Hindawi
International Journal of Agronomy
Volume 2022, Article ID 5423576, 13 pages
https://doi.org/10.1155/2022/5423576

Research Article

Effect of Row Spacing and Frequency of Weeding on Weed Infestation, Yield Components, and Yield of Rice (*Oryza sativa* L.) in Bench Maji Zone, Southwestern Ethiopia

Bana Daba[1] and Getachew Mekonnen[2]

[1]*College of Agriculture and Natural Resources, Mizan Tepi University, Mizan, Ethiopia*
[2]*College of Agriculture and Natural Resources, Wolkite University, Wolkite, Ethiopia*

Correspondence should be addressed to Getachew Mekonnen; dessiemekdes@yahoo.com

Received 14 October 2021; Revised 13 March 2022; Accepted 15 June 2022; Published 24 June 2022

Academic Editor: Magdi Abdelhamid

A field experiment was conducted in Bench Maji Zone at Guraferda district during the 2020 main cropping season to assess the effect of row spacing and frequency of weeding on weeds, yield components, and yield of rice and to estimate the economic feasibility of weed control practices of rice. Factorial combination of three-row spacing (20, 25, and 30 cm) and six weeding frequencies (one-hand weeding and hoeing at 2, 3, and 4 weeks after emergence, two-hand weeding and hoeing at 2 and 5 weeks after emergence, and weed-free check and weedy check) were laid out in randomized complete block design with three replications. Weed control efficiency, days to 50% heading, days to 90% physiological maturity, plant height, and straw yield were significantly affected by weeding frequencies but not by row spacing. Significantly higher panicle length (24.07 cm), number of productive tillers (209.08 m^{-2}), number of kernels per panicle (252.22), grain yield (4303.0 $kg \cdot ha^{-1}$), aboveground dry biomass (10295.4 $kg \cdot ha^{-1}$), and harvest index (40.79%) were observed under 25 cm row spacing, compared with 20 and 30 cm. Significantly higher panicle length (25.81 cm), number of productive tillers (257.71 m^{-2}), number of kernels per panicle (172.33), thousand kernels weight (35.44 g), grain yield (5226.7 $kg \cdot ha^{-1}$), aboveground dry biomass (11696.3 $kg \cdot ha^{-1}$), and harvest index (44.92%) were recorded under complete weed-free check plots. However, the highest net return (46,394.87 $ETB \cdot ha^{-1}$) was obtained from the combination of 25 cm row spacing and two-hand weeding and hoeing at 2 and 5 weeks after emergence, as the cost of maintaining weed-free plots was much higher. Thus, practicing two-hand weeding and hoeing at 2 and 5 WAE and 25 cm row spacing was found to be both agronomically and economically feasible for Rice (NERICA-4) production in the Guraferda area.

1. Introduction

Rice (*Oryza* species) is an annual cereal crop belonging to the family of Poaceae [1]. In Ethiopia, rice is cultivated in an area of about 30,600 ha [2]. Further, it has been reported that 4% of the total cereal crop production in the country is contributed by rice. Despite the abovementioned importance and coverage of an area, its productivity is very low. The average national yield of rice is less than 1 ton ha^{-1}. Some of the factors contributing to the low yield of rice are lack of high-yielding cultivars, lodging, weed infestation, water logging, low moisture, and improper spacing and fertility conditions [3].

Different row spacing significantly affected the number of fertile tillers and total tillers per square meter. Wider row spacing reduces the crop's competitive ability with weeds because it increases the space available for the weeds between the rows and decreases the competitive ability of the crop [4]. Some of the commonly used row spacing in different parts of Africa (Nigeria, Senegal, and Tanzania) is 25–30 cm [5]. It is, therefore, necessary to determine the optimum plant population [6] per unit area and spacing to obtain a high yield [7]. The maximum benefit with respect to rice yield can be obtained when planting is done with proper spacing [8].

Among cultural weed control methods, hand weeding and hoeing can reduce weed emergence up to 80%, resulting in a 69% increase in wheat yield compared with standard seed bed preparation [9]. On the other hand, close planting by reducing row spacing can reduce weed infestation when compared with wide row spacing [10]. Narrow row widths reduce the biomass of later emerging weeds by decreasing the light available for weeds located below the crop canopy [11]. The growth of weeds decreases significantly in the order of increasing frequency of weeding. Weeding twice or thrice suppresses weed growth, increases the yield of a crop, and maximizes profit in crop production [12]. Mola and Belachew [13] reported that rice required at least two early weedings (15 and 30 days after emergence) for efficient weed management, which led to significantly higher crop yields.

Agronomic practices like weed management and row spacing are the most yield-reducing factors in rice production. However, there have been limited or no scientific research efforts that assessed the row spacing and weeding frequency in rice production in the study area. Thus, proper row spacing and weed management need to be determined for optimum rice yield in the study area. Therefore, the objectives of this study were to assess the effect of row spacing and frequency of weeding on weeds infestation, yield components, and yield of rice and to estimate the economic feasibility of weed control practices of rice in the study area.

2. Material and Methods

2.1. Description of the Study Area. The experiment was conducted at Mizan-Tepi University research site, Guraferda district, Kuja Kebele in Bench Maji Zone of Southern Nations, Nationalities and People's Regional state, Southwestern Ethiopia in the 2020 main cropping season. The study of experimental site is located at 06°44′01.2″ N latitude, 35°11′58.6″E longitude, and altitude of 960 m above sea level (Figure 1). The rainfall pattern of this area was characterized by bimodal distribution with small rainy season *belg* (March–June) and main rainy season *meher* (July–November) with annual average rainfall of 1800–1200 mm [14].

2.2. Experimental Materials. The rice variety New Rice for Africa (NERICA-4) source from Mizan-Tepi University (MTU) was used for this experiment. NERICA rice varieties have been developed by Africa Rice scientists, and they are expanding and bringing the rice green revolution to different countries of Africa including Ethiopia. The new rice for Africa (NERICA-4) was developed by crossing *Oryza glaberrima* Steud and *Oryza sativa* L. The key features of the new varieties are the panicle can hold up to 400 grains compared with the 75–100 grains of its African parents, with an increase in yield from 1 to 2267.5 kg·ha^{-1} which can increase to 4535.9 kg·ha^{-1} with fertilizer use. It also matures 30–50 days earlier than traditional varieties, contains 2% more protein than its parents, and resists pests, tolerates drought, and infertile soils better than Asian varieties. The adoption and cultivation of new rice varieties are increasing faster than any other food crop in many African countries [15].

2.3. Treatments and Experimental Design. There were 18 treatments comprising the combination of three-row spacing namely 30 cm (S_1), 25 cm (S_2), and 20 cm (S_3) and six weeding frequencies (W_1 = one-hand weeding and hoeing at 2 weeks after crop emergence (WAE), W_2 = one-hand weeding and hoeing at 3 WAE, W_3 = one-hand weeding and hoeing at 4 WAE, W_4 = two-hand weeding and hoeing at 2 and 5 WAE, W_5 = weed-free check, and W_6 = weedy check). The treatments were arranged in a factorial arrangement in a randomized complete block design (RCBD) with three replications.

2.4. Experimental Procedure and Management. The experimental field was cultivated by a tractor initially and prepared by human labor at sowing to create a good seed bed. The gross plot size was 3.0 m × 2.0 m (6 m^2) containing 15 rows for 20 cm, 12 rows for 25 cm, and 10 rows for 30 cm inter-row spacing. The net plot areas were 3.84 m^2 for 30 cm, 4 m^2 for 25 cm, and 4.16 m^2 for 20 cm row spacing which were excluding the outer row of each side of the gross plot of each treatment unit and in each plot, 0.2 m row lengths at the end of each row were left to be a border to avoid the border effect. The path between experimental plots and replications was separated by 0.5 and 1.0 m, respectively. The plots were prepared as per the layout, leveled manually, and the seed was drilled in furrows manually on July 9, 2020. Each treatment combination was assigned by a random number table to experimental units within a block. Hand weeding and hoeing as per the treatment were done in the assigned plots at an appropriate time. The weeds in complete weed-free plots were removed as and when emerged to keep the plots free from the weeds. Urea and NPS (19% N, 38% P, and 7% S) fertilizers were used as a source of nitrogen, phosphorus, and sulfur nutrients, respectively. Finally, the crop was harvested when the crop reached harvesting maturity on October 17, 2020.

