EFFECTS OF TILLAGE AND PLANTING METHODS ON RICE GROWTH AND YIELD IN KENYA

BY

RAPHAEL KINYANJUI WANJOGU

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DECLARATION

Student

This thesis is my original work and has not been presented for a degree in any other University.

Sign: ________________ Date 13/10/2000

Mr. Raphael Kinyanjui Wanjogu

Supervisors

This thesis has been submitted for examination with our approval as University supervisors.

Sign ________________ Date 13/10/2000

Dr. E Mbaka Njoka

(Senior Lecturer)

Sign ________________ Date 16/10/2000

Dr. John Mburu Njoroge

(Senior Lecturer)

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DEDICATION

This thesis is dedicated to

My dear wife, Grace Muthoni

And our sons

Stephen Wanjogu, Philip Gatua, and Simon Peter Ngatara.

ABSTRACT

This research aimed at studying the effects of zero tillage and wet seeding (direct sowing of pre-germinated rice) on flooded rice to develop a better production package for farmers to enhance rice production in Kenya. Zero tillage using glyphosate was compared with ploughing and rotavation. Rotavation is the conventional tillage method that involves tilling flooded paddy fields with roto-tillers. Wet seeding was tested against the standard method of rice establishment, transplanting. Two commercial rice varieties, NIBAM 10 and NIBAM 108, were grown during 1998 and 1999. NIBAM 10 and NIBAM 108 were cultivated in Mwea Irrigation Research Station while in Ahero Irrigation Research Station only NIBAM 108 was cultivated. A split plot randomized complete block design was used with tillage as the main plot and rice establishment method as the subplot. Data was collected on yield, yield components and other plant growth parameters.

Zero tillage gave similar results to the conventional method (rotavation). Zero tillage crop gave an average yield of 4917 kg/ha at Ahero and 6834 kg/ha in Mwea as compared to 4577 kg/ha and 6833 kg/ha, respectively for control with NIBAM 108. Yields of "NIBAM 10" under zero tillage averaged 2658 kg/ha while that of control came to 2799 kg/ha. Zero tillage reduced crop growth duration by 4 days above control. Among the plant establishment methods, wet seeding recorded better crop growth rate and yield performance giving an overall of 18% more yields than transplanting. It also reduced crop cycle by an average of 11 days. These results suggest that the wet seeding system can be recommended for enhancement of rice production in the regions under study. The combination of zero tillage and wet seeding had no adverse effect on the rice yield and growth characters. The methods can be applied for both long rain and short rain seasons of the two study regions. However, in Mwea the short rain crop had higher yield and better plant growth than the long rain crop. The Mwea site environment gave better rice growth and yield irrespective of the season used than Ahero site. The study tends to indicate that planting rice by wet seeding method in zero tilled paddy field result to multiple benefits as compared to the conventional system. The system is recommended for irrigated rice schemes to increase paddy field utilization and rice yields with possible reduction of drudgery.

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1.0 CHAPTER ONE

1.1 BACKGROUND INFORMATION

Rice (*Oryza sativa* L.) is the leading cereal in calorie production per hectare (De Datta, 1981). It is grown in more than 150 million hectares falling second to wheat (FAO, 1997; Labrada, 1996). Rice consumption has increased in Africa displacing staple food crops such as root crops, tubers, maize, millet and sorghum due to its ease of preparation and high energy value (Werblow, 1997). This has created high demand for rice that has led to increase in importation (Dashiell, *et al.,* 1993; FAO 1997). Projected deficit for rice by the year 2010 is estimated to be 19 million tonnes in Africa (Thomson and Metz, 1997). By the year 2000, global output of paddy rice would have to increase by 33 million tonnes to meet the expected demand of 402 million tonnes (Yap, 1997). The bulk rice production increase would have to be obtained by raising yields per unit area due to scarcity of land for expansion (Yap, 1997). The sub-Saharan countries will have to import 32% of rice to meet the projected rice consumption by the year 2010 (Yap, 1997).

Rice demand in Kenya has continued to increase as indicated by a rise in rice imports. In 1994, rice imports in Kenya stood at 93,520 tonnes against national production of about 60,000 tonnes (FAO, 1996 & 1997). The consumption growth rate rose from 8% in 1992 to 12% in 1996 while production has almost remained static. The area under rice cultivation has also remained unchanged at about 10,000 ha since 1994, (GOK, 1994; FAO, 1996; 1997 & 1998; NIB, 1996a).

Most of the rice cultivated in Kenya is irrigated (92%). The rest is rainfed (NIB, 1994). Mwea is the main rice growing area producing 73% of the total paddy produced in Kenya (NIB, 1994). The main planting method is transplanting.

Production of rice in Kenya has remained below the country's annual demand resulting to increased imports. This necessitated the need to direct research priorities towards overcoming rice production hindrances. Production of rice can be increased through intensive use of the already existing rice fields. This can be achieved through adoption of land preparation and planting methods that reduce drudgery and encourage double/intensive cropping. The government of Kenyans policy lays emphasis on seeking ways to boost local rice production through more and better use of chemical inputs, more efficient management of soil and water resources as well as improved crop husbandry practices (Werblow, 1997).

The current land preparation and plant establishment methods pose hindrances to increased rice productivity. Transplanting method is reported to decrease rice yield, cause drudgery, require high labour, cause poor paddy levels and health risks (Dingkuhn *et al.*,1990). Transplanting shock, over age seedlings, poor transplanting style and low tiller population are the main causes of low yield in transplanted rice (Rajendra and Narsa, 1980; Vandra *et al.*, 1994). Conventional tillage methods and planting systems involves high drudgery, and health risk particularly to women and children (NIB, 1996b). This lowers human output and land utilization. Farmers avoid double cropping leaving land and other resources idle during most part of the year (NIB, 1996b). Farmers are therefore not able to produce enough rice to meet their family food and income requirements. Besides this, transplanting make farmers work for long hours in standing waters. Standing water provide a conducive environment for water borne diseases such as malaria and bilharzia (NIB, 1994). In addition to this, transplanting encourages child labour and contributes to the Kenya's highly rated (41.3%) abuse of child labour and gender inequality (Bouland, 1997; FAO, 1997;). Women in Africa account for 60-80% of Agricultural labour force (FAO, 1997). In irrigated schemes, women and school children are the main source of transplanting labour force.

Rotavation and ploughing tillage methods interfere with paddy filed levels, which are expensive and difficult to restore. Rotavation also makes the rice fields remain flooded for a long time discouraging double cropping. This calls for a need to research on crop establishment and land preparation practices that would eliminate these problems to encourage higher rice production.

Several research attempts have been made before in rice schemes to increase rice production through intensive cropping without success. The packages possibly failed to address the plant establishment and tillage problems faced by the rice plant and the farmer. This study aimed at establishing simpler ways of raising irrigated rice while reducing the above mentioned problems without compromising yield.

Land preparation system involves flooding and tilling land under water, by use of rota-tillers. Once rotavated, the fields remain under water up to crop maturity. This is thought to contribute in lowering paddy rice yields in the long run besides aggravating water borne disease problem (NIB, 1996b). Rotavation is unsuitable during periods of prolonged rainfall due to bogging down of tractors as was experienced during El nino rains (MIS, 1998;). The consequences are delays in land preparation leading to poor rice yields. Rotavation is unsuitable for intensive paddy rice production in rice schemes because it leads to paddy soil fertility deterioration, upsurge of pests and diseases, drudgery and ultimately poor yields (NIB, 1986). These problems have made the Kenyan rice farmer to revolve in a vicious cycle of poverty. As a means to restore the soils fertility, dry land tillage (ploughing) was recommended especially for double cropping system (NIB, 1996b). However, farmers reject ploughing because it destroys paddy field levels, which involve high drudgery to restore.

In this regard, alternative tillage and planting methods have to be put in place to enhance rice production to in Kenya by the year 2000-2013 (GOK, 1994). With appropriate tillage and planting methods the rice production potential of established irrigated rice regions can be highly exploited (NIB, 1984), hence the need to undertake this study centering on the following objectives:

1.2.0 OBJECTIVES

1.2.1 General Objective:

To investigate the effects of tillage and planting methods on growth and yield of irrigated rice in Kenya.

1.2.2 Specific Objectives

1.2.2.1 To determine the effect of tillage on growth and yield of NIBAM 10 and 108 rice varieties.

1.2.2.2 To determine the effect of planting method on growth and yield of

NIBAM 10 and 108 rice varieties.

1.2.2.3 To determine the effect of combining different tillage and planting methods on growth and yield of NIBAM 10 and 108 rice varieties.

1.3.0 Hypothesis

1.3.1 There is no significant growth and yield difference between the tillage methods

1.3.2 There is no significant growth and yield difference between transplanting and wet seeding methods

1.3.3 There is no significant growth and yield difference between the combinations of tillage and plant establishment methods

2.0 CHAPTER TWO

2.1.0 LITERATURE REVIEW

2.1.1 Rice production systems.

Rice is a semi-aquatic annual grass, which thrives and yields best when flooded for two-thirds or all of its life cycle (Labrada, 1996; De Datta, 1981). Rice production systems are thus classified according to availability of water as: Irrigated, Rain-fed, Flood-prone or deep water. According to establishment method, rice is either; transplanted at 8 to 35 day old seedling into puddled soils, broadcast or drill - seeded into dry soil or broadcast as pre-germinated seeds onto wet (puddled) soil (De Datta, 1981). In the world 53% of cultivated rice is irrigated, 27% lowland rainfed, 12% upland rice and 8% deep water rice (Labrada, 1996).

2.1.2 Wet seeding and transplanting

Transplanting is the most popular crop establishment method in irrigated rice growing regions (De Datta, 1981). The transplanted rice is raised as seedlings in nursery and then transplanted at an average age of 21-28 days after sowing. However, since labour has become expensive and limited, transplanting is increasingly being replaced by direct seeding (De Datta, 1986). Direct seeding is reported to eliminate labour demands for seedbed preparation, seedling care, seedlings uprooting and transplanting. Direct seeded is also reported to reduce rice crop cycle from seedling to maturity with an average of 15 days depending on the region and variety because of the absence of transplanting shock (IRRI, 1987). Little information is available on specific husbandry requirements of wet direct-seeded flooded rice in the tropics (De Datta, 1986).

2.1.2.1 Transplanting

Some studies indicate that growth kinetics, assimilate partitioning patterns and nitrogen economy of irrigated rice depend on cultural practices, particularly on planting techniques (Dingkuhn *et al.*, 1990; Schnier *et al.*, 1990a; IRRI, 1987). In Maharashtra , India grain yields were reduced by an average of 60% when seedlings were transplanted at 60 days after sowing instead of 20 days after sowing (Kamdi *et al.*,1991)). A field trial in Faridpur Bangladesh indicated that rice yield decrease with delay in transplanting date (Ali *et al.*, 1995). Transplanting of 40 and 55 day old rice seedlings gave considerably lower grain yields than when normal aged (25 days) seedlings were used (Rajendra and Narsa, 1980). Delay in transplanting reduced seedling dry matter (Vandra *et al.*, 1994). The transplanted crop takes time (average 15 days) to recover from transplanting shock (IRRI, 1987; NIB, 1986). Transplanting can give low tiller density due to wide seedling spacing often reduce plant density resulting to under utilization of; (i) light for photosynthesis, (ii) water resources and (iii) soil mineral nutrients (Forbes and Wartson, 1992). Schenier *et al.*, 1990b also observed that direct seeded rice exhibited faster crop establishment and a more productive vegetative growth phase because transplanting shock was absent and tiller number greater. Transplanting requires 25 persons per acre (62 man-days/ha) (NIB, 1996b). In another experiment by Thabonity *et al.*, (1994) transplanted rice had the highest labour requirement (646 man-hours /ha) and matured significantly later as compared to wet or dry sowing.

2.1.2.2 Wet seeding

Wet seeding cover over 80% of rice cultivated area in many Asian countries such as Malaysia, Philippines & Thailand and there is a trend towards increasing use of wet seeding in other rice growing countries (Labrada, 1996).

Wet seeded crop is favoured by fast-unchecked growth which shortens the crop cycle (Schnier *et al.*, 1990b). According to Moody, (1993), wet seeding may require special attention in weed control. The cultivars used should have excellent seedling vigour and good tillering ability (Moody and Cordova, 1985). Fast establishing short growth duration cultivars with high seedling vigour, which possess the ability to compete and smother weeds are suitable for wet seeding (Moody, 1996; Khush, 1993; Hassan, 1996). Wet seeding allows manipulation of seed rate to smother weeds without adverse effect on yield (Akobundu, 1996;). Fast growing varieties in wet seeding culture combined with broad-spectrum herbicide could also help solve weed problem (Moody, 1996). Wet seeding saves on land since nursery plots are not required. It also saves on labour (Moody, 1993) requiring only few man-hours for broadcasting (1-manday/1.6ha). In Philippines, IRRI, wet seeding had a cost saving advantage over transplanting due to its labour saving aspect (Erguiza *et al.*, 1990). Wet seeding could enable the grower to achieve the correct plant density by achieving faster growth and better plant establishment to increase yield (Forbes and Wartson, 1992; Dimgkuhn *et al.*, 1990). Correct plant density is vital for attainment of maximum yield. Rice plants produce tillers to attain maximum plant population in order to make optimal use of the available resources for better growth and high yield production. Research findings by

De Datta *et al.*, (1988; 1986) indicate that wet seeded rice plants recover more of the applied nitrogen than the transplanted plants. Transplanted flooded rice recovers only 20-40% of the applied N because of N losses and poor fertilizer management (De Datta *et al.*, 1988; 1986).

2.1.2.3 Water use and water use efficiency

In a field trial in Thailand on a heavy clay acid sulphate soil, total water requirement was 1154, 1105 and 1040mm with transplanting, wet sowing and dry sowing, respectively. Grain yield per mm of water used was lower in transplanting than in wet and dry sown crops (3.07, 3.65 and 3.77 kg/ha/mm, respectively (Thabonity *et al.*, 1994). Bhuiyan, (1995), found that wet seeding system was superior to the traditional transplanting system in terms of water efficiency. The report also indicated that wet seeding rice culture had greater drought tolerance, lower labour requirement for crop establishment and weed control.

Wet Seeding in Asia showed that good field drainage and good water control were essential. The Consultation Group on International Agricultural Research Institute (CGIAR) and the International Rice Research Institute (IRRI) reported that wet seeding use 20-25% less water (EAS, 1999).

2.1.3 Effect of plant establishment methods on rice growth

Plant establishment method influences plant growth characters by affecting plant density (Forbes and Watson, 1992). The more densely rice is planted, the fewer the number of stems per hill, but the number of stem per area increase as reported by Matsuo and Hoshikawa, (1993). A similar observation was reported by Kiyochika,

(1989) which indicated that with an increase in the number of hills per unit area the number of tillers per plant or per hill decreases and the number of main culms and primary tillers become greater. In dense planting, the space become very limited, enough only for the growth of the main stem, and the other tillers, which were to vie with it, become dormant. However the direct sown plants grow under low-density conditions from germination to early growth stage, as compared to the plants grown in nursery beds (Kiyochika, 1989). The form of seedlings of the same age varies depending on the raising method.

