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Effect of Weeding Regime and Row Direction on Growth and Yield of Upland Rice in Uganda

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study determined the effects of row direction and integrated weed management on the growth, productivity and economics of upland rice at Ikulwe Research Station using a completely randomized block design, replicated thrice with NAMCHE 5 upland rice in Uganda (2021b & 2022b). 12 treatments with 6 weeding regimes namely Pre- emergence Butanil (PREB) + 1hand hoeing (HH), 2HH, 3HH, PREB + Post emergence Butanil (POEB), weekly weeding (42 days) and control (EW & NS orientation) were adopted. Nitrogen (100 kg) Phosphorus (60 kg) and Potash (40 kg) were applied ha^{-1}. Collected data on plant height, tillers, leaves, panicles; and grains were subjected to ANOVA (13th edition Genstat). Higher growth and yield parameters were in EW than NS direction. Leaves (27-28 leaves), height (65-70 cm), tillers (5-6 tillers and panicles (4-5 panicles) plant^{-1} were high under 2HH, PREB +1HH, PREB + POEB and 3HH (EW) compared to similar treatments in NS direction during 2021b and 2022b. Grain yield (2.34 t ha^{-1}; HH), (2.26 t ha^{-1}; PREB + 1 HH), (2.01 t ha^{-1}; PREB + POEB), (1.89 t ha^{-1}; 3HH) was significantly high in 2021b. During 2022b increased panicles (4-5 panicles), panicle length (21 cm), grains panicle^{-1} (110-117

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grains) and grain yield (3.8 - 4.4 t ha^{-1}) were recorded relative to 2021b. Weekly weeding (EW) developed high grains $panicle^{-1}$ (102 grains) and grain yield (3.0 t ha^{-1}) in 2022b relative to reduced tillers (4.5 tillers), filled panicles (3.6 panicles) and grain yield (1.9 t ha^{-1}) in 2021b. Row directions had no effect on leaf width and grass biomass was numerically higher under EW than NS direction. Benefit Cost Ratios and Marginal Rate of Returns were optimum under 2HH and PREB + 1HH (EW). 2HH and PREB + 1HH (EW) may be recommended in Uganda having been the most economic technologies.

Keywords: Benefit cost ratio; butanil; integrated weed management; post-emergence; pre-emergence.

1. INTRODUCTION

Weeds limit the yield in rice production worldwide. Technologies for weed control in rice do not consider the critical period of weed control; ignore an integrated weed management (IWM) approach and row directions. Rice (*Oryza sativa* L.,) has ranked second to maize as a food crop in Uganda for over two decades [1] and providing 20% of the world's dietary energy supply [2]. Over 50% of the world population depends on rice as daily food [3]. Given the increasing demand for rice due to an escalating human population and shift from paddy to upland, it is paramount to generate technologies that would enhance the productivity of upland rice. The crop has been characterised with reduction in profits due to decline in productivity which is associated with drought, poor soil fertility coupled with an increase in incidences of weeds, pests and diseases. Despite the increased production, productivity (1.80 MT ha^{-1}) is still declining (1) relative to the attainable potential (5-6 MT ha^{-1}). The yield of rice can be increased with improved cultivation practices like optimum planting time, planting density, fertilizer management, adequate spacing, proper row direction and weed management. Among the limiting factors, the infestation of weed is one of the most important constraints in the cultivation of rice. The effects of weeds on rice are reduced yield and quality mostly due to competition for nutrients, water and sunlight and in upland direct seeded rice yield reductions are as high as 74% [4]. Weeds are the greatest yield limiting factor in rice production [5], compete with rice for space, nutrients, air, water and light and thus adversely affect rice growth and yields. Weeds promote pests and disease problems by serving as alternate hosts and reduce efficiency of harvesting. Sunil et al. [6], reported losses of 80% in rice yield due to weeds. Higher yield losses due to weeds in upland rice have been observed in Uganda. Phuong et al. [7], observed complete rice crop failure. Weed control in transplanted rice by mechanical and cultural means is an expensive method especially at peak periods requiring labor [8]. In Uganda, the traditional methods of weed control include hand hoeing and preparatory land tillage. Manual weed control is effective against many weeds but difficult to apply due to scarcity and rising wages of labor and its dependence on prevailing weather conditions [9].

Chemical methods are limited to commercial farmers and include application of pre-emergence and post-emergence herbicides but have proven to effectively control weeds at the correct dosages [10]. The production costs therefore increase due to weed control costs. Therefore, use of herbicides integrated with hand hoeing is paramount and gaining popularity. But herbicidal weed controls have some negative impacts on the environment. Yield loss depends upon some variables like magnitude of weed infestation, type of weed species, time of association with crops, fertilization, competitive ability of the variety and cultural management accomplished with control of the pest. Anwar et al. [11], reported that the variety NERICA 4 to be more tolerant to weed pressure than other varieties. This may be attributed to allelopathic influence of NERICA rice in weed control [12, 13], a property that reduces the costs of hand weeding in crop rotation and intercropping systems [14]. A number of studies indicate that weed control through both traditional and chemical methods influence plant height, tiller number, crop growth rate, yield attributes and yield of rice [15]. Proper row direction produces maximum Leaf Area Index (LAI) and higher light interceptions which influences the tillering, panicle initiation, growth, filling and subsequently the grain yield of rice. Anwar et al. [5], reported the east - west (EW) row direction to more effectively control weeds in the rice interow and allow the rice crop to more effectively compete with weeds for the light between the rows. This gives higher growth, yield parameters, grain and biomass yield over north - south (NS) row direction. Improper row orientation affects the physiological activities of rice plant and can reduce potential yield by 15-25% [16].