2.5. Data Collected

2.5.1. Weed Parameters. Weed community: the weed flora present in the experimental field was recorded from weedy check plots by placing a quadrat (0.25 m × 0.25 m) randomly at two spots in each plot. Weed dry biomass: while recording weed density, the biomass was harvested from each quadrate and the harvested weeds were placed into paper bags separately. The samples were sun-dried for 3–4 days and thereafter were placed in an oven at 65°C till their constant weight and subsequently, the dry weight was measured. The dry weight was expressed in g m^{-1}. Weed control efficiency (WCE): it was calculated from weed control treatments in controlling weeds and using the following formula:

$$\mathrm{WCE} = \frac{(\mathrm{WDC} - \mathrm{WDT})}{\mathrm{WDC}} \times 100, \quad (1)$$

where WCE is the weed control efficiency, WDC is the weed dry matter in weedy check, and WDT is the weed dry matter in a particular treatment.

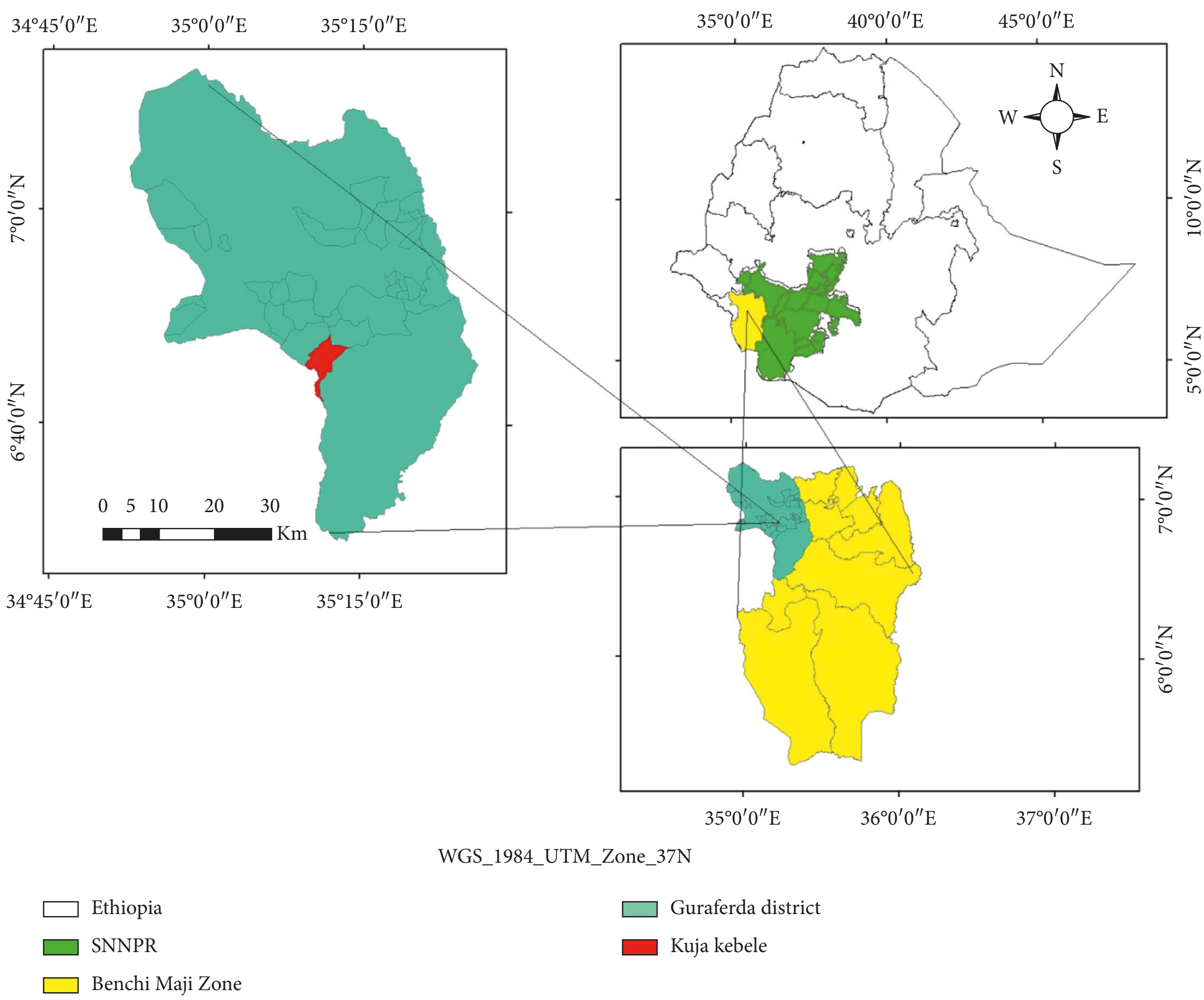

Figure 1: Map showing the experimental site of Guraferda Woreda, Bench Maji, Southwestern Ethiopia.

Weed index (WI): it was measured from a particular treatment when compared with a weed-free treatment and expressed as a percentage of yield potential under weed-free and calculated with the help of the following formula:

$$\mathrm{WI} = \left(\frac{X - Y}{X}\right) \times 100, \quad (2)$$

where WI is the weed index, X is the yield in complete weed-free, and Y is the yield in a particular treatment.

2.5.2. Crop Parameters. Days to 50% heading (DH): it was recorded by counting the number of days from the date of sowing to the time when the ears or panicles were fully visible or produced head above the sheath of the flag leaf on 50% of the plants from each net plot that was determined by visual observation. Days to 90% physiological maturity: days to physiological maturity was recorded by counting the number of days from the date of sowing to the time when the grain hardened and the straw turned light yellow and becomes dry and brittle in 90% of the plants in a net plot area. It is also indicated by the senescence of the leaves as well as the free threshing of seeds from the glumes when pressed between the thumb and the forefinger. Plant height (cm): the average height of 10 randomly selected plants from the net plot area of each plot was measured in centimeters from the ground or base to the tip of the panicle at maturity and means were taken. Panicle length (cm): it was measured from 10 randomly selected plants of the inner rows in centimeters and the mean length was recorded on each plot by measured from the node where the first panicle branch starts to the tip of the panicle at maturity. Number of total tillers: the average total number of tillers was counted from 1 m row length of two randomly taken from net plot area at harvesting and converted into m^2. Number of productive tillers: the average number of productive (panicle bearing tillers) or effective tillers was counted from 1 m row length of two randomly taken of net plot area at harvesting and converted into m^2. Thousand kernel weight (TKW, g): thousand grains were counted after threshing at random from each plot and their weights were measured with sensitive balance in grams after adjusting the grain moisture content to 12.5%. Number of kernels per panicles (NKPP): it was counted from 10 randomly selected plants from the inner rows of each plot and the mean kernel number was taken at harvesting. Aboveground dry biomass yield per hectare (ABY kg·ha^{-1}): total biomass or biological yield was measured in grams by weighting the sun-dried total aboveground plant biomass (straw + grain) from the net plot area of each plot and converted to kilograms per hectare measured at harvest. Grain yield per hectare (GY kg·ha^{-1}): grain yield was measured by taking the weight of the grains threshed from the net plot area of each plot and converted to kilograms per hectare after adjusting the grain moisture content to 12.5%. Straw yield per hectare (SY kg·ha^{-1}): straw yield was determined by subtracting grain yield from total aboveground biomass.

Harvest index (HI, %): it was calculated as the ratio of grain yield to biological yield and expressed in percentage as follows:

$$\text{HI}\,(\%) = \frac{\text{Grain yield}}{\text{Total dry biomass}} \times 100. \quad (3)$$

2.5.3. Data Analysis. The data collected and measured parameters from the experiment at different growth stages were subjected to statistical analysis as per the experimental designs for each experiment using SAS (Statistical Analysis Software) version 9.2 to analyze the data using ANOVA and GLM procedures. Mean separation of significant treatments was carried out using the least significant difference (LSD) test at a 5% level of probability [16].

