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RESEARCH PAPER

Rice (*Oryza sativa* L.) establishment methods under irrigated and rain-fed lowlands of Kenya: Effect on growth and yield

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Abstract

An experiment was conducted at Ahero and Mwea during July 2017 to January 2018 season; to assess effect of direct seeding (DS) and transplanting (TP) on growth and yield of four rain-fed (NERICA1 & 4, Komboka, MWUR4) and four irrigated (SARO5, Komboka, NIBAM11, MWIR2) varieties, on Kenyan lowlands. A split plot on randomized complete block design (RCBD) was used with three replicates; three seeds hill^{-1} were dibbled, later thinned to one on DS plots, one seedling was transplanted on TP plots. A (20x15) cm spacing used on both DS and TP plots. Data was subjected to analysis of variance, separation of means using Turkey's test at 5% probability level. Results on plant height, productive tillers hill^{-1}, grain weight hill^{-1}, 1000 seed weight, yields (rain-fed) showed non-significance ($p > 0.05$). Days to flowering onset (rain-fed) had significant differences on DSR and TPR. Productive tillers hill^{-1} (Irrigated) were significant ($p<0.05$) while grain yield, grain weight hill^{-1}, 1000 seed weight, days to flowering onset (irrigated) were not significant ($p>0.05$). Grain yield (t ha^{-1}) on rain-fed varieties indicated TP-Komboka (5.6), TP-NERICA1 (4.6) compared to Komboka and MWUR 4 (DS) at 4.9 and 4.3 respectively. Grain yield (t ha^{-1}) (irrigated) had no yield gain on either TP or DS though they differed significantly with NIBAM 11 and MWIR 2 (TP) at 4.9 and 6.9 while DS- (MWIR2 and NIBAM11) at 5.9 and 4.8 respectively. Harvest index positively correlated to grain yield (rain-fed; $r=0.693$, $p<0.001$) (irrigated $r=0.696$, $p<0.001$). Variable costs were TP (KES: 81,850) compared to DS (KES 61,900). Although DS yielded less compared to TP, the aspect of water and labour saving would motivate its wide adoption contributing to enhanced rice productivity.

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Introduction

Demand for rice (*Oryza sativa*) as a consumable cereal crop continues to grow in Kenya and stands as the third preferred staple after maize and wheat (NIB, 2008; Okech *et al.*, 2008, Kimani *et al.*, 2011), with an annual production estimate of 500 million tons (Onyango, 2014). It forms a major part of the diet for the urban population and has become popular in the rural areas. Urban households on relatively lower income are likely to spend a higher portion of their budget on rice compared to families with a higher income scale (Africa Rice, 2011). The high costs of fuel makes rice a better and preferred choice as it cooks fast thus saving time and energy requirements (Mati, 2011). However, rice production is inadequate and the deficit is bridged through imports (Mati *et al.*, 2011). Yield of rice in sub-Saharan Africa is estimated at 1.9t ha^{-1} and 2.2t ha^{-1} under rain-fed upland and irrigated lowland conditions, respectively (Diagne, 2013). Constraints to optimal rice production in Kenya include limited farmer knowledge on appropriate agronomic practices, water scarcity, unavailability of good quality seeds, declined soil fertility, high price of inputs, low market prices, labour shortages and land ownership systems (Emong'or, 2009; Onyango, 2014).

Water scarcity is one of the major constraint for rain-fed and irrigated rice production in sub-Saharan Africa (MoA, 2004). In Kenya, rice farming is done by small holders who transplant rice seedlings from nursery beds to fields that are later flooded with water. This practice is costly and leads to loss of water (Chauhan, 2013). Direct seeding (DS) of dry rice seeds is not widely practiced among the farmers within the study area despite its known benefits that include less labour costs in farm operations such as puddling, nursery establishment and transplanting. Previous studies indicated that DS had a 50% reduction on labour costs, reduced risk of low plant density and saved on water (Pandey, 1999). Similarly, effect of recurrent drought due to climate change has reduced water for flooded irrigation (Mati, 2009; Fisher *et al.*, 2007), and to some extent reduced grain yields.