Most tiller buds of young and middle seedlings degenerate when densely sown and the 1st and 2nd tiller buds of young seedlings degenerate while only 3rd tiller buds survive. The 1st and 4th tiller buds of middle seedlings (5 leaf ages) degenerate while keeping the 5th and 6th tiller buds inside. The development of tillers is affected by various environmental conditions including manuring, planting density and climatic conditions such as light, temperature, and water supply (Matsuo and Hoshikawa, 1993).

Tillers develop from tiller nodes in rice stem (Kiyochika, 1989). They start growing from the second node. On sparsely sown nursery beds mature seedlings have second node tillers but on thickly sown nursery bed second node also become dormant. In transplanting seedlings, tillers from third and fourth nodes do not usually come out due to their degeneration caused by transplanting. This is caused by root pruning and wilting that occurs at transplanting. In shallow direct seeding tillers grow from all the lower nodes giving rise to mainly primary tillers (Kiyochika, 1989). The tillers at the 2nd and upper nodes develop and emerge in directly sown rice under favourable conditions

(Matsuo and Hoshikawa, 1993). Katayama, (1931) observed that the nodes at which tillers developed went up when seedlings grew in a nursery over a long period.

The depths at which seedlings are transplanted likewise affect tillering. Matsuo, (1950) observed that the nodes at which tillers occur went up as the seedlings were transplanted more deeply from 3 cm to 6 cm and further to 9 cm.

The panicle weight per hill and per unit area showed a similar trend to the tiller pattern (Matsuo and Hoshikawa, 1993). The more densely the rice was planted the lower the weight of panicles per hill. However the increase of panicle weight per area was rather small. Kondo, (1944) observed similar results, indicating that panicle weight per unit area demonstrated only a small increase under a high density because average weight of individual panicles decreased. In the case where the density reached a very high level, the panicle weight per area did not vary. Matsuo and Hoshikawa, (1993) reported that panicle weight decline is due to a decrease in the number of grains per panicle as well as in the average kernel-weight. Thus under dense planting the growth amount of each plant decreases and the size of hill plants, panicles and hulls becomes small. However, the overall amount of growth as a population is increased since a plant community thickly grows. Kambayashi *et al*., (1983) also reported that the number of grains in the rachis – branch remained constant regardless of planting densities, amount of fertilizers and cultivars.

Kanda and Sato, (1963) and Kanda and Nishizawa showed that the number of stems and panicles per hill decreased in a regular manner in accordance with increased plant density. Plant height was also promoted to a certain level at the first period of growth, while in the later period, the elongation was depressed. This growth pattern was almost the same for different varieties.

Plant establishment influence growth pattern and yield components from a viewpoint of dry matter production (Kiyochika, 1989). Accordingly great attention has been drawn to the leaves as an assimilative organ (Matsuo and Hoshikawa, 1993). Kanda and Nishizawa, (1967) demonstrated that the development pattern of leaf area was parallel to that of the stem number, and the canopy structure greatly varied among cultivars. Until the middle of growing period, the canopy showed little difference among different cultivars or planting densities. The difference in canopy structure due to varying planting densities was insignificant at the heading time. Akita, (1982abc) reported that under dense planting, the leaf area per hill was small but the leaf area index was large. He observed a greater distribution of leaves in the upper part when the rice was densely planted.

2.1.4.0 Zero Tillage

Tillage is important and to reduce land preparation cost without sacrificing grain yields, farmers should limit tillage to a minimum (De Data, 1981; Buchanan and King, 1993). Reduced tillage systems have been developed to become valuable alternative systems in crop production. These methods reduce the time and labour input, reduce the range of equipment necessary, conserve fuel and reduce the number of passes of tractor over the land to be sown. These systems, however, need to be developed and tailored towards cultivation on different soils, and scale of farm operation (De Datta, 1981).

Conservation tillage generally provides yields equal to or greater than those from conventional tillage (Phitops, 1980). Arogo (1989), found no difference in yield ability between corn and Soybean grown under different tillage systems which included zero tillage. Lee *et al.*, (1999) observed that heading date, culm length and panicle number were similar in the no tillage and tillage treatments. Spikelet number per unit area and percentage of ripened grains increased significantly particularly in the plowing treatment followed by rota-tilling. Yield increased significantly with tillage but 1000-grain weight was not affected. In rota-tilled and Ploughed + rota-tilled treatments, vertical and horizontal root distribution was more uniform than in zero-tillage. According to Aslam *et al.*, (1993), in Pakistan no-tillage increased wheat yield by 10-41%. The increased yield in no-tillage crops was associated with higher tiller numbers, better seedling establishment and fewer weeds. The cost of cultivation and sowing was 85% less with no-tillage as compared to the conventional system.

Investigations at the Ahero Irrigation Research Station indicated that after 3-4 weeks of submergence, fields had physical characteristics similar to those tilled with a rota-tiller and then submerged for the same length of time (Croon, 1978). Comparative yields were obtained on tilled and non-tilled fields. Provided no abundant weed growth or stubble re-growth were present at submergence, weed growth could be adequately controlled by maintaining a water-layer of 10cm in the field (Croon, 1978).

One of the primary objectives of conservation tillage is to keep some plant residue on the soil surface. According to Dickey, (1987), conventional mould board plough systems leave only 1-5% of soil covered with crop residues, reduced tillage 15-25%, while zero tillage systems leave 50-100%. No tillage (NT) plots are generally high in soil water especially in the upper portion of the profile than conventionally tilled (CT) plots. This is due to increased water infiltration rate and reduced evaporation losses characteristic of any residue covered plots (Dickey, 1987). Unger, (1984) found that precipitation was stored with efficiencies of 45%, 36% and 28% under no till (NT), stubble mulch (SM) and mould board ploughing, respectively. He found that more soil water was available throughout the season in the no-tillage plots.

Kitur, (1982), while working with corn concluded that no tillage N fertilizer efficiency was slightly higher than that of the conventional system. However, conservation tillage practices, which leave most of the crop residues on or near the surface, also tend to encourage higher microbial populations in the surface few cm. Higher numbers of earthworms on no-till plots may increase water infiltration and aeration to reduce denitrification (Hendrix, 1986). Franzhuybbers and Ashad, (1996) while working on wheat, Brassica and Barley, found that at the end of 6 years Soil Micro-biology Content (SMBC) was 7% greater in roto-tillage (RT) and 9% greater in ZT than in conventional tillage (CT).

2.1.4.1 Labour and energy requirement

Conservation tillage practices are associated with lower labour and energy requirements. Studies indicate that labour and energy requirements are cut significantly when some conservation tillage practices are used resulting to lower labour costs

(Simith and Baltazar, 1992). Likewise, fewer machines are required which also tends to reduce costs. There is also reduced fuel consumption. Even when herbicides are used in most cases conservation tillage systems have been found to require less total energy than do their conventional counterparts (Brady, 1990).

In US, conservation tillage has been on rapid increase. It is projected that by the year 2000, about 75% of USA will be under conservation tillage (Brady, 1990).

2.4.1.1 Herbicide use in no-tillage

The discovery of paraquat (1,1-dimethy1-4,4'-bipyridyliumion) and glyphosate N-(Phosphonomethyl glycine) stimulated considerable interest in reduced tillage techniques due to their broad spectrum activity and lack of toxic residues (De Datta, 1981, Klingman *et al.*, 1982; Powell, 1983). Application of Roundup (glyphosate) prior to sowing can be done in zero tillage (Corbin and Pratley, 1992). Trials in Sri-lanka showed that both direct-seeded and transplanted rice could be established with minimum tillage. Minimum and zero tillage techniques in rice involve the application of non-residual, broad spectrum, pre-plant herbicides to control weeds, ratoon and volunteer rice (De Datta, 1981).

Use of herbicides in Philippines reduced upland rice production costs and increased returns, because it maintained a comparative high grain yields than conventional tillage (Smith and Baltazar, 1992; Moody, 1996). In Laos, Philippines application of glyphosate before planting upland rice reduced labour input for weeding by 30-60% (Roder *et al.*, 1995). He reported that broad-spectrum application of glyphosate at the rate of 2.5 kg a.i/ha eliminated the need for weeding before planting and reduced the weed biomass during rice growing season. When planting was done just before or immediately after glyphosate application, the first weeding after planting was delayed substantially. This eliminated weeding before planting and the first weeding after planting significantly reduced labour input (Roder *et al.*, 1995). Application of glyphosate 13 days before seeding on no-tillage plots where *Paspalum scrobicultum* and *Fimbristylis littoralis* were the most prevalent weeds gave grain yields similar to those obtained with one ploughing and two harrowings in Philippines (IRRI, 1975).

In this study glyphosphate was applied to clear rice stubbles, ratoon, volunteer rice and weeds to give room for the wet sown rice.

3.0 CHAPTER THREE

3.1.0 MATERIALS AND METHODS

3.1.1 Sites

This study was conducted at Ahero Irrigation Research Station (AIRS) in Kisumu and Mwea Irrigation Research Station (MIRS) in Kirinyaga, Kenya. Ahero lies 1160m above sea level, Lat. 0° 09'S and Long. 34° 56'E. The site lies in Agro-ecological zone L (lowland) which is humid (Jaetzold and Schimdt, 1982). It experiences mean minimum and maximum temperatures of 18°C and 28°C (NIB, 1991). It has an annual solar radiation of 540 cal. cm/day. It receives an average annual rainfall of 1000 mm. During the study period the climate was suitable for rice cultivation (appendix 1). Soils are the vertisol which are deep, grey-black in colour rich in phosphorus and potassium (NIB, 1998). Initial soil analysis result indicated an average pH of 6.9, 0.004 %N, 58 ppm P and 1.0 me/100g K (Appendix 2).

Mwea is located at 1159 m above sea level and stretches between latitude 0°37'S and 0°45S and longitudes 37°14'E and 37°26'E. It has a mean minimum and maximum temperature of 17 °C and 26 °C, respectively. The annual average solar radiation is 573 cal. cm/day which is above 600 cal. cm/day in January - May and September - November. It falls below 500 cal. cm/day during the June - August and December periods (NIB, 1996c). It receives mean annual rainfall of 940 mm. During the study period weather was suitable for rice cultivation (Appendix 3). The site lies in Agro-Ecological Zone L that has high agricultural potential with deep vertisols characterized by dark black colour. Initial soil analysis result indicated an average pH of 6.3, 0.028 %N, 14.4 ppm P and 0.6 me/100g K (Appendix 2).

3.1.2 Experimental design

A split plot randomized complete block design with two factors at 3 and 2 levels were used. The factors were allocated as follows;

(i) Main plots – Tillage methods; 3 levels

(ii) Subplots – Rice establishment methods at 2 levels

Tillage methods were;

1) Rotavation - achieved by roto-tilling flooded paddy field at a depth of 15-20cm
2) Ploughing – tilling by means of a tractor drawn plough at a depth of 15-20cm
3) Zero tillage - done by spraying glyphosate at a rate of 6 l/ha to kill weeds and volunteer rice.

The planting Methods were;

1) Transplanting – Seedlings are first grown in the nursery to be transplanted at 4.5 leave number age
2) Wet seeding – Pre-germinated seeds sown by broadcasting them directly into the main field.

The gross main plot size was 448 m^2 and subplot 224 m^2 (Appendix 4).

3.1.3 Treatments

Main Plot treatments;

1) Rotavation (conventional)

2) Ploughing

3) zero tillage

Sub plot treatments;

1) Transplanting (conventional)

2) Wet seeding

The treatments were replicated three times and laid out in the field as shown in appendix 4 at the two sites.

3.1.4. Cultivars

The materials for this study included two commercial rice varieties (NIBAM 10 and 108) from National Irrigation Board research centers of Ahero and Mwea. NIBAM 108 is a non-aromatic medium to tall rice variety. It has a medium to high tillering, and takes an average of 145 days to mature under the conventional system. It is an Indica with medium thin grains and has high milling and cooking qualities. It is the main commercial variety at Ahero. NIBAM 10, is an aromatic medium to tall Indica variety, which is early maturing with average growth duration of 130 days. It has high quality, long and slender grains. It is the main commercial variety at Mwea. NIBAM 108 was grown at both Ahero and Mwea while NIBAM 10 variety was only grown in Mwea.

3.1.5 Planting and crop management

NIBAM 108 was planted for two seasons at Ahero during long and short rains 1998 from 30/4/98 to 9/9/98 and from 5/9/98 to 8/1/99, respectively. The same variety was planted in Mwea during short rains 1998 and long rains 1999 from 8/8/98 to

31/12/98 (1st season) and 5/2/99 to 30/6/99(2nd season), respectively. NIBAM 10 was planted in long rains 1998 and long rains 1999 from 9/3/98 to 4/8/98 (1st season) and from 6/2/99 to 16/6/99 (2nd season), respectively.

Main field Seed/Seedling bed was prepared by either rotavation (conventional); dry ploughing or Zero tillage. Zero tillage was achieved by application of glyphosate (36 %) herbicide at a rate of 6.0 Lt./ha to clear the rice stubbles, volunteer rice and weeds. Flooding 10-15 days after herbicide application followed this. Ploughing was done by tractor drawn disc plough followed by harrowing after drying.

Rotavation was achieved by means of roto-tillers one day after flooding. Seeds were sown onto the nursery for transplanting at the rate 50 kg/ha. Twenty-eight and twenty one day old seedlings for Mwea and Ahero, respectively, were then transplanted at 2 seedlings per hill spaced 20x20 cm apart as recommended (NIB, 1996). For the wet seeding treatment, pre-germinated seeds were broadcasted into the main field at a rate of 50 kg/ha (Schenier *et al.*, 1990a).

Sulphate of Ammonia was applied in 3 splits at a rate of 104 kg N/ha. One-third at planting and the other at tillering and panicle initiation stages (Matsushima, 1984).

Seeds were dressed with Benlate (fungicide) at 2 g per kg of seed to control fungal diseases before pre-germination. No other disease control measure was carried out. Furadan 5G, was applied at a rate of 1 g/m² at 35 days after sowing and transplanting respectively to control stem-borers, case worms, leaf miners, rice maggots and rice beetles.

Weeds that germinated during early crop growth period were controlled by means of a contact selective herbicide, satunil, at 8 days after planting in all treatments. Weeds coming up after this were removed manually. All other cultural practices were carried out as per the irrigation scheme recommendations (NIB, 1996c).

3.1.6 Parameters measured

Data on various variables was collected as specified in standard evaluation systems for rice IRRI, (1988) and Gomez and Gomez, (1984).

Yield data was obtained from the inner 2m x 5m. The following parameters were observed, measured and recorded for analysis:

3.1.6.1 Tiller number at seedling stage, panicle initiation and maturity stages

Tiller count was taken from $1m^2$ area for both wet seeding and transplanting except seedling stage where tillers were counted per plant.

3.1.6.2 Plant height at vegetative phase (seedling stage) and at maturity stages.

Plant height was measured from the ground level to the tip of the longest leaf/panicle of three randomly selected hills per plot.