Adjustment of row spacing [17] and direction is necessary to eliminate crops light competition and create suitable micro-climate for obtaining the maximum grain yield of rice through solar radiation and increased photosynthesis. Rice is a C3 plant that uses the C3 pathway in the dark reaction of photosynthesis and use the Calvin cycle. In C3 plants the photosynthesis process occurs when the stomata are open and thus such crops are more efficient in synthesizing metabolites when in EW than NS orientation [17].

In Uganda few studies have attempted to establish the most effective and economical integrated weed management options in upland rice ecosystems and research on row direction in rice is limited. It was reported [18] that any weed management approach should be aimed at controlling weeds only during the critical period of weed competition for a more cost effective and eco-friendly weed management. The critical period of weed control is defined as the time period in the crop growth cycle, during which weeds must be controlled to prevent unacceptable yield loss [19,20], observed the critical period for NERICA rice to be 14-42 days after sowing and weed control before or after that period had negligible effect on rice grain yield. Weed control outside the critical period may not reduce crop yields below acceptable levels and is negligible [8,5]. Adoption of diverse technology like an integrated weed management using hand hoeing and herbicides is essential for weed management because weed communities are highly responsive to management practices [21, 22,23], found 2HH and Pre-emergence (Atrazine) + 1HH the most cost effective weed control technologies in maize. Therefore this experiment was conducted with the objective of determining the effects of integrated weed management and row direction on growth, yield and economic feasibility of upland rice in Uganda.

2. MATERIALS AND METHODS

2.1 Field Experiment

An experiment was carried out at the National Agricultural Research Organisation (NARO), Ikulwe station in Mayuge District of Uganda during the second rain season of 2021b and 2022B (September-December). Ikulwe is located at $00^{0}26'23.2N$ $033^{0}28'40.9E$, at 1209 meters above sea level. The rainfall at the site during the cropping season (Sept – Dec) was 652 mm during 2021b and 850.6 mm during 2022b (Table 1a). The mean minimum and maximum temperatures during 2021b cropping season were $19.8^{0}C$ and $33^{0}C$ against the annual average temperatures of $18.3^{0}C$ and $32^{0}C$. During 2022b the mean cropping season's minimum and maximum temperatures were $19.5^{0}C$ and $31^{0}C$. The properties of the luvisol soil were established before conducting the experiment and the amounts of organic matter (3.3%), available nitrogen (0.18%), exchangeable phosphorus (5.04 mg kg^{-1}) and 5.05 mg kg-1 exchangeable potassium established. The pH of the soil was 5.6 with textural sand (54%), silt (23%) and clay (23%). The study consisted of 12 treatments with 6 weeding regimes viz. T1= Pre-emergence, Butanil-70; (PREB) 500 EC @ 2.5 l ha^{-1}, T2 = 2 hand hoeing (HH) @ 14 days after emergence (DAE) & 28 DAE, T3= 3HH @ 14, 28 & 42 DAE, T4= PREB, 500 EC @ 1.0 l ha^{-1} & post-emergence, Butanil-70 (POEB) @ 28 DAE, T5=Weekly weeding up to 42 DAE, T6= Control (No weeding) and two row directions, viz. S1= East-West row direction, S2 =North-South row direction. Similar seeding density (200 rice seeds m^{-2} or 50 kg ha^{-1}.was adopted. Butanil-70 (Butachlor + propanil) herbicide used in the experiment is both a pre-and post-emergence type. The experiment was laid out in a randomized complete block design replicated thrice. Thus the total number of unit plots was 36 each measuring 4 × 5 m. The distance between unit plots and replications were 1 m and 1 m, respectively. NAMCHE 5 rice variety was used and the seeds were collected from Pride project, at Namulonge Uganda. Rice seeds were planted by drill method at a spacing of 45 cm between rows and 12.5 cm within the row (1 seed). Fertilizers were applied in the plots @ 100 kg ha^{-1}, 60 kg ha^{-1}, 40 kg ha^{-1} of N, P_2O_5 and K_2O in the form of Urea, Triple Super Phosphate and Muriate of Potash (MP), respectively. The entire amount of TSP and MP were applied as basal at planting and Urea was top dressed in three equal splits at 15 DAE, 30 DAE (tillering stage) & 45 DAE (panicle initiation stage). At 21 DAE 10 plants were selected and tagged for biometric data measurements on plant height, number of tillers, number of leaves, leaf length and width. The plant height was taken from the base of the plant to the base of the flag leaf at panicle initiation stage and the longest and widest parts of the leaves were taken on the tagged plants. Prior to harvest 10 plants per plot were selected randomly (excluding border hills) for collection of data on yield parameters. At harvest (100 DAE), plants within a quadrant were harvested, dried on a cemented floor and the panicles were carefully removed, threshed, cleaned and further dried in the Agronomy Field Laboratory to record the data on grain yield. Weeds in a 1 m square quadrat were completely cut at the ground level and oven dried at 80 °C for 12 hours till constant weight and dry biomass was determined. Data was collected on the yield parameters namely panicles per plant, filled panicles, empty panicles and grains per panicle. All data collected was subjected to analysis of variance using 13th edition of Genstat software. Fischer's least significant difference (LSD) test at *P*< .05 was used to separate treatment.

2.2 Rainfall during 2021b and 2022b

The data on rainfall received during the growing season (September-December) 2021b and 2022b) and measured at Ikulwe Research station is indicated in Table 1a. The weekly and monthly total rainfall during 2022b was higher than during 2021b. The total seasonal rainfall during 2022b was higher (850.6 mm) than during the cropping season (652.0 mm) of 2021b.