Due to increasing demand for rice in Kenya, this research focused on productivity improvement per unit area while reducing variable costs incurred in production and management practices as well as promotion of rice varieties with less water requirements compared to conventional flooding systems. Therefore, this study was set with an objective to determine effect of direct seeding and transplanting on growth, yield and labour saving aspect on selected rain-fed and irrigated rice varieties among small holders of Kenyan lowland ecology.

Material and methods

Site description

The study was carried out at Ahero and Mwea during the 2017 main rice growing season. The season is usually between July and December of every year. Mwea is located Mwea East sub-county, Kirinyaga County, latitude 0° 37' S, longitude 37° 20' E and elevation 1159m above sea level. The area received unevenly distributed rainfall during the cropping season with lowest amount in the month of July, 2017 (8.1mm) and highest amount (152.8mm) October, 2017. Maximum and minimum mean temperatures at Mwea ranged from 26°C - 30°C and 14.6°C -18°C, respectively. The soils are of low fertility and classified as deep nitosol, well drained dusky-red to dark reddish-brown, friable clay (Jaetzold *et al*, 2005).

Ahero is located at latitude 00 09'S and longitude 34° 58' E, elevation 1168m above sea level within Kano plains, 25Km along Kisumu-Kericho highway in Kisumu county. During the cropping season, the area received highest rainfall amount of 105mm in November, 2017 and lowest as 70.9mm in September 2017. Mean maximum and minimum temperatures at Ahero ranged between 30.5°C -32.9°C and 16.4°C -17.3°C, respectively. Soils are classified as deep black cotton with high contents of clay (Jaetzold *et al*, 2005) which cracks when dry due to shrinkage and swells on wetting. Soils were sampled before crop establishment to ascertain fertility and texture status (Table 1).

Treatments and Experiment design

Four rain-fed (NERICA 1&4, Komboka, MWUR4) and four irrigated (SARO5, Komboka, NIBAM11, MWIR2) rice varieties were DS and TP on rain-fed and irrigated lowland ecology respectively.

Komboka variety is adaptable to both rain-fed and irrigated environments. A split plot design was used with method of establishment as main plot and variety as subplot. Plant spacing of 20cm x 15cm (inter and intra row) was used on all varieties. On DS plots, 3 dry seeds hill^{-1} were dibbled at 3cm depth and later thinned to one after 15 days. One seedling was transplanted/hill after 21 days in nursery on TP plots. A basal application of NPK 23:23:0 at 60kg ha^{-1} as per soils report recommendations was used.

Data Collection

Crop growth data

Five plants within three middle rows of each variety were tagged and used for purpose of plant height and number of tillers assessment at each sampling. Number of tillers on each of the five tagged plants were counted and recorded while plant height (cm) was measured with a meter ruler to the nearest one decimal from soil level to the tallest plant within a hill. Measurements on growth parameters was repeated after every seven days on DS and TP plots. Growth data on TP crop commenced 7 days after establishment which coincided with 28 days after DS. These sampling dates were maintained because DS was done the same date with soaking seeds with water for nursery establishment. Thus, biological processes for DS rice on moist soils and the soaked seeds for nursery establishment started simultaneously, termed as biological starting date (BSD). In total, seven samplings were done to assess the trend on tiller number and plant height.

The number of days to flowering were counted from BSD to the time when the first plant on each variety flowered; regarded as flowering onset.

Yield and Yield Components

At physiological maturity when plant foliage turned yellowish/brown and grains estimated between 18 to 23% moisture content, the five tagged plants within the three middle rows were harvested separately and used for yield and yield measurements as follows: Tillers with panicles were selected for each of the five hills and counted and recorded as number of productive tillers hill^{-1}. Grains obtained from each hill were adjusted to 11.5% moisture content and weight recorded as grain weight hill^{-1}. Shoot biomass dry weight (g) above ground recorded after the five harvested plants were air dried and weighed when two consecutive readings of each sample was constant. Grains from all panicles within a hill were threshed and winnowed and, number of filled and unfilled grains counted and recorded. Counting of 1000 seeds per plot was done manually and their weight recorded. Harvest index (HI) was determined as ratio of grain yield to yield of aboveground biomass (grains inclusive). Total grain yield (t ha^{-1}) was computed by adding the weight of grains harvested from the middle three rows to grain weight of five sampled plants and then adjusted to 11.5% moisture content.