3.1.6.3 Panicle number per m^2 (effective tillers) - This was determined from three sampling points of $1/16^{th}$ m^2 in size taken at random. This was expressed as productive tillers/m^2 by average calculation.

3.1.6.4 Grain number per panicle

This was the average number of filled grains per head taken from 3 randomly selected hills from each plot.

3.1.6.5 1000 kernel weight

This was determined from 1000 filled grains obtained from threshed winnowed paddy of randomly sampled hills.

3.1.6.6 Days to Physiological maturity

This was the period taken (days) from sowing to the date when the plant vegetative parts dried up through normal physiological process and 80% grain turned yellow at 85% maturity.

3.1.6.7 Grain yield

The weight of the grain from each plot was taken after threshing and cleaning. The weight was corrected to grain yield per ha at 14% moisture content.

3.1.6.8 Harvest Index (HI)

This was determined from the weight of all the above ground shoot and grain weight of the same plot. HI (%) was then calculated as follows:

HI = {Grain weight /(Grain weight + Above ground shoot weight)} x 100

3.1.7 Data Analysis

The statistical analysis was done using statistical analysis program SAS, (1996). The data obtained was subjected to analysis of variance (ANOVA) for each trait and means were separated using List significant difference (LSD). The differences at $P \leq 0.05$ and 0.01 levels of significance were reported.

4.0 CHAPTER FOUR

4.1 RESULTS AND DISCUSSION

The mean squares for analysis of variance (ANOVA) are presented in Appendices 5 to13.

4.1.1 Grain Yield (Kg/ha

NIBAM 108:

At Ahero, the grain yield differences were highly significant (P≤0.01) among tillage and plant establishment methods in the first season (Table 1).

Table 1: Effect of cultivation and plant establishment methods on grain yield of NIBAM 108 at Ahero Kenya for two seasons.

Methods	Grain yield (kg/ha)	
	1st Season	2nd Season
Cultivation method		
Rotavation	4461.8a	4493.0a
Ploughing	3215.0b	5560.0a
Zero Tillage	5122.8a	4713.0a
Planting Method		
Transplanting	3558.1b	4082.3b
Wet seeding	4975.0a	5761.9a
Season means#	**4266.6a**	**4922.1a**
SE	96.2	811.0
CV%	12.2	16.5

Key: Means followed by the same letter within a factor per season are not significantly different at p≤0.05 level;
= Season means followed by the same letter along the row are not significantly different

Zero tillage recorded significantly higher grain yields (p≤0.01) than ploughing and rotavation during the first season. There was no significant grain yield difference among the tillage methods during the 2nd season (Table 1). In both seasons, wet seeding recorded higher grain yield than transplanting with the second season yield difference (1679.6 kg/ha) being highly significant ($p \leq 0.01$) Appendix 1). There were no significant yield differences between the two cropping seasons in Ahero site (Table 1). At Mwea, there were no significant yield differences among the tillage as well as within the plant establishment treatments (Table 2 and 30). However the short rains 1998 crop had significantly ($p \leq 0.01$) higher yield than the long rain 1999 crop (Table 2). Significantly higher yields ($p \leq 0.01$ were obtained at Mwea than at Ahero during short rains and long rains seasons (Tables 31 and 32).

Table 2: Effect of cultivation and plant establishment methods on yield of NIBAM 108 at Mwea, Kenya for two seasons.

Methods	Grain yield (kg/ha)	
	1st Season	2nd Season
Cultivation method		
Rotavation	7647.5a	6018.2a
Ploughing	7809.0a	7106.7a
Zero Tillage	7346.7a	6321.0a
Planting Method		
Transplanting	7391a	6485.6a
Wet seeding	7811a	6480.3a
Season means#	**7601.1a**	**6482.9b**
SE	176	106
CV%	12.6	8.9

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

There was no significant grain yield differences resulting from the interaction between tillage and planting methods in all the studied cases (Appendix 5, 6 and 7).

NIBAM 10:

Grain yield differences were not significant among the tillage methods during the first season (Table 3). During the second season, ploughing scored highly significant yield differences than rotavation and zero tillage. The grain yield from wet seeded crop was significantly higher than for transplanted crop at $p \leq 0.05$ in the first and second seasons by 94% and 8%, respectively (Table 3). The second season's yield were significantly higher ($p \leq 0.01$) than those of the first season (Appendix 1 and 12; Table 33). The differences are attributed to low temperatures at flowering and the El nino rainfall effect experienced during the first season. This is further explained by the recorded higher grain sterility (Table 33).

NIBAM 108 gave significantly higher yield than NIBAM 10 in both seasons (Table 34). Mwea site had significantly higher yields ($p \leq 0.01$) than Ahero site in both long and short rains seasons (Tables 31 and 32).

Table 3. Effect of cultivation and planting methods on grain yield of NIBAM 10 in Mwea Kenya for two seasons

Methods	Grain Yield (kg/ha)	
	1st Season	2nd Season
Cultivation method		
Rotavation	1173.5a	4423.8b
Ploughing	1623.8a	5000.0a
Zero Tillage	1056.7a	4259.3b
Planting Method		
Transplanting	873.1b	4394.6b
Wet seeding	1696.2a	4727.8a
Seasons mean#	**1284.7b**	**4561.2a**
SE	117	48
CV%	49.1	5.7

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

From the results, rice plants of both varieties grown in zero tilled land generally demonstrated the potential to give similar grain yield as in the conventional method of cultivation (Table 1, 2 and 3). It is only in the first season at Ahero that rice plants from zero tillage significantly out yielded those under ploughing system ($P \leq 0.01$). In all other seasons, grain yields from rice plants grown in all the three tillage systems were not different except in second season for NIBAM 10 where ploughing crop recorded significantly higher yield difference than rotavation and zero tillage. This implies that land prepared by zero tillage supported the growth of the rice plants without compromising grain yield.

These results are in agreement with those obtained by Phitops, (1980), which indicated that zero tillage crops generally yields equal or greater than those from conventional tillage system. Arogo, (1989) also found no difference in yield of crops grown under different tillage systems which included zero tillage. Similar observations were made elsewhere (Smith and Baltazar, 1992 and Moody, 1996). These researchers reported that zero tillage using herbicides maintained a comparatively higher grain yield than conventional tillage. It therefore follows that, the most appropriate tillage method irrespective of planting method would be judged by its cost.

Among the plant establishment methods, wet seeded rice gave on average, better grain yield in Mwea and Ahero with each cultivar used. From the results it is evident that wet seeding was superior to transplanting in terms of rice grain yield production. The wet seeded rice plants had better growth than the transplanted ones giving higher grain yields. This can be attributed to the better tiller production per unit area observed in wet seeding system than in transplanting (Tables 9 to 18). These made the wet seeded rice plants best suited for efficient and maximum use of the available land, soil and water resources for better growth and yield as reported by De Datta, (1988). Wet seeding system possibly eliminated the problems associated with the transplanting system as reported by IRRI, (1987). It is reported that rice yield are decreased by delay in transplanting, poor transplanting style, transplanting shock, low plant density in random transplanting, and non-uniform growth that occur due to gapping. Schnier *et al.*, (1990b), also indicated that wet seeding crop has yield advantage due to favoured fast unchecked growth. According to Schnier *et al.*, (1990ab) wet seeding eliminates transplanting shock, ensure correct planting density and prevent yield loss caused by use of over age seedlings in transplanting. This may partly explain the obtained better grain yield in wet seeding compared to transplanting. Minimized transplanting problems and absence of transplanting shock possibly enabled the wet seeded plants to form a better crop canopy for higher photosynthesis. It also possibly allowed wet seeded rice plants to form a better and more uniform root system. This enabled the wet seeded plants to fully exploit soil and water nutrient resources to achieve better growth and higher yield than the transplanted rice plant. In accordance with De Datta *et al.*, (1986; 1988) wet seeded rice plants might have recovered more of the applied nitrogen than the transplanted rice, which recovers only 20-40% of the applied N. It can then be deduced that wet seeding enabled rice plants to utilize solar radiation, water and soil nutrients converting these efficiently into photosynthates better than the transplanted plants. This was reflected by comparatively better rice growth and grain yields (Table 1 to 3). Additionally, the cost advantages reported by other researchers (Erguiza *et al.*, 1990) for wet seeding makes the system worthy incorporating in rice production systems of Kenya to enhance rice production subject to gross margin analysis.

Through out the study NIBAM 108 gave high yield irrespective of the tillage and planting method applied. This variety out yielded NIBAM 10 in both seasons at Mwea. The season differences observed in yield at Mwea tend to suggest the short rain season as the most suitable for rice growing. This is confirmed by the fact that farmers grow rice mainly in the short rain season. This is also in agreement with the area recommended cultural practices for rice. On the other hand, the results confirm that rice can be grown in both short and long rain seasons in Ahero to achieve similar yields. Mwea site gave consistently higher yield with NIBAM 108 since the cropping programme coincided with the best temperatures and solar radiation for rice production (Appendix 3). The Ahero site crop period coincided with low minimum temperatures and solar radiation, which might have interfered with panicle development resulting to poor fertilization.

4.1. 2 1000 Kernel Weight (g)

NIBAM 108:

In both Ahero and Mwea, 1000 kernel weight was not significantly different among tillage and plant establishment methods as shown in the ANOVA table (Appendices 5 – 6 and Tables 4-6).

Table 4: Effect of cultivation and plant establishment methods on 1000 kernel weight (g) of NIBAM 108 at Ahero, Kenya for two seasons

Method	1000 kernel weight(g)	
	1st Season	2nd Season
Cultivation Method		
Rotavation	26.9a	26.0a
Ploughing	26.8a	25.6a
Zero Tillage	26.6a	25.7a
Planting Method		
Transplanting	26.7a	25.8a
Wet seeding	26.9a	25.7a
Seasons mean#	**26.8a**	**25.8b**
SE	0.2	0.2
CV%	5.0	5.1

Key: Means followed by the same letter within a factor per season are not significantly different at p≤0.05 level;
= Season means followed by the same letter along the row are not significantly different

Table 5: Effect of cultivation and planting methods on 1000 kernel weight (g) at Mwea, Kenya for two seasons - variety NIBAM 108

Methods	1000 kernel weight (g)	
	1st Season	2nd Season
Cultivation method		
Rotavation	23.5a	20.9a
Ploughing	24.9a	21.2a
Zero Tillage	24.3a	20.2a
Planting Method		
Transplanting	24a	20.5a
Wet seeding	23a	21.1a
Seasons mean#	**24a**	**20.8b**
SE	0.2	0.1
CV%	3.9	2.9

Key: Means followed by the same letter within a factor per season are not significantly different at p≤0.05 level;
= Season means followed by the same letter along the row are not significantly different

NIBAM 10:

Kernel weight was not significantly different among tillage methods in both seasons (Table 6). Wet seeding had significantly heavier kernels in both seasons 5% and 9% in the first and second seasons respectively.

Table 6: Effect of cultivation and planting methods on a 1000 kernel weight of NIBAM 10 in Mwea Kenya for two seasons

Methods	1000 Kernel weight (g)	
	1st Season	2nd Season
Cultivation method		
Rotavation	19.7a	19.3a
Ploughing	19.8a	19.1a
Zero Tillage	19.4a	18.9a
Planting Method		
Transplanting	19.2b	18.2b
Wet seeding	20.2a	19.9a
Seasons mean#	**19.6a**	**19.1a**
SE	0.1	0.04
CV%	2.8	0.9

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

Grain weight was significantly different ($p \leq 0.01$) among the seasons and locations (Tables 4,5, 31 and 32) for NIBAM 108. First season crop grains were heavier compared to those of the second season. Mwea site grains were lighter than Ahero ones. Similar grain weights were recorded for NIBAM 10 among seasons. NIBAM 108 had significantly heavier grains than NIBAM 10 (Table 6 and 34).

There was no significant interaction observed between tillage and planting methods on 1000 kernel weight in all the cases as shown by the ANOVA (Appendix 5, 6 and 7).

From these results it appears that kernel development and grain filling were similar for the three tillage methods resulting in rice plants with similar kernel sizes.

According to Matsushima, (1984), kernel weight is determined during the reproductive phase. Presence of any adverse conditions during this phase results to poor grain filling and therefore low kernel weights. The observed similarities in kernel weights imply that rice plants grown in zero tilled land had suitable growth environment prior to onset of reproductive phase as is availed by ploughing and rotavation cultivation systems. Accordingly, the effect of zero tillage on rice plant kernel weight is the same as that of the conventional cultivation system. This lead to the conclusion that yield differences among tillage treatments would be due to other yield component factors and not 1000 kernel weight. These results agree with the findings of Lee *et al.*, (1999) in Korea, which indicated that tillage had no effect on 1000 kernel weight.

NIBAM 108 kernel weights remained the same irrespective of the planting method applied. This suggests that changing planting method might not affect kernel development and grain filling for this cultivar. Consequently, yield differences in this cultivar between planting methods would be as result of differences in other yield components and not kernel weight. With NIBAM 10, the higher kernel weights obtained (Table 4) may partly explain the yield differences obtained (Table 3) between planting methods. Plants of NIBAM 10 that were established by wet seeding seems to give a better partitioning of assimilates to grain filling producing heavier kernels than in transplanting. This agreed with the findings of Hou *et al., (*1994) which indicated that in broadcast sowing, yield increase could be due to improved panicle and grain characteristics that include 1000 kernel weight. Consequently, wet seeding could be rated better than transplanting in its influence to kernel weights of NIBAM 10.

The differences observed in grain weight among seasons, locations and varieties indicate that these factors are differ in their influence to rice growth and yield. However, absence of significant interaction implies that any tillage method can combine with either of the plant establishment systems to give comparative kernel weights.

4.1.3 Grain Number Per panicle

NIBAM 108:

At Ahero, there was no significant difference in grain number per panicle among tillage treatments during the 1st season (Table 7). In the second season, ploughing crop recorded significantly lower grains number per panicle than rotavatiion and zero tillage. Transplanting gave significantly higher grain number per panicle than wet seeding during the first season (Table 7). No significant grain number differences were obtained among the rice establishment treatments during the second season. Second season (long rains 1998) had significantly higher grain number per panicle than the first season (short rains 1998) (Tables 7 and 29).

NIBAM 108:

At Mwea, there was no significant different grain numbers per panicle amongst tillage methods in both seasons (Table 8).

Table 7: Effect of cultivation and planting methods on number of grains per panicle for NIBAM 108 variety at Ahero, Kenya for two seasons

Methods	Number of grains per panicle	
	1st Season	2nd Season
Cultivation Method		
Rotavation	51.8a	85.2a
Ploughing	46.7a	71.7b
Zero Tillage	46.5a	83.8a
Planting Method		
Transplanting.	58.7a	85.2a
Wet seeding	38.0b	75.2a
Seasons mean#	**48.34b**	**80.2a**
SE	1.7	1.9
CV (%)	10.1	12.5

Key: Means followed by the same letter within a factor per season are not significantly different at p≤0.05 level;
= Season means followed by the same letter along the row are not significantly different

Table 8: Effect of cultivation and planting methods on number of grains per panicle for NIBAM 108 variety at Mwea, Kenya two seasons

Methods	Number of grains per panicle	
	1st Season	2nd Season
Cultivation method		
Rotavation	69.2a	49.5a
Ploughing	70.2a	53.3a
Zero Tillage	73.7a	56.2a
Planting Method		
Transplanting	100.8a	50.1a
Wet seeding	69.9b	47.9b
Seasons mean#	**71.0a**	**53b**
SE	2.1	1.1
CV (%)	16.0	11.2

Key: Means followed by the same letter within a factor per season are not significantly different at p≤0.05 level;
= Season means followed by the same letter along the row are not significantly different

The conventional method of transplanting seedlings gave highly significant

($p \leq 0.01$) number of grains per panicle during the two seasons (Table 8; Appendix 6). The first season had significantly higher grain number per panicle than the second season crop (Table 8 and 33)

Among the locations, there was significant grain number difference for NIBAM 108 (Tables 31 and 32).