2.3 Economic Analysis

Economic analysis of various treatments was determined according to the method by [24]. According to this method the fixed cost (non-treatment) comprised rice seed, fertilisers and machinery inputs and variable costs were the treatment expenditure. A 10% reduction in yield (adjusted yield) is made for economic analysis, considering losses due to harvesting and transportation from the field to the market [25]. Net benefits were obtained by subtracting every variable cost from the gross income. The calculations were in local currency (Uganda Shillings). For calculation of costs 1 US dollar was equivalent to 3,700 Uganda shillings (Ush).

2.3.1 Benefit cost ratio

The Benefit cost ratio provides a competitive advantage and was determined by the formulae:

$$BCR = \frac{\textbf{Gross income } (\textbf{Ush})}{\textbf{Gross cost } (\textbf{Ush})}$$

2.3.2 Marginal rate of returns (MRR%)

The marginal analysis determines the dominance of a treatment on the preceding treatment and estimated through ordering the treatments in increasing order of returns. Marginal cost is the change in cost when an additional unit of a good or service is produced. It is the additional cost you incur when you produce additional units of a product. Marginal benefit is the difference you receive when you make a different choice. The MRR was calculated using the following formula:

$$MRR\ (\%) = \frac{marginal\ net\ benefit\ (Ush)}{marginal\ cost\ (Ush)}$$

Table 1a. Rainfall received during 2021b and 2022b

Month		**2021b**		**2022b**	
September	**Week**	**Weekly rainfall (mm)**	**Weekly total rainfall (mm)**	**Weekly total rainfall (mm)**	**Weekly total rainfall (mm)**
	1	7.3	141.7	110.1	222.9
	2	35.4		34.3	
	3	40.0		48.9	
	4	59		29.6	
October					
	1	86.4	223.0	76.2	228.7
	2	27.1		39.6	
	3	97.9		96.5	
	4	9.6		16.4	
November					
	1	18.9	155.1	19.2	155.1
	2	3.7		18.8	
	3	28.9		13.6	
	4	103.6		103.5	
December					
	1	25.8	132.2	15	243.9
	2	42		106.7	
	3	63.9		90.3	
	4	0.5		31.9	
Total			**652.0**		**850.6**

3. RESULTS

3.1 Growth Parameters and Yield for Rice during 2021b

Table 2a indicates the data on growth parameters namely number of leaves, tillers and plant height taken at panicle initiation stage (45 days after emergence) and on panicles plant^{-1} and yield (100 DAE) for NAMCHE 5 upland rice planted in EW and NS directions under different Integrated Weed Management Options at Ikulwe station during 2021b. Mean number of leaves, plant height, number of tillers and filled panicles per plant were significantly different. Treatments with an EW orientation produced significantly (*P* < .05), higher growth and yield attributes than under NS orientation. 2HH, PREB + 1HH, PREB + POEB and 3HH (EW) produced higher numbers of leaves (27-28 leaves), plant height (65-70 cm), number of tillers (5-6 tillers), filled panicles per plant(4-5 panicles) and significantly (*P* < .05), higher rice grain yield 2.34 kg ha^{-1} (2HH), 2.26 kg ha^{-1} (PREB + 1 HH), 2.0 t ha^{-1} (PREB + POEB) and 1.90 kg ha^{-1} (3 HH) than other treatments. Yield parameters reduced to 4.5 tillers, 3.6 panicles and the rice grain yield (1.3 t ha-1) due to weekly weeding in EW direction. The treatment however, recorded similar number of leaves and plant height to the other treatments. Treatments in NS orientation except weekly weeding produced significantly lower *(P*<.05), leaves (19-23 leaves) than rice in the EW row direction (27-28 leaves). High numbers of filled panicles per plant and numerically higher rice grain yield (1.25 t ha^{-1}) were recorded under weekly weeding amongst NS treatments. Lower number of leaves, tillers, filled panicles per rice plant and grain yield were produced by PREB + POEB, PREB+ 1HH, 2HH and 3HH in NS than under EW row orientation.

The weedy check recorded the lowest numbers of leaves (11-12 leaves), tillers (2 tillers), panicles (2-3 panicles) and rice grain yield amongst all treatments. Field observations indicated higher grass biomass in the EW than NS direction. However row direction did not affect the growth and yield of rice under the controls without weed control treatments.

3.2 Growth Parameters for Rice during 2022b

Data in Table 2b indicates the number of leaves, tillers and plant height, length and width of leaves taken at panicle initiation stage (45 days after emergence) for NAMCHE 5 planted in EW and NS directions under different integrated weed management options at Ikulwe station. A similar trend of observation was made in the data for both seasons. Treatments significantly (*P*< .05) differed except for leaf width during 2022B. EW orientation recorded significantly higher (*P*< .05), data than the NS row orientation. Plant height and leaf length in both EW and NS row directions were at par except under the weedy checks that recorded lower observations. 2HH, PREB + 1 HH besides weekly weeding (EW) recorded significantly (*P*< .05), higher rice growth. PREB + POEB and 3HH (EW) recorded lower numbers of leaves (27 leaves) and tillers (5-6 tillers) than other treatments in similar orientation. High numbers of leaves (36.4 leaves), tillers per plant (8 tillers), numerically high plant height (55.8 cm) and leaf length (44.2 cm) were recorded under weekly weeding in NS relative to other treatments in similar orientation. 2HH and 3HH treatments (NS) produced numerically high number of leaves (30 & 28 leaves), plant height (61 & 58 cm) and length of leaves (41 & 43 leaves) per plant. Weedy checks under the EW and NS row directions recorded the lowest plant height (8 & 10 cm), number of tillers (2 & 3 tillers) and leaf length (25 & 26 cm) amongst the treatments.