Statistical Analysis

Data on growth and yield components were subjected to analysis of variance (ANOVA) using GenStat Edition 15th statistical software (VSN International, Jan.2011). Separation of means was by Turkey's test at 5% probability level whenever there was significant difference. Data for rain-fed and irrigated varieties were analyzed separately due to their differences in growth adaptability with regard to water requirements.

Partial Economic Analysis

Partial budget concept was supported by variable costs incurred in DS and TP practices and their mean grain yields used to calculate total revenue (yield x output price) based on prevailing market prices. Total variable costs (TVC) considered were mainly on land and crop management practices (land preparation, weeding, irrigation management, pesticides, harvesting operations, and transportation). Net Return was calculated as the difference between the total revenue (TR) and TVC.

Results and discussions

Soils chemical and texture status

Soils were collected (0-20cm depth) for analysis to ascertain fertility statuses before crop establishment. Soil physical characteristic (colour) on both rain-fed and irrigated blocks at Ahero were homogenous thus only one sample was taken while two samples were tested from Mwea due to physical soil colour differences.

Results of analysis indicated adequate levels of nutrients necessary for rice growth except for percentage total nitrogen (Table 1) that indicated limiting levels. Absence of adequate organic matter was corrected through addition of well decomposed manure at rate of 2.0t ha^{-1} a month before crop establishment.

Table 1. Status of soils sampled at trial sites (0-20cm depth).

Element/ Component	Site		
	Mwea Irrigated	Mwea Rain-fed	Ahero
Texture Grade	Sandy clay	Sandy clay	Sandy clay loam
Sand %	46	46	48
Clay %	44	42	34
Silt %	10	12	18
Soil pH $_{1:1}$	5.12	5.78	6.30
Total Nitrogen %	0.18*	0.17*	0.15*
Manganese me%	1.76***	0.53**	1.50**
Phosphorus ppm	45**	290***	35**
Sodium me%	0.43**	0.35**	0.87**
Copper ppm	8.64**	3.10**	2.78**
Iron ppm	590***	108**	345***
Zinc ppm	7.00**	6.00**	4.08*

* Low, **adequate, ***high.

Growth parameters under rain-fed system

Plant height and Tiller number

Plant height (cm) on rain-fed varieties significantly [F $_{(3,\ 112)}$ = 6.72, P< 0.001] differed by establishment method across sites. Higher plants were recorded under DS compared to TP (Table 2). For DS, variety MWUR 4 at Ahero recorded highest (52.8cm) while Komboka had the least (33.4cm) mean height compared to NERICA1 (43.7cm) and Komboka (31.8cm) for TP, respectively. At 70 days after BSD, the overall mean plant height (60.4cm) on DS- rain-fed varieties (Table 4) significantly [F $_{(6,\ 96)}$ = 4.45, P< 0.001] differed compared to TP (54.1cm). Interaction between rain-fed varieties and establishment method on plant height was not significant ((P>0.05) (Table 3).

Numbers of tillers on rain-fed varieties were not significantly (P>0.05) affected by method of establishment across the sites (Table 2). Again, the varieties by establishment method interaction was not significant (Table 3) on tiller number.

However, there was significant [F $_{(6,\ 96)}$ = 2.61, P = 0.022) rain-fed varieties by stage of growth (BSD) interaction effect with the number of tillers recorded (Table 4). At 70 days after BSD, DS plants recorded a higher number (15) of tillers compared to TP (13).

Table 2. Effect of establishment method on rain-fed variety's height and tiller number at Ahero and Mwea sites.

		AHERO		MWEA	
Establishment method	Varieties	Plant height (cm)	Tiller Number	Plant height (cm)	Tiller Number
Direct Seeding	1	47.84	8.57	39.19	8.01
	2	49.07	7.38	36.69	5.56
	3	33.4	13.9	26.63	9.94
	4	52.78	7.32	37.19	5.64
Transplanting	1	43.7	6.76	33.14	5.62
	2	42.62	5.82	35.2	5.57
	3	31.83	10.26	26.4	8.25
	4	38.92	4.71	36.82	4.64
	CV %	15.4	30.5		
	LSD $_{0.05}$	6.667	2.297		
	p-value	0.001***	0.25 ns		

Where varieties 1=NERICA1; 2=NERICA4; 3=KOMBOKA and 4=MWUR4

Table 3. Effect of Establishment method on variety's plant height and number of tillers across rain-fed sites.