NIBAM 10:

The NIBAM 10 grain number per panicle was not significantly different among the three tillage methods during the first season. During the second season, grain number per panicle varied significantly ($p \leq 0.05$) among the tillage methods. Ploughing gave the highest grain number per panicle followed by rotavation (Table 9). Among the planting methods, non-significant differences of grain number per panicle were obtained during the first season. During the second season transplanting had significantly ($p \leq 0.05$) higher number of grains per panicle than wet seeding (Table 9).

Table 9: Effect of cultivation and planting methods on number of grains per panicle on NIBAM 10 variety at Mwea, Kenya for two seasons

Methods	Number of grains per panicle	
	1st Season	2nd Season
Cultivation method		
Rotavation	16.5a	52.2a
Ploughing	14.7a	62.2a
Zero Tillage	18.3a	45.5b
Planting Method		
Transplanting	15.3a	61.1a
Wet seeding	17.7a	45.4b
Seasons mean#	**16.5b**	**53.3a**
SE	0.7	1.2
CV%	22.1	12.2

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

The long rain 1998 NIBAM 10 crop had lower grain number than the second season crop (Table 33). The number of grains per panicle in NIBAM 108 were twice that of NIBAM 10 (Table 34).

No significant interaction was observed on number of grains per panicle between the tillage and the plant establishment treatments with NIBAM 108 (Appendix 5, 6 and 7). However, when NIBAM 10 was used, significant interaction was observed during the second season (Table 10 and Appendix 7)). Under rotavation, grain number per panicle from transplanting and wet seeding treatments were not significantly different (Table 10). Transplanting treatment gave highly significant grain number per panicle than wet seeding in ploughing method. The rice plants from the combination of zero tillage and transplanting gave highly significant grain number per panicle than plants from the wet seeding/zero tillage combination treatment (Table 10).

Table 10. Effect of interaction of tillage and plant establishment on number of grains per panicle for NIBAM 10 during the second season at Mwea, Kenya

Tillage	Plant establishment (P)			
	Transplanting	Wet seeding	Tillage means	Difference
Rotavation	53.0	51.3	52.17	1.67ns
Ploughing	78.3a	46.0b	62.2	32.33**
Zero Tillage	52.0a	39.0b	45.5	13*
P-means	61.1a	45.44b	53.28	15.67**

Key: In a row means followed by the same letter are not significantly different; ** = Significant at 1% level; * = Significant at 5% level; ns = not significant; SED = 5.29

The results indicate that tillage methods had no significant effect on grain number per panicle of NIBAM 108 except in the second season at Ahero (Table 7). The similar grain number per panicle obtained under zero tillage and rotavation at Ahero and Mwea in the second season, imply that changing tillage methods has no significance on the number of grains per panicle that rice plants produce. From these results, it is evident that rice plants growth did not face adverse conditions under zero tillage cultivation system. Zero tillage can therefore support healthy plant growth that produces the same number of grains per panicle as the rotavation method. The results also imply that yield differences among the tillage treatments would be due to other yield components and not grain number per panicle.

Planting method influenced NIBAM 108 variety grain number per panicle differently (Table 7, 8 and 9). Higher grain number difference averaging 32% was recorded in transplanting over wet seeding. Transplanted NIBAM 10 gave 34% higher grain number per panicle than when wet seeded during the second season. This suggests that the transplanted rice plants maximized yield by concentrating on increasing grain number per panicle at lower plant density, while wet seeded rice plants capitalized on high plant population of lower grain number per panicle. This agrees with the findings of Kondo, 1994 and Matsuo and Hoshikawa, (1993). Wet seeding gave higher grain number per unit area possibly because it gave higher number of productive tillers per unit area (Table 11 to 20) than transplanting. This could be partly attributed to the higher grain yields observed in wet seeding than transplanting (Table 1 to 3). The significant yield differences observed between the second season and season one confirms their differences for rice production as observed climatically.

The interaction observed in tillage and plant establishment methods for NIBAM

10 (Table 10), suggests that both wet seeding and transplanting methods can be adopted in rotavation tillage to produce similar number of grains per panicle in this cultivar. However, since wet seeding is reported by Erguizar *et al.*, (1990) to have cost saving advantage over transplanting, it would be superior to the transplanting method. In both zero tillage and ploughing, transplanted plants produced higher grain number per panicle than the wet seeded plants (Table 10) suggesting that plants transplanted in these systems of tillage capitalize on number of grains per panicle for yield production. This affirm that transplanted plants increase panicle grain number to achieve maximum yields unlike the wet seeded plants which capitalize on panicle number per unit area. When the cost saving advantage of wet seeding (Erguizar *et al.*, 1990) is considered together with the ability to produce higher grain number per unit area, it becomes the method of choice in boosting rice production. According to Smith and Baltazar, (1992) and Aslam *et al.*, (1993), zero tillage lowers production cost. Consequently, a combination of wet seeding and zero tillage would be of great advantage. The result shows that the short rain season at both sites gives higher grain number per panicle and could be the most suitable for rice cultivation than long rain season as reflected by higher yield. This agrees with the recommended cultural practices of the region. The short rain season benefits from higher temperatures and solar radiation than long rains season (Appendix 1 and 2).

4.1.4.0 Tillering ability

4.1. 4.1 Tiller number per plant at seedling stage

NIBAM 108; At Ahero, only the wet seeded plants had significantly high tiller number per plant than the transplanted seedlings in the second season (Table 11). At Mwea, the wet seeded plants had significantly high tillering ability than the transplanted ones as observed in both seasons (Table 12).

NIBAM 10:

Wet seeded plants produced significantly higher tiller number per plant than transplanted ones in both seasons (Table 13). The second season of NIBAM 10 gave higher tiller number at transplanting than the first season (Table 13).

There was no significant interaction of tillage and planting treatment methods observed on tiller number per plant at transplanting stage in all studied cases (Appendix 5, 6 and 7).

Table 11: Effect of cultivation and plant establishment methods on tillers per plant at seedling stage of NIBAM 108 in Ahero, Kenya for two seasons

Method	Tillers/plant at seedling stage	
	1st Season	2nd Season
Cultivation method		
Rotavation	2.7a	3.5a
Ploughing	2.8a	2.7a
Zero Tillage	3.2a	3.0a
Planting Method		
Transplanting	2.7a	1.8b
Wet seeding	3.1a	3.7a
Seasons mean#	**2.9a**	**2.7a**
SE	0.1	0.1
CV (%)	27.1	21.2

Key: Means followed by the same letter within a factor per season are not significantly different at p≤0.05 level;
= Season means followed by the same letter along the row are not significantly different

4.1.4.2 Tiller number per m² at Panicle Initiation Stage

NIBAM 108;

Among the tillage treatments at Ahero, ploughing crop had higher tiller count. Highly significant tiller number mean differences at panicle initiation were obtained among the planting methods (Table 14). Wet seeding gave higher number of tillers per m² in both seasons. At Mwea, wet seeded plants had significantly higher tiller counts at panicle initiation in both seasons than the transplanted plants (Table 15). The first season crop had higher tillers at panicle initiation than in the second season.

Mwea site also recorded higher tiller number at panicle initiation stage than Ahero site (Table 31 and 32).

Table 12: Effect of cultivation and planting methods on tiller number per plant at seedling stage in Mwea, Kenya for two seasons - variety NIBAM 108

Methods	Tiller No/plant at seedling stage	
	1st Season	2nd Season
Cultivation method		
Rotavation	4.0a	4.2a
Ploughing	4.7a	3.8a
Zero Tillage	4.7a	3.8a
Planting Method		
Transplanting	2.7b	2.8b
Wet seeding	6.2a	5.1a
Seasons mean#	**4.4a**	**3.9a**
SE	0.2	0.2
CV (%)	19.1	24.6

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different.

Table 13: Effect of cultivation and planting methods on tiller number per plant at seedling stage of NIBAM 10 in Mwea Kenya for two seasons

Methods	Tiller No./plant at seedling stage	
	1st Season	2nd season
Cultivation method		
Rotavation	1.8a	3.2a
Ploughing	1.8a	3.0a
Zero Tillage	1.8a	3.0a
Planting Method		
Transplanting	1.33b	2.0b
Wet seeding	2.33a	4.1a
Seasons mean#	**1.8b**	**3.1a**
SE	0.1	0.2
CV(%)	38.6	40.8

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

Table 14: Effect of cultivation and plant establishment methods on tillers per m^2 at panicle initiation of NIBAM 108 in Ahero, Kenya for two seasons

Method	Tillers /m^2 at panicle initiation	
	1st Season	2nd Season
Cultivation method		
Rotavation	661.5b	783.2a
Ploughing	688.7b	693.8a
Zero Tillage	724.8a	720.2a
Planting Method		
Transplanting	460.2b	499.0b
Wet seeding	923.1a	965.8a
Seasons mean#	**691.7a**	**732.4a**
SE	11	19
CV(%)	8.6	14.3

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different.

Table 15: Effect of cultivation and planting methods on tiller number per m^2 at panicle initiation stage in Mwea, Kenya for two seasons - variety NIBAM 108

Methods	Tiller number per m^2 at panicle initiation stage	
	1st Season	2nd Season
Cultivation method		
Rotavation	867.2a	1218.3a
Ploughing	898.7a	1231.5a
Zero Tillage	894.9a	1249.5a
Planting Method		
Transplanting	397.4b	798.7b
Wet seeding	1376.3a	1667.6a
Seasons mean#	**886.9b**	**1233.1a**
SE	16	31
CV(%)	10.0%	13.8

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different.

NIBAM 10:

Only wet seeded plants attained significantly higher tiller number per m² at panicle initiation than those transplanted in both seasons (Table 16). NIBAM 10 tiller number was lower than that of NIBAM 108 (Table 34).

There was no significant interaction of tillage and planting treatment methods observed on tiller number per m^2 at panicle initiation stage (Appendix 5, 6 and 7). No significant tiller count differences were noted among tillage treatments as indicated by ANOVA (Appendix 6).

4.1.4.3 Productive tillers (Panicle number) per m² at maturity

NIBAM 108:

At Ahero, there was no significant variation in tillering ability among the tillage methods in both seasons (Table 17 and Appendix 5). Wet seeding had significantly higher number of tillers per m² ($P \leq 0.01$) in both seasons. The second season crop had higher tiller number at maturity than the first season.

Table 16: Effect of cultivation and planting methods on tiller number per m² at panicle initiation stage of NIBAM 10 in Mwea, Kenya for two seasons

Methods	Tiller No./m² at panicle initiation stage	
	1st Season	2nd Season
Cultivation method		
Rotavation	700a	1149.7a
Ploughing	525a	1140.8a
Zero Tillage	600a	1153.7a
Planting Method		
Transplanting	383.3b	673.0b
Wet seeding	833.3a	1623.1a
Seasons mean#	**608.3b**	**1148.1a**
SE	112.1	274.1
CV(%)	18.4	23.9

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

At Mwea, tillering variations at maturity were not significantly different among the tillage treatments (Table 17). Wet seeding had the highest tiller number per m² at maturity in both seasons (Table 17). As in Ahero, the second season had higher tiller number at maturity than the first season crop. NIBAM 108 gave significantly higher tiller number at maturity in Mwea than in Ahero during the first season (Table 34).

Table 17: Effect of cultivation and plant establishment methods on productive tillers per m^2 at maturity of NIBAM 108 in Ahero, Kenya for two seasons

Methods	Number of productive tillers per m^2	
	1st Season	2nd Season
Cultivation method		
Rotavation	579.3a	720.3a
Ploughing	453.0a	715.8a
Zero Tillage	634.0a	700.8a
Planting Method		
Transplanting	389.1b	464.7b
Wet seeding	721.8	960.0a
Seasons means$^{\#}$	**555.4b**	**712.3a**
SE	19	23.3
CV(%)	18.6	17.7

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
\# = Season means followed by the same letter along the row are not significantly different

Table 18 Effect of cultivation and planting methods on number of productive tillers per m^2 at maturity in Mwea, Kenya for two seasons - variety NIBAM 108

Methods	Number of productive tillers per m^2	
	1st Season	2nd Season
Cultivation method		
Rotavation	762.3a	906.7a
Ploughing	703.2a	965.8a
Zero Tillage	747.5a	941.2a
Planting Method		
Transplanting	422.8b	622.2b
Wet seeding	1052.4a	1255.6a
Seasons mean$^{\#}$	**737.6b**	**938.3a**
SE	10.3	17
CV(%)	7.6	10.7

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
\# = Season means followed by the same letter along the row are not significantly different.

NIBAM 10:

Tillage methods did not have any significant effect on tillering of NIBAM 10 (Table 19). Wet seeding gave the highest tiller number per m^2 in both seasons. The second season crop had the highest number of tillers at maturity.

Table 19: Effect of cultivation and planting methods on number of productive tillers per m^2 at maturity of NIBAM 10 in Mwea, Kenya for two seasons

Methods	Total No of productive tillers per m^2 at maturity	
	1st Season	2nd Season
Cultivation method		
Rotavation	770.5a	1142.2a
Ploughing	760.8a	1058.0a
Zero Tillage	663.7a	1209.0a
Planting Method		
Transplanting	402.8b	841.7b
Wet seeding	1060.6a	1431.1a
Seasons mean#	**731.7b**	**1136.4a**
SE	25	19
CV(%)	18.6	9.1

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
\# = Season means followed by the same letter along the row are not significantly different

There was no significant productive tiller number differences at maturity resulting from the interaction of tillage and planting methods. (Appendix 5, 6 and 7).

The tillering results imply that at seedling stage all tillage systems provided suitable soil tilth for equal tillering.

High plant density in the nursery could have contributed to the observed lower tiller number and therefore reduced plant vigour of the transplanting seedlings as a result of increased competition for scarce resources. This conforms to Forbes and

Wartson, (1992) indication that plants vigour reduces at condensed plant density. When such rice plants are delayed before transplanting, tillering and yield are reduced (Ali *et al.*, 1995). Wet seeding gave higher tiller number per plant (plant density) than the conventional method of transplanting (Tables 11, 13 and 14). This high tiller number per plant for wet seeded crop is an indication of promoted vegetative growth of plant parts. This fast growth rate did not compromise yield but increased it as reflected in Tables 1 to 3. This suggests that each rice plant had enough room for harvesting water and soil nutrients as well as solar radiation. Higher number of primary tillers per plant at seedling stage in the wet seeded plants possibly enabled the rice plants to exploit available resources better than the transplanted ones.