3.3 Yield Parameters and Yield of Rice during 2022b

Data on yield parameters and yield taken at harvest (100 DAE) of rice planted in EW and NS row directions is presented in Table 2c. EW row direction treatments produced significantly (*P*< .05) high panicles (4-5 panicles) per plant, longer panicles (18-22 cm), and rice grain yield (3.0-4.4 t ha^{-1}). 2HH, PREB + 1HH and 3HH in the EW row direction gave numerically higher panicles (3.9-4.8 panicles), panicle length (20.6-21.2 cm), grains per panicle (110-117 grains) and grain yield of (4.40, 4.20, 4.0 and 3.8 t ha^{-1}). Weekly weeding (EW) produced lower grains panicle^{-1} (102 grains) and grain yield (3.0 t ha^{-1}). Weekly weeding and PREB + POEB (NS) produced reduced panicle length (16 & 17 cm), filled panicles (3.0 panicles) and grains per panicle (92 grains). Weedy checks gave lower number of leaves, plant height, number of tillers and shorter leaves than all other treatments.

3.4 Biomass of Weeds in Weedy (Control) Treatments

EW orientation controls produced on average 10 t ha^{-1} compared to a lower weight of 7.5 t ha^{-1} of weeds in the NS row direction.

3.5 Economic Analysis during 2022b

3.5.1 Production costs and income

Economic analysis of treatments is indicated in Table 3. Higher gross income, grain yield and adjusted yield were under 2HH and PREB + 1HH in the EW row direction. 3HH (EW) and PREB + POEB (EW) similarly recorded high grain yield and monetary returns. The latter 2 treatment however, had high variable production costs with low net gross income. Highest total variable costs (1,590 Ush per hectare) were observed under the weekly weeding with low grain yield and gross net income.

3.5.2 Benefit cost ratios for weeding regimes in Wand NS directions during 2021a and 2022b

The maximum Benefit Cost Ratios (BCR) was observed in 2HH and PREB + 1HH in the EW

Table 2a. Growth parameters and yield for NAMCHE 5 planted in EW and NS directions under different integrated weed management options at Ikulwe station during 2021b

Treatment	Data per plant				Grain yield ($t\ ha^{-1}$)
	Leaves	Height (cm)	Tillers	Filled panicles	
2HH (EW)	27.7a	64.8a	5.8a	4.8a	2.34a
PREB + 1 HH (EW)	28.3a	67.9a	5.7a	4.8a	2.26a
PREB + POEB (EW)	26.9a	69.7a	5.0a	4.4a	2.01a
3HH (EW)	26.7a	64.8a	5.1a	4.0a	1.90a
Weekly weeding (EW)	26.6a	64.7a	4.5b	3.6b	1.29b
Weekly weeding (NS)	26.8a	57.3b	4.2b	3.8a	1.25b
PREB + POEB (NS)	22.6b	61.0b	4.0b	3.5b	1.20b
PREB+ 1HH (NS)	22.3b	59.1b	3.7b	3.3b	1.21b
2HH (NS)	20.7b	55.1b	3.8b	3.5b	0.81b
3HH (NS)	18.9b	53.8c	3.3b	3.5b	0,63b
WEEDY (EW)	10.6c	61.1b	2.0c	2.4c	0. 34c
WEEDY (NS)	12.1c	56.5b	1.6c	2.3c	0.33c
P = (.005)	<0.001	<0.001	<0.001	0.002	0.002
LSD	8.2	7.07	1.20	1.12	44.4
(CV %)	19.7	6.1	21.7	16.7	44.4

Values with different letters in a column are significantly different at $P \leq 0.05$, HH = hand hoeing, EW = east - west, NS = north - south, PREB = pre- emergence Butanil, POEB = post emergence Butanil, $t\ ha^{-1}$ = tons per hectare

Table 2b. Growth parameters for NAMCHE 5 planted in EW and NS directions under different integrated weed management options at Ikulwe station during 2022B

Treatment	Data per plant				
	Leaves	Height (cm)	Tillers	Leaf length (cm)	Leaf width (mm)
2HH (EW)	45.5a	64.8a	9.9a	39.3a	19.6
PREB + 1HH (EW)	37.7a	51.0a	8.0a	37.3a	17.0
Weekly weeding (EW)	41.9a	55.4a	7.5a	39.4a	10.7
PREB + POEB (EW)	27.4b	51.3a	5.3b	43.2a	17.9
3HH (EW)	27.4b	64.8a	6.0b	39.9a	14.3
Weekly weeding (NS)	36.4a	55.8a	8.0a	44.2a	10.7
PREB + POEB (NS)	25.0b	43.5a	4.7b	40.0a	17.0
PREB + 1HH (NS)	26.4b	48.6a	5.8b	37.7a	15.6
2HH (NS)	30.2b	57.2a	4.2b	43.4a	18.5
3HH (NS)	27.6b	60.9a	5.8b	40.8a	17.1
WEEDY (EW)	10.0c	35.0b	3.0c	26.0b	11.2
WEEDY (NS)	7.85c	34.1b	2.4c	25.3b	9.1
P = (.005)	< 0.001	0 .004	< 0.001	< 0.001	0.68
LSD	9.86	29.6	2.38	7.4	NS
(CV %)	13.1	11.6	13.1	7.3	36.3

Values with different letters in a column are significantly different at $P \leq .05$, HH = Hand Hoeing, EW = East - West, NS = North – South, PREB = Pre- emergence Butanil, POEB = Post emergence Butanil

Table 2c. Yield parameters and yield for NAMCHE 5 planted in EW and NS directions under different integrated weed management options at Ikulwe during 2022B

