hassan (2002) *Rice ratooning management*. Parkistan Journal of Applied Sciences, 2 (1): 29-35.

OECD (1999) *Consensus document on the biology of Oryza sativa (rice).* Report No. ENV/JM/MONO (99)26, OECD Environmental health and Safety Publications, Paris.

Oka, H. I. (1998) *Origin of cultivated rice*. Experimental Genetics, 1:45-51.

Olofsdotter, M., Valverde, B. E. and Madesen, K. H. (1999) *Resistant Rice (O. sativa).* A *threat or a solution.* Report of the global workshop on red rice control 30th August - 3rd September Varadero, Cuba, pp:123 - 145.

Olowe, T., S. O. Dina, A. O. Oladiran, and B. A. Olunuga (1987) *The control of weed, pest and disease complexes in cowpea (Vigna unguiculata (L.) Walp.) by the application of pesticides singly and in combination*. Crop Protection, 6 (4): 222-225.

Oosterhuis, D. M. and Jernstedt, J. (1999) *Morphology and anatomy of the cotton plant*. In, W. C. Smith, J. T. Cothren, (eds.) Cotton: Origin, History, Technology and Production. John Wiley and Sons, Inc., New York, pp 175-206.

Orr, R.L., Cohen, S.D. and Griffin, R.L. (1993) *Genetic non-indigenous pest risk assessment process*. Animal and plant health inspection service, USDA.

Ogwang, J.A. and Molo, R. (2003). *Water hyacinth, Eichhornia crassipes: A case of successful Biological Control in Lakes Kyoga and Victoria-Uganda.* Uganda Journal of Agricultural Sciences, 8: 245-252.

Overfield, D., Murithi, F.M., Muthamia, J.N., Ouma, J.O., Birungi, K.F., Maina, J.M., Kibata, G. N., Musembi, F. J., Nyanyu, G., Kamidi, M., Mose, L.O., Odendo, M., Ndungu, J., Kamau, G., Kikafunda, J. and Terry. P.J. (2001) *Analysis of the constraints to adoption of herbicides by smallholder maize growers in Kenya and Uganda.* The BCPC Conference Weeds, 907-912.

Palchamy, A. and Kolandaswamy, S. (1982) *Correlation and path coefficient study of ratoon rice varietites Viagai and Bhavani*. Madras Agricultural Journal, 69 (10): 693-694.

Parago, J.F. (1963) *A review of work on rice ratooning in the Philippines*. Agricultural and Industrial Life, 25 (7) 8-9, 39.

Parker, C. and Fryer, J.D. (1975) *Weed control problems causing major reductions in world food supplies*. FAO Plant Protection Bulletin, 23:83-95.

Panetta, F.D. (1993) *A system of assessing proposed plant introductions for weed potential*. Plant Protection Quarterly, 8:10-14.

Panetta, F.D. Pheloung, P.C., Lonsdale, M., Jacobs, S., Mulvaney, M. and Wright, W. (1994) *Screening plants for weediness: a procedure for assessing species proposed for importation into Australia*. A report commissioned by the Australian Weeds Committee.

Parker, I.M., Simberloff, D., Lonsdale, W.M. (1999) *Impact: Towards a framework for understanding the ecological effects of invaders*. Biological Invasions, 1: 3-19.

Pande, H. K. (1994) *Improved upland rice farming systems*. Food and Agriculture Organization of the United Nations, Rome. pp 31-108.

Peng, S., Khush, G.S., Cassmsn, K. G. (1994) *Evolution of the new plant ideotype for increased yield potential*. Page 5-20. In Cassman, K. G. (ed.) Breaking the potential in favourable environments, IRRI, Philppines.

Pheloung, P.C. (1995) *Determining the weed potential of new plant introductions to Australia. Agriculture protection board report*. West Australian Department of Agriculture, Perth, Western Australia.

Pheloung, P.C., Williams, P.A. and Halloy, S.R. (1999) *A weed risk assessment model for use as a biosecurity tool for evaluating plant introductions*. Journal of Environmental Management, 57: 239-251.

Pimentel, D., McNair, S. and Janecka, J. (2001) *Economic and environmental threats of alien plant, animal and microbe invasions*. Agriculture, Ecosystems and Environment, 84: 1-20.

Potts, B.M., Barbour, R.C., Hingston, A.B. (2001) *Genetic pollution fromfarm forestry using eucalyptspecies and hybrids*. A report for the RIRDC/L&WA/FWPRDC; Joint venture agro forestry program.102-105.

Prashar, C.R.K. (1970) *Paddy ratoons*. World Crops, 22 (3): 145-147.

Pratt, D.J. Greenway, P.J., and Gwynne, M.D. (1966) *A classification of East African rangeland, with an appendix on terminology*. Journal of Applied Ecology, 3: 369-382.

Pysek, P., Richardson, D.M., Rejmánek, M., Grady, L. W., Williamson, M. and Kirschner, J. (2004) *Plants in Checklists and Floras: Towards Better Communication between Taxonomists and Ecologists*. Taxon, 53 (1): 131-143.

Randall, J. M. (1997) *Defining weeds of natural areas*. Pp. 18-25 in: Luken, J. 0. & Thieret, J. W. (eds.), Assessment and Management of Plant Invasions. Springer, New York.

Reddy, T.G., Mahadevappa, M. and Kulkarni, K.R. (1979). *Ratoon cropping of rainfed rice*. International Rice Research Newsletter, 4 (5): 25-26.

Rehman H., Farooq, M., and Barsa, S.M.A. (2007) *Rice ratooning: A technology to increase production*. 9th Internet Edn., DAWN-Business, Pakistan.

Reichard, S.E (2001) *The search for patterns that enable invasion prediction*. Weed risk assessment (ed by Groves, R.H. Panetta, E.D. and Virtue, J.G.) pp 10-19. CSIRO Publishing, Melbourne, Australia.

Reichard, S.E. and Hamilton, C.W. (1997) *Predicting invasions of woody plants introduced into North America*. Conservation Biology 11: 193-203.

Reissig, W.H., Heinrichs, J.A., Litsinger, J.A., Moody, K., Fiedler, L., Mew, T.W. and Barrion, A.T. (1986) *Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia*. IRRI, Los Banos, Philippines, pp: 9-15.

Rejmanek, M. (1996) *Species richness and resistance to invasions* Pages 153-172 in G.H. Orians, G.H. Dirzo, R. and Cushman, J.H. editors. *Diversity and processes in tropical forest ecosystems*. Springer-Verlag, New York, USA.

Rejmanek, M. and Richardson, D.M. (1996) *What attributes make some plant species more invasive*? Ecology, 77 (6): 1655-1661.

Remison, S.V. (1978) *The performance of cowpea (Vigna unguiculata (L) Walp) as influenced by weed competition*. Journal of Agricultural Science, 90: 523-530.

Republic of Kenya (1998) *National guidelines for the release of genetically modified organisms (GMO_S) into the environment*. Nairobi, Kenya: National Council for Science and Technology.