Establishment Method	Varieties	Plant height (cm)	Tiller number
Direct Seeding	1	43.5	8
	2	42.9	6
	3	30.0	12
	4	45.0	6
Transplanting	1	38.4	6
	2	38.9	6
	3	29.1	9
	4	37.9	5
CV (%)		15.4	30.5
LSD$_{(0.05)}$		6.874	2.213
p-value		0.073ns	0.340ns

Varieties 1=NERICA1; 2=NERICA4; 3=KOMBOKA and 4=MWUR4

Results indicated that plant height and tiller number displayed an increasing trend across crop growth stages, thus no extremities in absence of growth limiting factors throughout growing season. Increase in height was progressively rapid from emergence to 70th day after biological starting date and this clearly indicated a growth pattern from vegetative to productive phase with no growth limiting factors (Krishnan *et al.*, 2011).

Tiller number was not statistically affected regardless of the method of establishment. A general overview of lower tiller numbers under DS and TP rain-fed varieties was probably due to in adequate soil moisture that reduced transpiration rate, a means to conserve more water for plant physiological processes (Ashfaq *et al,* 2015).

Table 4. Effect of establishment method on plant height and number of tillers at different growth stages (BSD) under rain-fed system.

Establishment Method	Days after BSD	Plant height (cm)	Tiller number
Direct Seeding	28	14.4	2
	35	22.2	4
	42	37.8	5
	49	42.5	8
	56	50.6	11
	63	54.7	13
	70	60.4	15
Transplanting	28	14.6	1
	35	19.7	3
	42	32.5	4
	49	38.2	6
	56	44.8	8
	63	48.8	11
	70	54.1	13
CV (%)		15.4	30.5
LSD$_{(0.05)}$		7.149	2.263
p-value		<0.001***	0.022*

Growth parameters under irrigated system

Plant height and Tiller number

Plant height was highly significant [F $_{(3,\ 112)}$ = 11.82, P<0.001] on different varieties across the sites on both DS and TP. Direct seeded, NIBAM11 was the tallest at Ahero (48.1cm) and Mwea (42cm) sites while MWIR2 was shortest at (33.2cm and 34.7cm at Ahero and Mwea respectively (Table 5). Again, TP-NIBAM11 variety recorded a high of 40.6cm (Ahero) and 38.9cm (Mwea). Least height on TP practice were posted by MWIR2 (34.9cm) at Ahero and Komboka (32.8cm) at Mwea (Table 5). However, plant height across different stages of growth was not significantly [F $_{(6,\ 96)}$ = 0.32, p=0.924] affected by establishment practice within the irrigated ecology (Table 6).

A significant [F $_{(3,\ 12)}$ = 7.07, p = 0.005] effect on plant height existed between variety and establishment interaction.

A glance on irrigated varieties on Table 7, indicates taller plants under DSR compared to TPR. NIBAM11 was tallest and posted a mean height of 45cm compared to shortest MWIR2 (34cm) on DSR. Transplanted NIBAM11 had high (39.8cm) and least for MWIR2 at 34.4cm (Table 7). NIBAM11 variety had a difference of 5.2cm between the two establishments. This variation was probably attributed by environmental factors since height is dependent on varietal inherent characteristics (Ashrafwzzaman *et al* 2009) though selected irrigated varieties were perceived as low to medium height thus less prone to lodging effect (Mohammad *et al* 2002). Increasing trend on height of irrigated varieties under DS compared to TP system could be attributed to absence of transplanting shock (Dingkuhn, 1990).

Number of tillers on irrigated varieties significantly differed by establishment practice across the sites [F $_{(3,\ 112)}$ = 3.4, p = 0.02] where the general trend indicated more tillers on DSR compared to TPR on both sites (Table 5). Direct seeded MWIR2 had the most number at (21) on both sites. Lowest tiller number was on NIBAM11 with 16 at Ahero, while at Mwea, SARO5, Komboka and NIBAM11 had 17 tillers each as lowest. Transplanted crop yielded less tillers where MWIR2 had 16 and 13 as highest at Ahero and Mwea respectively.