Treatment	Mean plant yield parameters			Grain yield
	Filled panicles	Panicle length (cm)	Grains panicle^{-1}	(t ha^{-1})
2HH (EW)	4.9a	21.2a	115a	4.40a
PREB + 1HH (EW)	4.0a	22.5a	117a	4.14a
3HH (EW)	3.8a	20.6a	116a	4.01a
PREB + POEB (EW)	3.8a	18.4b	110a	3.84a
Weekly weeding (EW)	3.8a	19.3a	102b	3.00b
2HH (NS)	3.0b	19.2b	92b	2.62b
Weekly weeding (NS)	3.0b	16.7c	92b	3.00b
PREB + POEB (NS)	3.0b	15.5c	93b	2.98b
POEB+ 1HH (NS)	2.7b	18.3b	90b	2.48b
3HH (NS)	3.0b	19.3b	92b	2.43b
WEEDY (EW)	1.0c	8.5d	11.5c	1.70c
WEEDY (NS)	1.0c	9.0d	9.5c	0.75c
P (.005)	<0.001	<0.001	<0.001	<0.001
LSD	1.2	2.0	23.6	1.20
(CV %)	16.7	4.5	10.2	22.2

Values with different letters in a column are significantly different at P≤0.05, HH = hand hoeing, EW = east - west, NS = north - south, PREB = pre- emergence Butanil, POEB = post emergence Butanil, t ha^{-1} = tons per hectare'

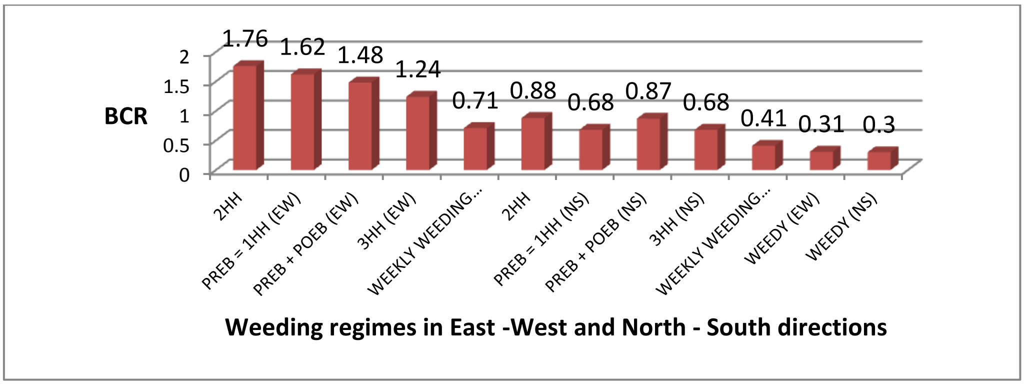

Fig. 1. Benefit Cost Ratios (BCR) for weeding regimes in EW and NS directions during 2021

The highest BCR were 1.76 (2HH) and 1.62 (PREB + 1HH) in 2021b and 3.3 (HH) and 2.9 (PREB + 1HH) during 2022b. The treatments PREB + POEB (EW), 3HH recorded and weekly weeding gave low BCR

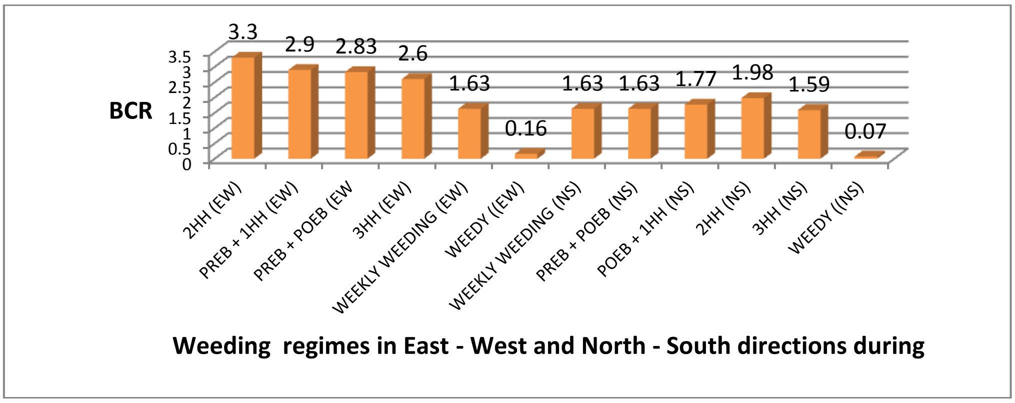

Fig. 2. Benefit Cost Ratios (BCR) for weeding regimes in EW and NS directions during 2022B

row direction during 2021b (Fig. 1) and 2022b (Fig. 2). NS orientation recorded lower BCR than EW row treatments. PREB + POEB (EW) and 3HH recorded low BCR.

Table 3. Economic analysis of the treatments

Parameter	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	Remarks
Grain yield ($t\ ha^{-1}$)	4.84	4.51	4.4	4.18	3.3	0.22	2.86	0.28	0.26	3.3	3.3	0.09	
Adjusted yield	4.4	4.1	4.0	3.8	3.0	0.2	2.6	2.5	2.4	3.0	3.0	0.08	Tons per ha (10% reduction at farm level)
Gross income	4,686	4,510	3,786	4,014	2,586	686	1,620	2,420	1,266	2,380	2,500	652	Rice price = 1,500 Ush
Labor, seed and fertilisers	2,070	2,070	2,070	2,070	2,070	2,070	2,070	2,070	2,070	2,070	2,070	2,070	Total labor cost
Herbicide application costs	0	125	0	250	0	0	0	125	0	250	0	0	Cost of herbicide + spraying labor
Weeding, harvesting & processing costs	400	390	600	0	1,200	30	400	200	600	0	1,200	30	Total weeding costs
Other variable costs	190	200	390	640	390	0	190	390	390	390	390	0	Cleaning and handling
Total Variable costs	590	715	990	640	1,590	30	590	715	990	640	1,590	30	Ush
Gross production costs	2,660	2,785	3,060	2,710	3,660	2,040	2,660	2,785	3,060	2,710	3,660	2,070	Ush
Net income (Benefits)	4,686	4,510	3,786	4,014	2,586	686	1,620	2,420	1,266	2,380	2,500	652	Ush per ha