Rhymes, J.M. (1996) *Extinction by hybridization and introgression*. Annual Review of Ecology and Systematics, 27:83-109.

Richardson, D.M. and Pysek, P. (2006) *Plant invasions: merging the concepts of species invasiveness and community invisibility*. Progress in physical geography, 30:409-431.

Rogers, N.K. and Buchanan, G.A. (1986) *Influence of row spacing on weed competition with cotton*. Weed Science, 24: 410-414.

Rowland, J. and Whiteman, (1993) Principles of dry land farming. In: Rowland, J. (Ed.) Dryland farming in Africa. Pp. 68-92. Macvmillian Press limited, London.

Sahrawat, K.L. Jones, M.P. and Diatta, S. (2001) *Response of upland rice to fertilizer phosphorus and its residual value in an Ultisol*. Communications in Soil Science and Plant Analysis, 32:2457-2468.

Sanchez-Oliguin, E., Arrieta-Espinoza, G. and Espinoza-Esquivel, A.M. (2007) *Vegetative and reproductive development of Costa Rican weedy rice compared with commercial rice (Oryza sativa)*. Planta Daninha, Visosa-MG, 25 (1):13-23.

Sanni, K.A. Ojo, D.K., Adebisi, M.A., Somado, E.A., Ariyo, O.J., Sie, M., Akintayo, I. and Tia, D.D. Ogunbayo, S.A., Cissé,B. Sikirou, M. and Adekoya, M.A. (2009) *Ratooning potential of interspecific NERICA rice varieties (Oryza glaberrima x Oryza sativa)*. International Journal of Botany, 5 (1): 112-115.

Sariam, O. and Surjit, S. (1990) *Effect of time of second nitrogen application on rice yield and yield components*. Mardi Research Journal, 18: 29–35.

Scott, J.K. and Panetta, P.D. (1993) *Predicting the Australian weed status of southern African plants*. Journal of Biogeography, 20: 87-93.

Semagn, K., Ndijiondjop, M.N. and Cissoko, M. (2006) *Microsatellites and agronomic traits for assessing genetic relationships among 18 New Rice for Africa (NERICA) varieties*. African Journal of Biotechnology, 5 (10) 800-810.

Sharif, Z., (1994) Nitrogen fertilizer use efficiency in flooded rice soils. *In: Proceedings of the 4th National Congress of Soil Science*, May 24-26, 1992, Islamabad, pp: 141–147.

Sharma, M. and Mahajan, P. (2009) *Biodiversity conservation through invasive exotic plant management*. Proceedings of international conference on energy and environment March 19-22. ISSN: 2070-3740.

Sibuga, K.P. (1997) *Weed management in Eastern and Southern Africa: Challenges for the 21st century*. 16th East African Biennial Weed Science Conference Proceedings, 5-11.

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R. and Cocho, O. (2004) *The economic impacts of weeds in Australia* (CRC for Australian Weed Management, Adelaide).

Singh, V.P. (1994) *Correlation studies in rice*. Agricultural Science Digest, 14 (3-4): 185-188.

Singh, S.S., Singh, S.J. and Mishra, S.S. (1992) *Weed management in transplanted rice (Oryza sativa) under mid-land calcareous ecosystem*. Indian Journal of Agronomy, 37: 173-176.

Skerman, P.J. and Riveros, F. (1990) *Tropical Grasses*. Food and Agriculture Organization of the United Nations, Rome, 23-26.

Smith, C.S., Londsdale, W.M. and Fortune, J. (1999) *When to ignore advice: Invasions predictions and decision theory*. Biological Invasions, 1: 89-96.

Sombroek, W.G., Braun, H.M.H. and van der Pouw, B.J.A. (1982). *Exploratory Soil Map and Agro-Climatic Zone Map of Kenya*, 1980. Scale: 1:1'000'000. Exploratory Soil Survey Report No. E1. Kenya Soil Survey Ministry of Agriculture-National Agricultural Laboratories, Nairobi, Kenya.

Space, J. C., Waterhouse, B. M., Miles, J. E., Tiobech, J. and Rengulbai, K. (2003) *Report to the Republic of Palau on Invasive Plant Species of Environmental Concern*. U.S.D.A. Forest Service, Pacific Southwest Research Station, Institute of Pacific Islands Forestry, Honolulu. Spencer, R. 1995-2002. Horticultural Flora of South-Eastern Australia, vol. 1-4. University of New South Wales Press, Sydney, 13-18.

Steel, R.G.D., Torrie, J.H. and Dicke, D.A. (1997) *Principles and procedures of statistics. A biometrical approach*. 3rd ed. McGraw-Hill Inc. New York, pp 193-194.

Steel, R.G.D. and Torrie, J.H. (1980) *Principles and Procedures of Statistics.* McGraw-Hill Book Co. Inc., New York, pp 124-156.

Su, Z.F., Zhang, J. and Wang, H.B. (1996). *On the relationship between developmental trend of tiller and formation of yield in rice population*. Proceedings of the 5th National Conference on Theories and Practice of Rice Production, New Theory and Practice for High Yield and High Profit Rice Production, (TPRP'96), China Agricultural Science and Technology Press, Beijing, pp 25-31.

Summerfield, R. J., Ellis, R.H., Craufurd P.Q., Aiming, Q., Roberts, E.H. and Wheeler, T.R. (1997) *Environmental and genetic regulation of flowering of tropical annual crops*. Euphytica, 96: 83-91.

Sun, Y.F., Liang, J.M., Ye, J., Zhhu, W.Y. (1999) *Cultivation of super-high yielding rice plants*. China Rice, 5: 38-39.

Sutaryo, B. and Supriharto, B. (1993) *Ratoon crop performance in some rice hybrids*. International Rice Research Institute. Los Banos, Philippines.

Swanton, C.J. and Weise, S.F. (1991) *Intergrated weed management. The rational and approach*. Weed Technology, 5: 657-663.

Szokolay, G. (1956) *Ratooning of rice on the Swaziland Irrigation scheme*. World Crops, 8 (2): 71-73.

Takahashi, N. (1984) *Seed germination and seedling growth*. Chapter 3, In, Tsunoda, S. and Takahashi, N. (eds) *Biology of Rice*, 7: 71-88.

Tanaka, A., Kawano, K. and Yamaguchi, J. (1966) *Photosynthesis, respiration and plant type of the tropical rice plant.* IRRI, Los Banos, Laguna, Philippines, pp 5-7.

Tanner, D.G. and Sahile. G. (1991). *Weed control research conducted on wheat in Ethiopia*. In Wheat Research in Ethiopia: A Historical Perspective. Institute of Agricultural Research and International Maize and Wheat Improvement Center.

Tari, D.B. (2011) *Effect of harvesting time and plant residual on agronomic traits of rice ratoon*. American-Eurasian Journal of Agricultural and Environmental Science, 11 (1): 129-132.