Table 5. Effect of Establishment method on variety's height, and number of tillers across the two sites on Irrigated Ecology.

		AHERO		MWEA	
Establishment method	Varieties	Plant height (cm)	Tiller Number	Plant height (cm)	Tiller Number
Direct Seeding	1	36.8	17	38.4	17
	2	35.9	19	37.4	17
	3	48.1	16	42.0	17
	4	33.2	21	34.7	21
Transplanting	1	35.2	15	33.9	9
	2	36.7	15	32.8	9
	3	40.6	10	38.9	11
	4	34.9	16	34.0	13
	CV %	7.4	21.9		
	LSD $_{0.05}$	3.781	4.859		
	p-value	0.001***	0.02*		

Where varieties 1=SARO 5; 2=KOMBOKA; 3=NIBAM 11 370 and 4=MWIR 2)

A highly significant [F $_{(6,\ 96)}$ = 11.96, P<0.001] effect existed between EST x BSD interaction on trend of tiller number.

Means comparison on tillers (Table 6) illustrated more tillers under DSR compared to TPR at every stage of assessment. The highest mean tiller number at 70 days after BSD was 31 for DS and 23 for TP, with differences ranging between 2 and 8 tillers across DS and TP.

Table 6. Effect of Establishment method on Plant height and number of tillers at different growth stages (BSD) on irrigated Ecology.

Establishment Method	Days after BSD	Plant height (cm)	Tiller number
Direct Seeding	28	18.1	5
	35	28.1	9
	42	30.5	14
	49	39.1	18
	56	45.7	22
	63	49.7	26
	70	56.9	31
Transplanting	28	15.2	3
	35	25.6	6
	42	28.4	9
	49	36.3	11
	56	43.2	16
	63	47.4	19
	70	54.0	23
CV (%)		7.4	21.9
$LSD_{(0.05)}$		4.117	5.396
p-value		0.924	<0.001***

Interaction on selected irrigated varieties and system of establishment (V x EST.) revealed non-significance ($P>0.05$) on tiller number (Table 7).

Yield and yield components of rain-fed varieties

Results showed non-significance ($P>0.05$) on grain weight hill^{-1}, number of productive tillers, 1000 seed weight and total grain yield (t ha^{-1}) on rain-fed varieties under DS and TP. However, number of days to flowering onset were significantly influenced on DS and TP (Table 8), with a significant reduction $[F_{(3,12)} = 9.5, P = 0.0024]$ on DS compared to TR by 12 days on NERICA 1, 11 days on NERICA 4 and 7 days on MWUR 4. However, an inverse effect on days to flowering onset was observed when Komboka was planted through DS as opposed to TP which might be due to chance (Table 8). Overall, number of days to flowering onset was reduced by 7-11days under DS (Table 8) compared to TP. Total grain yield (t ha^{-1}) was not statistically affected under DS and TP, but there were noticeable marginal differences (Table 8) ranging from 0.5t ha^{-1} (MWUR4), 0.7t ha^{-1} (Komboka) and 1.1t ha^{-1} (NERICA 4). However, NERICA 1 maintained the same grain yield (4.6t ha^{-1}) on DSR and TPR. Weight of 1000 seeds of rain-fed varieties und DS and TP and share same opinion with Hailu (2010) that weight of thousand seeds is a varietal inherent yield component least affected by environmental factors.

Table 7. Effect of Establishment method on variety' plant height and number of tillers under irrigated Ecology.

Establishment Method	Varieties	Plant height (cm)	Tiller number
Direct Seeding	1	37.6	17
	2	36.7	18
	3	45.0	17
	4	34.0	21
Transplanting	1	34.6	12
	2	34.7	12
	3	39.8	10
	4	34.4	14
CV %		7.4	21.9
$LSD_{(0.05)}$		3.871	4.824
p-value		0.005**	0.891

Where varieties 1=SARO 5; 2=KOMBOKA; 3=BASMATI 370 and 4=MWIR 2)

Table 8. Effect of establishment method on Yield parameters of four rain-fed varieties on Rain-fed Lowland Ecology.