T_1 = 2HH (EW), T_2 = PREB + 1HH (EW), T_3 = 3HH (EW), T_4 = PREB + POEB (EW), T_5 = Weekly weeding (EW), T_6 = WEEDY CHECK (EW), T_7 = 2HH (NS), T_8 = PREB + 1HH (NS), T_9 = 3HH (NS), T_{10} = PREB + POEB (NS), T_{11} = Weekly weeding (NS), T_{12} = WEEDY CHECK (NS),

Table 4. Marginal rate of returns (2022b)

Treatments	Variable costs (Ush)	Net profits (Ush)	Marginal costs (Ush)	Marginal net benefits (Ush)	MRR (%)
Weedy check (EW)	30	686			
2HH (EW)	590	4,686	**560**	**4000**	**714.3**
PREB + POEB (EW)	640	4,014	**50**	**D**	
PREB + 1HH (EW)	715	4,510	**75**	**496**	**661.3**
3HH (EW)	990	3,786	**275**	**D**	
Weekly weeding (EW)	1590	2,586	**600**	**D**	

D = Dominance due to the high cost of production, MRR = Marginal rate of return (%), 1 Us Dollar = 3,700 Ush.

3.5.3 Marginal rate of return from the experiment

Marginal rate of return (MRR %) for EW orientation were positive but lower values than zero were recorded for all NS orientation (Data not shown) and under PREB + POEB, 3HH and weekly weeding in EW (Table 4). 2HH (EW) and PREB + 1HH (EW) produced the highest MRR of 714% and 661% respectively.

4. DISCUSSION

4.1 Growth, Yield Parameters and Yield for Rice during 2021b and 2022b

Results for the growth and yield parameters in EW and NS row directions had a similar trend during 2021b and 2022b cropping seasons. Higher biometric data collected and yield during 2022B may be attributed to the higher and evenly distributed rainfall during the latter season. Significantly higher growth and yield than rice in EW than NS row directions. Results may be attributed to increased development of the growth and yield attributes in rice a C3 plant. C3 plants established in the EW row direction smother weeds within the inter-rows, eliminate crops competition for light, soil moisture and nutrients and create suitable micro-climate for growth. Generally C3 plants have high rates of photorespiration [22] and have lower numbers of chloroplasts than C4 plants Rising Cabondioxide levels gives comparative advantages to C3 plants through increased photosynthesis, biomass production and yield compared to C4 plants. C4 plants benefit from rising global temperatures than C3 plants [22]. EW row direction thus, eliminates crops' light competition and creates suitable micro-climate for enhanced physiological processes and growth of rice. Results are supported by [7] and [17]. 2HH, + 1 HH, PREB + POEB and 3HH in the EW direction produced higher growth attributes, yield attributes and grain yield than other treatments. This may be attributed to more effective control of the weeds at the critical period (CP) of weed control under the treatments. CP for upland rice is on average 15 - 45 days after seed germination (DAG) and this coincided with the period when hand hoeing (14, 28 & 42 days after seed emergency (DAE) and time of application of both the pre (planting) and post emergence (28 DAE) herbicides were applied. [19,20], reported the critical period for NERICA rice to be 14-42 days after sowing. [26], observed chemical weed control to increase the growth and yield of associated rice crop.

Weed free conditions up to 42 DAE of rice in the EW row direction reduced the yield parameters and rice grain yield relative to the other treatments in EW row orientation. Reduction in yield attributes and yield is associated with the high exposure of the root zone and plant roots to high temperatures, increased moisture and nutrients loss through erosion leaching and evaporation, Rice being a C3 plant is adapted to cool conditions. Similar number of leaves and plant height under the weekly weeding and all EW row treatments may be associated with possible equivalent interception of solar radiation and nutrient and water uptake by rice coupled with reduced competition with weeds under conditions of low weed density for rice under the 3 different treatments. EW orientation could have had similar above ground conditions for the CP (15 - 45 DAG) of weed control. Lower number of leaves, tillers, panicles per rice plant and grain yield per hectare for rice the NS row direction than rice in the EW row orientation under all treatments may be attributed to possible low interception of solar radiation during the CP of weed control and reduced uptake of soil moisture and nutrients that may be associated with inter-species competition between rice and increased weed densities in the NS row directions. Weekly weeding in NS direction gave high leaves, panicles per plant and numerically high rice grain yield. Results may be attributed to effective interception of solar radiation soil moisture and nutrients during the critical period of weed control under this treatment. [15], reported weed control to significantly influence plant height, tiller number, crop growth rate, yield attributes and yield of rice. Weedy checks produced low numbers of leaves, tillers, panicles and rice grain yield amongst all treatments. This may be linked to reduced physiological processes that influence crop growth, development and yields of the rice crop due to competition with weeds for space, nutrients, air, water and light. Reduced yield losses of 74% and 80% were reported by [4, 6] in rice. [7], reported 100% yield loss due to weed infestation in rice. Higher grass biomass under the weedy check in the EW than NS direction may be attributed to the higher biomass development due to higher interception of solar radiation by weeds between rice rows in the EW than SW row direction. Physiological processes that would enhance rice crop growth were hindered by the high weed density irrespective of the rice row direction.