Tateoka, T. (1964*) Notes on some grasses. XVI. Embryo structure of the genus Oryza in relation to their systematic*. American Journal of Botany, 51: 539-543.

Terry P.J. (1996) *The use of herbicides in the agriculture of developing countries*. Second International Weed Control Congress, 601-609.

Thakur, D.S. and Patel, S.R. (1998) *Growth and sink potential of rice as influenced by the split application of potassium with FYM in ceptisols of eastern central India*. Journal of Potassium Research, 14 (1/4): 73-77.

The Presidential/Congressional Commission on Risk Assessment and Risk Management, (1997) *Risk Assessment and Risk Management in Regulatory Decision-making*. Washington, DC.

Thompson, G. A., Hiatt, W. R., Facciotti, D., Stalker, D. M. and Comai, L. (1987). *Expression in plants of a bacterial gene coding for glyphosate resistance*. Weed Science, 35: 19 -23.

Thuiller, W., Richardson, D.M., Pyseks, P., Midgley, G., Hughes, G. and Rouget, M. (2005) *Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale*. Global Change Biology, 11:2234-2250.

Toure, A., Sogbedji, J. M. and Gumedzoe, Y.M.D. (2013) *The critical period of weed interference in upland rice in nortern Guinea savanna: Field measurement and model prediction.* African Journal of Agricultural Research, 8 (17): 1748-1759.

Toure, A., Rodenburg, J., Saito, K., Oikeh, S., Futakuchi, K., Gumedzoe, D. and Haut, J. (2011) *Cultivar and weeding effects on weeds in rice yields in a degraded upland environment of the coastal savanna.* Weed Technology, 25:322-329.

Traynor, P. and Macharia, H.K. (2003) *Analysis for biosafety system for biotechnology in Kenya: Application of a conceptual framework*. ISNAR Country Report 6. The Hague, the Netherlands: International Service for National Agricultural Research. 5-7.

Tucker, K.C. and Richardson, D.M. (1995) *An expert system for screening potentially invasive alien plants in South African fybos*. Journal of Environmental Management, 44: 309-338.

Tursun, N., Bukun, B., Karacan, S.C. Ngouajio, M. and Mennan, H. (2007) *Critical period of weed control in leek (Allium porrum L.)*. HortScience, 42(1): 106-107.

University of Philippines (1970) *Rice production manual.* International Rice Rresearch Institute. Philippines, (Mimeo).

Usman, A., Adagba, M.A., Kehind, J.K., Ukwungwu, M.N. and Ogunshola, T. (2001) *Weed in rice*. In: WARDA (2003), pp 75-79.

Vange, T. and Obi, I.U. (2006) *Effect of planting date on some agronomic traits and grain yield of Upland rice varieties at Makurdi, Benue state, Nigeria.* Journal of Sustainable Development in Agriculture and Environment, 2 (1): 40-45.

Vaughan, D.A (1994) *The wild relatives of rice*. A genetic resource handbook. Internata Rice Research Institute. Los Banos, Philippines, 1-20pp.

Vaughan, D.A. and Morishima, H. (2003) Biosystematics of the genus Oryza. Chapter 1.2. In: Smith C.W., Dilday, R.H. eds. *Rice. Origin, History, Technology and Production*. John Wiley and Sons Inc., Hoboken, New Jeysey. Pp 27-65.

Van Acker, R.C., C.J. Swanton, and S. Weise. 1993. *The critical period of weed control in soybean (Glycine max (L.) Merr.)*. Weed Science, 41:194–200.

Veasey, E.A., Karasawa, P.P., Santos, M.S., Rosa, E. Mamani, E. and Oliveira, C.X. (2004) *Variation in the loss of seed dormancy during after- ripening of wild and cultivated rice species.* Annals of Botany, 6:94-96.

Vries, J. and Toenniessen, G. (2001) *Securing the harvest*. *Biotechnology breeding and seed systems for Africa crops*. CAB international, New York, pp 134.

Walton, C. and Parnell, T. (1996) *Weeds as quarantine pests.* 11th Australian Weeds Conference Proceedings. Shepard, R.C.H., ed. Weed Science Society of Victoria Inc., Frankston, Australia. pp 462-463.

Wanjogu, R. K., Mugambi, G., Adoli, H.L., Shisanya, S.O. and Tamura, M. (1995) *Mwea Rice Production Manual*. Mwea Irrigation Agricultural Development Project.

Wanjogu, R. K. and Mugambi, G. (2001) *Rice Research in Kenya. Improvement of rice production in eastern and southern Africa region through research*. Proceeding of workshop in rice research in Kenya, Malawi, Zambia and Tanzania. Moshi, Tanzania, pp 15-23.

Wanyonyi, M. and Akuno, W. (1997) *Participatory evaluation of rice varieties for waterlogged areas of Weonia, Trans-Nzioa district, North Rift Region.*

WARDA, (1999) *Rice interspecific hybridization project*. Research highlights 1999. Africa/ Asia Joint Research on Interspecific Hybridization between African and Asian Rice Species *Oryza glaberrima* Steud and *Oryza sativa* L.

WARDA, (2001) *Annual Report* 2001-2, Features.

Watson, D.J. (1952) *The physiological basis of variation in yield*. Advanced Agronomy, 14:101-104.

Weaver, S.E. and Tan, C.S. (1983) *Critical period of weed interference in transplanted tomatoes (Lycopersicon esculentum): growth analysis*. Weed Science, 31: 322-329.

Web, B.D., Bollich, C.N. and Scott, J.E. (2002) *Comparative quality characteristics of rice from first and ratoon crops*. Texas Agriculture Experiment Progress Report, 3324c. 12.

Weber, E. and Gut, D. (2004) *Assessing the risk of potentially invasive plant species in Central Europe*. Journal of Nature Conservation, 12: 171-179.

Wilcove, D.S., Rothstein, D. Dubow, J., Phillips, A. and Losos, E. (1998) *Quantifying threats to imperiled species in the United States*. Bioscience, 48: 607-615.

Williams, P.A. (1997) *Ecology and management of invasive weeds*. Conservation Sciences Publication No. 7. Wellington, Department of Conservation, pp 67.

Williams, P.A. (2000) *Guidelines for weed-risk assessment in developing countries*. FAO Corporate Document Repository.

Williams, P.A., Wilton, A. and Spencer, N. (2002) *A proposed conservation weed risk assessment system for the New Zealand borders*. Department of Conservation, Wellington.

Williamson, M. (1998) *Measuring the impact of plant invaders in Britain*. Pp 57-68 in Starfinger, U., Edwards, K., Kowarik, I., Williamson, M. (Eds): Plant invasions: ecological mechanisms and human responses. Backhuys Publishers, Leiden.

Williamson, M. (1999) *Invasions*. Ecography, 22: 5-12.

Windrlechner, M.P., Thompson, J.R., Iles, J.K. and Dixon, P.M. (2004) *Models for predicting the risk of naturalization of non-native woody plants in Iowa*. Journal of Environmental Horticulture, 22: 23-31.