2.5.4. Partial Budget Analysis. The partial budget analysis as described by [17] was done to determine the economic feasibility of the weed management practices. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested. It was calculated by taking into account the additional input and labor cost involved and the gross benefits obtained from weed management practices. The average yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same weed management practices and subject to partial budget and economic analysis was performed following the CIMMYT partial budget methodology [17]. The field price of rice was calculated as the sale price minus the costs of harvesting, threshing, winnowing, bagging, and transportation. The total cost that varied included the sum of the cost of seed and labor cost where hand weeding and hoeing are required. The net benefit was calculated as the difference between the gross field benefit (ETB·ha^{-1}) and the total costs (ETB·ha^{-1}) that varied.

3. Results and Discussion

3.1. Weed Parameters

3.1.1. Weed Community. The major weeds in the experimental field were broadleaved, grassy, and sedges. A total of 18 weed species found infesting the experimental fields belonged to 11 families. In the experimental plots, broadleaved weeds predominated over grassy weeds and sedged weeds in terms of infestation and kind too. Here the recorded broadleaved weeds are 11 in number, while grass weeds are 4, and the recorded sedge was 3. The major weed species competing vigorously with rice were *Ageratum conyzoides* L., *Amaranthus hybridus* L., *Digitaria sanguinalis* L. (Scop.), *Eleusine indica* L., and *Cyperus rotundus* L. Plant families of Poaceae, Asteraceae, and Cyperaceae were the most common weed families competing vigorously with rice, followed by Amaranthaceae and Fabaceae (Table 1). The weed flora present in the experimental field is presented in Table 1.

In agreement with the result of this study, [13, 18] reported that among the annual and perennial weeds, *Cyperus assimilis*, *Cyperus esculentus*, and *Cyperus rotundus* of the family Cyperaceae are terrible weeds and *Amaranthus* spp., *Eleusine indica*, *Commelina benghalensis*, *Setaria pumila*, *Phalaris paradoxa*, *Xanthium spinosum*, and other broad-leaved and grasses weeds are important in the southwestern parts of the country. From the same location, [14] reported that Poaceae, Asteraceae, and Chenopodiaceae were the major weed families competing vigorously with rice. The present study is agreed with the results reported by those authors. The possible reason for more weed species occurrence in the experimental field could be related to poor weed management practices and favorable environmental factors such as soil type, altitude, and previous crop grown at the site and more rainfall at the early stage of the crop growth. In line with this result, [19] reported that altitude, rainfall, the month of planting, number of weeding, and soil type were the major environmental and crop management factors that influenced the number of weeds species distributions.

3.1.2. Weed Dry Weight. Weed dry weight was reduced by closer row spacing. The minimum weed dry weight (79.12 g·m^{-2}) was recorded under 20 cm row spacing, while the maximum weed dry weight (194.8 g·m^{-2}) was observed in wider (30 cm) row spacing. This result implies that weed dry weight decreased significantly as the inter-row spacing decreased from 30 to 20 cm. On the other hand, weeding frequencies had a significant effect on weed dry weight at crop harvest. The minimum weed dry weight was observed in weed-free check (negligible) which was statistically in parity with two-hand weeding and hoeing at 2 and 5 WAE (19.40 g·m^{-2}). While the maximum weed dry weight (542 g·m^{-2}) was recorded under weedy check (control), which was significantly higher dry weight than all other weeding frequencies.

Weed dry weight at crop harvest was significantly influenced by the interactions of row spacing and weeding frequencies. The minimum weed dry weight (6.73 g·m^{-2}) was recorded under the treatment combinations of 20 cm row spacing with two-hand weeding and hoeing at 2 and 5 WAE. However, it did not differ significantly with the combinations of weed-free check with three-row spacing, two-hand weeding and hoeing at 2 and 5 WAE with 25 and 30 cm row spacing, 20 cm row spacing with one-hand weeding and hoeing at 2, 3, and 4 WAE, and 25 cm row

Table 1: Weed community recorded in a rice field at the experimental site in 2020 main cropping season.

Weed species	Family	Life form (category)
Ageratum conyzoides L.	Asteraceae	Annual (broadleaved weed)
Amaranthus hybridus L.	Amaranthaceae	Annual (broadleaved weed)
Amaranthus spinosus L.	Amaranthaceae	Annual (broadleaved weed)
Amaranthus viridis Hook. F.	Amaranthaceae	Annual (broadleaved weed)
Bidens pilosa L.	Asteraceae	Annual (broadleaved weed)
Cassia mimosoides L.	Fabaceae	Annual (broadleaved weed)
Centrosema pubescens benth.	Fabaceae	Perennial (broadleaved weed)
Chromolaena odorata L. R.M. king & H. Rob	Asteraceae	Perennial (broadleaved weed)
Commelina benghalensis L.	Commelinaceae	Annual (broadleaved weed)
Cynodon dactylon (L.) pers.	Poaceae	Perennial (grassy weed)
Cyperus eragrostis lam.	Cyperaceae	Perennial (sedge)
Cyperus haspan L.	Cyperaceae	Perennial (sedge)
Cyperus rotundus L.	Cyperaceae	Perennial (sedge)
Digitaria sanguinalis L. (scop.)	Poaceae	Annual (grassy weed)
Echinochloa colona (L.) link.	Poaceae	Annual (grassy weed)
Eleusine indica (L.) gaertner.	Poaceae	Annual (grassy weed)
Euphorbia geniculata Ortega	Euphorbiaceae	Annual (broadleaved weed)
Physalis minima L.	Solanaceae	Annual (broadleaved weed)

spacing with one-hand weeding and hoeing at 3 and 4 WAE (Table 2). While the maximum weed dry weight (774.33 gWAEm^{-2}) was observed under the treatment combinations of 30 cm row spacing with weedy check which was significantly higher than all the interactions of row spacing and weeding frequencies (Table 2). Weeds in weedy check plots with three-row spacing accumulated higher dry weight than the other all row spacing interaction with weeding frequencies and also there were significant differences within weedy checks.

The lower weed dry matter weight recorded under narrower row spacing with weeding frequencies was might be due to lower weed densities (Table 2) and the higher competitive effect of the crop which can suppress weed infestation. The present result is directly supported by the findings of [20] who reported that due to lesser space for weed development, better crop competition for development resources, crop growth, early space covering, and light interception might have effectively controlled the weeds. A similar result was also noticed by [21]. At the early crop growth stage, hand weeding and hoeing controlled the emerged weeds, and those weeds which would emerge later might have failed to accumulate sufficient dry matter due to the competition offered by well-grown crop plants. Further, the weed seeds under depleted soil seed bank that might have been brought to the upper soil layer by hand weeding and hoeing, though germinated and emerged later, were in their initial growth stage and thus accumulated less dry weight.

On the other hand, the higher weed dry weight observed in weedy check under wider row spacing might be due to higher weed density that provided an opportunity for the weeds to compete vigorously for nutrients, space, light, water, and carbon dioxide resulting in higher biomass production. Similar findings to the present study were reported by [22] who reported that the treatment combinations of weedy check with the widest spacing (30 cm × 20 cm) produced the highest weed dry biomass weight (40.2 gWAE m^{-2}) than the narrower spacing (20 cm × 10 cm).

3.1.3. Weed Control Efficiency. There were no significant differences in row spacing for weed control efficiencies (Table 3). Weed control efficiency was significantly influenced by weeding frequencies. The highest weed control efficiency was observed under weed-free check (100%), which was statistically at par with two-hand weeding and hoeing at 2 and 5 WAE (96.7%), whereas the minimum weed control efficiency (negligible) was observed in weedy check plots (Table 3). The weed control efficiency observed due to the response of one-hand weeding and hoeing at 2, 3, and 4 WAE was statistically similar to each other. This result further elucidates that weed-free plots and two-hand weedings and hoeing at 2 and 5 WAE were more effective in reducing weed density and dry biomass weights of weeds as compared with the weedy check and had greater weed control efficiency over one-hand weeding and hoeing (Table 3).

3.1.4. Weed Index. Weed index measures the effectiveness of a particular treatment compared with a weed-free check and is expressed as a percentage of grain yield under a weed-free check thus higher weed index means greater loss of yield due to weeds. Weed index was significantly influenced by row spacing. The lowest weed index (21.24%) was observed under 20 cm row spacing, while the maximum weed index (28.99%) was observed in 30 cm row spacing (Table 3). This result indicates that the weed index increased with the increase in row spacing from 20 to 30 cm. This finding is in close agreement with the study of [21] who reported that weed index increased with the increase in row spacing from 15 to 20 cm and the decline at 25 cm row spacing of bread wheat.