Tillage treatments in general had no effect on tillering ability of the rice plants at panicle initiation (Tables 14, 15 and 16). Each tillage method gave similar number of tillers at panicle initiation stage irrespective of the rice establishment method applied. This indicates that zero tillage can support similar rice plant growth as the conventional tillage method. Wet seeding treatment had significantly higher tiller number than transplanting at panicle initiation stage. Wet seeded rice plants therefore maintained better plant growth even at panicle initiation stage. This might explain the observed high tiller number per unit area at maturity in wet seeding treatment (Table 17, 18 and 19).

In this study, changing tillage method did not alter the yield component of productive tillers (panicles) number in rice growth (Tables 17, 18 and 19). This concurred with the findings of Lee *et al.*, (1999) who observed that there was no difference in tiller number under different tillage methods. This partly explains the yield similarity of rice crop from the three tillage systems (Table 1 to 3). Rice can therefore be grown in zero tilled paddy fields to achieve tiller numbers equal to those obtained from the conventional tillage system. However, different plant establishment methods significantly affected productive tiller numbers. Wet seeding had the highest tiller count per m^2 compared to transplanting. It is possible that the wet seeded crop achieved better plant density within a short time (during early growth period) than the transplanted ones (Plate 1 and 2) which is in agreement with the findings of Wu, (1992). This might have enabled the wet seeded plants to maximize on few but quality primary tillers per plant. This may partly explain the high yield obtained from wet seeded rice plants. Maximum plant density combined with good root system of direct seeded crop as reported by Jules, (1981) probably enabled rice plants to make better use of solar radiation and soil and water nutrients to influence better plant growth rate and high yields as indicated by Forbes and Watson, (1992). From these results wet seeding appears to have the major influence on rice yield improvement.

As observed for other parameters the rice plants produced higher tillers at Mwea site than at Ahero during the long rain season. This continues to affirm Mwea as better suited climatically for rice production than Ahero.

4.1.5.0 Plant height

4.1.5.1 Plant height at early vegetative phase (Seedling stage)

\NIBAM 108;

At Ahero, the wet seeded crop was significantly taller than the transplanted crop at seedling stage (Table 20). There was no significant height difference among the other treatments. At Mwea, plant height at seedling stage was not significant among the tillage and planting method treatments in both seasons (Appendix 6).

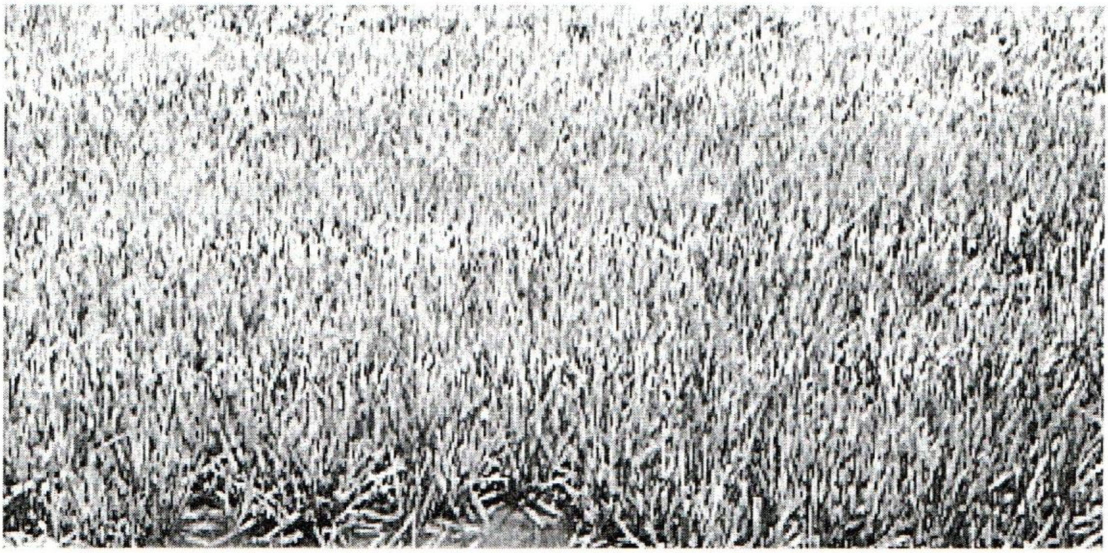
NIBAM 10;

Plant height differences were not significant among the tillage treatment methods (Table 21). The wet seeded plants were significantly taller ($P \leq 0.05$) than the transplanted seedlings in the first season. During the second season, the transplanted seedlings were significantly taller ($p \leq 0.01$) than the wet seeded plants.

Table 20: Effect of cultivation and plant establishment methods on Plant height (cm) at vegetative phase (seedling stage) of NIBAM 108 in Ahero, Kenya for two seasons

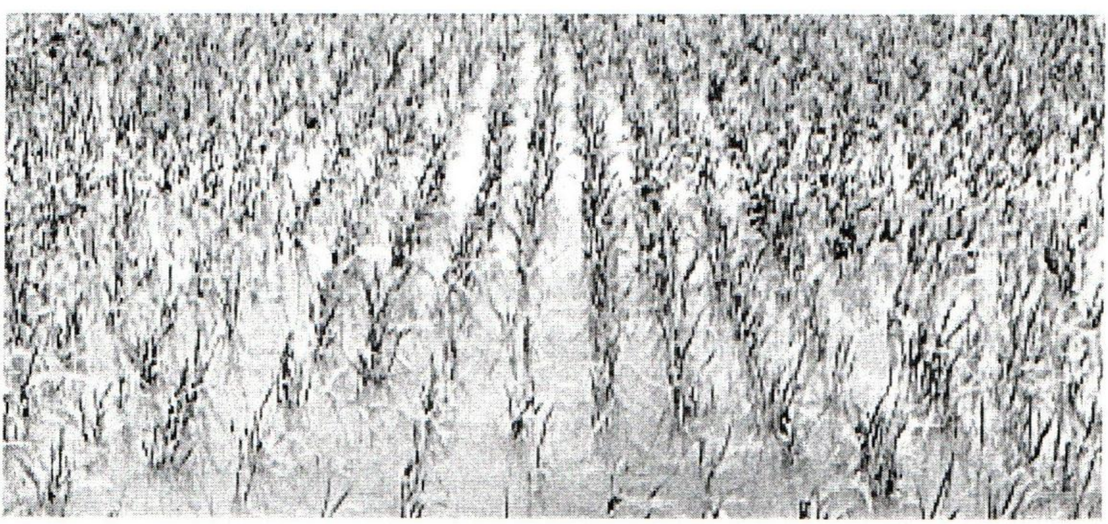
Method	Plant height (cm) at transplanting	
	1st Season	2nd Season
Cultivation method		
Rotavation	12.7a	14.7a
Ploughing	12.7a	14.3a
Zero Tillage	13.3a	15.0a
Planting Method		
Transplanting	11.8b	13.1b
Wet seeding	14.0a	16.2a
Seasons mean#	**12.9b**	**14.2a**
SE	0.1	0.2
CV(%)	5.5	7.4

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different



Source: Author's trial photograph, 1999

Plate 1. Wet seeded rice crop 58 days after sowing



Source: Author's trial photograph, 1999

Plate 2. Transplanted rice crop 58 days after sowing

Table 21: Effect of cultivation and planting methods on plant height at early vegetative phase (seedling stage) in Mwea, Kenya for two seasons - variety NIBAM 10

Methods	Plant height(cm) at transplanting stage	
	1st Season	2nd Season
Cultivation method		
Rotavation	20.3a	25.8a
Ploughing	24.2a	25.8a
Zero Tillage	22.5a	27.5a
Planting Method		
Transplanting	21.4b	29.3a
Wet seeding	23.2a	23.4b
Seasons mean#	**22.3b**	**26.4a**
SE	0.2	0.5
CV(%)	5.2	10.1

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

There was no significant plant height difference at transplanting resulting from the interaction between tillage and planting treatment in all the studied cases (Appendix 5, 6, 7).

4.1.5.2 Plant height at maturity (cm)

NIBAM 108;

During the two seasons at Ahero, mean plant height differences were not significant among all the treatments (Table 22). Similarly, at Mwea there was no significant mean plant height difference among the treatments in both seasons with exception of the transplanted plants, which had significantly high height differences in the second season (Table 23). However, the long rain 1999 crop was taller than the

Short rain crop (Table 30). Mwea Long rain crop was significantly taller than Ahero one (Table 32).

Table 22: Effect of cultivation and plant establishment methods on plant height (cm) at maturity of NIBAM 108 in Ahero, Kenya for two seasons

Methods	Plant height (cm) at maturity	
	1st Season	2nd Season
Cultivation method		
Rotavation	75.7a	75.5a
Ploughing	72.2a	72.5a
Zero Tillage	73.7a	68.5a
Planting Method		
Transplanting	76.9a	74.6a
Wet seeding	70.8a	69.8a
Seasons mean#	**73.9a**	**72.2a**
SE	1.2	1.2
CV(%)	9.6	8.4

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

NIBAM 10:

Cultivation method did not significantly influence plant height at maturity (Table 24). Transplanting treatments had taller plants than wet seeding treatments in both seasons. There was no significant plant height difference at maturity resulting from the interaction between tillage and planting treatment methods in all the studied cases (Appendix 5, 6, 7).

Table 23: Effect of cultivation and planting methods on Plant height at maturity(cm) at Mwea, Kenya for two seasons - variety NIBAM 108

Methods	Plant height (cm)	
	1st Season	2nd Season
Cultivation method		
Rotavation	71.7a	74.0a
Ploughing	68.2a	80.0a
Zero Tillage	68.3a	76.7a
Planting Method		
Transplanting	70.1a	79.0a
Wet seeding	69.0a	74.8b
Seasons mean#	**69.6a**	**76.9b**
SE	0.5	0.6
CV(%)	4.7	4.3

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

Table 24: Effect of cultivation and planting methods on plant height (cm) at maturity for NIBAM 10 in Mwea, Kenya for two seasons

Methods	Plant height(cm)	
	1st Season	2nd Season
Cultivation method		
Rotavation	82.3a	111.2a
Ploughing	87.2a	115.7a
Zero Tillage	85.8a	113.3a
Planting Method		
Transplanting	91.1a	120.1a
Wet seeding	79.1b	106.7b
Seasons mean#	**85.1b**	**113.4a**
SE	5.9	11.4
CV%	7.0	10.1

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

A long culm is an indication of favourable growth condition for proper vegetative growth (Kiyochika), 1989). All tillage methods appear to have provided suitable environment for proper plant physiological and morphological growth during the vegetative phase (Table 20, 21). Tillage practices influenced plant height in a similar manner. The influence of planting methods on plant height at transplanting was not consistent. Generally, the wet seeded crop gave similar plants ($p \leq 0.01$) than the transplanted ones. This indicates that wet seeding treatment also provided suitable environment to enable plants to harvest solar radiation as well as utilize soil and water nutrients, which gave, better growth and higher yields as compared to the conventional system (Table 1 to 3).

Rice plants from all tillage methods were of the same height at maturity (Tables 22, 23, and 24). Generally plant morphological growth was similar in both wet seeded and transplanted plants of NIBAM 108 (Table 22, 23). The wet seeded NIBAM 10 rice plants were shorter than the transplanted ones by an average of 12% in both seasons, respectively (Table 24). NIBAM 10 appear to have responded positively to wet seeding by partitioning most of its assimilates to grain yield rather than to vegetative growth as reflected by short pant height (Table 24) and high grain yield (Table 3). The shortening of the rice plants was associated with an increase in yield. This is expected because NIBAM 10 is a tall-unimproved cultivar whose performance would be increased by acquiring short stature. It is a weak cultivar whose seedlings are easily damaged if poorly handled during transplanting. If widely spaced at transplanting as is common at farmer management level, yields are decreased NIB, (1996c). It is possible that wet seeding minimized these problems.

4.1.6 Harvest Index (HI) (%)

NIBAM 108

In both seasons at Ahero, harvest index differences were not significant among all treatments. Both tillage and plant establishment methods had average HI of 51.7 and 44.1 during the first and second season, respectively.

Transplanting treatment had significantly higher harvest index ($p \leq 0.01$) than wet seeding in Mwea during the first season (Table 25). The second season crop had significantly higher HI than that of the first season.

Table 25: Effect of cultivation and planting methods on Harvest Index (%)in Mwea, Kenya for two seasons - variety NIBAM 108

Methods	Harvest Index (%)	
	1st Season	2nd Season
Cultivation method		
Rotavation	47.8a	45.50a
Ploughing	51.2a	47.8a
Zero Tillage	50.0a	45.5a
Planting Method		
Transplanting	53.4a	49.3a
Wet seeding	45.9b	43.2a
Seasons mean#	**49.7a**	**46.3b**
SE	0.7	0.7
CV(%)	7.6	8.0

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different.

NIBAM 10

Transplanting method resulted in significantly higher ($p \leq 0.01$) harvest index (41.1) than wet seeding (37.1) but tillage had no influence on the trait.

Additionally, interaction between tillage and planting methods was not significant (Appendix 5, 6, 7).

Tillage treatments did not differently affect harvest index (Table 25). Accordingly rice plants had similar growth among the tillage treatments that led to the same yields obtained (Table 1-3). The rice plants partitioned a similar ratio of photosynthates to grain yield and shoot development. However, the lower harvest index recorded on wet seeded plants in Mwea indicated high shoot weight, which could be due to higher recovery of the applied nitrogen as reported by De Datta *et al.*, (1988; 1986). The higher harvest index observed in transplanting treatment suggests higher canopy photosynthesis and a better conversion of photosynthates to harvestable yields. The higher the partitioning ratio of dry matter produced by photosysnthesis to grains the larger becomes the grain yield.

4.1.7 Days to physiological maturity

NIBAM 108;

The crops under zero tillage matured significantly earlier ($p \leq 0.05$) at Ahero than under both rotavation and ploughing in season one (Table 26). Wet seeded crop matured significantly earlier ($P<0.01$) than the transplanted crop.

Table 26: Effect of cultivation and plant establishment methods on days to physiological maturity for NIBAM 108 in Ahero, Kenya for two seasons

Method	Maturity period(days)	
	1st season	2nd season
Cultivation method		
Rotavation	142.5a	135.0a
Ploughing	141.8b	135.2a
Zero Tillage	141.0b	134.0a
Planting Method		
Transplanting	148.9a	140.7a
Wet seeding	134.7b	128.1b
Seasons mean#	**141.8a**	**134.7b**
SE	0.8	0.9
CV(%)	0.6	0.7

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

Table 27: Effect of cultivation and planting methods on days to physiological maturity stage in Mwea, Kenya for two seasons - variety NIBAM 108

Methods	Days to 85% maturity stage	
	1st Season	2nd Season
Cultivation method		
Rotavation	148.2a	150.0a
Ploughing	147.8a	151.5a
Zero Tillage	144.8b	150.5a
Planting Method		
Transplanting	151.2a	154.3a
Wet seeding	142.7b	147.6b
Seasons mean#	**146.9b**	**150.9a**
SE	1.3	0.5
CV(%)	0.9	0.3

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

At Mwea, zero tillage crop matured significantly earlier than the conventional crop in the first season (Table 27). Transplanted crop matured significantly later than wet seeded crop in both seasons.