WTO (1994) *Agreement on the application of sanitary and phytosanitary measures.* World Trade Organization, Uruguay Round of Multinational Trade Negotiations. New York, World Trade Organization.

Yoshida, S. and Hayakawa, Y. (1970) *Effects of mineral nutrition on tillering of rice*. Soil Science and Plant Nutrition, 16: 186-191.

Yoshida, S. (1972) *Physiological aspects of grain yield*. Annual Review of Plant Physiology, 23: 437-464.

Yoshida, S. and Parao, F.T. (1976) *Climatic influence on yield and yield component of lowland rice in the Tropics.* In: International Rice Research Institute. Climate and Rice Los Barrios, Philippines, pp 471-494.

Yoshida, S. (1981) *Fundamental of Rice Crop Science*. IRRI-Manila, Philippines.

Zafar N, Aziz S, Masod S. (2004) *Phenotypic divergence for agro-morphological traits among landrace genotypes of rice (Oryza sativa L.) from Pakistan.* International Journal of Agriculture and Biology, 2: 335–339.

Zandstra, H.G. and Samson, B.T. (1979) *Rice ratoon management*. Paper presented at the International Rice Research Conference, 17-21 April 10 p.

Zhong, X., Peng, S., Sheehy, J.E., Visperas, R.M. and Liu, H. (2002) *Relationship between tillering and leaf area index: quantifying critical leaf area index for tillering in rice*. Journal of Agricultural Science, 138: 269-279.

APPENDICES

Appendix 1.1: The 18 upland NERICA rice varieties with their pedigree (After Semagn *et al*., 2006)

Rice variety	Pedigree	Backcross
NERICA 1	WAB 450-1-B-P-38-HB	WAB 56-104/CG 14//WAB56-104
NERICA 2	WAB 450-11-1-P31-1-HB	WAB 56-104/CG 14//WAB56-104
NERICA 3	WAB 450-1-B-P-28-HB	WAB 56-104/CG 14//WAB56-104
NERICA 4	WAB 450-1-B-P-91-HB	WAB 56-104/CG 14//WAB56-104
NERICA 5	WAB 450-11-1-1-P31-HB	WAB 56-104/CG 14//WAB56-104
NERICA 6	WAB 450-1-B-P-160-HB	WAB 56-104/CG 14//WAB56-104
NERICA 7	WAB 450-1-B-P-20-HB	WAB 56-104/CG 14//WAB56-104
NERICA 8	WAB 450-1-BL1-136-HB	WAB 56-104/CG 14//WAB56-104
NERICA 9	WAB 450-B-136-HB	WAB 56-104/CG 14//WAB56-104
NERICA 10	WAB 450-11-1-1-P41-HB	WAB 56-104/CG 14//WAB56-104
NERICA 11	WAB 450-16-2-BL2-DV1	WAB 56-104/CG 14//WAB56-104
NERICA 12	WAB 880-1-38-20-17-P1-HB	WAB 56-50/CG 14//WAB56-50
NERICA 13	WAB 880-1-38-20-28-P1-HB	WAB 56-50/CG 14//WAB56-50
NERICA 14	WAB 880-1-32-1-2-P1-HB	WAB 56-50/CG 14//WAB56-50
NERICA 15	WAB 881-10-37-18-3-P1-HB	CG 14/WAB 181-18//WAB 181-18
NERICA 16	WAB 881-10-37-18-9-P1-HB	CG 14/WAB 181-18//WAB 181-18
NERICA 17	WAB 881-10-37-18-13-P1-HB	CG 14/WAB 181-18//WAB 181-18
NERICA 18	WAB 881-10-37-18-12-P3-HB	CG 14/WAB 181-18//WAB 181-18

Appendix 3.1: Upland rice seeds used in the study (Photo by Author)

Appendix 3.2: Selection of upland rice seeds by water floating method (Photo by Author)

Appendix 3.3: Weeds identification by use of quadrant at the study site
(Photo by Author)

Appendix 3.4: Harvesting NERICA rice by hand cutting using sickle knives
(Photo by Author)

Appendix 3.5: Threshing NERICA rice by hand beating on large stone

Appendix 3.6: Winnowing NERICA rice (Photo by Author)

Appendix 3.7a: Weed species found at study site one of the current study

Weed species	**Family**	**Weed type**	**Life span[1]**
Abutilon mauritianum (Jacq.) Sweet	Malvaceae	Broadleaf	P
Acalypha indica L.	Euphorbiacea	Broadleaf	P
Alysicarpus rugosus (Willd.) DC. ssp.rugosus	Leguminosae	Broadleaf	A
Ajuga remota Benth.	Labiatae	Broadleaf	A
Asystasia schimperi T. Anderson	Acanthaceae	Broadleaf	A
Amaranthus hybridus L.	Amaranthaceae	Broadleaf	A
*Basilicum polystachion (*L.) Moench	Labiatae	Broadleaf	P
Brachiara eruciformis (Sm.) Griseb	Poaceae	Grass	A
Brachiara leucacrantha (K. Schum.) Stapf	Poaceae	Grass	A
Branchiara serrata (Thunb.) Stapf	Poaceae	Grass	P
Bidens pilosa L.	Compositae	Broadleaf	A
Cardiospermum halicacabum L.	Sapindeceae	Broadleaf	A
Cleome monophylla L.	Capparaceae	Broadleaf	A
Commelina benghalensis Wall	Commelinaceae	Broadleaf	A/P
Conyza sumatrensis (Retz.) E. Walker	Compositae	Broadleaf	A
Corchorus trilocularis L.	Tiliaceae	Broadleaf	A
Cyperus rigidifolius Steud.	Cyperaceae	Sedge	P
Cyperus compressus L.	Cyperaceae	Sedge	P
Desmondium ramosissimum G. Don	Leguminosae	Broadleaf	A
Euphorbia geniculata Orgeg	Euphorbiacea	Broadleaf	A/P
Euphorbia granulate Forssk.	Euphorbiaceae	Broadleaf	P
Euphorbia hirta L.	Euphorbiaceae	Broadleaf	A
Erucastrum arabicum Fisch. & C.A. Mey.	Cruciferae	Broadleaf	A
Glycine wightii (Wight & Am.)	Leguminosae	Broadleaf	A
Hibiscus palmatus Forssk.	Malvaceae	Broadleaf	A
Indigofera ambelacensis Schweinf.	Leguminosae	Broadleaf	P
Indigofera arrecta A. Rich.	Leguminosae	Broadleaf	P
Indigofera brevicalyx Bak	Leguminosae	Broadleaf	P
Indigofera spinosa Forssk.	Leguminosae	Broadleaf	P
Ipomoea coscinosperma Choisy	Convolvulaceae	Broadleaf	A
Ipomea mombassana Vatke	Convolvulaceae	Broadleaf	A
Ipomoea wightii (Wall) Choisy	Convolvulaceae	Broadleaf	A
Ludwigia stolonifera (Gull & Per. Raven)	Onagraceae	Broadleaf	P
Oxygonum sinuatum (Meisri.) Dammer	Polygonaceae	Broadleaf	A
Pavonia patens (Andr.) Chiov.	Malvaceae	Broadleaf	A/P
Portulaca oleracea L.	Portulacaceae	Broadleaf	P
Phyllanthus amarus Schumach. & Thonn.	Euphorbiaceae	Broadleaf	A/P
Physalis angulata L.	Solanaceae	Broadleaf	A
Physalis minima L.	Solanaceae	Broadleaf	A
Sida ovata Forssk	Malvaceae	Broadleaf	P
*Sorghum verticilliflorum (*Steud.) Stapf.	Poaceae	Grass	A
Sonchus asper (L.) Hill	Compositae	Broadleaf	A