Weeding frequency also had a significant effect on weed index. The lowest weed index was observed in weed-free check (negligible) followed by two-hand weeding and hoeing at 2 and 5 WAE (9.19%). However, the weed index recorded under two-hand weeding and hoeing at 2 and 5 WAE was statistically at par with a plot treated by one-hand weeding and hoeing at 3 WAE. While the highest weed index

Table 2: Interaction effects of row spacing and weeding frequencies of rice on weed dry weight at harvest ($g \cdot m^{-2}$) at Kuja in 2020 main cropping season.

Weeding frequencies (WF)	Row spacing (RS)		
	30 cm	25 cm	20 cm
One-hand weeding and hoeing at 2 WAE	136.27^{d}	80.67^{defg}	50.97^{fghi}
One-hand weeding and hoeing at 3 WAE	124.97^{de}	74.00^{defgh}	41.17^{fghi}
One-hand weeding and hoeing at 4 WAE	101.67^{def}	66.33^{efghi}	34.17^{fghi}
Two-hand weeding and hoeing at 2 and 5 WAE	31.57^{ghi}	19.90^{ghi}	6.73^{hi}
Weed-free check	0.00^{i}	0.00^{i}	0.00^{i}
Weedy check	774.33^{a}	510.00^{b}	341.67^{c}
LSD (0.05) WFXRS = 69.06		CV (%) = 31.29	

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after crop emergence; means in columns and rows followed by the same letter(s) are not significantly different at a 5% level of significance.

Table 3: Main effect of row spacing and weeding frequencies of rice on weed control efficiency (%) and weed index (%) at Kuja in 2020 main cropping season.

Treatments	Weed control efficiency	Weed index
Row spacing		
30 cm	74.77^{a}	28.99^{a}
25 cm	75.33^{a}	23.31^{ab}
20 cm	76.89^{a}	21.24^{b}
LSD (0.05)	NS	5.94
Weeding frequencies		
One-hand weeding and hoeing at 2 WAE	83.67^{b}	22.98^{bc}
One-hand weeding and hoeing at 3 WAE	85.84^{b}	16.66^{cd}
One-hand weeding and hoeing at 4 WAE	87.75^{b}	27.52^{b}
Two-hand weeding and hoeing at 2 and 5 WAE	96.70^{a}	9.19^{d}
Weed-free check	100.00^{a}	0.00^{e}
Weedy check	0.00^{c}	70.72^{a}
LSD (0.05)	6.60	8.40
CV (%)	9.10	35.75

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after crop emergence; means in columns of the same parameter followed by the same letter(s) are not significantly different at a 5% level of significance.

(70.72%) was recorded under weedy check plots, which indicates a 70.72% yield loss in unweeded check plots (Table 3). Such yield losses due to weed competition were also reported by [14]. This result is in agreement with the finding of [23] who reported that the lowest weed index was observed in weed-free checks followed by two-hand weeding (4.45%) and the highest was obtained in weedy checks (71.79%). Like higher weed control efficiency achieved under a particular treatment, the weed index decrease showed that higher weed index correlated with poor weed control. It was observed that the highest grain yield was recorded due to a lower weed index in the corresponding treatment and vice versa. This result is in conformity with [24].

3.2. Crop Parameters

3.2.1. Days to 50% Heading. Days to 50% heading had significantly influenced by weeding frequencies. The highest days to 50% heading were recorded under weedy check (no weeding) and the lowest days to 50% heading was observed in weed-free check plots. The result indicates that weed-free check significantly attained earlier producing head or panicles followed by two-hand weeding and hoeing at 2 and 5 WAE. However, days to heading did not significantly vary between the treatments of one-hand weeding and hoeing done at 2 and 3 WAE (Table 4). In weedy check, the shading of crop plants by weeds might have reduced sunlight interception thus prolonging the vegetative growth and resulting in delayed days to producing head. This indicates that heading was delayed due to weed infestation throughout the crop growth over other treatments. In line with this result, [25] identified that the plants in unweeded plots took the highest time to reach 50% flowering.

3.2.2. Days to 90% Physiological Maturity. Maturity period of rice has direct relationship with days to 50% heading. Factors that retard days to heading may also retard time of maturity. Like that of days to heading, significantly longer days to 90% physiological maturity were recorded under weedy check plots. While significantly shorter days to 90% physiological maturity was observed in weed-free check plots, which was statistically at par with plots treated by two-hand weeding and hoeing at 2 and 5 WAE (Table 4). Generally, as the weeding frequency decreased, the days to physiological maturity tended to be prolonged. The days to maturity for two-hand weeding and hoeing at 2 and 5 WAE

Table 4: Main effect of row spacing and weeding frequencies on phenological and growth parameters of rice at Kuja in 2020 main cropping season.

Treatment	DH	DPM
Row spacing		
30 cm	61.25[a]	88.83[a]
25 cm	61.10[a]	88.83[a]
20 cm	61.08[a]	88.78[a]
LSD (0.05)	NS	NS
Weeding frequencies		
One-hand weeding and hoeing at 2 WAE	61.00[c]	89.00[b]
One-hand weeding and hoeing at 3 WAE	61.00[c]	89.00[b]
One-hand weeding and hoeing at 4 WAE	62.00[b]	89.00[b]
Two-hand weeding and hoeing at 2 and 5 WAE	60.17[d]	87.89[c]
Weed-free check	59.00[e]	87.00[c]
Weedy check	63.70[a]	91.00[a]
LSD (0.05)	0.83	1.07
CV (%)	1.42	1.26

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after crop emergence; DH = days to 50% heading; DPM = days to 90% physiological maturity; PH = plant height (cm); PL = panicle length (cm); means in columns of the same parameter followed by the same letter(s) are not significantly different at 5% level of significance.

and completely weeded plots were significantly earlier than the other weeding frequencies. This implies that the number of days to physiological maturity was significantly delayed due to weed infestation throughout the crop growth over other treatments. In line with this result, [26] reported that the days required to attain physiological maturity increased as the duration of weed interference was prolonged. In a weedy check, the shading of crop plants by the weed canopy might have reduced sunlight radiation, thus prolonging the vegetative growth and resulting in delayed days to physiological maturity. This in turn might have reduced vegetative growth and delayed the transition to the reproductive period and physiological maturity of rice. This result is in harmony with the findings of [14] who exhibited that the plants in unweeded plots took the highest time to reach 90% physiological maturity in upland rice. Similarly, [27] reported that with an increase in the dry weight of *Parthenium*, the duration required by the common bean plants to reach physiological maturity was prolonged.

3.2.3. Number of Total Tillers. The significantly higher number of total tillers (249.74 m^{-2}) and lower number of total tillers (200.19 m^{-2}) were recorded under row spacing of 20 and 30 cm, respectively (Table 5). This result shows that the number of total tillers per meter square area decreased significantly with the increase in row spacing from 20 to 30 cm. This finding is in agreement with the study of [28] who found that narrow spacing produced a greater number of tillers per meter square area as compared with wider spacing. The higher total tillers per unit area recorded under 20 cm row spacing might be due to reduced intra-plant competition as higher as the same seed rate was used which was further enhanced due to lack of weed competition as the plots were kept completely weed-free. Similarly, [29] also showed an increase in tillers and panicle density by decreasing row spacing. Likewise, [30] reported that under narrow row spacing (11.25 cm apart rows), although the number of tillers per unit area was more yet the number of tillers per plant was definitely less due to the dilution effect and limited space available for a rice plant to thrive than wider row spacing. Previous studies of [31] also support our result regarding total tillers and productive tillers of direct-seeded rice.

Weeding frequencies also had a significant effect on the number of total tillers. The analyzed result showed that the highest number of total tillers per meter square area (272 m^{-2}) was recorded under weed-free check a plot which was statistically in parity with those of two-hand weeding and hoeing at 2 and 5 WAE. While significantly, the lowest number of total tillers per meter square area (151.17 m^{-2}) was obtained in weedy check plots (Table 5). A similar result was reported by [21] who reported that a lower number of tillers under weedy checks was due to the unavailability of more space for better light interception, reduced nutrients, and moisture availability for the crop due to the presence of weeds.