At both sites the long rain crop took longer to mature than the short rain crop (Tables 26 and 27).

NIBAM 10;

The zero tilled crop matured 3 days earlier than other cultivation methods crop in both seasons (Table 28). Wet seeded crop also matured significantly earlier than the transplanted crop in both seasons.

There were no significant growth duration differences at physiological maturity resulting from the interaction of tillage and planting treatment in all the cases (Appendix 5, 6 and 7).

Table 28: Effect of cultivation and planting methods on days to physiological maturity of NIBAM 10 in Mwea Kenya for two seasons

Methods	Days to 85% maturity	
	1st Season	2nd Season
Cultivation method		
Rotavation	133a	133a
Ploughing	133a	133a
Zero Tillage	131b	130b
Planting Method		
Transplanting	144a	136a
Wet seeding	120b	128b
Seasons mean#	**132a**	**132a**
SE	0.2	0.2
CV(%)	1.0	0.9

Key: Means followed by the same letter within a factor per season are not significantly different at $p \leq 0.05$ level;
= Season means followed by the same letter along the row are not significantly different

These results indicate that rice planted in zero tilled land had generally shortened growth period by an average of 4 days as compared to other test tillage methods (Tables 26, 27 and 28). Zero tillage has therefore an extra advantage of reducing the time taken for the varieties to mature over ploughing and rotavation methods. Zero tillage tends to contribute to increased growth rate without compromising plant growth and grain yield. This is because the studied plant growth parameters and grain yields were comparatively the same in all tillage methods. When compared to transplanting, wet seeding shortened rice growth period by on average, 10 days (Tables 26, 27 and 28). This observation is supported by the faster growth rate observed in wet seeding at seedling stage (Tables 11-13). It is an indication that transplanting shock lengthened plant growth cycle by checking growth as indicated by Schnier *et al*., 1990b. The extended period in transplanting is probably spent in replacement of the roots that are cut during seedling uprooting and leaves that die due to transplanting shock. As such, nutrients were probably diverted to these functions at the expense of plant growth and yield in transplanted plants. Accordingly, lower yields were generally obtained in transplanting than in wet seeding (Tables 1, and 3). A short growth cycle that does not compromise yield has an advantage of saving on water use and time spent in rice fields. Consequently wet seeding rice in a zero tilled paddy field results in double cost saving. This combination does not compromise rice grain yield as indicated by lack of interaction of tillage and plant establishment treatments (Appendix 5, 6, and 7). The system of combining zero tillage with wet seeding could facilitate cultivation of two rice crops per year in paddy fields since it would take shorter period than in the conventional system. The shorter growth duration observed in Ahero as compared to Mwea for NIBAM 108 is attributed to the warmer climate with higher relative humidity and solar radiation, and longer sunshine hours experienced in Ahero than in Mwea (Appendix 1 and 3).

4.1.8 Combined effect of zero tillage and wet seeding (interaction) on rice growth and yield

There was no significant yield difference resulting from the interaction of zero tillage and wet seeding compared to the conventional system (rotavation / transplanting) (Tables 1, 2 and 3). All the other plant growth and yield components except grain number per panicle, responded similarly among tillage and planting method combinations. There was significant difference in grain number per panicle for NIBAM 10 resulting from the interaction of tillage and planting method. Grain number per panicle for NIBAM 10 was highest in the ploughing/transplanting combination. These results indicate that NIBAM 108 variety produces similar number of grains per panicle under zero tillage/wet seeding system as compared to when cultivated under the conventional system. These imply that any of the three tillage methods could be used to grow the two test rice varieties using either wet seeding or transplanting. However, the best-cost effective combination would be zero tillage versus wet seeding. This is because each of these methods has cost saving and other advantages such as ease of application time saving, over the conventional system. This findings agree with what was reported elsewhere by Smith and Baltazar, (1992); Aslam *et al.*, (1993); elsewhere. The planting of rice under zero tillage should therefore be recommended as a cheaper method of producing rice in Kenya subject to cost analysis.

Table 29. Effect of tillage and planting methods on yield, bearing components and growth of NIBAM 108 at Ahero, Kenya during the first and second season

Variable	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m² At maturity	Plant height at maturity (cm)	Harvest index (%)	Tiller/ Plant at 21 DAS	Plant height at 21 DAS (cm)	Tillers/m² at panicle initiation	Maturity Period (days)
Tillage Method										
Rotavation	4477.4a	26.5a	68.5a	649.8a	75.6a	45.8a	2.6a	13.7a	722.3a	138.6a
Ploughing	4387.6a	26.2a	59.2b	584.4a	72.3a	48.5a	2.8a	13.5a	691.3a	138.5a
Zero tillage	4918.0a	26.2a	65.2ab	667.4a	71.1a	48.0a	3.1a	14.2a	722.5a	137.5a
Planting method										
Transplanting	3820.2a	26.2a	71.9a	426.9b	75.7a	46.2a	2.2b	12.4b	479.6b	144.8a
Wet seeding	5368.4b	26.3a	46.6b	840.9a	70.3b	48.7a	3.4a	15.1a	944.4a	131.7b
SEASON										
LR 1998	4266.6a	26.8a	48.3b	555.4b	73.8a	50.8a	2.9a	12.9a	691.7a	141.8a
SR 1998	4922.1a	25.6b	80.2a	712.3a	72.2a	44.1a	2.7a	14.7a	732.4a	134.7b
SE	216	0.2	2	20	1	2	0.1	0.2	14	0.1
C.V.	25.4	4.4	14.6	17.4	8.4	20.6	24	6.0	10.7	0.6

Key: LR = Long rains; means followed by the same letter along the column for each factor are not significantly different; DAS = Days after sowing

Table 30. Effect of tillage and planting methods on yield, bearing components and growth of NIBAM 108 at Mwea, Kenya during the first and second season

Variable	Yield (Kg/ha)	1000 kernel wt(g)	Grains per panicle	Tillers/m^2 At maturity	Plant height at maturity (cm)	Harvest index (%)	Tiller/ Plant at 28 DAS	Plant height at 28 DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Tillage Method										
Rotavation	6833 a	22 b	59 a	836 a	73 a	47 a	4.1 a	19.5a	1043 a	150 a
Ploughing	7458 a	25 a	62 a	834 b	74 a	50 a	4.3a	19.6a	1065 a	150 a
Zero tillage	6835 a	22 b	65 a	844 a	73 a	48 a	4.3a	19.3a	1072 a	148 b
Planting method										
Transplanting	6938 a	24 a	71 a	523 b	75 a	51 a	2.7b	19.6a	598 b	153 a
Wet seeding	7146 a	24 a	53 b	1154 a	72 a	45 b	5.7a	19.3a	1522 a	145 b
Season										
SR 1998	7601 a	24 a	71 a	738 b	70 a	50 a	4.4a	21.5a	887 b	147 b
LR 1999	6482 b	21 b	53 b	939 a	77 b	46 b	3.9a	17.4b	1233 a	151 a
MEAN	7042	22.5	62	838	73	48	4.2	19.5	1060	149
SE	166	0.2	2	16	8	0.6	0.2	0.3	22	0.2
C.V.	13	4	18	11	6	7	19.5	7.6	11	0.6

Key: LR = Long rains; SR = Short rains; Means followed by the same letter along the column for each factor are not significantly different; DAS = Days after sowing

Table 31. Effect of tillage and planting methods on yield, bearing components and growth of NIBAM 108 at Ahero and Mwea, Kenya during the first season (Short rains 1998)

Variable	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant height at maturity (cm)	Harvest index (%)	Tiller/ Plant at 21 and 28 DAS	Plant height at 21 and 28 DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Tillage Method										
Rotavation	6070.3a	24.7a	77.17a	741.33a	73.58a	43.25a	3.25a	18.4a	825.17a	141.58a
Ploughing	6684.6a	25.25a	70.92a	709.42a	70.33a	49.42a	3.67a	17.8a	796.25a	141.50a
Zero tillage	6029.9a	25.016a	78.75a	724.17a	68.67a	48.00a	3.8a	18.1a	807.50a	131.42a
Planting method										
Transplanting	5736.7b	25.13a	84.44a	443.72b	72.33a	47.94a	2.2b	17.3b	448.22b	145.94a
Wet seeding	6786.5a	24.87a	66.78b	1006.22a	69.39a	45.83a	4.9a	189a	1771.06a	135.72b
Location										
Location 1 (Mwea)	6760.1a	24.24b	71.00a	737.61a	69.56a	49.67a	4.4a	21.6a	886.89a	146.94a
Location 2 (Ahero)	4922.1b	25.76a	80.22a	712.33a	72.17a	44.11a	2.7b	14.67b	732.39b	134.72b
SE	192	0.2	2.5	17.6	0.9	1.1	0.1	0.2	18.7	0.1
C.V.	4	4	18	13	7	13	18	6	13	0.7

Key: LR = Long rains; means followed by the same letter along the column for each factor are not significantly different; DAS = Days after sowing

Table 32. Effect of tillage and planting methods on yield, bearing components and growth of NIBAM 108 at Ahero and Mwea, Kenya during the second season (long rains 1998/9

Variable	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m² At maturity	Plant height at maturity (cm)	Harvest index (%)	Plant height at 21 and 28 DAS (cm)	Tiller/ Plant at 21 and 28 DAS	Tillers/m² at panicle initiation	Maturity Period (days)
Tillage Method										
Rotavation	5240.0a	23.92a	50.67a	744.5a	74.83a	49.85a	27.5b	3.42a	939.92a	146.67a
Ploughing	5160.8a	24.01a	50.00a	709.42a	76.08a	48.58a	27.75b	3.33a	960.08a	146.67a
Zero tillage	5723.4a	23.41a	51.33a	787.58a	75.17a	47.75a	29.67a	3.5a	978.17a	145.75a
Planting method										
Transplanting	5021.8b	23.58a	53.39a	505.67b	77.94a	49.67a	26.33b	2.7b	629.44b	151.61a
Wet seeding	5727.7a	23.98a	42.94b	988.67a	72.78b	47.39a	30.28a	4.1a	1295.33a	141.11b
Location										
Location 1 (Mwea)	6482.9a	20.78a	53.00a	938.89a	76.89a	46.28a	34.83a	3.9a	1233.11a	150.94a
Location 2 (Ahero)	4266.6b	26.77b	48.33a	555.44b	73.83b	50.78a	21.78b	2.9b	691.67b	141.78b
SE	104	0.2	1.2	20	0.9	1.5	0.3	0.2	23	0.2
C.V.	10.5	401	12.7	14.3	6.3	16.2	9.0	24.4	13.1	0.6

Key: LR = Long rains; means followed by the same letter along the column for each factor are not significantly different; DAS = Days after sowing

Table 33. Effect of tillage and planting methods on yield, bearing components and growth of NIBAM 10 at Mwea Kenya during the first and second season

Variable	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant height at maturity (cm)	Grain sterility	Tiller/ Plant at 28 DAS	Plant height at 28 DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Tillage Method										
Rotavation	2798.7a	19.49a	34.33a	956.3a	96.8a	24.0a	2.5a	23a	924.8a	132.8a
Ploughing	3312.7a	19.47a	38.42a	909.4a	101.4a	27.3a	2.4a	25a	832.9a	133.0a
Zero tillage	2658.0a	19.12a	31.92a	936.3a	99.6a	25.7a	2.4a	25a	876.8a	130.3a
Planting method										
Transplanting	2633.8b	18.67b	38.22a	622.2b	105.6a	27.8a	1.7b	25.4a	528.2b	139.8a
Wet seeding	3212.0a	20.05a	31.56b	1245.8a	92.9b	23.5a	3.1a	23.3b	1226.2a	124.3b
Season										
1 (LR98)	1285b	19.64a	16.5b	731.7b	85.1b	36.3a	1.8b	22.3b	608.3b	132.2a
2(LR99)	4561a	19.08a	53.3a	1136.4a	113.4a	15.1b	3.1a	26.4a	1148.1a	131.9a
SE	110	0.1	1	0.5	24	4	0.2	0.4	36	0.3
C.V.	20.5	1.9	16.8	30.7	13.7	2.1	37	7.7	22.4	1.1

Key: LR = Long rains; means followed by the same letter along the column for each factor are not significantly different; DAS = Days after sowing

Table 34. Effect of tillage and planting methods on yield, bearing components and growth of NIBAM 108 and 10 at Mwea Kenya during the first and second season

Variable	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant height at maturity (cm)	Harvest index (%)	Tiller/ Plant at 28 DAS	Plant height at 28 DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Tillage Method										
Rotavation	3715a	21a	47a	896a	85a	44a	3.3a	21.3a	984a	141a
Ploughing	4140a	20a	50a	872a	88a	45a	3.3a	22.3a	949a	141a
Zero tillage	3687a	19a	48a	890a	86a	44a	3.3a	22.2a	974a	139a
SE	148	3	4	27	2	0.9	1.3	0.3	39	0.8
Planting method										
Transplanting	3692a	20a	55a	572b	90a	47a	2.2b	22.5a	563b	146a
Wet seeding	4002a	21a	42b	1200a	82b	41b	4.4a	21.3a	1375b	135b
Variety										
NIBAM 108	7042a	22.5b	62a	838b	73b	48a	4.2a	19.5b	1060a	149a
NIBAM 10	2922b	19.7a	35b	934a	99a	41b	2.4b	24.4a	878b	132b
Season										
LR 1998 N 10 & SR 1998 N 108	4443a	.21.9a	44b	735b	77b	46a	3.1a	21.9a	748b	140a
LR 1999	3251b	19b	53a	1038a	95a	43b	3.5a	21.9a	1191a	141a
SE	121	2	4	22	1.6	1.6	1	0.2	32	0.8
C.V.	18.85	7.6	37.6	15.0	11.0	8.2	17	27.9	19.6	2.9

Key: LR = Long rains; means followed by the same letter along the column for each factor are not significantly different; DAS = Days after sowing

5.0 CHAPTER FIVE

5.1.0 CONCLUSION AND RECOMMENDATION

5.1.1 Zero tillage

The ultimate purpose of having a ready seed/seedling bed to enhance rice growth and yield was realized through application of zero tillage cultivation method. This study indicates that zero tilled land can support growth of wet seeded rice plants as well as the conventional tillage method. Zero tillage allowed rice plants to grow and yield the same as those from the conventional tillage method. The method generally gave yields similar to those obtained in ploughing as shown by the two commercial varieties. It resulted in comparative rice growth and yield in both long and short rain seasons. Generally, the observed plant growth parameters responded to zero tillage in a similar manner as in rotavation and ploughing tillage methods. The studied yield components were comparatively influenced by the tillage treatments. This implies that any of the tillage method can be applied to obtain comparable yield. Irrigated rice can therefore be effectively planted in paddy fields that have been prepared by zero tillage. Zero tillage also reduced crop growth cycle without compromising yield. This would be of paramount advantage to the rice farmer. It implies reduced expenditure in terms of irrigation water and labour as well as the crop escapes from adverse weather conditions such as drought and cold. As a result zero tillage system of cultivation at both Mwea and Ahero can be recommended.