Sesbania sesban (L.) Merr.	Leguminosae	Broadleaf	A/P
Xanthium pungens Wallroth	Compositae	Broadleaf	A

[1]A = Annual weeds, P = Perennial weeds, A/P = Annual and Perennial weeds

Appendix 3.7b: Weed species found at site two of the current study

Weed species	**Family**	**Weed type**	**Life span**[1]
Abutilon mauritanum (Jacq.) Sweet	Malvaceae	Broadleaf	P
Acalypha indica L.	Euphorbiaceae	Broadleaf	P
Ajuga remota Benth.	Labiatae	Broadleaf	A
Alyscicarpus glumaceus (Vahl) DC.	Leguminosae	Broadleaf	A
Alternanthera sessilis (L.) DC	Amaranthaceae	Broadleaf	A
Ageratum conyzoides L.	Compositae	Broadleaf	A
Amaranthus hybridus L.	Amaranthaceae	Broadleaf	A
*Basilicum polystachion (*L.) Moench	Labiatae	Broadleaf	P
Brachiara eruciformis (Sm.) Griseb	Gramineae	Grass	A
Brachiara leucarcrantha (K. Schum.) Stapf	Gramineae	Grass	A
Celosia anthelminthica Asch.	Amaranthaceae	Broadleaf	A
Celosia argentea L.	Amaranthaceae	Broadleaf	A
Celosia schweinfurthiana Schinz	Amaranthaceae	Broadleaf	A
Cleome monophylla L.	Capparaceae	Broadleaf	A
Commelina benghalensis Wall	Commelinaceae	Broadleaf	A/P
Corchorus trilocularis L.	Tiliaceae	Broadleaf	A
Crotalaria spinosa Benth.	Leguminosae	Broadleaf	P
Cyperus exaltatus Retz	Cyperaceae	Sedge	P
Cyperus difformis L.	Cyperaceae	Sedge	P
Cyperus rigidifolius Steud.	Cyperaceae	Sedge	P
Conyza sumatrensis (Retz.) E. Walker	Compositae	Broadleaf	A/P
Datura metel L.	Solanaceae	Broadleaf	A
Dinebra retroflexa (Vahl) Panz. Var. retroflexa	Gramineae	Grass	A
Echinochloae colona (L) Link	Gramineae	Grass	A/P
Eclipta prostata (L.) L	Compositae	Broadleaf	A
Erucastrum arabicum Fisch. & C.A. Mey.	Cruciferae	Broadleaf	A
Euphorbia hirta L.	Euphorbiaceae	Broadleaf	A
Euphorbia prostrata Aiton	Euphorbiaceae	Broadleaf	A
Euphorbia inaequilatera Sond.	Euphorbiaceae	Broadleaf	P
Euphorbia geniculata L.	Euphorbiaceae	Broadleaf	A
Ipomoea coscinosperma Choisy	Convolvulaceae	Broadleaf	A
Hibiscus trionum L.	Malvaceae	Broadleaf	A/P
Hibiscus cannabinus L.	Malvaceae	Broadleaf	A
Nicandra physaloides Gaertn	Solanaceae	Broadleaf	A
Portulaca oleracea L.	Portulacaceae	Broadleaf	P
Phyllanthus amarus Schumach. & Thonn.	Euphorbiaceae	Broadleaf	A
Physalis peruviana L.	Solanaceae	Broadleaf	A
Rottboellia cochinchinensis (Lour.) Clayton	Gramineae	Grass	A/P
Rhynchosia minima (L.) DC. var minima	Leguminosae	Broadleaf	A
Sesbania sesban (L.) Merr.	Leguminosae	Broadleaf	A/P
Sida ovata Forssk	Malvaceae	Broadleaf	P
Sonchus asper (L.) Hill	Compositae	Broadleaf	A
Sonchus oleraceus L.	Compositae	Broadleaf	A
Sphaeranthus bullatus Mattf.	Compositae	Broadleaf	A/P
Sphaeranthus suaveolens (Forssk) DC.	Compositae	Broadleaf	P
*Sorghum verticilliflorum (*Steud.) Stapf.	Gramineae	Grass	A
Vigna schimperi Bak.	Leguminosae	Broadleaf	A
Xanthium pungens Wallroth	Compositae	Broadleaf	A

[1]A = Annual weeds, P = Perennial weeds, A/P = Annual and Perennial weeds

Appendix 3.8: Correlation coefficients **(**r**)** for Grain yield (GY), percentage filled spikelets (% FS), Productive tillers (PTi), Plant height (PH), Leaf area index (LAI), Tillering (Ti) and Panicle number (PN) for upland rice varieties from the main crop

GY	1						
%FP	0.350***	1					
PTi	0.586***	0.412***	1				
PH	-0.053ns	-0.213**	-0.362***	1			
LAI	-0.238**	-0.154ns	-0.190**	-0.176**	1		
Ti	0.601***	0.368***	0.800***	-0.291***	-0.061ns	1	
PN	0.521***	0.145ns	0.524***	0.272***	-0.313**	0.440***	1
	GY	**%FP**	**PTi**	**PH**	**LAI**	**Ti**	**PN**

, *, ns: Significant at p<0.05, p<0.001 and non-significant respectively.

Appendix 3.9: Correlation coefficients **(**r**)** for Grain yield (GY), percentage filled spikelets (% FS), Productive tillers (PTi), Plant height (PH), Leaf area index (LAI), Tillering (Ti) and Panicle number (PN) for upland rice varieties from the ratoon crop

GY	1						
%FP	0.274***	1					
PTi	0.528***	0.132ns	1				
PH	0.172ns	0.401***	-0.175**	1			
LAI	-0.091ns	0.042ns	-0.101ns	0.059ns	1		
Ti	0.487***	0.341***	0.766***	0.296***	-0.041ns	1	
PN	0.133ns	0.291***	0.182**	0.437***	0.017ns	0.509***	1
	GY	**%FP**	**PTi**	**PH**	**LAI**	**Ti**	**PN**

, *, ns: Significant at p<0.05, p<0.001 and non-significant respectively.