3.2.4. Number of Productive Tillers. The highest average number of productive tillers (226.82 m^{-2}) per meter square area was observed in-row spacing of 20 cm. While significantly the lowest mean number of productive tillers (182.85 m^{-2}) per meter square area was recorded under row spacing of 30 cm. However, the number of productive tillers obtained from 20 cm row spacing was statistically at par with that observed in 25 cm row spacing (Table 5).

Mekonnen [32] reported that 20 cm row spacing produced significantly more effective tillers as compared with 25 and 30 cm row spacing. The number of effective tillers per unit area is one of the limiting factors of grain yield [33]. The greater tiller numbers at the narrow row spacing were likely due to more uniform spatial distribution and less in-row plant-to-plant competition compared with the wider row spacing [34]. Increased light capture by a canopy has been reported in wheat with narrow row spacing configurations [35].

The highest number of productive tillers per meter square area (257.71 m^{-2}) was recorded under weed-free check, which was statistically in parity with the plots treated by two-hand weeding and hoeing at 2 and 5 WAE. Whereas significantly the lowest number of productive tillers per meter square area (107.61 m^{-2}) was observed in weedy check plots (Table 5). A similar finding was reported by [21] who reported that the highest number of productive tillers per unit area from the weeded plot is due to a higher number of the total tiller and low densities of weeds. The result is also in agreement with the findings of [10] who reported a significant reduction in weed population and weed dry weight in closer (15 cm) and bidirectional sowing than wider spacing (22.5 cm) in wheat that enhanced higher total and productive tiller per unit area.

3.2.5. Number of Kernels Per Panicle. The numbers of kernels per panicle were significantly affected by different row spacing. The maximum average number of kernels per

Table 5: Main effect of row spacing and weeding frequencies on yield components of rice at Kuja in 2020 main cropping season.

Treatment	TT	PT	KPP	TKW
Row spacing				
30 cm	200.19^{c}	182.85^{b}	129.28^{c}	33.83^{a}
25 cm	224.68^{b}	209.08^{a}	152.22^{a}	31.56^{b}
20 cm	249.74^{a}	226.82^{a}	143.28^{a}	29.33^{c}
LSD (0.05)	20.19	20.13	10.84	1.58
Weeding frequencies				
One-hand weeding and hoeing at 2 WAE	230.74^{bc}	214.93^{bc}	140.00^{cd}	31.56^{b}
One-hand weeding and hoeing at 3 WAE	236.46^{bc}	225.54^{b}	153.33^{bc}	33.22^{ab}
One-hand weeding and hoeing at 4 WAE	212.82^{c}	195.00^{c}	129.33^{d}	31.44^{b}
Two-hand weeding and hoeing at 2 and 5 WAE	246.01^{ab}	236.72^{ab}	163.67^{ab}	33.33^{ab}
Weed-free check	272.00^{a}	257.71^{a}	172.33^{a}	35.44^{a}
Weedy check	151.17^{d}	107.61^{d}	90.89^{e}	24.44^{c}
LSD (0.05)	28.56	28.47	15.33	2.24
CV (%)	13.26	14.41	11.30	7.39

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after crop emergence; TT = number of total tillers (no. m^{-2}); PT = number of productive tillers (no. m^{-2}); KPP = number of kernels per panicle; TKW = thousand kernel weights (g); means in columns of the same parameter followed by the same letter(s) are not significantly different at 5% level of significance.

panicle (152.22) was recorded under 25 cm row spacing. While the minimum kernels number (129.28) was obtained in 30 cm row spacing. However, it was statistically in parity with the number of kernels per panicle obtained in response to the row spacing of 25 and 20 cm (Table 5). The observed difference indicates that the variation in the number of kernels due to row spacing was not consistent; there is an increase in the number of kernels due to an increase from 20 to 25 cm, but a decrease in the number of kernels as row spacing increased from 25 to 30 cm. This result is in line with the finding of [36] who reported that the highest number of grains per panicle (123) was obtained from the optimum spacing of 25 cm × 10 cm than wider spacing (30 × 10 cm; 118) and narrower spacing (15 × 10 cm; 107). Also, the result is in close agreement with the study of [22] who stated that optimum spacing (25 cm × 15 cm) gave the highest number of total grains per panicle (112.40) which was statistically similar to 30 cm × 20 cm spacing (112.2) but superior to 20 cm × 10 cm spacing (107.4).

The highest mean number of kernels per panicle (172.33) was recorded under weed-free plots which did not vary significantly with the plots treated by two-hand weeding and hoeing at 2 and 5 WAE. While the lowest number of kernels per panicle (90.89) was observed in weedy check plots (Table 5). Similar results were reported by [13, 21, 37] who stated that the removal of weeds from the crop at a time could boost the yield components and yield.

In line with this result, [38, 39] who reported that the unweeded plot had a lower number of grains per panicle compared with the weeded plot in rice. Similar findings are also reported by [40] who stated that numbers of grains per spike were significantly reduced with the increased weed infestation and significantly increased with the weed-free period in wheat crop.

3.2.6. Thousand Kernel Weight. The highest thousand kernel weight (33.83 g) was recorded under 30 cm row spacing, whereas the lowest (29.33 g) was observed in 20 cm row spacing (Table 5). The highest thousand weight which was recorded under 30 cm row spacing might be due to the availability of more space for better light interception, more nutrients available, and moisture for crop or grain development, as compared with narrow row spacing. This result is in agreement with the findings of [41] who reported that wider row spacing (22.5 cm) produced more 1000-grain weight (40.16 g) as compared with narrow row spacing of 11.25 cm (38.81 g). Similarly, [42] concluded that increased grain weight at wider row space.

On the other hand, thousand kernel weights had significantly influenced by weeding frequencies. The highest thousand kernel weights (35.44 g) were recorded under weed-free plots which were statistically in parity with two-hand weeding and hoeing at 2 and 5 WAE and one-hand weeding and hoeing at 2 WAE. Meanwhile, significantly the lowest (24.44 g) thousand kernel weights were observed in weedy check plots (Table 5). This might be due to the unavailability of more space for better light interception, nutrient availability, and moisture for crop or grain development. This was due to the high infestation of the weed population which had not been disturbed till crop harvest. In agreement with these findings, [26, 43] who reported that thousand seed weights increased with the increasing length of weed-free conditions and decreased with the increasing length of weedy conditions.

3.2.7. Aboveground Dry Biomass Yield. Biomass yield represents the overall growth performance of the plant as well as the crop and is considered to be the essential yield parameter to get useful information about the overall growth of the crop. It is highly inclined by crop nutrition and planting distance. Row spacing had a prominent effect on the biomass yield of rice. The highest biomass yield (10295.4 kg·ha^{-1}) was observed in 25 cm row spacing, while the lowest biomass yield (9486.1 kg·ha^{-1}) was recorded under 30 cm row spacing. However, the biomass yield recorded under 25 cm row spacing was statistically at par with the biomass yield obtained under 20 cm row spacing (Table 6). The higher biomass yield recorded under 20 and 25 cm row spacing might be due to the fact that optimum plant spacing ensures the plant grows properly with its aerial and underground parts by utilizing more solar radiation and nutrients. This finding is in line with the study of [22] who reported that optimum spacing (25 cm × 15 cm) produced significantly the highest biomass yield than the widest spacing (30 cm × 20 cm) and closest spacing (20 cm × 10 cm) of rice. In close agreement with the present result, [32, 41] reported that more biomass yield was produced under narrow spacing than wider spacing.

Weeding frequency also had a significant effect on aboveground dry biomass yield. The highest aboveground dry biomass yield (11,696.3 kg·ha^{-1}) was recorded under weed-free check which was statistically similar to the plots treated by two-hand weeding and hoeing at 2 and 5 WAE. While the lowest aboveground dry biomass yield (6,024.1 kg·ha^{-1}) was observed in weedy check plots (Table 6). The increased aboveground dry biomass under weed-free treatments could be due to the crop plants utilizing the resources more efficiently which resulted in higher tiller numbers per unit area (Table 6). The present result is in agreement with the findings of [44] who reported that the increased dry matter weight of the crop was highly governed by the length of the weed-free period. On the other hand, significantly the lowest aboveground dry biomass yield was obtained under weedy check plots. This might be due to severe competition for growth resources resulting in lower availability of nutrients for the crop thus causing a reduction in the number of tillers thereby low straw yield. Similar to the present result, [14] reported that prolonged weed competition resulted in reduced biomass accumulation and lesser panicle length per plant and thousand seed weight which ultimately translated into lower grain yield.