5.1.2 Wet Seeding

Wet seeding had the most influence on grain yield. The two rice varieties generally responded better to wet seeding than transplanting by yielding higher. Wet seeding had also more influence on the plant growth components than transplanting. The most significant effect of wet seeding on rice plant growth parameters was increased tiller numbers per unit area. This enabled rice plants to attain optimal plant density, giving higher yield per unit area as indicated by Kiyochika, (1989); Forbes and Wartson, (1992) as well as Matsuo and Hoshikawa, (1993). This seemed to have enabled the wet seeded crop to optimally use the available nutrient resources and have higher recovery of the applied fertilizer N as reported by De Datta *et al*., (1986; 1988).

The Kenyan rice farmers have often lost yield due to low plant density commonly associated with random transplanting (Matsuo and Hoshikawa, 1993). Transplanting of over age seedlings and poor transplanting style at farmer management level aggravate this problem as reported by Katayama, 1931 and Matsuo 1950. Practicing wet seeding would minimize the losses associated with transplanting to the wellbeing of the rice farmer in Kenya. Wet seeding also shortened the plant growth period without compromising grain yield. This is an added advantage for it means reduced water use, labour and enabling late maturing varieties to escape adverse weather periods. The shortening of maturity period also makes the genotype drought escape as reported by Wortmann, (1998), a factor of great advantage in Western Kenya rice Schemes where water stress is common. This coupled with reported ability of wet seeding to save 20-25% water would be of enormous benefit to the rice farmer. If wet seeding is adopted, it would give more time for land preparation, will reduce drudgery among farmers and possibly allow rice crop to escape adverse effects brought by pests and diseases. Considering the observed attributes of the wet seeding rice establishment method, there is high possibility of growing two rice crops per season in rice schemes. The short rain crop appears to do better than the long rain crop in both sites. Hence, implementation of wet seeding as the method of rice establishment might improve the long rain crop.

5.1.3 Zero tillage and wet seeding interaction

Combining zero tillage with wet seeding does not compromise plant growth and yield as observed throughout this study. Performance of zero-tilled wet seeded rice crop was similar to that of conventional tillage and ploughing. Generally, zero-tillage and wet seeded rice had similar growth characteristics as that of conventional tillage and ploughing.

Zero tillage could therefore be a suitable method of enhancing rice yield in Kenya. The advantage of zero tillage is that, it reduces labour, machinery, fuel use, and could increase soil fertility as reported by Smith and Baltazar, (1992). It is also time saving being a major reported device for reducing drudgery among farming communities. Wet seeding has also proved its worth in ensuring maximum utilization of growth resources that have been difficult to fully utilize with the conventional production method. In light of the foregoing, it can be concluded that wet seeding rice in zero tilled land would provide multiple benefits. Consequently, combination of zero tillage and wet seeding should be adopted as new advantageous system of enhancing rice production in Kenya. However, further research is needed to study the economics of the system, incorporate other commercial rice varieties in the system as well as enhance fertilizer management for zero tillage , and wet seeding. Nevertheless, irrespective of the economics involved, zero tillage and wet seeding could be recommended for paddy rice production as they would lead to better utilization of resources and reduced drudgery to especially women and children

The study confirmed short rain rice crop to be superior to the long rain crop in growth and yield. This implies that a long rain crop (second crop) would require more attention to produce. The growth and yield of Mwea site crop was superior to that of Ahero. This suggests that more rice fields could be developed in Mwea to enhance rice production in Kenya..

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APPENDIX

Appendix 1a. Meteorological data for Ahero irrigation research station, Kenya covering 1998

Month 1998	Air max. (°C)	Temp min. (°C)	Rel. hum. (%)	Sun-shine (hours)	Solar rad. (Cal/cm/day)	Wind speed (kph)	Evap. pan (mm).	Rain - fall (mm).
Jan	29.7	17.6	79	6.4	500	3.09	4.5	
Feb	30.6	17.2	73	7.4	530	3.44	5.1	
Mar	32.3	17.3	69	8.6	575	3.60	6.0	99.9
Apr	30.5	18.6	80	7.0	560	3.20	5.0	218.2
May	29.7	18.2	76	6.4	491	3.00	5.3	200.9
Jun	29.5	15.6	74	7.1	507	2.84	5.4	45.1
Jul	29.2	15.6	74	6.0	467	2.98	4.2	11.4
Aug	30.3	15.9	72	6.5	485	3.25	4.7	99.8
Sep	30.9	15.5	67	7.3	539	3.39	5.7	79.2
Oct	30.1	16.9	70	7.0	490	3.12	5.2	162.1
Nov	31.4	15.8	62	7.7	535	2.52	5.2	36.9
Dec	33.0	13.5	54	9.5	575	2.07	7.0	9.0
Total:	**367.2**	**197.7**	**850**	**86.9**	**6254**	**36.52**	**63.3**	**962.5**
Mean:	30.6	16.5	71	7.2	521	3.04	5.3	

Appendix 1b. Meteorological data for Ahero irrigation research station, Kenya covering January –August 1999

Month 1999	Air max. (°C)	Temp min. (°C)	Rel. humidity (%)	Sun-shine (hours)	Solar rad. (Cal/cm/day)	Wind speed (kph)	Evap. pan (mm).	Rain - fall (mm).
Jan	32.3	15.0	62	8.8	544	4.03	5.9	56.1
Feb	34.8	15.6	46	9.7	608	4.65	7.4	3.5
Mar	30.9	18.3	70	6.9	515	4.02	5.1	161.1
Apr	29.8	17.7	67	7.9	513	3.10	5.4	144.8
May	29.8	16.4	68	8.9	525	2.74	5.0	93.7
Jun	30.1	15.5	66	8.4	534	2.75	5.1	39.8
Jul	29.9	15.4	64	7.6	521	2.80	4.8	78.8
Aug	30.4	16.9	64	7.8	529	3.07	5.2	101.0
Total:	**248.0**	**130.8**	**507**	**66.0**	**4289**	**27.16**	**43.9**	**678.8**
Mean:	31.0	16.4	64	8.3	536	3.40	5.5	

Source: Ahero irrigation research station situated 500m from the experimental plots

Appendix 3. Initial soil analysis results for Mwea and Ahero sites respectively

Treatments	$_pH$	N%	P(ppm)	K (me/ 100g)
Zero tillage & Wet seeding	6.20	0.035	11.5	0.68
Zero tillage & Transplanting	6.37	0.028	16.0	0.59
Rotavation & Wet Seeding	6.08	0.032	13.5	0.55
Rotavation & Transplanting	6.37	0.021	13.0	0.57
Ploughing & W/Seeding	6.40	0.025	15.0	0.62
Ploughing & T/planting	6.64	0.025	17.5	0.59
Mean	6.34	0.028	14.4	0.60
Mean for Ahero	6.9	0.04	58	1.00

Appendix 3a. Meteorological data for Mwea irrigation research station, Kenya covering 1998

Month	Air temp		Rel. hum.	Sun-shine	Solar rad. (Cal/cm/ day)	Wind Speed	Evap. pan	Rain fall	Rainy days
	Max.	Min.							
	°C	°C	%	Hours	Lang	Kph	mm	mm	
Jan	27.7	17.6	80	6.9	566	5.05	4.2	174.9	11
Feb	29.7	16.4	67	8.3	663	3.99	5.5	82.9	6
Mar	29.9	16.7	71	8.2	655	4.60	5.6	96.8	5
Apr	29.8	18.0	77	8.0	618	3.69	4.9	233.2	12
May	27.3	17.8	65	6.5	561	4.21	5.2	137.0	
Jun	26.2	16.2	82	5.1	462	1.72	3.7	41.8	1
Jul	23.8	15.2	83	2.1	298	1.30	2.3	10.1	4
Aug	26.1	16.0	60	4.6	471	5.08	5.1	7.0	.
Sep	28.3	16.7	75	6.0	589	4.37	5.0	8.2	2
Oct	30.2	16.3	70	7.6	642	4.01	6.2	6.5	2
Nov	28.0	16.5	81	6.8	559	4.83	4.7	108.3	13
Dec	29.6	14.0	69	9.7	679	4.30	6.1	1.3	1
Total	336.6	197.4	880	79.8	6763	47.15	58.5	908.0	
Mean	28.1	16.5	73	6.7	564	3.93	4.9		

Appendix 3b. Meteorological data for Mwea irrigation research station, Kenya covering 1999

Month	Air max. (°c)	Temp min. (°c)	Rel hum. (%)	Sun-shine hours	Sol rad. (Cal/cm/ day)	Wind speed (kph)	Evap pan (mm)	Rain fall (mm)	Rainy days
Jan	30.8	14.2	70	9.3	645	4.73	6.7	17.6	1
Feb	31.9	14.3	67	10.1	696	5.86	7.8	1.5	1
Mar	31.6	17.2	52	8.4	639	6.42	8.2	94.0	
Apr	28.8	17.6	83	8.1	587	3.23	5.1	108.3	12
May	27.3	17.8	65	6.5	561	4.21	5.2	137	
Jun	25.8	16.5	64	5.4	491	3.92	4.7	12	
Jul	25.2	15.8	63	4.3	441	4.67	4.5	6	
Aug	26.1	16.0	60	4.6	471	5.08	5.1	7	
Total	227.5	129.4	524	56.7	4531	38.12	47.3	383.4	
Mean	28.4	16.2	66	7.1	566	4.77	5.9		

Source: Mwea irrigation research station situated 200m from the experimental plots

Appendix 4. Sample treatment unit layout in the field for both Ahero and Mwea

REP I		REP II		REP III	
PWS	PTP	ZTP	ZWS	RTP	RWS
RTP	RWS	PWS	PTP	ZTP	ZWS
ZWS	ZTP	RWS	RTP	PWS	PTP

Legend:

PTP = ploughing and transplanting
PWS = Ploughing and wet seeding
RTP = Rotavation and Transplanting
RWS = Rotavation and wet seeding
ZTP = Zero tillage and Transplanting
ZWS = Zero tillage and wet seeding

Subplot size = 16 x 14m (224 m^2)

Tillage = 3 levels
Seedling establishment = 2 levels

Appendix 5. Mean square for all variables measured for tillage and planting methods on NIBAM 108 at Ahero, Kenya during the first (Short rains 1998) and second (long rains 1999) seasons

Source of variations	Df	Yield (kg/ha)	1000 grain wt (g)	Grain No. per panicle	Tillers per m^2 at maturity
First season					
Rep	2	408610.4	0.2	36.5	14110.7
Tillage	2	5631342.4**	0.2	55.2	51709.6
RepxTillage	4	739374.2	1.3	48.4	16305.2
Ptm	1	9034083.6**	0.2	1922**	498002**
PlmxTill	2	401990.4	2.9	36.2	10724.7
PtmxTilxRep	6	270680.6	1.8	71.4	10718.6
Total	17				
2nd Season					
Rep	2	201217.2	0.6	231.1	38134.5
Tillage	2	1904727.1	0.3	332.1	625.5
RepxTillage	4	5812434.3**	0.4	20.5	160.1
Ptm	1	12694080.9*	0.0	450	1104098.0**
PtmxTill	2	466816.1	0.2	180.5	17593.2
PtmxTillxrep	6	657634.8	1.8	100	15934.3
Total	17				

Key: * = Significant at p≤0.05; ** = Significant at p≤0.01; Df = degrees of freedon; ,

Rep = replicate; Ptm = Planting Method; Til/Till = tillage

Appendix 5. cont.

Source of variations	DF	Plant height (cm) at maturity stage	Harvest Index (%)	Tiller No. at 42 DAS	Plant height 42 DAS	Tiller No. /m² at panicle initiation stage	Maturity Period (days)
First season							
Rep	2	14	37.6	0.7	2.4	4146	1.4
Tillage	2	18.5	22.9	0.4	0.9	6057.2	3.4*
RepxTillage	4	9.3	164	0.9	0.6	465.7	0.4
Ptm	1	168.1	10.9	0.9	22.2**	964197.6**	910.2**
Ptm xTill	2	13.4	123	0.7	0.9	17260.1	0.1
Ptm x Till x Rep	6	40.3	101	0.6	0.5	3520.2	0.6
Total	17						
2nd Season							
Rep	2	36.2	0.4	0.1	1.2	25030.9	0.2
Tillage	2	74	238	0.4	0.7	12642.9	2.4
RepxTillage	4	34.4	72.5	0.3	1.3*	3577.6	0.7
Ptm	1	102.7	50	16.1**	43.6**	980466.7**	636.1
Ptm xTill	2	34.9	4.7	0.7	0.2	4741.6	0.4
Ptm x Till x rep	6	37	87.1	0.3	1.2	11007.1	0.8
Total	17						

Key: * = Significant at $p \leq 0.05$; ** = Significant at $p \leq 0.01$; Df = degrees of freedon; , Rep=replicate; Ptm = planting method; Till = tillage; DAS = Days after sowing

Appendix 6. Mean square for analysis of Variance measured on all variables for tillage and planting methods on NIBAM 108 during the 1st (Short rains 1998) and 2nd Seasons (long rains 1999) in Mwea, Kenya

Sources of Variation	Df	Yield (kg/ha)	1000 kernel wt (g)	Grain No. per panicle	Grain sterility (%)	Tillers per m2 at maturity	Plant height (cm) at maturity
First season							
Rep.	2	2985817.6	0.8	580.5	72.2	8908.7	48.7
Tillage	2	330335.1	3.2	33.5	10.9	5720.7	20.7
Rep x Till	4	1451809.6	1.2	296.5	81.6	2018	42.9
Ptm	1	794220.1	1.1	2888**	32.0	1784160.5**	5.6
Ptmx Till	2	837018.4	2.6	136.2	52.7	8634.5	11.7
Ptm x Till x Rep	6	909264.4	0.9	129.6	39.8	3111.3	10.5
Total	17						
2nd Season (long rains 1999)							
Rep.	2	697836.2	1.5	6.2*	29.6	73840.2*	42.4
Till	2	1890933.4*	1.6	67.2	44.2	4755.4	54.2
Rep x Till	4	567127.1	0.6	11.1	2.8	9933.2	20.1
Ptm x Till	2	414093.7	0.1	18.7	38.9	5166.5	8.2
Ptm	1	122.7	1.6	470.2**	76.1	1805000**	80.2*
Ptm x Till x Rep	6	331678.2	0.4	35.2	17.6	10168.8	10.9
Total	17						

Key: * = Significant at $p \leq 0.05$; ** = Significant at $p \leq 0.01$ Df = degrees of freedom;; Rep = replicate; Ptm = Planting Method; Till = tillage; wt = weight.

Appendix 6. cont.