Appendix 4.1: Stubble of NERICA rice crop after harvesting the main crop (Photo by Author)

Appendix 4.2: ANOVA table for grain yield (Kg ha^{-1}) for main crops one and two combined.

Source of variation	d.f.	sum of squares	mean square	F	p
Block	2	5492176	2746088	5.83	
Trt	9	54762557	6084729	12.92	0.001***
Residual	18	24743985	1374666		
Variety	4	62334580	15583645	33.08	0.001***
Trt.Variety	36	23560955	654471	1.39	0.113ns
Residual	80	37681562	471020		
Total	149	208575815			

***, ns: Significant at $p<0.001$ and non-significant respectively.

Appendix 4.3: ANOVA table for grain yield (Kg ha^{-1}) for ratoon crops one and two combined.

Source of variation	d.f.	sum of squares	mean square	F	p
Block	2	3392302	1696151	18.65	
Trt	9	1904509	211612	2.33	0.022**
Residual	18	2883341	160186		
Variety	4	5633397	1408349	15.48	0.001***
Trt.Variety	36	2684432	74568	0.82	0.743ns
Residual	80	7276046	90951		
Total	149	23774027			

, *, ns: Significant at p<0.05, p<0.001 and non-significant respectively.

Appendix 4.4: ANOVA table for grain yield (Kg ha^{-1}) for total (main + ratoon).

Source of variation	d.f.	sum of squares	mean square	F	p
Block	2	5575714	2787857	3.94	
Trt	9	72592071	8065786	11.41	0.001***
Variety	4	101758954	25439739	35.98	0.001***
Trt.Variety	36	28786813	799634	1.13	0.312ns
Residual	98	69288851	707029		
Total	149	278002404			

***, ns: Significant at p<0.001 and non-significant respectively.

Appendix 4.5: ANOVA table for ratooning ability of the upland rice varieties

Source of variation	d.f.	sum of squares	mean square	F	p
Block	2	8214.4	4107.2	9.61	
Trt	9	7330.5	814.5	1.91	0.06ns
Variety	4	11778.1	2944.5	6.89	0.001***
Trt.Variety	36	9612.6	267	0.62	0.944ns
Residual	98	41893.4	427.5		
Total	149	78829.1			

***, ns: Significant at p<0.001 and non-significant respectively.

Appendix 6.1: Weed Risk Assessment question sheet

	Botanical ame:			Outcome:	
	Common name:			Score:	
	Family name:			Assessor:	
			History		
A	1 *Domestication/ cultivation*	1.01	Is the species highly domesticated? If answer is ‘no’ go to question 2.01		
C		1.02	Has the species become naturalised where grown		
C		1.03	Does the species have weedy races		
			Biogeography		
	2 *Climate and distribution*	2.01	Species suited to Kenyan climates (0-low; 1-intermediate; 2-high)		2
		2.02	Quality of climate match data (0-low; 1-intermediate; 2-high)		2
C		2.03	Broad climate suitability (environmental versatility)		
C		2.04	Native or naturalized in regions with tropical or sub-tropical climates		
		2.05	Does the species have a history of repeated introductions outside its natural range		
C	3 *Weed elsewhere*	3.01	Naturalised beyond native range		
E		3.02	Garden/amenity/disturbance weed		
A		3.03	Weed of agriculture/horticulture/forestry		
E		3.04	Environmental weed		
		3.05	Congeneric weed		
			Biology/Ecology		
A	4 *Undesirable traits*	4.01	Produces spines, thorns or burrs		
C		4.02	Allelopathic		
C		4.03	Parasitic		
A		4.04	Unpalatable to grazing animals		
C		4.05	Toxic to animals		
C		4.06	Host for recognised pests and pathogens		
C		4.07	Causes allergies or is otherwise toxic to humans		
E		4.08	Creates a fire hazard in natural ecosystems		
E		4.09	Is a shade tolerant plant at some stage of its life cycle		
E		4.10	Grows on a wide range of soil conditions?		
E		4.11	Climbing or smothering growth habit		
E		4.12	Forms dense thickets		
E	5 *Plant type*	5.01	Aquatic		
C		5.02	Grass		
E		5.03	Nitrogen fixing woody plant		
C		5.04	Geophyte		

C	6 *Reproduction*	6.01	Evidence of substantial reproductive failure in native habitat	
C		6.02	Produces viable seed	
C		6.03	Hybridises naturally	
C		6.04	Self-fertilisation	
C		6.05	Requires specialist pollinators	
C		6.06	Reproduction by vegetative propagation	
C		6.07	Minimum generative time (years)	1
A	7 *Dispersal mechanisms*	7.01	Propagules likely to be dispersed unintentionally	
C		7.02	Propagules dispersed intentionally by people	
A		7.03	Propagules likely to disperse as a produce contaminant	
C		7.04	Propagules adapted to wind dispersal	
E		7.05	Propagules buoyant	
E		7.06	Propagules bird dispersed	
C		7.07	Propagules dispersed by other animals (externally)	
C		7.08	Propagules dispersed by other animals (internally)	
C	8 *Persistence attributes*	8.01	Prolific seed production	
A		8.02	Evidence that a persistent propagule bank is formed (>1 yr)	
A		8.03	Well controlled by herbicides	
C		8.04	Tolerates or benefits from mutilation, cultivation or fire	
E		8.05	Effective natural enemies present in Kenya	

A= Aagricultural, E = Environmental, C= Combined

Appendix 6.2: Sample questionnaire used in the survey

Questionnaire on invasiveness of New Rice for Africa (NERICA) rice varieties

INSTRUCTIONS

This questionnaire is designed to gather general information on ***the potential invasiveness of New Rice for Africa (NERICA) rice varieties***. Four NERICA varieties i.e. NERICA-1, NERICA-4, NERICA-10 and NERICA-11 will be assessed. The data collected will be used for purposes of this research only. Do not write your name anywhere on this questionnaire to ensure complete confidentiality. Please read each question carefully and tick (√) the answer that best reflects your opinion. Fill in your comments or suggestions in the spaces provided. Fill in one questionnaire for each rice variety. Kindly respond to all questions.

RICE VARIETY: NERICA-1

PRELIMINARY

(i) Gender: ☐ Male ☐ Female

(ii) Age (in years): ☐ Below 20 ☐ 21-40 ☐ 41-60 ☐ Above 60

(iii) Occupation: ☐ Farmer ☐ Researcher ☐ Teacher/Lecturer
☐ Horticulturalist ☐ Agriculturalist ☐ Student ☐ Extension officer
☐ Other (Please specify)………………………………………………………

HISTORY/BIOGEOGRAPHY

1.0 Domestication/Cultivation

1.01 Are you aware of NERICA? ☐ Yes ☐ No ☐ Somehow

1.02 (a) Do you cultivate NERICA-1 ☐ Yes ☐ No

1.02(b) If yes to (a) above, how long have you cultivated the variety?

☐ Less than 5yrs ☐ 5-10yrs ☐ 10-15yrs ☐ 15-20yrs

1.02(c) Where did you get the first planting material of this variety from?