Establishment Method	Variety	Days to flowering				G.Wt.h^{-1} (g)	P.T h^{-1}	1000 seed Wt. (g)	Y t h^{-1}
		Onset	50%	100%	F.G.R				
Direct Seeding	1	71	85	97	0.143	2.4	11	23.9	4.6
	2	76	86	96	0.145	2.3	8	21.9	4.4
	3	104	109	115	0.174	1.8	12	25.1	4.9
	4	79	87	94	0.119	2.67	10	23.3	4.3
Transplanting	1	83	96	104	0.106	2.6	10	23.1	4.6
	2	87	96	103	0.107	2.7	9	22.2	5.5
	3	100	108	114	0.3	1.7	14	22.3	5.6
	4	86	95	101	0.093	2.5	11	24.4	4.8
CV (%)		4.8	5.4	3.8	38.1	30.5	24.4	12.8	33.8
$LSD_{(0.05)}$		8.204	5.937	7.084	0.0772	1.07	2.509	3.31	2.305
p-value		0.002**	0.069	0.368	0.024*	0.34	0.521	0.422	0.735

Varieties: 1=NERICA1; 2=NERICA4; 3=KOMBOKA and 4=MWUR4

(Filled grains Ratio= F.G.R) (Panicle Wt. /hill g = P.Wt.h^{-1} g) (Productive tillers/hill = P.T h$^{-1)}$ (Yield t/ha = Y t h$^{-1)}$

**: Very significant

Days to flowering onset on rain-fed varieties significantly differed by establishment method. Direct seeded rice attained flowering onset 7-11days earlier than transplanted crop on rain-fed varieties probably due absence of transplanting shock and damaging of roots during seedlings transfer from nursery to main field which confirmed similar report by IRRI (2008) that direct seeded crop reach physiological maturity earlier than transplanted crop. Grain yield on DS and TP rain-fed varieties were statistically equivalent confirming previous reports by Kukal and Aggrawal (2002). However, results confirmed yields of NERICA4 at 5.5t ha^{-1} (TP) compared to 4.4t ha^{-1} (DS) (Table 8) which concurs with Seyuom (2011), who reported that NERICA grown under ideal conditions can achieve over 5.4t ha^{-1}. Similarly, Komboka posted maximum grain yield (t ha^{-1}) at 5.6 and 4.9 under TP and DS respectively, exceeding prior trials with potential production of rain-fed varieties on rain-fed lowlands at 1.2t ha^{-1} (Diagne, 2013). Maximum number of productive tillers were observed on DS-MWUR4 and TP Komboka (Table 8) and agrees with Ratna *et al*, (2015) that higher yields are directly related to higher number of productive tillers.

Yield and yield components of irrigated varieties

Results for total grain yield (t ha^{-1}) confirmed non-significance on DS and TP across the four irrigated varieties. However, marginal differences in grain yield (t ha^{-1}) were noted on TP-MWIR2 and TP-NIBAM11 compared to the same varieties under DS which had an increment of 1.0 and 0.1 (t ha^{-1}) respectively (Table 9). In contrast, yield on DS-Komboka increased by 0.3 (t ha^{-1}) while SARO5 maintained same productivity (5.8t ha^{-1}) practice. Number of productive tillers differed significantly [$F_{(3, 12)} = 3.75$, $p = 0.041$] under TP and DS. Komboka recorded same number of productive tillers (Table 9) on DS and TP. SARO5 and MWIR2 increased tiller number on DS by 5 and 7 respectively. In contrast, NIBAM11 increased one tiller under TP. Grain weight $hill^{-1}$ and thousand seed weight on irrigated varieties were not statistically different (P>0.05) under DSR and TPR. Equally, the number of days to flowering onset was not significantly (P>0.05) affected under DS and TP. Grain yield on both DS and TP irrigated varieties were statistically similar and previously affirmed by Kukal and Aggrawal (2002). Maximum grain yield (t ha^{-1}) was 6.9 (MWIR) and 5.9 (MWIR2, Komboka) under TP and DS respectively which surpasses a report by Diagne (2013) that within irrigated lowlands, potential production for irrigated rice stood at 2.2t ha^{-1}.