4.2 Yield Parameters and Yield of Rice during 2022b

Rice in EW row direction produced significantly high panicles per plant, longer panicles and rice grain yield. Results may be accredited to increased development of the growth, yield attributes and yield of rice which is a C3 plant. When C_3 plants are planted in the EW row direction, they smother weeds within the inter-rows resulting into reduced competition between rice and weeds for nutrients and air. Results are supported by [17] who reported that crops EW orientation reduces light competition and creates suitable micro-climate for obtaining the maximum rice grain yield through solar radiation interception and increased photosynthesis. This condition could have led to enhanced crop physiological processes like water and nutrient uptake, solar radiation absorption and increased deposition of assimilates in the yield components and high grain yield. Increased crop growth by C3 in EW row direction was similarly observed by [7]. [16] similarly observed that improper rice row orientation affects crop growth and yields. 2HH, PREB + 1 HH and weekly weeding (EW) recorded higher yield parameters and grain yield than other treatments. This is associated with effective control of the weeds done at the critical period (CP) of weed control (15-45DAG) under the treatments. The 3 treatments exhibited weed free conditions during the CP that enhanced development of yield attributes and grain yield. [19, 20] emphasized the significance of weed control during the CP in order to maximize rice yields. Grains per panicles, length of grains, and grain yield under weekly weeding was low. High exposure of the root zone and plant roots to high temperatures, increased loss of moisture and nutrients from the soil may have caused the result. On the contrary, [16] observed highest rice grain yield (6.71t ha^{-1}) under weed free conditions. PREB + POEB treatment in the NS row direction similarly produced short rice panicles which may be attributed to reduced nutrient uptake from the soil under conditions of highly exposed soil conditions under the treatment. Lower number of leaves, plant height, number of tillers and shorter leaves under the weedy checks than all other treatments relates to possible reduction in the physiological process that promote crop growth. Weeds have been reported to reduce rice crop growth yield attributes and yield [5, 6, 7]. EW control treatment produced 10 Mt Ha^{-1} compared to a lower weight of 7.5 Mt Ha^{-1} of weeds in the NS row direction. This could have resulted from the higher absorption of incident radiation, ambient soil conditions and reserve moisture in EW orientation. Such conditions could have favored higher weed seed germination and development than under NS direction. The latter was reported by [5] who noted that crops in EW are more competitive than in NS orientation.

4.3 Economics of Weed Management Options

4.3.1 Production costs and income

2HH and PREB + 1HH (EW) produced high net income due to the high gross returns arising from high rice grain yields and low net costs of production in 2021b and 2022b. Low net gross income from 3HH and PREB + POEB and weekly weeding (EW), despite relatively high grain yield was due to high variable production costs. Highest variable costs were under weekly weeding due to high variable labor costs.

4.3.2 Benefit cost ratio

Maximum BCR that were observed under 2HH and PREB + 1HH in the EW row direction during 2021b and 2022b originated from the high rice grain yield and accrued net income with relatively low production costs. Low BCR under PREB + POEB (EW) and 3HH were due to high production labor costs.

4.3.3 Marginal rate of return

High and positive marginal rate of return (MRR %) for EW orientation during 2022B signified the superiority of EW over NS direction in economic benefits from rice production. The high MRR % under 2HH (EW) and PREB + 1HH (EW) during 2022B indicated that the 2 treatments were the most economical for any additional investment of added costs. Kaiira *et al*, (2014) similarly recommended 2HH and pre application of Atrazine herbicide (2 L ha^{-1}) as the most economical for maize production in Uganda. Lower values of MRR (< 0) were recorded for all treatments in NS orientation and under PREB + POEB, 3HH and weekly weeding (D) in EW orientation due to high investment costs under the treatments.

5. CONCLUSION

The numbers of leaves, plant height, tillers $plant^{-1}$, leaf length, total panicles $plant^{-1}$, panicle length and grains $panicle^{-1}$ significantly differed under treatments during 2021b and 2022b. The 2021b (EW) treatments namely; 2HH, PREB + 1HH, PREB + POEB and 3HH (EW) produced higher numbers of leaves (27-28 leaves), plant height (65-70 cm), number of tillers (5-6 tillers) and filled panicles $plant^{-1}$ (4-5 panicles). The corresponding rice grain yield was 2.34, 2.26, 2.0 and 1.90 kg ha^{-1} respectively. In 2022b (EW) 2HH, PREB + 1HH, PREB + POEB and 3HH gave numerically higher filled panicles $plant^{-1}$(4-5 panicles), panicle length (18-22 cm), grains $panicle^{-1}$ (110-117 grains) with respectively high grain yield of 4.40, 4.20, 4.0 and 3.8 t ha^{-1}. During 2021b the yield parameters reduced to 4.5 tillers, 3.6 filled panicles and a rice grain yield of 1.3 t ha^{-1} due to weekly weeding in EW direction. Weekly weeding (EW) in 2022b on the contrary, produced high numbers of leaves (36 leaves), tillers per plant (8 tillers), plant height (56 cm), leaf length (44 cm), filled panicles (4.0 panicles), long panicles (19 cm) and grains $panicle^{-1}$ (102 grains) but a lower grain yield of 3.0 t ha^{-1}. The 4 treatments namely; 2HH, 3HH, PREB + 1HH and PREB + POEB in the NS direction produced significantly lower growth, yield parameters and grain yield relative to treatments in the EW row direction. During both cropping seasons, the weedy check recorded the lowest numbers of leaves (11-12 leaves), tillers (2 tillers), panicles (2-3 panicles) and rice grain yield amongst all treatments. Row direction did not affect the growth and yield of rice under the weedy checks (controls). Field observations during 2021b and data for 2022b indicated higher grass biomass in the EW than NS direction. The highest BCR were 1.8 (2HH) and 1.6 (PREB + 1HH) during 2021b and 3.0 (HH) and 3.0 (PREB +1HH) during 2022b in the EW direction. PREB + POEB and 3HH (EW) recorded low BCR and NS recorded lower BCR than EW orientation. Lower BCRs were observed under all NS row direction and under PREB + POEB, 3HH and weekly weeding in EW orientation due to high investment costs. Based on the results 2HH and PREB + 1HH in the EW row direction gave maximum BCR and MRR and the options may be recommended in upland rice ecosystems.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Uganda Bureau of Statistical. Statistical Abstracts; 2021.
2. Ashraf MM, Awan TH, Manzoor M, Ahamad M, Safdar M E. Screening of herbicides for weed management in transplanted rice. Journal of. Animal and. Plant. Science. 2006;16:1-2.
3. Zeiglar R, Barclay A. The relevance of rice. 2008;1:3-10.
DOI 10.1007/s12284-008-9001-z..
4. Ramzan M. Evaluation of various planting methods in rice-wheat cropping systems