☐ National Irrigation Board (NIB) ☐ Gene bank ☐ other farmers
☐ Other (Please specify)……………………………………………………..………

1.03 Does the variety grow naturally without human input?

☐ Yes ☐ No ☐ I don’t know

1.04 (a) Does the variety have weedy races?

☐ Yes ☐ No ☐ I don't know

(b) If yes, name some………………………………………………………………

2.0 Climate and Distribution

2.01 How do you rate the suitability of the variety to Kenyan Climate?

☐ Low ☐ Intermediate ☐ High

2.02 To which of the following climates is the variety adapted? (Tick more than one as applicable)

☐ Tropical ☐ Sub-tropical ☐ Warm temperate (Mediterranean)

☐ Cold temperate ☐ Arid

☐ Other (Please specify)………………………………………………………………

2.03 (a) Is the variety found to grow in a wide range of climate types?

☐ Yes ☐ No ☐ I don't know

(b) If yes to (a) above, please name some ……………………………………………

2.04 Is the variety native or naturalized in regions with tropical or sub-tropical climates?

☐ Yes ☐ No ☐ I don,t know

2.05 Does the variety have a history of repeated introductions outside its natural range?

☐ Yes ☐ No ☐ I don't know

3.0 Weed Elsewhere

3.01 Does the variety occur and reproduce naturally outside the cultivated fields?

☐ Yes ☐ No ☐ I don't know

3.02 Apart from the cultivated fields, where else would you find the variety? (Tick more than one as applicable) ☐ Other gardens ☐ Parklands ☐ Road side

☐ Quaries ☐ Fallow lands ☐ Others (Please specify)………………………

3.03 (a) Does the variety occur in the following areas?

Area	Response		
	Yes	No	I don't know
Forests			
Flower farms			
Agricultural fields			

(b) If yes to (a) above, does it cause productivity/yield loss to the crops where found?

Area	Response		
	Yes	No	I don't know
Forests			
Flower farms			
Agricultural fields			

3.04 (a) Is the variety known to affect the normal activity of a natural ecosystem e.g. affect biomass, growth, reproduction etc)? ☐ Yes ☐ No ☐ I don't know

(b) If yes to (a) above, please explain………………………………………………………

3.05 (a) Do you know of any other species or variety within the genus *Oryza* that have been documented as weeds or wild rice i.e. uncultivated rice? (Congeneric weeds). ☐ Yes ☐ No ☐ Not sure

(b) If yes to (a) above please name some;

(i)……………………………………………………………………

(ii)…………………………………………………………………..

(iii)………………………………………………………………….

BIOLOGY/ECOLOGY

4.0 Undesirable traits

4.01 Does the variety produce the following?

Structure	Response		
	Yes	No	Not sure
Thorns			
Spines			
Burrs			
Bad smell			

4.02 (a) Is the variety known to suppress the growth of other species?

☐ Yes No ☐ Not sure ☐

(b) If yes to (a) above, by what means? (Tick more than one as applicable)

☐ Chemical e.g. hormonal ☐ Excessive tiller production

☐ Excessive stem height

4.03 (a) Is the variety known to be parasitic?

☐ Yes ☐ No ☐ Not sure

(b) If yes to (a) above, state the hosts and effects on the host?

Host name	**Effect on the host**

4.04 (a) (i) Do herbivores feed on the variety?

☐ Yes ☐ No ☐ Not sure

(ii) If yes to (a) (i) above, which animals? (Tick more than one as applicable).

☐ Birds ☐ Wild animals ☐ Domestic animals

(b) (i) Is the variety unpalatable to grazing animals at any stage in its life cycle?

☐ Yes ☐ No ☐ Not sure

(ii) If yes to (b) (i) above, at what stage? (Tick more than one as applicable)

☐ Seedling ☐ Reproductive ☐ Ripening ☐ Maturity

4.05 Is the variety known to be toxic to animals?

☐ Yes ☐ No ☐ Not sure

4.06 (a) (i) Is the variety a host of any pests?

☐ Yes ☐ No ☐ Not sure

(ii) If yes to (a) (i) above, which pests?

☐ Weeds ☐ insects ☐ rodents ☐ birds

☐ Other (Please specify)…..……………………………………………

(b) (i) Is the variety attacked by any pathogens?

☐ Yes ☐ No ☐ Not sure

(ii) If yes to (b) (i) above, which pathogens? (Tick more than one as applicable).

☐ Bacterial ☐ Viral ☐ Fungal

4.07 (a) Does the variety cause allergies to humans?

☐ Yes ☐ No ☐ Not sure

(b) Is the variety toxic to humans? ☐ Yes ☐ No ☐ Not sure

(c) If yes to (a) or/and (b) above, what is the mode of transmission? (Tick more than one as applicable)

Transmission mode	Harm	
	Allergy	**Toxin**
Physical contact		
Inhalation of pollen from the variety		
Ingestion		
Injection		
Other (Please specify)		

4.08 (a) Is the variety likely to create a fire hazard in the natural ecosystem?

☐ Yes ☐ No ☐ Not sure

(b) If yes to (a) above, by what method? (Tick more than one as applicable)

☐ Accumulation of dry matter ☐ Standing dry plant material

☐ Post harvest material accumulation

(c) At what stage is the variety likely to create the highest fire hazard?

☐ Seedling ☐ Reproductive ☐ Ripening ☐ Maturity

☐ After harvesting

4.09 (a) Does the variety tolerate shade at any stage in it's life cycle?

☐ Yes ☐ No ☐ Not sure

(b) If yes to (a) above, at what stage?

☐ Seedling ☐ Reproductive ☐ Ripening ☐ Maturity

4.10 (a) In which soils does the variety grow? (Tick more than one as applicable)

☐ Loam ☐ Clay ☐ Sandy

☐ Other (Please specify)..

4.11 Does the variety show any climbing growth habit?

☐ Yes ☐ No ☐ Not sure

4.12 Does the growth of the variety form dense thickets that exclude other plant varieties? ☐ Yes ☐ No ☐ Not sure

5.0 PLANT TYPE

5.01 Does the variety grow on the following water bodies? (Tick more than one as applicable)

Water body	Response		
	Yes	No	Not sure
River			
Lakes			
Ponds			

5.02 To which family does the variety belong?

☐ Poaceae ☐ Leguminosae ☐ Cyperaceae

5.03 Is the variety a nitrogen fixing woody plant?

☐ Yes ☐ No ☐ Not sure

5.04 Does the variety produce any of the following structures? (Geophyte) (Tick more than one as applicable)

Structure	Response		
	Yes	No	Not sure
Tubers			
Corms			
Bulbs			

6.0 REPRODUCTION

6.01 (a) Are the following factors known to affect the yield of the variety?

	Response		
Factor	Yes	No	I don't Know
Predators			
Pests			
Diseases			
Drought			
Cold weather			

(b) If none of the above, please give suggestions on what could affect the yield of this variety?………………………………………………………….……………….