Table 9. Effect of establishment method on Yield parameters of four Irrigated varieties on Irrigated lowland Ecology.

Establishment Method	Variety	Days to Flowering			F.G.R	P.T $h^{-1)}$	G.Wt. h^{-1} g)	1000 Seed Wt. (g)	Y t h^{-1}
		Onset	50%	100%					
Direct Seeding	1	102	109	115	0.145	20	2.3	23	5.8
	2	95	102	110	0.122	17	2.3	21.8	5.9
	3	94	100	107	0.15	22	2.3	22.7	4.8
	4	106	114	118	0.211	25	2.7	21.7	5.9
Transplanting	1	103	111	117	0.162	15	2.4	24.3	5.8
	2	98	105	111	0.227	17	2.2	23.7	5.6
	3	98	103	108	0.193	23	2.1	21.1	4.9
	4	108	115	119	0.172	18	2.3	23.1	6.9
CV (%)		1.9	1.5	1.6	48.2	24.3	14.3	13.7	38.3
$LSD_{(0.05)}$		2.478	1.599	2.121	0.0075	3.975	0.502	2.633	2.468
p-value		0.371	0.105	0.193	0.117	0.041*	0.466	0.299	0.831

Varieties 1=SARO 5; 2=KOMBOKA; 3=NIBAM 11and 4=MWIR 2)

(Filled grains Ratio= F.G.R)(Productive tillers/hill = P.T $h^{-1)}$ (Panicle Wt. /hill g = P.Wt.h^{-1} g) (Yield t/ha = Y t $h^{-1)}$

*: significance.

Grain output is largely determined by number of panicles per plant where genotype with higher panicle number are certain to yield more grain (Thakur, 2011). However, Patra (1992) had a contrary opinion that varieties may have higher grain yield and yet possess lower number of panicles per plant comparatively as depicted by TP- MWIR2 and DS-Komboka (Table 9). Increased production of effective tillers was observed on MWIR2 (28%) and SARO5 (25%) on irrigated varieties agreeing to results by Islam (2009) that varieties with more productive tillers per unit area are likely to yield more grain compared to those with few tillers.

Filled Grains Ratio

Ratio of filled grains on rain-fed varieties were statistically [$F_{(3, 12)} = 4.53, P<0.024$] affected under DS and TP methods. As indicated by filled grain ratios of irrigated varieties under evaluation (Fig. 1), TP-Komboka posted higher ratio (0.3) compared to DS (0.174). Direct seeded NERICA 4 and 1, had a ratio of 0.145 and 0.143 respectively. MWUR4 had the least filled grain ratios with 0.093 and 0.119 under TP and DS respectively. However, filled grain ratio on irrigated varieties was not statistically significant under DS and TP though Komboka recorded a higher ratio (0.23) on TP (Table 9) compared to 0.12 on DSR system.

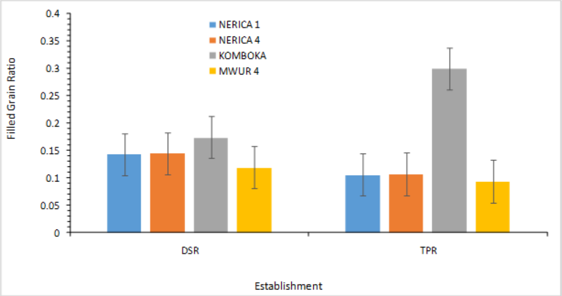

Fig. 1. Effect of establishment practice on filled grain ratio of four rain-fed varieties, error bar represent LSD.

Correlation Analysis

Correlation results indicated a strong linear, and positive relationship between harvest index ($r=0.696, p<0.001$) and grain yield (Fig. 2) on irrigated varieties. Similarly, there was a strong positive correlation between harvest index and grain yield ($r=0.693, p<0.001$) on rain-fed varieties (Fig. 3). Positive correlation between grain yield and harvest index on both rain-fed and irrigated varieties may possibly increase grain productivity and points to similar results on bread wheat (Gelalcha and Hanchinal, 2013).