Sources of Variation	Df	Harvest Index (%)	Tiller NO./ Plant at 42 DAS	Plant height (cm) 42 DAS	Tillers NO. /m^2 at PI	Maturity Period (days)
First season						
Rep.	2	12.2	0.4	2.7	16610.7	0.2
Till	2	17.2	0.9	1.7	1772.4	20.2**
Rep x Till	4	27.3	0.2	2.9	1320.4	0.4
Ptm	1	256.9**	56.9**	0.2	4312005.6**	329.4**
Ptm x Till	2	5.1	0.9	0.9	1807.7	1.6
Ptm x Till x Rep	6	14.2	0.7	0.8	7840.5	1.7
2nd Season						
Rep.	2	3.7	2.1	0.4	59570.4	3.6*
Till	2	10.9	0.2	1.6	1468.7	1.6
Rep x Till	4	11.5	0.7	4.2	3397355.6**	206.7**
Ptm	1	168.1	24.5	2.7	3145.6	1.6
Ptm x Till	2	24.9	0.7	1.6	15895.4	0.2
Ptm x Till x Rep	6	13.8	0.9	3.3	28832.1	0.2
Total	17					

Key: * = Significant at p≤0.05; ** = Significant at p≤0.01 Df = degrees of freedom; Rep = replicate; Ptm = Planting Method; Till = tillage; wt = weight; DAS = Days after sowing.

Appendix 7. **Mean square for all variables measured for tillage and planting methods on NIBAM 10 at Mwea, Kenya during the first (1998) and second season (1999)**

Source of Variations	Df	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant ht at maturity
1st season						
Rep	2	125543.2	0.0	8.2	16360.2	24.1
Tillage	2	538128.2	0.3	20.2	20948.2	37.4
Rep x Tillage	4	1016647.6	1.1	18.8	34687.8	66.7
Planting method	1	3048803.6*	5.5**	24.5	1947022.2**	648**
Ptm x Till	2	208098.7	0.1	28.2	8320.4	22.2
Ptm x Till x rep	6	2388188	0.3	13.3	18450.8	35.3
2nd Season						
Rep	2	1099363.5**	0.1	55.1	18646.1	203.4
Tillage	2	908493.5	0.3	422.2*	34351.7	30.4
Rep x Tillage	4	332468.5*	0.6**	81.4	19118.6	162.3
Planting method	1	499666.7*	12.5**	11055**	1563501.4**	813.4*
Ptm x Till	2	14396.1	0.0	360.7*	23551.7	112.7
Ptm x Till x rep	6	68040.9	0.0	41.9	10649.9	129.8
Total	17					

Source of Variations	DF	Harvest index (%)	Tiller/ Plant at 42 Days after sowing	Plant height at 42 Days after sowing	Tillers/m^2 at panicle initiation	Maturity Period (days)
1st season						
Rep	2	.	0.2	0.5	17604.2	1.2
Till	2	.	0	22.2**	46250*	8.2**
Rep x T	4	.	0.2	2.9	18385.4	0.3
Ptm	1	.	4.5**	14.2**	911250**	2473.4**
PtmxTill	2	.	0	5.4	12916.7	0.4
Ptm x Till x rep	6	.	0.5	1.3	12569.4	1.7
Total	17					

Key: DF degrees of freedom wt = weight;.. ht= height ** = highly Significant; at $P \leq 0.01$

*= significant at $P \leq 0.05$; Rep=replicate; Ptm= Planting Method;

Till = tillage;

Appendix 7 cont.

Source of Variations	DF	Harvest index (%)	Tiller/ Plant at 42 DAS	Plant height at 42 DAS	Tillers/m^2 at panicle initiation	Maturity Period (days)
2nd Season						
Rep	2	20.2	0.1	6.7	144067.4	0.7
Till	2	1.1	0.1	5.6	258.7	19.1**
Rep x T	4	21.6	0.3	5.6	19517.1	11.1*
Ptm	1	72**	20.1*	156.6**	4062200.1**	256.9**
Ptm x T	2	5.2	0.1	3.6	44653.4	3.7
Ptm x T x rep	6	5.1	1.6	7.1	75104.9	1.3
Total	17					

Key: Df = degrees of freedom wt = weight;..** = highly Significant; at $P \leq 0.01$

*= significant at $P \leq 0.05$; Rep = replicate; Ptm= Planting Method;

Till = tillage; DAS = Days after sowing

Appendix 8. Mean square for all variables measured for tillage and planting methods on NIBAM 108 at Ahero, Kenya during the first and second season

Source of Variations	Df	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant ht at maturity (cm)	Harvest index (%)	Tiller/ Plant at 21 DAS	Plant height at 21 DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Rep	2	646848.3	0.17	45.44	38720.86	28.58	15.19	0.8	3.03	23743.44*	1.08
Tillage	2	967051.08	0.32	268.44	22955.03	64.75	24.11	0.8	1.4	3885.53	5.25**
Planting m	1	21572928.44	0.08	2116.00**	1542564.00**	266.78*	53.78	12.3**	64.0	1944630.**	1534.03**
Sea	4	3867777.77	9.30*	9152.11**	221527.11**	25.00	100.00	0.3	26.4	14924.69	448.03**
Rep x Tillage	2	2710757.03	1.27	40.11	24462.69	20.83	102.44	0.7	1.4	2485.69	0.71
Ptm x Till	1	7526.36	0.91	30.33	27814.75	37.19	47.44	1.3	0.3	19875.58	0.36
Till x Sea		6569018.36*	0.09	118.78	29380.03	27.75	136.33	0.0	0.1	14814.53	0.53
PTM x Sea		155236.00	0.12	256.00	59536.00*	4.00	7.11	4.7**	1.8	34.03	12.25**
Ptm x Till x Sea	2	861280.08	2.04	186.00	503.08	11.08	80.11	0.1	0.8	2126.03	0.08
Ptm x Till x rep x:Sea	18	1360109.12	1.35	88.22	12132.68	37.68	95.4	0.5	0.7	5792.23	0.61
Total	35										

Key: DF degrees of freedom wt = weight;.. ht= height ** = highly Significant; at P≤ 0.01 *= significant at P≤0.05; Rep=replicate; planting M./Ptm= Planting Method; Till = tillage; DAS = Days after sowing

Appendix 9. Mean square for ANOVA of all variables measured for tillage and planting methods on NIBAM 108 at Mwea, Kenya during the first and second season

Source of Variations	Df	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant ht at maturity	Harvest index (%)	Tiller/ Plant at 28 DAS	Plant height at 28 DAS	Tillers/m^2 at panicle initiation	Maturity Period (days)
Rep	2	2644581	0.3	338	66849 **	61	3.4	2.1	0.8	67774 *	2.8
Tillage	2	1556275	2.8	94	341	7	24.5	0.1	0.2	2829	14.8
Planting m	1	387298.7	0.02	2844 **	3589130 **	64	420 **	78.0**	0.7	7682136 **	529
Sea	1	11251552	107 **	2916 **	364615 **	484	103 **	2.3	156.3	1078828 **	114
Rep x Tillage	4	762077.7	0.4	145	4295	24	32	0.6	4.7	2167	1.4
Ptm x Till	2	749366.778	1.4	69	6719	1.6	18	0.1	0.7	13851	1
Till x Sea	2	664993	2.0	6	10136	68	3.5	1.0	0.1	413	7
PTMxSea	1	407044	2.7	513	30	22	4.7	3.4*	2.3	27225	7
Ptm x Till x Sea	2	501745	1.2	85	7081	18	12	1.4	1.1	3852	0.7
Ptm x Till x rep x:Sea	18	808402	1.0	119	7895	19	12	0.7	2.2	1382	0.9
Total	35										

Key: DF degrees of freedom wt = weight;.. ht= height; ** = highly Significant at $P \leq 0.01$; *= significant at $P \leq 0.05$; Rep=replicate; planting M./Ptm= Planting Method; Till = tillage; DAS= days after sowing; Sea = season

Appendix 10. Mean square for all variables measured for tillage and planting methods on NIBAM 108 at Mwea and Ahero, Kenya during the first and shortr rains (first) season 1998

Source of Variations	Df	Yield (Kg/ha)	1000 kernel wt (g)	grains per panicle	Tillers/m^2 At maturity	Plant ht at maturity (cm)	Harvest index (%)	Tiller/ Plant at 28 DAS	Plant height at 28 DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Rep	2	4430934.33*	1.34	48.02	41260.36*	3.44	7.19	0.3	3.7	6313.02	0.33
Tillage	2	1615241.33	0.83	205.86	3061.86	75.02	125.19	1.1	1.0	2549.69	18.08**
Planting m	1	9919350.25**	0.61	2809.00**	2847656.25**	78.02	40.11	66.7**	25.0**	4702392**	940.44**
Loc	1	64590690.03**	20.7**	765.44	575.69	61.36	277.77*	26.7**	427.1**	214832.2**	1344.44**
Rep x Tillage	4	4980575.17*	1.11	205.69	8518.56	81.02*	83.56	0.3	1.8	4819.03	0.91
Ptm x Till	2	94080.33	1.01	5.08	24772.58	15.52	3.69	1.0	0.6	6039.08	1.69
Till x Loc	2	619820.8	2.6	159.7	3284.4	19.7	29.5	0.2	1.4	11865.6	4.5
PTM x Loc	1	3568950.69	0.51	529.00	40602.25*	30.25	266.77*	6.3**	18.8**	590080.03	25.00**
Ptm x Till x Loc	2	1209754.11	1.75	311.58	1455.08	31.08	6.02	0.6	0.003	510.19	0.25
Ptm x Till x rep x Loc	18	1092787.85	0.99	186.10	9014.94	25.00	37.96	0.4	1.2	10447.69	0.87
Total	35										

Key: DF degrees of freedom wt = weight;.. ht= height ** = highly Significant; at P≤ 0.01 *= significant at P≤0.05; Rep=replicate; planting M./Ptm= Planting Method; Till = tillage; DAS = Days after sowing; Loc = location

Appendix 11. Mean square for all variables measured for tillage and planting methods on NIBAM 108 at Mwea and Ahero Kenya during the second (Long rains 1998/9) season

Source of Variations	Df	Yield (Kg/ha)	1000 kernel wt (g)	grains per panicle	Tillers/m^2 At maturity	Plant ht at maturity (cm)	Harvest index (%)	Tiller/ Plant at 28 DAS	Plant height at 42DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Rep	2	160287.58	1.35	26.66	65572.0*	45.03	17.69	2.6*	7.86**	22038.69	1.36
Tillage	2	1112918.08	1.25	5.33	18394.08	5.03	6.77	0.1	0.11	6745.53	3.36*
Planting m	1	4483806.25**	1.44	2146.77**	2099601.0	240.25**	46.69	17.4**	51.36**	3990672**	992.25**
Loc	1	44211417.4**	322.8**	196.0*	1323266.8**	84.0	182.3	10.0**	182.3**	2638459**	756.25**
Rep x Tillage	4	1248912.04*	0.91	42.42	17465.33	10.61	82.07	0.9	1.53	2165.28	1.02
Ptm x Till	2	606877.08	1.44	24.77	9388.08	1.58	61.44	0.5	0.77	32709.69	0.08
Till x Loc	2	6409357.7**	0.5	117.0	38070.9	67.7	27.0	0.5	1.0	780.4	1.6
PTMxLoc	1	4550400.03*	0.32	245.44*	203401.0**	8.03	132.25	0.5	23.36**	370881.0**	124.69**
Ptm x Till xLoc	2	209207.03	1.50	30.11	6503.08	20.03	86.33	8.0**	0.77	445.75	0.19
Ptm x Till x rep x:Loc	18	318712.66	0.969	41.17	11398.59	22.49	61.83	0.9	1.08	1536.31	0.87
Total	35										

Key: DF degrees of freedom wt = weight;.. ht= height ** = highly Significant; at P≤ 0.01 *= significant at P≤0.05; Rep = replicate; planting M./Ptm= Planting Method; Till = tillage; Loc = location; DAS = Days after sowing

Appendix 12. Mean square for all variables measured for tillage and planting methods on NIBAM 10 at Mwea Kenya during the first and second season

Source of Variations	Df	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant ht at maturity (cm)	Tiller/ Plant at 28DAS	Plant height at 28 DAS	Tillers/m^2 at panicle initiation	Maturity Period (days)
Rep	2	944670.33	0.06	12.28	6535.86	85.58	0.1	4.5	97600.36	0.86
Tillage	2	1422417.58*	0.53*	129.53*	6651.36	63.33	.03	14.7*	25362.69	2603**
Ptm	1	3008490.25**	17.22**	400.00**	3500017.36**	1456.69*	21.8**	36.0**	4410700.**	2162.25**
Season	1	96619070.3**	2.8**	12173.4**	1474200.7**	1456.7*	13.4**	148.0**	2621701**	6.4
Rep x Tillage	4	577453.54	1.59**	54.49	37970.94	177.92	0.03	6.7	27181.44	6.36
Ptm x Till	2	165958.58	0.11	257.25**	2030.53	115.44	0.03	3.4	46160.03	1.19
Till x Season	2	24204.1	0.3	312.9**	48648.5	1.1	0.03	13.0*	21146.0	568.0**
Ptm x Season	1	539980.03	0.72	729.00**	10506.25	4.69	2.8	132.3**	562750.03**	568.03**
Ptm x Till x Sea	2	56536.19	0.03	131.58*	29841.58	19.44	0.03	3.4	11410.03	2.03
Ptm x Till x rep x:Sea	18	357975.36	0.14	34.26	16382.62	82.14	0.8	3.5	38726.27	2.23
Total	35									

Key: DF degrees of freedom wt = weight;.. ht= height ** = highly Significant; at P≤ 0.01 *= significant at P≤0.05; Rep=replicate; planting M./Ptm = Planting Method; Till = tillage; DAS = Days after sowing; Sea = Season

Appendix 13. Mean square for all variables measured for tillage and planting methods on NIBAM 108 and 10 at Mwea, Kenya during the first and second season

Source of Variations	Df	Yield (Kg/ha)	1000 kernel wt(g)	grains per panicle	Tillers/m^2 At maturity	Plant ht at maturity (cm)	Harvest index (%)	Tiller/ Plant at 28 DAS	Plant height at 28 DAS (cm)	Tillers/m^2 at panicle initiation	Maturity Period (days)
Var	1	735007194.3**	925**	13230.2**	165120.9**	12194.0**	942.2**	55.1**	430.2**	594958.7**	5151.1**
Rep	2	1756908.0*	275.8	200.1	15790.0	70.5	9.9	1.6	1.0	156322*	0.9
Planting m	1	1728870.1	125.6	2688.9**	7088867.5**	1065.7**	468.2**	91.1**	24.5	11867380**	2415.1**
Tillage	2	1547077.0	22.9	63.38	3845.1	52.6	13.4	0.01	7.1	7788.2	40.0
Sea	1	25569115.6**	926**	1586.7	1652562.0**	5706.7**	103.4**	2.3	0.1	3532039.0**	62.3
Error	64	525562.3	15.6	331.2	17711.3	89.5	13.5	1.0	1149.5	35953.2	16.5
Total	71										

Key: DF degrees of freedom wt = weight;.. ht= height ** = highly Significant; at P≤ 0.01 *= significant at P≤0.05; Rep=replicate; planting M./Ptm= Planting Method; Till = tillage; Sea = season; DAS = Days after sowing