6.02(a) Does the variety produce viable seeds?

☐ Yes ☐ No ☐ Not sure

(b) If yes to (a) above, can the variety produce more than 2,000 viable seeds per square metre under natural conditions?

☐ Yes ☐ No ☐ Not sure

6.03 (a) Does the variety hybridize naturally?

☐ Yes ☐ No ☐ Not sure

(b) If yes to (a) above, with which varieties or species?

……………………………………………………………………………………

6.04 Is the variety capable of self-fertilization?

☐ Yes ☐ No ☐ Not sure

6.05 What is the pollinating agent of the variety? (Tick more than one as applicable).

Pollination agent	**Response**		
	Yes	No	Not sure
Wind			
Animals			
Birds			
Self			
Water			
Insects			

6.06 Through which of the following structures does the variety propagate? (Tick more than one as applicable).

Propagation mode	**Response**		
	Yes	No	Not sure
Rhizomes			
Stolons			
Root fragments			
Suckers			
Division			
Cuttings			
Seeds			

6.07 How long (in years), does the variety take to complete a cycle (germination to seed production)?

☐ 1 year ☐ 2-3 yrs ☐ 4-5yrs ☐ More than 5yrs

7.0 DISPERSAL MECHANISM

7.01 Are the propagules (any structure, sexual or asexual, which serve as a means of reproduction) able to grow on disturbed areas (e.g roadsides, farm paddocks)?

☐ Yes ☐ No ☐ Not sure

7.02 Does the variety have desirable properties, e.g. edible fruit, attractive flowers, sweet scent etc that would make people intentionally disperse it?

☐ Yes ☐ No ☐ Not sure

7.03 Are the propagules likely to disperse as contaminants of produce? (Produce is the economic output from any agricultural, forestry or horticultural activity).

☐ Yes ☐ No ☐ Not sure

7.04 Are the propagules adapted to wind dispersal e.g. seeds contained within an explosive capsule or pod?

☐ Yes ☐ No ☐ Not sure

7.05 Does the variety have structures e.g. seeds, pods, flowers etc that easily detach from the plant and can float over water?

☐ Yes ☐ No ☐ Not sure

7.06 (a) Does the variety have propagules that can be consumed by birds?

☐ Yes ☐ No ☐ Not sure

(b) (i) If yes to (a) above which of the following propagules (Tick more than one, as applicable)

Propagule	
Seeds	
Fruits	
Seed pods	
Flowers	
Other (Please specify)	

(ii) Would the propagules in b (i) above grow after defecation by birds? e.g. indigestible seed. ☐ Yes ☐ No ☐ Not sure

7.07 Does the plant have adaptive structures such as burrs or prickles that easily attach on animals or their clothing's?

☐ Yes ☐ No ☐ Not sure

7.08 Does the variety have propagules that are eaten by other animals (apart from birds), dispersed and grow after defecation?

☐ Yes ☐ No ☐ Not sure

8.0 PERSISTENCE ATTRIBUTES

8.01 What is the approximate number of seeds that are produced by the variety per meter square per year?

☐ Less than 5000 ☐ 5000-10000 ☐ 10001-15000 ☐ more than 15000

8.02 How long do the seeds remain viable in the soil?

☐ Less than one year ☐ One year ☐ More than one year

8.03 Is the variety easily controlled by herbicides?

☐ Yes ☐ No ☐ Not sure

1.04 (a) Does the variety tolerate the following disturbances?

Disturbance	**Response**		
	Yes	No	I don't know
Mutilation			
Fire			
Trodding			
Cultivation			

8.04 (b) Does the variety benefit from the above disturbances?

Disturbance	**Response**		
	Yes	No	I don't know
Mutilation			
Fire			
Trodding			
Cultivation			

8.05 (a) Does the variety have natural enemies?

☐ Yes ☐ No ☐ Not sure

(b) If yes to (a) above, name some...

The time taken and effort put in filling this questionaire is highly appreciated.

Appendix 6.3: Weed Risk Assessment scoring sheet

		a	b	c	d	e
Section		Question	Response[1]	Score	*N* score	*Y* score
A	C	1.01			0	-3
	C	1.02			-1	1
	C	1.03			-1	1
		2.01		The response for these questions is 2 unless a climate analysis is done		
		2.02				
	C	2.03			0	1
	C	2.04			0	1
		2.05				
	C	3.01			Refer to lookup table	
	E	3.02				
	A	3.03				
	E	3.04				
	C	3.05				
B	C	4.01			0	1
	C	4.02			0	1
	C	4.03			0	1
	A	4.04			-1	1
	C	4.05			0	1
	C	4.06			0	1
	C	4.07			0	1
	E	4.08			0	1
	E	4.09			0	1
	E	4.10			0	1
	E	4.11			0	1
	C	4.12			0	1
C	E	5.01			0	5
	C	5.02			0	1
	E	5.03			0	1
	C	5.04			0	1
	C	6.01			0	1
	C	6.02			-1	1
	A	6.03			-1	1
	C	6.04			-1	1
	C	6.05			0	-1
	A	6.06			-1	1
	C	6.07				
	A	7.01			-1	1
	C	7.02			-1	1
	A	7.03			-1	1
	C	7.04			-1	1
	E	7.05			-1	1
	E	7.06			-1	1
	C	7.07			-1	1
	C	7.08			-1	1
	C	8.01			-1	1
	C	8.02			-1	1
	A	8.03			1	-1
	A	8.04			-1	1
	C	8.05			1	-1
		Total score [3]				
		Outcome [4]				
		Agricultural score[6]				
		Environmental[6]				

Only score 1.02 and 1.03 if you answered yes to 1.01

Lookup table for section 3.										
Locate value of inputs and lookup output for each										
Yes to questions 3.01 - 3.05										**default**
Inputs	2.01	0	0	0	1	1	1	2	2	**2**
	2.02	0	1	2	0	1	2	0	1	**2**
Results	3.01	2	1	1	2	2	1	2	2	**2**
	3.02	2	1	1	2	2	1	2	2	**2**
	3.03	3	2	1	4	3	2	4	4	**4**
	3.04	3	2	1	4	3	2	4	4	**4**
	3.05	2	1	1	2	2	1	2	2	**2**
No to questions 3.01 - 3.05										
Input	2.05	?	N	Y						
Results	3.01	-1	0	-2						
	3.02-3.05	0	0	0						

Procedure for scoring assessment

1 Record appropriate responses in column b.
2 Look up score in columns d & e and record result in column c.
3 Calculate total score.
4 Lookup and record recommendation.
5 Verify that minimum number of questions from each section are answered.
6 Compute Agricultural (A&C) and Environmental (E&C) scores: if either score is less than 1, the outcome pertains to the other sector.

Lookup table for 6.07			
years	1	2	4
score	1	0	-1

Score	Outcome
< 1	Accept
1-6	Evaluate
> 6	Reject

Section	Minimum # questions[5]
A	2
B	2
C	6
Total	10