3.2.8. Grain Yield. The grain yield of rice had significantly influenced by different row spacing. The highest grain yield (4303.0 kg·ha^{-1}) was recorded under 25 cm row spacing, while the lowest grain yield (3563.0 kg·ha^{-1}) was observed in 30 cm row spacing (Table 6). This result indicates that optimum row spacing of 25 cm gave significantly higher grain yield than closer row spacing of 20 cm and wider row spacing of 30 cm. The reasons for higher grain yield recorded under 25 cm row spacing might be due to fewer crop-weed competition that ensured sufficient supply of plant nutrients for rice plant growth and low intra-crop competition for nutrients, radiation, and better photosynthates translocation to grains which resulted in higher grain yield.

The highest grain yield recorded under 25 cm row spacing also might be due to the highest number of kernels panicle^{-1} (152.22) and the highest number of productive tillers m^{-2} (Table 5). This finding is in agreement with the study of [36] who stated that the optimum spacing of 25 cm × 10 cm gave the highest grain yield (2176 kg ha^{-1}) than the wider spacing of 30 cm × 10 cm and closer spacing of 15 cm × 10 cm of rice. In contrast to this result, [32] who stated that narrow row spacing (20 cm) gave significantly higher grain yield than wider (30 cm). The lowest grain yield (3563.0 kg·ha^{-1}) was observed under wider (30 cm) row spacing, thus reducing grain yield per unit area. [45] reported that improper spacing reduced yield up to 20–30%.

On the other hand, weeding frequencies significantly influenced the grain yield of rice. The highest grain yield (5226.7 kg·ha^{-1}) was recorded under weed-free check, followed by that of two-hand weeding and hoeing at 2 and 5 WAE (4743.4 kg·ha^{-1}; Table 6). However, the grain yield recorded under two-hand weeding and hoeing at 2 and 5 WAE was statistically at par with the plots treated by one-hand weeding and hoeing at 3 WAE. While significantly the lowest grain yield (1535.3 kg·ha^{-1}) was observed in weedy check plots. The present result is in line with the findings of [23] who reported that the highest grain yield (7696 kg·ha^{-1}) was obtained in weed-free check, followed by two-hand weeding (7353 kg·ha^{-1}) in rice plants. The higher grain yield obtained under weed-free check treatments might be due to lower weed competition, thus utilizing the available resources to its maximum benefit resulting in improvement of yield attributes like increasing numbers of productive tillers per unit area, panicles length, the number of grains per panicle, 1000-grain weight, and then finally grain yield with better weed control efficiency and lower weed indices.

Significantly the lowest yield was observed under weedy check plots than all the other treatments. This was probably due to the result of severe weed competition by uncontrolled weed growth, which resulted in a significantly low number of productive tillers per unit area, grains per panicle, and 1000-grain weight as compared with other treatments. Similar findings to the present study were reported by [5, 14, 21].

3.2.9. Straw Yield. Row spacing had no significant effect on straw yield. But numerically, the narrowest row spacing (20 cm) produced the highest straw yield (6186.8 kg·ha^{-1}) and the lowest straw yield was produced by the widest row spacing (30 cm; 5923.1 kg·ha^{-1}; Table 6). On the other hand, the straw yield of rice was significantly influenced by weeding frequencies. The highest straw yield (6493.7 kg·ha^{-1}) was observed under two-hand weeding and hoeing at 2 and 5 WAE which was statistically at par with the other treatments except for weedy check plots. While significantly the lowest straw yield (4488.8 kg·ha^{-1}) was recorded under weedy check plots (Table 6). Higher weed infestation not only reduced the grain yield but also hampered the plant growth and tillering capacity and ultimately reduced straw yield and also biological yield in weedy check plots. This finding is in line with the study of [22] who reported that the highest straw yield (4.80 t·ha^{-1}) was obtained from the two-hand weeding treatment and significantly the lowest straw yield (4.20 t·ha^{-1}) was observed from the unweeded treatment. Similarly, [38] reported that weed-free conditions produced the highest straw yield (6.55 t·ha^{-1}) and the lowest straw yield (5.62 t·ha^{-1}) was obtained from the no weeding regime. Similar observations were found by [39, 46].

3.2.10. Harvest Index. The ability of a cultivar to convert the dry matter into economic yield is indicated by its harvest index. The higher the harvest index value, the greater the

Table 6: Main effect of row spacing and weeding frequencies on yield and yield components of rice at Kuja in 2020 main cropping season.

Treatment	AGDB	GY	SY	HI
Row spacing				
30 cm	9486.1[b]	3563.0[c]	5923.1[a]	36.09[c]
25 cm	10295.4[a]	4303.0[a]	5992.4[a]	40.79[a]
20 cm	10164.8[a]	3978.0[b]	6186.8[a]	38.03[b]
LSD (0.05)	676.56	304.78	NS	1.71
Weeding frequencies				
One-hand weeding and hoeing at 2 WAE	10187.0[c]	4026.4[cd]	6160.6[a]	39.37[cd]
One-hand weeding and hoeing at 3 WAE	10601.9[bc]	4355.3[bc]	6246.5[a]	40.95[bc]
One-hand weeding and hoeing at 4 WAE	10146.3[c]	3801.0[d]	6345.3[a]	37.19[d]
Two-hand weeding and hoeing at 2 and 5 WAE	11237.0[ab]	4743.4[b]	6493.7[a]	42.18[b]
Weed-free check	11696.3[a]	5226.7[a]	6469.6[a]	44.92[a]
Weedy check	6024.1[d]	1535.3[e]	4488.8[b]	25.2[e]
LSD (0.05)	956.81	431.03	625	2.42
CV (%)	10.01	11.40	10.81	6.60

CV = coefficient of variation; LSD = least significant difference; WAE = weeks after crop emergence; AGDB = aboveground dry biomass of rice (kg ha^{-1}); GY = grain yield (kg·ha^{-1}); SY = straw yield (kg·ha^{-1}); HI = harvest index (%). Means in columns of the same parameter followed by the same letter(s) are not significantly different at a 5% level of significance.

physiological potential of the crop for converting dry matter to grain yield. On the other hand, it reflects the division of photosynthates between the grains and the vegetative plant parts and improvements in the harvest index emphasize the importance of carbon allocation in grain production. Row spacing had a significant effect on the harvest index. The highest harvest index (40.79%) was observed under the row spacing of 25 cm which was significantly different from the other two spacings. While the lowest harvest index (36.09%) was observed in the row spacing of 30 cm (Table 6). This result is in line with the finding of [22] who stated that significantly the highest harvest index was observed in optimum spacing (25 cm × 15 cm) and the lowest harvest index was observed in narrower spacing (20 cm × 10 cm). Similar results were reported by [47] who found that the highest harvest index was observed under 25 cm row spacing in rice crops, but statistically at par with 20 cm row spacing. Likewise, [47] reported that a higher harvest index was reported in 25 cm row spacing, but statistically similar with 20 cm row spacing in wheat crop.

The harvest index was also significantly influenced by weeding frequencies. Significantly the lowest harvest index (25.2%) was recorded under weedy check plots. While the highest harvest index (44.92%) was observed in weed-free checks which were significantly different from the other weeding frequencies (Table 6). Hoque et al. [48] reported that harvest index was highest in the weed-free crop but it was identical with that in one-hand weeding, two-hand handing and three-hand weeding where the lowest was produced in the crop not weeded at all. In line with this finding, [21] reported the variation in harvest index was most probably due to variation in the number of total tillers, number of grains per spike, 1000-grain weight, and grain yield of wheat. The significantly lower harvest index obtained under the weedy check might be due to severe weed competition with the crop for the growth factors, which restricted the growth and development of the crop in weedy check plots. The lowest harvest index recorded under weedy check plots was reported by [14, 22, 26].