Punjab, Pakistan. Rice Crop Report. 2003-2004;4-5.

5. Anwar MP, Juraimi AS, Puteh A, Salemat A, Man A, Hakim MA. Seeding method and rate influence on weed suppression in aerobic rice. African Journal of Biotechnology. 2011;10(68):15259-15271.

6. Sunil CM, Shekara BG, Karyanmurthy KN, Shankaralingapa BC. Growth and yield of aerobic rice as influenced by integrated weed management practices. Indian Journal of weed Science. 2010;42(34): 180-183.

7. Phuong LT, Denich M, Vlek PL, Balsubramanian V. Suppressing weeds in direct seeded lowland Rice: Effects of methods and rates of seeding. Journal of Agronomy and Crop Science. 2005;191;185-194.

8. Begum M, Juraimi AS, Rajan A, Omar SRS, Azmi M. Critical period competition between *Fimbristylis miliacea* (L) Vahl and rice (MR 220). Plant Prot Quar. 2008;23(4):153-157.

9. Rao AN, Jhonson DE, Sivaprasad V, Ladha JK, Mortimer AM. Weed management in direct seeded rice. Advances of Agronomy. 2007;93:153-155.

10. Hakim MA, Juraimi AS, Karim R, Sirajul M. Effectiveness of herbicide to control rice weeds in diverse saline environments. Sustainability. 2021;13(2053).
DOI: 10.3390/su13042053.

11. Labrada, R. Weed management in rice, in: Auld, B.A. & Kim, K.U. eds. FAO Plant production and protection paper No. 139: 2003;259-272, FAO, Rome.

12. Kaiira MG, Chemining'wa GN, Ayuke F, Baguma Y. Weed control using rice, cymbopogon, desmodium, mucuna and maize stover allelopathic water extracts. International Journal of Agriculture Innovations and Research. 2019a;8(1):11-17.

13. Kaiira MG, Chemining'wa GN, Ayuke F, Baguma Y. Weed control using rice, cymbopogon, desmodium, mucuna and maize. International Journal of Plant and soil Science. 2019b;29(1):1-14.

14. Kaiira MG, Chemining'wa GN, Ayuke F, Baguma Y, Atwijukire E. Production potential of allelopathic rice, cymbopogon, desmodium, mucuna and maize. Journal of Agricultural Science. 2021;13(9):201-212.

15. Cheema MWA, Rasool T, Munir H, Iqbar MM, Naz T, Haq MIU, Mustafa A, Naddem M, Ullah S. Weed control in wheat through different sorghum formulations as an organic herbicide. Asian Journal of Agricultural Biology. 2020;8(2):129-137.

16. International Rice Research Institute. Proceedings of the workshop on Azolla use, Fuzhou, Fujian, China, 31March-5 April 1985; 1987.

17. Boyd NS, Brenman EB, Smith RF, Yokota R. Effect of seeding rate and planting arrangement of rye cover crop and weed growth. Agronomy Journal. 2009;101:47-51.

18. Juraimi AS, Uddin MdK, Anwar MdP, Mohamed MTM, Ismail MR, Man A. Sustainable weed management indirect seeded rice culture: A review. Australian Journal of Crop Science. 2013; 7(7):989-1002.

19. Dogan MN, Unay A, Box O, Albay F. Determination of optimum weed control timing in maize. Turk J Agric For. 2004;28:349-354.

20. Amadou T, Sogbedji L, Yawovi MD. The critical period of weed interference in upland rice in northern Guinea savanna: Field measurement and model prediction. African Journal of Agricultural Research. 2013;8(17)1748-1759.
DOI:10.5897/AJAR12.1688

21. Buhler DD, Liebman M, Obrycki JJ. Theoretical and practical challenges to an IPM approach to weed management. Weed Science. 2000;48:274-280.

22. Anwar PMd, Islam MKM, Yeasmin S, Rashid HMd, Juraimi AS, Ahmed S, Shrestha A. Weeds and their response to management efforts in a changing climate. Agronomy. 2021;11(10):1921;1-20.

23. Kaiira MG, Kagoda F. Exploring cost-effective maize integrated weed management approaches under intensive farming systems. Uganda Journal of Agricultural Sciences. 2014;15(2):191-198.

24. Byerlee D. From agronomic data to farmer recommendation: An economic training manual, CIMMYT, Mexico, DF. 31-33.

25. Arif M, Cheema ZA, Khalif A, Hassan A. Organic weed management in wheat

through allelopathy. International Journal of Agricultural Biology. 2015;17:127-134.

26. Muhammad AO, Kawsar H, Rabiul HC, Chowdhury NT, Md Khairul I. Assessment of different weed control methods on growth and yield performance of T. Aua Rice. Agric. Research & Tech; Open access Journal. 2020;24(3): 556267.

DOI: 10.19080/ARTOAJ.2020.24.556267

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