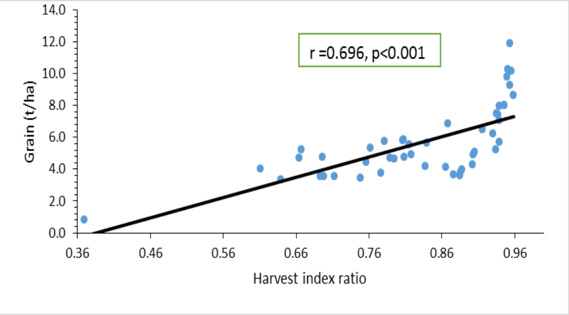

Fig. 2. A Positive linear correlation between harvest index and grain yield on irrigated varieties.

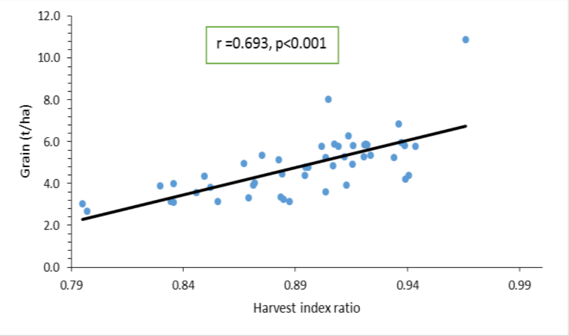

Fig. 3. A Positive linear correlation between harvest index and grain yield on rain-fed varieties.

Partial Budget Analysis

Partial budget was established based on mean yield of four rain-fed varieties under DS (4.6t h^{-1}) and mean of four irrigated yields under TP (5.8t h^{-1}). The decision was arrived at due to statistical similarity in yield performance under each category thus no significant variation. Labour was hired and composed of both manual and mechanized. Mean grain yield (DS and TP) was used to calculate total revenue (yield x output price) based on prevailing market price per a kilogram of rice. Variable costs were higher on TPR compared to DSR (Table 10) specifically on land puddling, nursery management practices and transplanting operations and bird scaring. Direct seeding excludes raising of seedlings in the nursery, uprooting and transplanting and therefore low variable costs with similar results by Kabir (2009). However, demand for weeding labour on DS spreads over longer period, as observed by Kumar and Ladha (2011), with four weeding operations to reduce crop-weed competition thus more grain yields, and probably a higher gross margin (Getachew *et al* 2017).

Table 10. Partial Cost Benefit Analysis of DS-Rain-fed and TP-Irrigated Methods.

Item Category	Cost Itemized	Value (KES) acre $^{-1}$	
		TPR	DSR
Land preparation			
	Plough, Rotavation &levelling	10,000	0
	Plough, Harrow	0	6,000
	Bunds & canal repair/	800	0
	Paddocking		5000
	Manure	5,000	5000
Nursery Management (10m^2)			
	Bed preparation, Seeds, & fertilizer	2,250	0
	(Seeding, Bird scare, weeding, Irrigation)	11,400	
Inputs+ Labour			
	Transplanting/ Seeding/gapping	9,400	7,350
	Fertilizer + pesticide +application	10,650	10,650
	Pesticides	300	300
Management Aspect			
	Weed control	4000	9600
	Bird scaring	11,250	9,500
	Irrigation management	10,000	2,500
	Harvesting	6000	6000
	Total Variable Costs	81,050	61,900
	Yield	2320 kg	1840kg
	Sale price	150 kg^{-1}	130 kg^{-1}
	Net Income	348, 000	239,200
	Net profit	267,950	177,300

Conclusion

Certainly, water for agricultural use continue to decrease and therefore a need to embrace sustainable practices entrenched to water conservation in crop production practices. Great potential is engrained in improvement of existing rain-fed and irrigated rice varieties through appropriate cultivation practices within the lowland ecosystems towards improvement of current food security status. Though grain productivity from this trial did not correspond to expected frontier towards a reduction in rice yield gap, results revealed a substantial improvement with reference to previous studies as mentioned earlier. To overcome water and labour challenges per unit area, DS becomes a viable and sustainable method for adoption in rice establishment. There is associated water trade-off savings under DS as well as ecosystem conservation and thus makes the practice more improved compared to TP.

Direct seeding of rain-fed varieties could also improve on food security status for small holders due to their shorter duration to maturity compared transplanted rain-fed and irrigated varieties.

Authors' declaration

Authors declare that no conflict of interest exists.

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