3.2.11. Partial Budget Analysis. An economic analysis result using the partial budget procedure [17] was done due to grain yield being significantly influenced by row spacing and weeding frequency. The result in Table 7 of this study showed that the weed-free check had a much higher total variable cost due to a much greater labor requirement for frequent manual weeding. The highest gross benefit was obtained with weed-free checks. The highest gross incomes in these treatments than in the other treatments were due to their higher yield. The lowest (11,880.00 ETB·ha^{-1}) gross return was recorded under the combined treatments of 30 cm row spacing with weedy check plots. The highest net benefits accrued to two-hand weeding and hoeing at 2 and 5 WAE. The highest net benefit from the aforementioned treatment could be attributed to a high yield, at a moderate cost. Furthermore, the low net benefit was attributed to low yield due to weed competition. From the economic point of view, it was obvious that the combined use of 25 cm row spacing and two-hand weeding and hoeing at 2 and 5 WAE was more profitable than the rest of the treatments.

Table 7: Partial budget analysis to estimate net benefit for weed management practices of rice in 2020 main cropping season.

Row spacing (cm)	Weeding frequency	Average yield ($kg \cdot ha^{-1}$)	Adjusted yield ($kg \cdot ha^{-1}$)	Gross benefit ($ETB \cdot ha^{-1}$)	Total variable cost ($ETB \cdot ha^{-1}$)	Net benefit ($ETB \cdot ha^{-1}$)
30	W1	3690.00	3321.00	36531.00	1897.40	34633.60
	W2	3876.00	3488.40	38372.37	1897.40	36474.97
	W3	3086.67	2778.00	30558.03	1897.40	28660.63
	W4	4508.70	4057.83	44636.16	3097.40	41538.76
	W5	5016.67	4515.00	49665.03	10297.40	39367.63
	W6	1200.00	1080.00	11880.00	697.40	11182.60
25	W1	4433.26	3989.94	43889.31	1963.14	41926.17
	W2	4696.60	4226.94	46496.34	1963.14	44533.20
	W3	4372.93	3935.63	43291.97	1963.14	41328.83
	W4	5005.86	4505.27	49558.01	3163.14	46394.87
	W5	5616.66	5054.99	55604.93	10363.14	45241.79
	W6	1692.70	1523.43	16757.73	763.14	15994.59
20	W1	3955.92	3560.33	39163.64	2148.00	37015.64
	W2	4493.32	4043.99	44483.84	2148.00	42335.84
	W3	3943.32	3548.99	39038.87	2148.00	36890.87
	W4	4715.55	4244.00	46683.98	3348.00	43335.98
	W5	5046.65	4541.99	49961.84	10548.00	39413.84
	W6	1713.29	1541.96	16961.54	948.00	16013.54

ETB = Ethiopian birr; and seed rates of 60, 48.3, and 43 $kg \cdot ha^{-1}$ were used for 20, 25, and 30 cm row spacing, respectively; cost of seed for planting = 15.80 $ETB \cdot kg^{-1}$; field price of rice grain = 11.00 $ETB \cdot kg^{-1}$; cost of hand weeding and hoeing at 2 WAE 72 persons, 35 DAE 48 persons @birr 50 per person; WAE = weeks after crop emergence; *W* = weeding frequency; W1, W2, and W3, are weeding by hand weeding and hoeing at 2, 3, and 4 WAE, respectively; *W*4 = weeding by two-hand weeding and hoeing at 2 and 5 WAE, *W*5 = weed-free check, and *W*6 = weedy check.

4. Conclusion

The treatment under 25 cm row spacing recorded significantly the highest panicle length, number of productive tillers, number of kernels per panicle, grain yield, aboveground dry biomass, and harvest index. While significantly higher panicle length, number of productive tillers, number of kernels per panicle, thousand kernels weight, grain yield, aboveground dry biomass, and harvest index were recorded under complete weed-free check plots. Based on partial budget analysis, the highest net return (46,394.87 $ETB \cdot ha^{-1}$) was obtained from the combination of 25 cm row spacing and two-hand weeding and hoeing at 2 and 5 WAE of upland rainfed rice production. Thus, it can be concluded that the combined use of 25 cm row spacing and weeding by two-hand weeding and hoeing at 2 and 5 WAE seems agronomically and economically profitable for rice variety NERICA-4 production and can be recommended tentatively for the study area [49, 50].

Data Availability

The data used for the analysis of this research results are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The author would like to pay our sincere tribute to Mizan-Tepi University for providing research site, NERICA 4 rice planting material to execute the research work and also related to the studies fund provided. The study was funded Mizan Tepi University.

References

[1] FAO (Food and Agricultural Organization of the United Nations), "Rice Market Monitor," *Trade and Markets division*, vol. 16, no. 1, pp. 1–38, 2013.

[2] CSA (Central Statistical Agency), *Agricultural Sample Survey Report on Area and Production of Major Crops*, Central Statistical Agency of Ethiopia, Addis Ababa, Ethiopia, 2016.

[3] T. Lakew, "Rice research and production in Ethiopia," in *Proceedings of the Agronomy Task Force and Processing and Value Addition Task Force Workshop*, Contonou, West Africa, 2011.

[4] P. Martin, B. Scott, J. Edwards, B. Haskins, and J. Smith, *Row Spacing in Cereal and Broad Leaf Crops*, Mallee Sustainable Farming, Mildura, Australia, 2010.

[5] WARDA (West African Rice Development Association), *NERICA: The New Rice for Africa-A Compendium. Africa Rice Center (WARDA)*, Rome, Italy, 2008.

[6] A. W. Baloch, A. M. Soomro, M. A. Javed, and M. Ahmed, "Optimum plant density for high yield in rice," *Asian Journal of Plant Science*, vol. 1, pp. 25–27, 2008.

[7] M. S. Hossain, A. A. Mamun, R. Basak, M. N. Newaj, and M. K. Anam, "Effect of cultivar and spacing on weed infestation and performance of transplant aman rice in Bangladesh," *Journal of Agronomy*, vol. 2, no. 3, pp. 169–178, 2003.

[8] M. R. Sultana, M. M. Rahman, and M. H. Rahman, "Effect of row and hill spacing on the yield performance of boro rice (cv. BRRI dhan45) under aerobic system of cultivation," *Journal of the Bangladesh Agricultural University*, vol. 10, no. 1, pp. 39–42, 2012.

[9] O. A. C. Ologbon and S. A. Yusuf, "Economics of weed control practices on rice farms in Obafemi-owode area of ogun state, Nigeria, ARPN," *Journal of Agricultural and Biological Science*, vol. 9, pp. 45–60, 2012.

[10] J. J. Sharma, "Effect of sowing methods and herbicides application on weeds in wheat," *Indian Journal of Weed Science*, vol. 22, pp. 94–96, 1995.

[11] A. Legere, F. C. Stevenson, A. Vanasse, and O. Lalonde, *Weed Management in Organic and Herbicide-free Systems under Conservation Tillage: The Ultimate Challenge Agriculture and Agri-Food Canada*, Saskatoon Research Centre, Saskatoon, Canada, 2011.

[12] M. N. Doğan, A. Ünay, O. Boz, and F. Albay, "Determination of optimum weed control timing in maize (zea mays L.)," *Turkish Journal of Agriculture*, vol. 28, pp. 349–354, 2004.

[13] T. Mola and K. Belachew, "Effect of weeding time on rice (*Oryza sativa* linn) yield and yield components at kaffa, southwest Ethiopia," *Journal of Biology, Agriculture and Health care*, vol. 5, no. 1, 2015.

[14] G. Mekonnen, M. Woldesenbet, and W. Alemu, "Effect of post emergence herbicides and their mixtures on weed dynamics, yield components and yield of rice (*Oryza sativa L.*), at Guraferda Woreda, south western Ethiopia," *Double Blind Peer Reviewed International Research Journal*, vol. 18, no. 6, pp. 2249–4626, 2018.

[15] K. Futakuchi, "Submergence damage in rice and challenges in expanding the crop's adaptability to submerged conditions in west and central Africa," in *Rice Is Life: Scientific Perspectives for the 21st Century*, K. Toriyama, K. L. Heong, and B. Hardy, Eds., pp. 4–7, Tokyo, Japan, 2005.

[16] K. A. Gomez and A. A. Gomez, *Statistical Procedures for Agricultural Research*, John Wiley and Sons Inc, Toronto, Canada, 2nd edition, 1984.

[17] CIMMYT (International Maize and Wheat improvement Center), *From Agronomic Data to Farmers Recommendations: Economics Training Manual. Completely Revised Edition*, CIMMYT, Mexico, North America, 1988.

[18] G. Mekonnen, M. Woldesenbet, and E. Yegezu, "Determination of critical period of weed-crop competition in rice (*Oryza sativa* L.) in bench Maji and kaffa zone, south western Ethiopia," *Journal of Plant Sciences*, vol. 5, no. 3, pp. 90–98, 2017.

[19] T. Tamado and P. Milberg, "Weed flora in arable fields of eastern Ethiopia with emphasis on the occurrence of parthenium hysterophorus," *Weed Research*, vol. 40, no. 6, pp. 507–521, 2000.

[20] Z. Y. Ashrafi, A. Rahnavard, and S. Sedigheh, "Analogy potential effects of planting methods and tank mixed herbicides on wheat yield and weed populations," *Journal of Agricultural Technology*, vol. 5, no. 2, pp. 391–403, 2009.

[21] D. Dalga, J. J. Sharma, and T. Tana, "Growth and yield of bread wheat (*Triticum aestivum* L.) as influenced by row spacing and weeding frequency in southern Ethiopia," *Science in Agriculture*, vol. 8, no. 1, pp. 19–30, 2014.

[22] A. Mohammed, "Influence of integrated weed management and spacing on the growth and yield of transplanted aman rice," M.Sc. thesis, Sher-e-Bangla Agricultural University, Dhaka,Bangladesh, 2007.

[23] M. Sachin, "Integrated weed management in upland rice (*Oryza Sativa* L.)," M.Sc. thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri, India, 2014.

[24] Y. Singh, V. P. Singh, G. Singh et al., "The implications of land preparation, crop establishment method and weed management on rice yield variation in the rice-wheat system in the Indo-Gangetic plains," *Field Crops Research*, vol. 121, no. 1, pp. 64–74, 2011.

[25] O. P. Gupta, "The nature of weed competition," in *Modern Weed Management with Special Reference to Agriculture in the tropIcs and Sub Tropics. A Text Book and Manual*Agrobios, Jodhpur, India, 2011.

[26] G. Mekonnen, J. J. Sharma, L. Negatu, and T. Tana, "Effect of planting pattern and weeding frequency on weed Infestation, yield components and yield [Cowpea (*Vigna unguiculata* (L.) Walp.]in wollo, northern Ethiopia," *Agriculture, Forestry and Fisheries*, vol. 6, no. 4, pp. 111–122, 2017.

[27] W. Mitiku, J. J. Sharma, and N. Lisanework, "Competitive effect of parthenium weeds on yield and yield components of common bean," *Ethiopian Journal of Weed Management*, vol. 5, pp. 1–11, 2012.

[28] H. Srepada and H. Vijayalaxmi, "Assessment of global rice production and export opportunity for economic development in Ethiopia," *International Journal of Science and research (IJSR), India Online ISSN*, vol. 2, pp. 2319–7064, 2013.

[29] L. T. Phuong, M. Denich, P. L. G. Vlek, and V. Balasubramanian, "Suppressing weeds in direct-seeded lowland rice: effects of methods and rates of seeding," *Journal of Agronomy and Crop Science*, vol. 191, no. 3, pp. 185–194, 2005.

[30] M. Ishfaq, N. Akbar, I. Khan et al., "Optimizing row spacing for direct seeded aerobic rice under dry and moist fields," *Pakistan Journal of Agricultural Research*, vol. 31, no. 4, pp. 291–299, 2018.

[31] B. S. Chauhan, V. P. Singh, A. Kumar, and D. E. Johnson, "Relations of rice seeding rates to crop and weed growth in aerobic rice," *Field Crops Research*, vol. 121, no. 1, pp. 105–115, 2011.

[32] A. Mekonnen, "Effects of seeding rate and row spacing on yield and yield components of bread wheat (*Triticum aestivum* L.) in gozamin district, east gojam zone, Ethiopia," *Journal of Biology, Agriculture and Health care*, vol. 7, no. 4, 2017.

[33] KM. Kakar, M. Arif, and S. Ali, "Effect of NP levels, seed rate and row spacing on wheat," *Pakistan Journal of Biological Sciences*, vol. 4, pp. 1319–1322, 2001.

[34] B. Auld, D. Kemp, and R. Medd, "The influence of spatial arrangement on grain yield of wheat," *Australian Journal of Agricultural Research*, vol. 34, no. 2, pp. 99–108, 1983.

[35] F. H. Andrane, A. Calvino, A. Cirilo, and P. Barbieri, "Yield responses to narrow rows depend on increased radiation interception," *Agronomy Journal*, vol. 94, pp. 975–980, 2002.

[36] A. Robert, "Effects of varietal differences, plant spacing and weeding regimes on weed density and yields of upland rice in Uganda," M.Sc. thesis, Kenyatta University, Nairobi, Kenya, 2011.

[37] A. Shrestha, B. D. Hanson, M. W. Fidelibus, and M. Alcorta, "Growth, phenology, and intraspecific competition between glyphosate-resistant and glyphosate-susceptible horseweeds (conyza canadensis) in the san joaquin valley of California," *Weed Science*, vol. 58, no. 2, pp. 147–153, 2010.

[38] Z. Khan, A. Hasan, P. Anwar, and M. Islam, "Weeding regime and plant spacing influence on weed growth and performance of transplant aman rice variety binadhan- 7," *Fundamental and Applied Agriculture*, vol. 2, no. 3, pp. 331–339, 2017.

[39] M. Z. Islam, "Effect of weeding regime on the growth and yield of BRRI dhan 31 under varying spacing's," M.Sc. thesis, Bangladesh Agricultural University, Mymensingh, Bangladesh, pp. 70-72, 2003.

[40] E. Zand, M. A. Baghestani, S. Soufizadeh, N. Bagherani, and R. Deihimfard, "Weed control and wheat (*Triticum aestivum* L.) yield under application of 2, 4-D plus carfentrazone-ethyl and florasulam plus flumetsulam: evaluation of the efficacy," *Crop Protection*, vol. 26, no. 12, p. 1759, 2007.

[41] H. Mali and J. Choudhary, "Performance of bread wheat (*Triticum aestivum* L.) varieties under different row spacing. Department of agronomy Rajasthan college of agriculture.

MPUAT, Udaipur (Raj.) India," *Journal of Wheat Research*, vol. 4, no. 2, pp. 55–57, 2012.

[42] M. Rafique, A. Ahmad, N. Muhammad, M. Siddique, and M. Kamran, "Effect of seeding densities and planting techniques on late sown wheat (*Triticum aestivum* L.) yield," *Journal of Agricultural Research*, vol. 35, no. 3, pp. 147–153, 1997.

[43] M. P. Anwar, A. S. Juraimi, B. Samedani, A. Puteh, and A. Man, "Critical period of weed control in aerobic rice," *Scientific World Journal*, vol. 2012, pp. 1–10, 2012.

[44] A. Mizan, J. Sharma, and W. Gebremedhin, "Estimation of critical period of weed-crop competition and yield loss in sesame (*Sesamum indicum* L.)," *Ethiopian Journal of Weed Management*, vol. 3, no. 1, pp. 39–53, 2009.

[45] IRRI (International Rice Research Institute), *Rice Production Manual*, UPLB, Los Banos, Philippines, 1997.

[46] A. Toufiq, "Integrated weed management in transplanted aman rice cv. BRRI Dhan 37," M.Sc. Thesis, Bangladesh Agricultural University, Mymensingh, Bangladesh, 2003.

[47] M. Hussain, Z. Mehmood, M. B. Khan, S. Farooq, D. J. Lee, and M. Farooq, "Narrow row spacing ensures higher productivity of low tillering wheat cultivars," *International Journal of Agriculture and Biology*, vol. 14, pp. 413–418, 2012.

[48] S. M. A. Hoque, M. D. Hossain, K. H. Talukder, M. Asaduzzaman, M. A. Sayed, and M. N. Hoque, "Effect of weeding regime on the weed infestation and crop performance of transplant aman rice," *J. Sci. Foundation*, vol. 9, pp. 27–40, 2011.